FERTILITY AND TOTAL ORGANIC CARBON IN OXISOL UNDER DIFFERENT MANAGEMENT SYSTEMS IN SAVANNAH OF PIAUÍ, BRAZIL[1]

[FERTILIDAD Y EL CARBONO ORGÁNICO TOTAL EN OXISOL BAJO DIFERENTES MANEJOS EN EL CERRADO PIAUIENSE, BRASIL]

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SUMMARY

The intensive use of natural resources for food production has ruptured the sustainability of agro-ecosystems. In this context, this study aimed to quantify chemical attributes of Oxisol under five management systems: 1 = conventional tillage (CT); 2 = no-tillage system with millet (NT + M); 3 = crop–livestock integration system with soybean (CL + S); 4 = CL with pasture (CL + P); and 5 = native forest (NF). The following soil depths were studied: 0.00–0.05, 0.05–0.10, and 0.10–0.20 m; and the following traits were quantified: total organic carbon (TOC), soil acidity (pH), soil potential acidity (H + Al) and soil fertility (Ca, Mg, P and K). All treatments modified soil chemical attributes in comparison to NF ($p < 0.01$). The highest phosphorus and potassium levels were observed under CL + S at all evaluated depths. The NT + M treatment increased Ca and Mg levels in layers 0.0–0.05 and 0.10–0.20, whereas CL + S increased base addition (BA), cation exchange capacity (CEC) and base saturation (BS) levels in layer 0.05–0.10 m. Finally, both CL systems improved soil chemical quality, increased surface TOC and carbon stock in depth.

Keywords: crop–livestock integration; pasture; no-tillage; conventional tillage.

RESUMEN

El uso intensivo de los recursos naturales para el sector agrícola para la producción de alimentos ha demostrado romper la sostenibilidad de los ecosistemas agrícolas. El objetivo de este estudio fue cuantificar los atributos químicos de un Oxisol bajo diferentes sistemas de manejo del suelo. Se evaluaron cinco sistemas de labranza: 1 = preparación convencional (PC); 2 = sistema de labranza con el mijo (SPD + M); 3 = Sistema de Integración de soja de cultivos y ganadería (CLIS + S); 4 = CLIS con el pastoreo (CL + P); 5 = Bosque Nativo (FN). Las profundidades estudiadas fueron de 0,00 a 0,05; 0,05 hasta 0,10 y 0,10 a 0,20 m. de carbono orgánico total (TOC), el potencial de hidrógeno (pH), la acidez potencial (H + Al) y la fertilidad del suelo (Ca, Mg, P y K). La acción antrópica modifica los atributos químicos del suelo en comparación con los sistemas de FN ($p < 0{,}01$). Los niveles de P y K fueron mayores en el CLIS + S en las tres profundidades. Ca y Mg en las profundidades de 0,00 a 0,05 y 0,10–0,20 fueron mayores en el SPD + M. En la profundidad de 0,05–0,10 m los valores de suma de base (SB), capacidad de intercambio catiônico (CIT), saturación de bases (SB) fueron mayores en el CLIS + S. El CLIS mejorar la calidad química del suelo, aumentar la superficie de cuna y las reservas de carbono en profundidad.

Palabras clave: integración cultivos-ganadería; pastoreo; labranza; labranza convencional.

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INTRODUCTION

Due to rising food demand, new technologies and sustainable production systems are being developed and adopted in several regions of Brazil. They all aim at higher productivity of already cultivated lands without the need to reach out for new native areas. The crop–livestock (CL) + no-tillage (NT) integration system is a genuinely Brazilian system, which has demonstrated to be fundamental to maintain agricultural and environmental sustainability under edaphoclimatic conditions in the Savannah and other Brazilian biomes (Loss *et al*., 2012) .

Savannah soils are being intensively used for the production of a variety of foods; however, the most common practices are pastures for cattle and dairy production, and grain crops (Souza and Alves, 2003). An alternative to mitigate some of the negative effects of agricultural practices on the soil is the use of mixed production systems, such as CL (Aquino *et al*., 2008), which can benefit grain production and livestock production, as well as provide positive socio-economic and environmental results (Ferreira *et al*., 2011).

The no-tillage system and the integrated crop–livestock system stand out from other production systems because they increase carbon and nutrient stocks in the soil, especially in rotation with annual crops (Loss *et al*., 2013) When combined, these systems alternate grain production with animal grazing on grasses and/or legumes in the same area. For that reason, they are complex systems by nature, with innumerable space-time interactions causing constant changes in physical, chemical and biological properties of the soil (Santos *et al*., 2009, Araújo *et al*., 2010).

Some studies report improvements in soil chemical attributes under CL + NT integrated system. Souza *et al*. (2008), studying phosphorus accumulation and its availability to plants under CL during seven years, observed an increase in total phosphorus content, in both inorganic and organic form, and in labile, moderately labile and not labile fractions. Other authors report changes in organic matter content (Jantalia *et al*., 2007; Leite *et al*., 2010; Silveira *et al*., 2011; Carvalho *et al*., 2010; Loss *et al*., 2012; 2013), variations in soil pH, cation exchange capacity (Cruz *et al*., 2012), exchangeable bases (Flores *et al*., 2008), and decreased levels of toxic aluminum in relation to conventional systems (Souza *et al*., 2009).

Systems which maintain or increase carbon content in soil, consequently increase cation exchange capacity (CEC) and the availability of nutrients for plants (Torres and Pereira, 2008 ant Torres *et al*., 2014). Further, such systems significantly reduce soil erosion by accumulating plant residues on soil surface (Araújo *et al*., 2010).

There have been several studies of CL systems in the Central–South regions of Brazil; however, to date, there are few reports that contemplate nutrient dynamics under CL in the Piauí region. Therefore, the objective of this work was to quantify chemical attributes of Oxisol submitted to different soil management systems in the Savannah.

MATERIAL AND METHODS

Experimental site

This study was conducted on the farm Nova Zelândia, located in the municipality of Uruçuí-PI, at 3º37' S and 43º22' W, at an altitude of 167 meters, on the banks of the Paranaíba river, southwest of state, dividing the states of Piauí and Maranhão, Brazil, more or less 453 km from Teresina, in an area that is inserted in the savannah biome.

The soil in the area was classified as Oxisol of clay-sandy loam texture (Embrapa, 2013), presenting the following chemical characteristics in the 0-20 cm layer (Table 1). However, the predominant soils in the state are the Oxisols (more than 50% of the total) and Entisols, with low fertility, requiring corrective applications, to better use the soil for the agricultural activity (Neves *et al*., 2015).

Table 1. Chemical attributes of the Oxisol in the savannah in Uruçuí-PI, in the agricultural year 2006/2007.

Sistema (2)	pH	P resina	K	Ca^{+2}	Mg^{+2}	$H + Al^{+3}$
	$CaCl_2$	mg dm^{-3}		$mmol_c dm^{-3}$		
SILP + S	5,0	26,5	2,88	17,25	14,75	25,75
SILP + P	4,8	23,5	2,98	16,25	10,5	33,50
SPD + M	5,2	17	1,23	21,50	17,5	25,25
PC	5,1	4,5	1,25	12,25	10,5	20,75
FN	3,9	4,0	0,7	6,25	7,0	100,25

The region's climate

According to the Köppen classification, the climate in the region is Aw, with rainy season from October to April (rainfall concentrated between January and March), annual precipitation of 1.200 mm, and average temperature 26.5°C.

Experimental design

Five soil management systems were studied: 1 = crop–livestock integration system where soybean was rotated with corn and millet was used as forage crop for 5 months (CL + S); 2 = crop–livestock integration system where soybean was rotated with corn and brachiaria was used as cover crop (in this treatment one of the areas was left for continuous grazing with 2.4 adult animal units per hectare) (CL + P); 3 = no-tillage system with millet as cover crop (NT + M); 4 = conventional tillage with plowing and soybeans in monoculture (CT); 5 = Savannah native forest (NF) as a reference of a natural soil condition (control) (Table 2). Soil sampling in the treatments was carried out during the 2006/7 production season.

The experimental design was randomized blocks with four replications, arranged in a scheme of subdivided plots. The plots were composed of five management systems and the subplots of three different sampling depths (0.00–0.05, 0.05–0.10, and 0.10–0.20 m), totaling 60 experimental units. In each treatment, four mini profile trenches (0.50 m deep, 0.40 m wide, 0,60 m long) were dug at random locations, each trench constituting a repetition, in which ten simple samples were collected to form a compound sample.

For each annual crop (rice, soybean and corn), the fertilization of planting and covering was carried out according to their nutritional need, whereas brachiaria and millet were sown, without fertilization, in order to take advantage of residue left by previous crops.

Evaluations

Soil chemical attributes were evaluated at three depths. Exchangeable Al, Ca and Mg levels were extracted with 1 mol L^{-1} KCl and potential acidity (H + Al) extracted with calcium acetate at pH 7.0. These attributes were later determined by titrations. Available P and exchangeable K were extracted with Mehlich^{-1} solution and determined by flame emission photometry and colorimetry, respectively (Embrapa, 2011).

Total organic carbon (TOC) was quantified according to Yeomans and Bremner (1988). First, 0.5 g of fine air-dried soil samples were weighed and sieved through 60 mesh. Next, the material was placed in a 250 mL Erlenmeyer flask to which 5 mL of potassium dichromate (0.167 mol L^{-1} $K_2Cr_2O_7$) and 7.5 mL of sulfuric acid (H_2SO_4) were added. Subsequently, the solution was heated in a digester block at 170°C for 30 minutes. Then, 80 mL of distilled water and 0.3 mL of the indicator solution (phenanthroline) were added to the stock solution with 0.2 mol L^{-1} ammoniacal ferrous sulfate solution.

The stock of C was determined using the following formula: Est C (Mg ha^{-1}) = (C x SBD x e)/10, where: C = total organic carbon in the layer (g kg^{-1}); SBD = soil bulk density (Mg m^{-3}); and e = thickness of the layer under analysis (cm) (Diniz *et al*., 2015).

Soil bulk density (SBD) was determined by volumetric ring method. First, samples from layers 0.00–0.05, 0.05–0.10, and 0.10–0.20 m were collected in rings of 48 mm in diameter and 53 mm in height with the Uhland soil sampler. Then, the samples were dried at 105ºC for 24 h (Embrapa, 2011).

Table 2. Land use history.

System	Production season					
	2001/02	2002/03	2003/04	2004/05	2005/06	2006/07
CT	NF	NF	NF	NF	Soja	Soja
CL+S	Rice	Soybeans	Corn+Cattle	Soybeans/Millet	Soybeans/Millet	Soybeans/Millet
CL+P	Rice	Soybeans	Corn+Cattle	Brach/Cattle	Brach/Cattle	Brach/Cattle
NT+M	NF	NF	Soybeans/Millet	Soybeans/Millet	Soybeans/Millet	Soybeans/Millet
NF	NF	NF	NF	NF	NF	NF

CT = conventional tillage; CL + P = crop–livestock integration with continuous grazing; CL + S = crop–livestock integration with soybean; NT + M = no-tillage with millet. Brach. Brachiaria; NF = Savannah native forest.

Statistical analysis

Obtained results were submitted to analysis of variance, and when necessary to regression analysis for quantitative attributes and to comparison by Scott-Knott test (p <0.01) for qualitative attributes as well. Statistical analyzes were performed using the SAS software, version 9.0.

RESULTS AND DISCUSSION

Analysis of soil fertility

The evaluated management systems significantly increased (p <0.01) soil chemical attributes at all depths when compared to the Savannah native soil (Table 3). This behavior is associated with the diversity that integrated production systems, such as no-tillage systems and crop–livestock integration system offer.

Regarding pH, all treatments increased this trait in the 0.00–0.05 m layer, when compared to the forest soil, which presented the lowest pH (Table 3). High pH in the layer 0.00–0.05 m was probably due to surface liming, which increased the level of exchangeable bases and neutralized H$^+$ ions in the soil solution. These values are in agreement with data obtained by Cruz *et al*. (2012) who, evaluating soil chemical attributes under CL system with corn and grass on Oxisol, also observed increased pH under this management systems when compared to NF soil.

Studies have also demonstrated that no-tillage system under pasture for grazing and soil permanent cover can increase pH, effective CEC, exchangeable bases and phosphorus levels, and reduce saturation by aluminum, thus promoting an accentuated recovery of soil fertility, and consequently a favorable environment for the development of cultivated crops (Souza *et al*., 2009).

All treatments demonstrated high nutrient levels in the top soil layer, but which decreased with depth (Table 3). These results are mainly associated with nutrient cycling that occurs in soils under NT. In the initial stages of decomposition of straw deposited on the soil by previous crop, nutrient cycling is accelerated for 45 days after the cover crop, and then continues slowly for 120 days (Torres *et al*., 2014).

Table 3. Chemical attributes of Oxisol under different management systems in Piauí Savannah.

System	pH	P	K	Ca	Mg	H + Al	BA	CEC	BS
	CaCl$_2$	Mg dm^{-3}			------------- mmol$_c$ dm^{-3} -------				%
0.00–0.05 m									
CL+S	5.1 a*	26.5 a*	2.9 a*	17.3 a*	14.8 b*	25.8 b*	34.9 b*	60.6 b*	58.5 a*
CL+P	4.8 a	23.5 a	2.1 b	16.3 a	8.8 c	33.5 b	29.7 b	63.2 b	46.8 a
NT+M	5.2 a	17.0 b	1.2 c	21.5 a	17.5 a	25.3 b	40.2 a	65.5 b	61.8 a
CT	5.1 a	4.5 c	1.4 c	12.3 b	10.5 c	20.8 b	24.0 c	44.8 b	54.3 a
NF	3.9 b	4.0 c	0.5 d	4.5 c	7.0 d	100.3 a	13.9 d	114.2 a	12.0 b
0.05–0.10 m									
CL+S	4.8 a	66.8 a	1.7 a	19.0 a	12.5 a	33.3 c	33.2 a	66.5 a^{ns}	51.0 a
CL+P	4.3 b	20.8 b	1.0 b	11.8 b	7.8 b	47.0 b	20.5 b	67.5 a	30.0 b
NT+M	4.6 a	8.0 c	0.7 b	14.0 b	11.5 a	43.0 b	26.2 b	69.2 a	38.5 b
CT	5.2 a	5.0 c	0.7 b	18.5 a	13.3 a	24.0 d	32.4 a	56.4 a	57.5 a
NF	3.8 c	3.0 c	0.4 c	3.3 c	2.8 c	79.0 a	6.4 c	85.4 a	7.8 c
0.10–0.20 m									
CL+S	4.5 a	24.3 a	1.9 a	11.5 a	7.0 a	35.5 a	20.4 a	55.9 a^{ns}	38.0 a
CL+P	4.1 a	7.3 b	0.8 b	8.0 b	4.8 b	47.3 a	13.6 b	60.8 a	22.8 a
NT+M	4.6 a	5.3 b	0.6 c	15.3 a	13.3 a	45.8 a	29.1 a	74.9 a	37.0 a
CT	5.1 a	3.8 b	0.4 c	12.3 a	11.0 a	20.3 a	23.6 a	43.9 a	54.5 a
NF	3.7 b	3.0 b	0.5 c	2.5 c	2.0 c	56.5 a	4.9 c	61.5 a	8.3 b
CV%	8.35	29.60	13.25	20.43	20.60	15.90	20.06	18.85	22.01

CT = Conventional tillage; CL + P = crop–livestock integration with continuous grazing; CL + S = Crop–livestock integration with soybean; CNT + M = No-tillage with millet. Brach. Brachiaria; NF = Savannah native forest. BA = Base addition, CEC = Cation exchange capacity; BS = Base saturation. ^{ns} = Not significant; * Means followed by the same lowercase letter in the columns do not differ at 5% probability level by the Scott-Knott test. P, K, Ca, Mg, H + Al, CEC and BA were transformed using the formula (x+1) ^{0,5} to meet the normality and homogeneity criteria for performing the statistical analysis.

In the CL system, residues are deposited on soil surface by the animals at concentrated levels. These results are in accordance with the data observed by Leite *et al*. (2010) who, studying chemical attributes and carbon stocks in Oxisol under no-tillage for 2, 4 and 6 years in Piauí Savannah, observed low pH and low nutrient content in deeper layers.

The CL + S system presented higher P content in layers 0.05–0.10 and 0.10–0.20 m than the other treatments (Table 3). These results may be due to annual application of P fertilizers, higher P release during the decomposition of plant residues, and lower P fixation due to reduced contact with inorganic constituents of the soil, as highlighted by Santos *et al*. (2009).

These results are also in accordance with those reported by Souza *et al*. (2008) who, studying the evolution and distribution of P in soil under no-tillage system and pasture for grazing for six years, verified that P mostly accumulates in moderately labile fractions, predominantly in inorganic form, at all intensities of grazing, and that the animal factor did not influence the accumulation. In addition, the highest P accumulation in this fraction occurs in the surface layer, down to about 0.10 m.

Among the studied management systems, the highest potassium (K) dynamics was under CL + S at all sampled depths. These values may be mainly associated with annual K fertilization for soybean production; nevertheless, potassium levels in the soil were generally low, not exceeding 2.88 mg dm^{-3}.

Evaluating K cycling and balance, and soybean yield under no-tillage combined with CL system, Ferreira *et al*. (2011) report high levels of K in dystroferric Oxisol after eight years of rotation. Torres and Pereira (2008), studying decomposition and cycling of nutrients of cover crops before corn and soybean, observed that the highest accumulation of K occurred under grasses (millet, sorghum and brachiaria) and the highest release of K occurred during the first 42 days after millet, brachiaria, and crotalaria.

Regarding the distribution of K levels in the soil profile, the lowest levels were found in the lowest layer, forming decreasing gradient of K concentration from the top layer down (Table 3). This fact corroborates the results obtained by Ferreira *et al*. (2009). Silveira *et al*. (2011), evaluating soil chemical attributes and productivity of irrigated corn and beans cultivated under CL system during a three-year experiment, report increased K levels (101 to 184 mg dm^{-3}) for a treatment with pasture–beans rotation irrigated in winter, and attribute these results to the high capacity of brachiaria for nutrient cycling.

The evaluated management systems influenced levels of Ca^{2+} and Mg^{2+} when compared to the control. The highest levels were found for the treatments NT + M and CL + S in layers 0.00–0.05 and 0.05–0.10 m respectively; however, no difference among the treatments was found in the 0.10–0.20 m layer (Table 3). There were small variations among the management systems, which can be caused by annual application of limestone. Souza and Alves (2003), studying chemical attributes of Savannah Oxisol under different managements, verified that no-tillage system provides the highest mean values for calcium and magnesium, relative to other systems.

Regardless of the depth, the lowest levels of Ca^{2+} and Mg^{2+} were observed in soil under NF. Oxisols are typically highly weathered, with relatively flat surface and intensive leaching process of exchangeable bases (Table 3). These results are in agreement with those reported by Flores *et al*. (2008) who, studying soil chemical attributes as a function of liming under no-tillage with CL system submitted to grazing, report high levels of exchangeable calcium and magnesium in the soil after 24 months of application, thus demonstrating that animal trampling helps incorporate superficial liming into deeper soil layers.

The treatments reduced potential acidity (H + Al) and cation exchange capacity (T), and increased sum of bases (SB) and base saturation (V%) down to 0.10 m. However, no difference among the treatments was observed for any of these traits in the 0.10–0.20 m (layer Table 3). Even though there were no differences among the management systems for SB and V%, higher levels were observed for NT + M and CL + S.

These results verify results obtained by Flores *et al*. (2008) and Leite *et al*. (2010) who, evaluating chemical attributes of savannah Oxisol under NT for various doses and forms of limestone application, observed that surface liming increased SB, T and V% and decreased exchangeable Al and potential acidity (H + Al) in the 0.00–0.05 layer m 6 months after liming, and that 18–30 months after liming the effect extended down to 0.10 m.

Total organic carbon (TOC) and carbon stock (C) in the soil

In general, soil density, total organic carbon (TOC) and carbon stock (C) are higher in systems with crop rotation, but when soil cover is maintained for a long period (Table 4). However, when analyzing the layers we observed that the level of TOC was higher in the top layer, which may be caused by the high deposition of plant residues and animal excrements in this layer.

The lowest values of TOC occurred in the conventional tillage system at the depths sampled, with higher values in the CL + S and NT + M values of 0.05-0.10 and 0.10-0.20 m, respectively (Table 4).The lowest soil organic matter (SOM) levels were observed under the conventional tillage system at all sampled depths, and the highest levels under CL + S and NT + M in layers 0.05–0.10 and 0.10–0.20 m, respectively (Table 4). Organic matter in the soil helps form amphoteric compounds that act as a buffer for pH alterations, which can elevate ionic strength of soil solution due to higher levels of exchangeable bases (Ca, Mg and K) in the surface layer. These results may also be due to or complemented by organic acids of low molecular weight, since the exudation of organic compounds by the root system may be responsible for a more homogeneous effect relative to the acidity of soil under pasture, since the distribution of animal residues is heterogeneous (Anghinoni *et al*., 2011).

Conversely, C stock was higher in deeper layers. This fact may be caused by high biomass of fine roots which are rapidly renewed, especially by grasses used in pasture, whose roots are characterized by intense exudation of organic compounds, thus increasing the levels of C in deeper layers (Coutinho *et al*., 2010).

According to Jantalia *et al*. (2007), high TOC levels under NT system down to 0.20 m are caused by high level of phytomass on the surface and reduced use of agricultural implements for soil preparation, thus increasing OM and decreasing decomposition of physically protected organic material in soil aggregates. Rossi *et al*. (2012), studying soil under soybean crop down to 0.00–0.40 m, found 11.60, 10.0, 10.0, and 7.9 Mg ha^{-1} of C in layer 0.0–0.05.

CONCLUSIONS

Soil management systems evaluated in this study modify soil chemical attributes relative to the native savannah soil. Crop–livestock integration systems improve soil chemical quality, increase total surface organic carbon, and deep carbon stock.

Table 4. Soil bulk density of (SBD), total organic carbon (TOC) and soil carbon stock (C stock) under different management systems in Piaui Savannah.

System	SBD	TOC			C stock		
	Mg m^{-3}	................g kg^{-1}................			………..Mg ha^{-1}………….		
	(mean)	0.0–0.05	0.05–0.10	0.10–0.20	0.0–0.05	0.05–0.10	0.10–0.20
		……...........................m………………….….					
CL+S	1.40 a*	9.19 Aa*	8.69 Aa*	6.52 Ba*	6.04 Ba*	6.20 Ba*	9.36 Ab*
CL+P	1.42 a	8.69 Aa	8.36 Aa	7.73 Aa	6.44 Ba	5.71 Ba	10.93 Aa
NT+M	1.32 b	8.31 Aa	5.84 Bb	6.49 Ba	5.23 Ba	3.75 Cb	9.21 Ab
CT	1.41 a	4.71 Ac	4.61 Ab	3.72 Ab	3.13 Bc	3.09 Bb	5.73 Ac
NF	1.30 b	7.05 Ab	5.90 Ab	4.46 Bb	4.46 Bb	3.85 Bb	5.95 Ac
CV%	5.0	…………..11.8……………			…………11.3…………		

CT = conventional tillage; CL + P = crop–livestock integration with continuous grazing; CL + S = crop–livestock integration with soybean; NT + M = no-tillage with millet; NF = Savannah native forest. * = Averages followed by the same lowercase letter in the columns and upper case in the row do not differ at 5% probability level (Scott-Knott test).

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