

Nutrient availability and organic matter content under different soil use and management

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ABSTRACT

The use of the system, handling and time adoption of these can effectively alter the quantity of organic matter (OM) and change the cycling of nutrients in the soil. This paper aimed at evaluating the availability of nutrients and OM contents in an Oxisol (Xanthic Ferralsol) located within a Cerrado area (Savannah ecosystem) of the Piauí State in Brazil, after years under different soil use and management systems. The treatments consisted of soils under no-tillage for three, six and nine years (NTS3, NTS6, and NTS9); pasture for two and six years (PA2 and PA6, respectively); eucalyptus plantation for six and 12 years (EU6 and EU12); conventional tillage system for two and eight years (CTS2 and CTS8) and native Cerrado (NC), which represented conditions of equilibrium. For each area, we assessed the levels of OM, pH in water, Al^{3+} , $H^+ + Al^{3+}$, P, K^+ , Ca^{2+} and Mg^{2+} at four soil depths (0.0-0.10, 0.10-0.20, 0.20-0.30 and 0.30-0.40 m) as well as the levels of Cu, Mn, Zn, Fe, B and S at 0.0-0.40 m depth, all with four replicates. Use and management systems provided significant effects on the availability of soil macronutrients and OM contents, but have inadequate levels of micronutrients in the soil, especially Boron. In areas under tillage, there is an increase in pH, availability of nutrients and OM in the surface layer, especially during the first six years of adoption of the system, while in the areas with nine years; there were an increase in P levels in subsurface. The areas under cultivation with eucalyptus show higher potential in increasing the OM levels in soil subsurface layers.

Key words: aluminum toxicity; chemical properties; soil fertility

Disponibilidade de nutrientes e teor de matéria orgânica sob diferentes sistemas de uso e manejo

RESUMO

O sistema de uso, manejo e o tempo de adoção destes pode alterar a quantidade de matéria orgânica (MO) e o ciclo de nutrientes no solo. Este trabalho teve como objetivo avaliar a disponibilidade de nutrientes e o teor MO em um Latossolo localizado em uma área de Cerrado (ecossistema Savana) do estado do Piauí no Brasil, após anos sob diferentes sistemas de uso e manejo do solo. Os tratamentos consistiram de solos sob de plantio direto com três, seis e nove anos de cultivo (NTS3, NTS6 e NTS9) áreas sob pastagem com dois e seis anos de cultivo (PA2 e PA6), áreas sob plantio de eucalipto com seis e doze anos de cultivo (EU6 e EU12), áreas sob sistema plantio convencional com dois e oito anos de cultivo (CTS2 e CTS8) e Cerrado nativo (NC), representando uma condição de equilíbrio. Para cada área, foram avaliados os teores de MO, pH em água, Al^{3+} , $H^+ + Al^{3+}$, P, K^+ , Ca^{2+} , Mg^{2+} , em quatro profundidades do solo (0-10, 10-20, 20-30 e 30-40 cm) e teores de Cu, Mn, Zn, Fe, B e S, na profundidade de 0-40 cm, todos com quatro repetições. Os sistemas de uso e manejo proporcionaram efeitos significativos na disponibilidade de macronutrientes no solo e nos teores de MO, mas apresentam níveis inadequados de micronutrientes no solo, especialmente boro. Nas áreas de plantio direto, há aumento de pH, disponibilidade de nutrientes e MO na camada superficial, especialmente nos primeiros seis anos de adoção do sistema, enquanto nas áreas com nove anos, houve um aumento nos níveis de P em subsuperfície. As áreas cultivadas com eucalipto apresentam maior potencial de aumento dos teores de MO nas camadas subsuperficiais do solo.

Palavras-chave: toxicidade de alumínio; propriedades químicas; fertilidade do solo

Introduction

The area covered with Cerrado vegetation in Piauí State stands out in Brazil by its size, reaching more than 11 million hectares, as well as its potential for agricultural use, especially for high-tech grain crops. Over 962,695 ha were cultivated with soybean [*Glycine max* (L.) Merrill], corn (*Zea mays*) and cotton (*Gossypium hirsutum* L.) crops in southwestern Piauí during the 2015/ 2016 crop season (Conab, 2016). Despite the high technological level of the farming systems utilized in Cerrado areas of the Piauí State, the predominance of monoculture associated with inadequate cultural practices, such as continuous soil inversion and lack of cover, have been compromised crop yields and caused soil degradation besides other environmental problems (Araújo et al., 2008; Leite et al., 2010b).

Strategies to maintain or increase crop yields and soil quality by reducing soil inversion as well as the use of ameliorants such as lime and fertilizers should be prioritized. Thus, studies (Araújo et al., 2008; Leite et al., 2010b; Pragana et al., 2012a; Cardoso Júnior et al., 2016) evaluating, sustainable agriculture in the state of Piauí requires the use of plant species more efficient in nutrient uptake associated with management systems able to accumulate nutrients in labile form.

Conservation systems usually promote positive changes in soil properties (Leite et al., 2010a; Moreira & Fageria, 2011; Moreira et al., 2011; Pragana et al., 2012a; b; Campos et al., 2013; Bressan et al., 2013) derived from a rise in the content of organic matter (OM) in the soil. The presence of OM in soils makes alterations in important chemical properties such as pH, cation exchange capacity (CEC) and nutrient availability, mainly in P content (Martínez et al., 2013). Moreover, the CEC in tropical soils is dependent of OM content, since it is the main source of negative charges regarding a high specific surface area, low point of zero charge (PZC) and deprotonation of carboxylic, alcoholic, and phenolic groups, which occur with increasing soil pH (Melo & Alleoni, 2009).

Shifting soil tillage from conventional to no-tillage systems promotes a series of chemical changes, mostly concerning nutrient availability (Pavinato & Rosolem, 2008). Overall, there has been a trend of nutrient accumulation in surface soil layers and particularly of Ca^{2+} , Mg^{2+} , K^+ and P. This buildup is due to the absence of soil inversion and nutrient storage within plant tissues, which after decomposition are released on to soil surface (Pavinato & Rosolem, 2008; Calegari et al., 2013). Changes in land use such as replacing grain crops with pasture monoculture or intercropped, crop-livestock systems, and permanent crops as eucalyptus have been considered less damaging to soil in some areas of the Brazilian Cerrado (Lopes & Guilherme, 2016). Even so, the effects of these practices on soils in Cerrado areas of Piauí are still unknown.

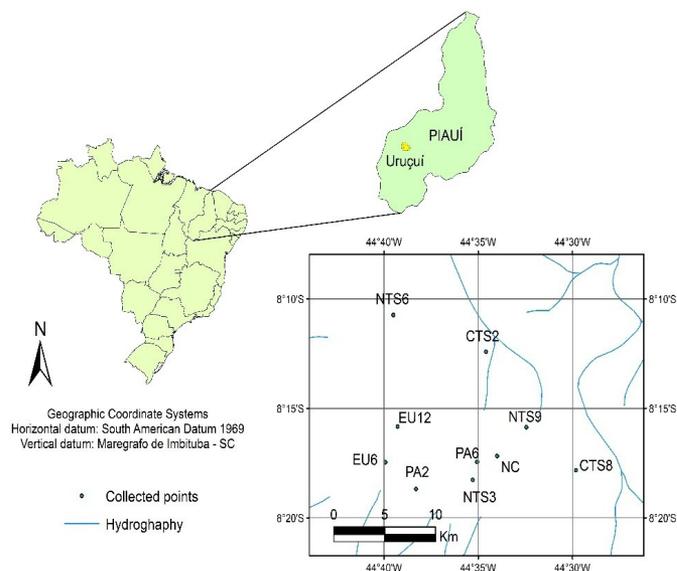
Given the above, studies evaluating the management systems effect, associated with different long-term land uses, are highlighted not only by the novel results but also upon presentation of most sustainable alternatives to sustain or enhance soil quality to the current production systems in transition areas of Cerrado to Caatinga. We hypothesized that the chemical characteristics and the soil organic matter content

tend to be higher under use and conservation management systems in subtropical humid conditions of Brazil's northeast. In this sense, the objective of this study was to assess the changes in nutrient availability and organic matter content in Cerrado Oxisols (Xanthic Ferralsol) located in the State of Piauí that are under different soil use and management systems.

Materials and Methods

The study was conducted in the county of Nova Santa Rosa, which is in the city of Uruçuí, Piauí State, Brazil (Figure 1). According to Köppen, local climate is classified as Aw tropical, which is characterized as warm and humid with an average temperature ranging from 23 to 24 °C. The region has an annual rainfall of between 800 and 1200 mm, with a rainy season extending from November to April (Aguiar & Gomes, 2004). In the study area, the dominant soils are Xanthic Ferralsols Dystric or Alic (IUSS Working Group WRB 2015) “Latosolos Amarelos álicos ou distróficos” as described by (Jacomine et al., 1986), which are typically deep, well drained, and acidic, with low fertility and within a flat to slightly rolling topography.

At the farm a particular sequence different soil use and management was studied that represents a popular practice in the area after Cerrado clearing. This implies that the experimental area was primarily not set up for scientific purposes. The experimental design was completely randomized with 10 treatments. They consisted of soil under no-tillage for three, six and nine years (NTS3, NTS6, and NTS9); pasture for two and six years (PA2 and PA6); eucalyptus for six and 12 years (EU6 and EU12); conventional system for two and eight years (CTS2 and CTS8) and native Cerrado (NC), which represented equilibrium conditions. Table 1 shows the full history of managements utilized in the studied areas.



NTS3: no-tillage system for three years, NTS6: no-tillage system for six years, NTS9: no-tillage system for nine years, PA2: pasture for two years, PA6: pasture for six years, EU6: eucalyptus plantation for six years, EU12: eucalyptus plantation for 12 years, CTS2: conventional tillage system for two years, CTS8: conventional tillage system for eight years, NC: native Cerrado.

Figure 1. Location of the study areas in the District of Nova Santa Rosa, Piauí State, Brazil.

Table 1. Oxisol under Cerrado history in the state of Piauí after various years of cultivation under different soil uses and management systems.

Systems ⁽¹⁾	Conventional planting				Management and/or conservationist use				
	Period	Crops annuals	Limestone Mg ha ⁻¹	*N-P-K ⁽²⁾ Kg ha ⁻¹	Period	Crops annuals	Limestone Mg ha ⁻¹	Gypsum Kg ha ⁻¹	N-P-K Kg ha ⁻¹
NTS3	1999/00-2009/10	A-S-S-S-S-S-S-S-S-S	5 ⁽³⁾ -AR	0-100-120 ⁽⁴⁾	2010/11-2012/13	Mt/Mi-Mt/S-Mt/Mi	AR	-	AR
NTS6	2002/03-2006/07	A-S-S-S-S-S	5-AR	0-100-120	2007/08-2012/13	Mt/S-Mt/Mi-Mt/S-Mt/Mi-Mt/S-Mt/Mi	AR	-	AR
NTS9	2001/02-2003/04	A-S-S	4.5-AR	0-100-80	2004/05-2012/13	Mt/S-Mt/S-Mt/Sg-Mt/S-Mt/S-Mt/S-Mt/Mi-Mt/S-Mt/S	AR	500 harvest 2010/11	AR
PA2	2001/02-2010/11	A-A-S-S-S-S-S-Mi-Mi	2-AR	130-100-120	2011/12-2012/13	<i>Urochloa brizantha</i>	-	-	AR
PA6	2000/01-2006/07	A-A-S-S-S-S-S-S	4-AR	130-100-120	2007/08-2012/13	<i>Urochloa brizantha</i>	-	-	AR
EU6	2006/07	A	5-AR	0-35-18	2007/08-2012/13	<i>Eucalyptus urophilla</i>	-	-	AR
EU12	2000/01	A	4-AR	0-35-18	2001/02-2012/13	<i>Eucalyptus urophilla</i>	-	-	AR
CTS2	2011/12-2012/13	A-S	0-AR	0-130-95	-	-	-	-	-
CTS8	2005/06-2012/13	S-S-S-S-S-S-Mi	5-AR	130-100-120	-	-	-	-	-
NC	-	-	-	-	-	-	-	-	-

⁽¹⁾NTS3: no-tillage system for three years, NTS6: no-tillage system for six years, NTS9: no-tillage system for nine years, PA2: pasture for two years, PA6: pasture for six years, EU6: eucalyptus plantation for six years, EU12: eucalyptus plantation for 12 years, CTS2: conventional tillage system for two years, CTS8: conventional tillage system for eight years, NC: native Cerrado. A: upland rice; S: Dryland soybean; Sg: Dryland sorghum; Mi: Dryland corn; Mt: millet, planting after soybean harvest; AR: correction and fertilization as required by the culture; ⁽²⁾N-P-K, respectively nitrogen, phosphorus, and potassium in the form of urea, simple superphosphate, and potassium chloride; ⁽³⁾initial soil correction; ⁽⁴⁾fertilization based on soybean crops, with nitrogen used only in crops with corn; *CaCO₃: relative power of total neutralization (90%).

Soil sampling for chemical properties was conducted in August 2013. Initially, we demarcated one-hectare plots using a GPS device and a measuring tape over all different management areas, starting from a point in the center of each plot. Then, from that area, 25 points were set distant from each other by 25 m. After that, four of the 25 points were randomly selected to constitute the four replicates for each area. For the area under NC, we stepped into a legal reserve for 15 m from its edge at four distinct points spread throughout the area, being 25 m apart from each other; so, we then proceeded plot demarcation using a GPS and a measuring tape. For each selected point (replicate), we collected eight soil samples, which were homogenized into a 600-g single sample. Samples were collected separately at 0.0-0.10, 0.10-0.20, 0.20-0.30 and 0.30-0.40 m depths.

For chemical attributes, samples were air-dried and passed through a 2-mm mesh sieve. We determined pH in water

(1:2.5), potential acidity (H⁺+Al³⁺) using SMP-buffer solution and exchangeable acidity (Al³⁺) using 1.0 mol L⁻¹ of KCl and titration with 0.025 mol L⁻¹ sodium hydroxide as proposed by Embrapa (2011). Total organic carbon (TOC) content was measured by wet digestion using a mixture of potassium dichromate and sulfuric acid under heating (Yeomans & Bremner, 1988). The Van Bemmelen factor (1.724) was used to convert the total TOC into a soil organic matter (SOM) content.

The phosphorus (P) and potassium (K⁺) were extracted by Mehlich-1 solution and determined by flame calorimetry and photometry, respectively. Calcium (Ca²⁺) and magnesium (Mg²⁺) were extracted with 1.0 mol L⁻¹ KCl and determined by atomic absorption spectrophotometry. Available zinc (Zn²⁺), manganese (Mn²⁺) and copper (Cu²⁺) were also extracted with Mehlich-1 and boron (B) with hot water and quantified by colorimetry. In addition, monocalcium phosphate at 500

Table 2. Particle size distribution, oxide contents extracted in TFSA by sulphuric acid digestion, and Ki and Kr rates of an Oxisol under Cerrado in the state of Piauí after various years of cultivation under different soil uses and management systems.

Use and management system	Sand ⁽¹⁾			Silt ⁽¹⁾			Clay ⁽¹⁾		
	g kg ⁻¹								
	0.0-0.20 m								
NTS3	760			40			200		
NTS6	770			30			200		
NTS9	810			50			140		
PA2	760			50			190		
PA6	760			70			170		
EU6	800			10			190		
EU12	800			30			170		
CTS2	750			60			190		
CTS8	800			50			150		
NC	700			60			240		
Sulphuric acid treatment 0.0-0.40 m									
NC	P ₂ O ₅	%SiO ₂	%Al ₂ O ₃	%Fe ₂ O ₃	%TiO ₂	%P ₂ O ₅	Ki ⁽²⁾	Kr ⁽³⁾	Al ₂ O ₃ /Fe ₂ O ₃
	0.01	9.19	8.99	4.43	0.486	0.006	1.74	1.32	3.18

NTS3: no-tillage system for three years, NTS6: no-tillage system for six years, NTS9: no-tillage system for nine years, PA2: pasture for two years, PA6: pasture for six years, EU6: eucalyptus plantation for six years, EU12: eucalyptus plantation for 12 years, CTS2: conventional tillage system for two years, CTS8: conventional tillage system for eight years, NC: native Cerrado. ⁽¹⁾Pipette method; ⁽²⁾Ki: molecular ratio SiO₂:Al₂O₃; ⁽³⁾Kr: molecular ratio SiO₂:(Al₂O₃+Fe₂O₃).

mg kg⁻¹ of P and 2.0 N acetic acid were used to determine S concentration (Embrapa, 2011). Based on K⁺, Ca²⁺, Mg²⁺, Al³⁺ and H+Al contents, we calculated sum of bases (SB), potential (T) and effective (t) cation exchange capacity calculated (CEC), base saturation (V) and aluminium (m) indexes according to Embrapa (2011). Soil particle size (Table 2) was determined by the pipette method (Embrapa, 2011). SiO₂, Al₂O₃, Fe₂O₃, TiO₂ and P₂O₅ content were determined after sulfuric acid digestion.

The data for variance homogeneity and normality at 95% probability were tested. The data obtained for each soil management and use system for each depth separately were analyzed. Each variable underwent analysis of variance (ANOVA) and, when significant, comparisons were performed by the Scott-Knott test ($p \leq 0.05$) using SISVAR software (Ferreira, 2014).

In addition, we used a multivariate technique. Since the variables were expressed in different measurement units, the data were standardized (mean = 0 and variance = 151.1) to ensure all variables contribute equally to the model, regardless of scale. We also performed principal component analysis (PCA) to narrow the range of variables to a meaningful amount (represented by the factors) and identify which variables belong to each factor, as well as check how much each variable explains each factor. The criterion used to choosing the number of factors was to select those variables with eigenvalues higher than one which are able to synthesize a cumulative variance above 157.75%. The Statistica software version 7.0 for multivariate analyses 158 was used (Statsoft, 2004).

Results and Discussion

The organic matter (OM) contents at 0.0–0.10 m depth were significantly higher in soils under NC and NTS6 than in the other treatments (Table 3). On the other hand, there was no differences among all treatments at the depth of 0.10–0.20 m. This similarity might be due to the increased organic waste amount left on soil during soybean and millet rotation between the maize crops during harvests 2007/08 to 2012/13 (Table 1), that was not observed in NTS9. Furthermore, EU6, EU12 and NC achieved major values at depths of 0.20–0.30 and 0.30–0.40 m. This shows that the removal of native vegetation and soil inversion caused significant losses in OM mainly in the topsoil. The similarity of OM contents found at 0.20–0.30 and 0.30–0.40 m depths in soils under EU and NC come from root deposition of organic residues that substantially increases throughout soil profile (Pegoraro et al., 2011).

The pH values of soil under cultivation were higher than under NC as an effect ameliorants such as lime and soil fertilization at planting. Among them, the highest pH values ($p \leq 0.05$) were observed in NTS3 and NTS6 at 0.0–0.10 m depth (Table 3). Matias et al. (2009) and Campos et al. (2011) also observed an increase in pH in the surface layer in areas under no-tillage. Contrarily, at 0.10–0.20, 0.20–0.30, and 0.30–0.40 m depth, the highest pH values were reached in soils under EU, being attributed to its higher OM amounts (Table 3). The soil pH values are increased with the addition of plant residue, which can be achieved either by ion exchange or complexation of H⁺ and Al³⁺ by Ca²⁺, Mg²⁺, K⁺ and others within the residue

Table 3. Average values of soil organic matter (SOM), pH in water, exchangeable Al³⁺, H⁺+Al³⁺, and aluminum saturation (m) of an Oxisol under Cerrado in the Piauí State after various years of cultivation under different soil uses and management systems.

Systems	SOM %	pH H ₂ O (1:2.5)	Al ³⁺ H ⁺ +Al ³⁺		m %
			cmol _c dm ⁻³		
0.0-0.10 m depth					
NTS3	2.71b	5.65a	0.10b	3.40b	2.99c
NTS6	3.52a	5.45a	0.17b	4.74b	4.56c
NTS9	3.10b	5.32b	0.12b	4.17b	3.19c
PA2	3.14b	5.30b	0.12b	4.53b	3.57c
PA6	3.31b	5.15b	0.35b	5.71b	11.95b
EU6	2.78b	5.37b	0.25b	4.40b	9.14b
EU12	3.21b	5.30b	0.22b	4.07b	9.60b
CTS2	3.08b	5.27b	0.25b	3.99b	10.90b
CTS8	2.94b	5.15b	0.22b	4.29b	8.07b
NC	3.82a	4.62c	1.75a	9.66a	88.29a
0.10-0.20 m depth					
NTS3	2.15a	5.17b	0.40c	4.59c	25.89b
NTS6	2.23a	4.97c	0.70b	5.82b	39.30b
NTS9	2.20a	5.02c	0.52c	5.39b	25.14b
PA2	2.45a	4.90c	0.62b	5.84b	32.40b
PA6	2.39a	5.00c	0.70b	5.97b	37.44b
EU6	2.45a	5.42a	0.35c	4.78c	15.04b
EU12	2.39a	5.25b	0.37c	4.54c	18.45b
CTS2	2.05a	5.10c	0.45c	4.17c	27.40b
CTS8	1.96a	5.00c	0.45c	4.17c	28.79b
NC	2.55a	4.72d	1.27a	7.06a	85.10a
0.20-0.30 m depth					
NTS3	1.51b	4.85c	0.50c	3.95b	40.40c
NTS6	1.38b	4.67d	0.80b	4.53b	72.24a
NTS9	1.67b	4.94b	0.42c	4.57b	25.36c
PA2	1.46b	4.60d	0.60c	4.05b	50.91b
PA6	1.55b	4.95b	0.62c	4.41b	59.29b
EU6	2.08a	5.20a	0.47c	4.40b	33.27c
EU12	1.96a	5.07a	0.55c	4.16b	35.18c
CTS2	1.44b	4.70d	0.57c	3.62b	58.33b
CTS8	1.61b	4.87c	0.50c	4.05b	33.99c
NC	1.84a	4.82c	1.12a	5.69a	83.54a
0.30-0.40 m depth					
NTS3	1.18b	4.62b	0.50c	3.33b	47.02b
NTS6	1.21b	4.45a	0.77b	3.83b	72.69a
NTS9	1.32b	4.82a	0.40c	3.52b	33.47b
PA2	1.35b	4.57b	0.52c	3.63b	49.22b
PA6	1.26b	4.85b	0.62c	3.93b	71.71a
EU6	1.95a	5.00a	0.57c	4.72a	54.25b
EU12	1.72a	4.92a	0.57c	3.93b	46.03b
CTS2	1.40b	4.80a	0.50c	3.15b	51.09b
CTS8	1.35b	4.67b	0.55c	3.43b	45.62b
NC	1.58a	4.87a	1.07a	5.08a	82.47a

NTS3: no-tillage system for three years, NTS6: no-tillage system for six years, NTS9: no-tillage system for nine years, PA2: pasture for two years, PA6: pasture for six years, EU6: eucalyptus plantation for six years, EU12: eucalyptus plantation for 12 years, CTS2: conventional tillage system for two years, CTS8: conventional tillage system for eight years, NC: native Cerrado. SOM: determined by the Walkley-Black method; pH in water, in a soil-water ratio of 1:2.5; Al³⁺: extractor 1 mol/L KCl and titration with 0.025 mol/L sodium hydroxide; H+Al: SMP-buffer solution. Means followed by different letters in the columns differ from each other by the Scott-Knott test at 5% probability in each depth.

and as consequence increasing base saturation (Pavinato & Rosolem, 2008). Ligand exchange reactions of organic anions with hydroxyl terminal groups of Fe and Al oxides have also been proposed as cause of elevated pH derived from OM increase (Pavinato & Rosolem, 2008).

Other acidity components as Al³⁺, H⁺+Al³⁺ and m were also affected ($p \leq 0.05$) by use and management, presenting lower values compared to NC, except for H⁺+Al³⁺ at 0.20–0.30 m depth in NTS6 and at 0.30–0.40 m in EU6, as well as form in NTS6 and PA6, in which values were similar to NC (Table 3). Overall, we found greater amounts of Al³⁺, H+Al and m within soil profile under NC. These results are associated with lower

pH values and exchangeable bases concentration. However periodic liming and fertilization decreased soil acidity in areas 191 under cultivation caused by both H^+ and Al^{3+} activities in soil solution. Carneiro et al. (2009) observed higher levels of Al^{3+} and lower of Ca^{2+} , Mg^{2+} and P in NC compared to cropping areas, which arises from the lack of acidity correction and fertilization in such originally dystrophic soil.

Available phosphorus levels, exchangeable bases and cation exchange capacity

The P content was significantly lower for soils under NC regardless depth, and the highest amounts were observed in the topsoil (Table 4). Comparing the areas under cultivation, we observed that NTS9 had the highest P levels ($p \leq 0.05$) except at 0.0–0.10 m depth, in which NTS6 stood out. Several studies have shown that no tillage topsoil has the largest amount of P

(Martínez et al., 2013). Such fact has been attributed to various causes as non-incorporation of phosphate fertilizers, the low mobility of the nutrient within the soil profile as well as a smaller contact of fertilizer with soil mineral fraction, which decreases P adsorption mainly by iron and aluminum oxides (Tiecher et al., 2012; Andrade et al., 2012).

NTS3 and NTS6 had higher exchangeable K^+ than other treatments at 0.0–0.10 m depth (Table 4). However, at the other depths, higher values were observed in NTS3 and CTS8, except at 0.30–0.40 m, at which CTS8 presented values higher than NTS3 did. Silva (2012) also reported a decrease in K^+ contents with soil depth in Cerrado areas of Piauí state under different management systems. The low amount of organic compounds in CTS8 (Table 3) as its low cation exchange capacity (Table 4), together with successive potassium fertilizations, may have contributed to K^+ leaching to subsurface soil layers. It is

Table 4. Phosphorus (P), potassium (K^+), calcium (Ca^{2+}), magnesium (Mg^{2+}), sum of exchangeable bases (SB), effective (t) and potential (T) cation exchange capacity, and base saturation (V) values of an Oxisol under Cerrado in the state of Piauí after various years of cultivation under different soil uses and management systems.

Systems	P	K^+	Ca^{2+}	Mg^{2+}	SB	t	T	V
	mg dm ⁻³		cmol _c dm ⁻³					
0.0-0.10 m depth								
NTS3	33.57b	113.50a	2.72a	0.92a	3.94a	4.04a	7.34c	53.72a
NTS6	46.90a	129.50a	2.85a	0.62b	3.81a	3.98a	8.55b	44.89a
NTS9	32.46b	59.00c	2.55a	1.10a	3.80a	3.93a	7.98b	47.74a
PA2	19.83c	79.00b	2.27a	1.02a	3.50a	3.63a	8.03b	43.57a
PA6	7.99d	43.50c	1.82b	0.87a	2.81b	3.16b	8.52b	33.29b
EU6	2.76e	16.50d	1.35b	1.07a	2.47b	2.72b	6.87c	35.94b
EU12	7.19d	26.50d	1.65b	0.67b	2.39b	2.62b	6.46c	36.91b
CTS2	12.50d	43.50c	1.37b	1.00a	2.48b	2.73b	6.47c	38.13b
CTS8	28.41b	94.00b	1.75b	0.65b	2.64b	2.87b	6.94c	38.11b
NC	0.84e	11.50d	0.10c	0.10c	0.23b	1.98c	9.89a	2.37c
0.10-0.20 m depth								
NTS3	18.91b	52.50a	1.15a	0.42c	1.71a	2.11a	6.30b	26.66a
NTS6	13.78b	37.00b	0.85a	0.22d	1.17a	1.87a	6.99a	16.77a
NTS9	30.72a	30.50b	1.05a	0.45c	1.58a	2.10a	6.96a	22.73a
PA2	14.18b	30.00b	0.87a	0.40c	1.35a	1.98a	7.19a	18.84a
PA6	8.03c	14.00c	0.95a	0.32b	1.31a	2.01a	7.28a	17.73a
EU6	1.71c	9.50c	1.17a	0.87a	2.08a	2.43a	6.86a	30.12a
EU12	3.22c	14.00c	1.17a	0.60b	1.81a	2.18a	6.36b	28.51a
CTS2	5.11c	22.00c	0.72a	0.47c	1.26a	1.71a	5.43c	23.17a
CTS8	21.60b	43.00a	0.80a	0.27d	1.18a	1.63a	5.36c	21.85a
NC	0.42e	8.50c	0.10b	0.10d	0.22b	1.50a	7.28a	3.06b
0.20-0.30 m depth								
NTS3	12.47a	34.00a	0.70a	0.27c	1.06a	1.56a	5.01b	19.45a
NTS6	4.00b	15.50c	0.16b	0.12d	0.31b	1.15b	4.85b	6.60b
NTS9	15.52a	26.00b	0.82a	0.37b	1.27a	1.69a	5.84a	21.63a
PA2	3.69b	16.00c	0.32b	0.22c	0.59b	1.19b	4.65b	12.72b
PA6	3.87b	10.00c	0.27b	0.12d	0.43b	1.05b	4.84b	8.93b
EU6	1.42b	7.00c	0.47a	0.52a	1.02a	1.49a	5.42a	18.65a
EU12	2.46b	11.00c	0.70a	0.32b	1.05a	1.60a	5.21b	20.12a
CTS2	2.53b	15.00c	0.22b	0.15d	0.41b	0.99b	4.03b	10.21b
CTS8	11.98a	42.00a	0.67a	0.25c	1.03a	1.53a	5.08b	20.26a
NC	0.49b	6.00c	0.10b	0.10d	0.22b	1.34a	5.91a	3.71c
0.30-0.40 m depth								
NTS3	7.04a	24.50b	0.40a	0.17b	0.64a	1.14a	3.97b	15.49a
NTS6	1.56b	11.00c	0.15b	0.12b	0.30b	1.08b	4.13b	7.10b
NTS9	7.97a	20.50b	0.50a	0.25a	0.80a	1.20a	4.33b	18.53a
PA2	2.60b	15.00c	0.30a	0.20a	0.54a	1.06b	4.17b	12.95a
PA6	1.35b	6.50d	0.12b	0.10b	0.24b	0.87b	4.18b	5.77b
EU6	1.13b	6.50d	0.20b	0.27a	0.49a	1.07b	5.22a	9.66b
EU12	1.64b	9.00d	0.45a	0.22a	0.70a	1.27a	4.63a	14.91a
CTS2	2.00b	12.00c	0.27b	0.17b	0.49a	0.98b	3.64b	13.16a
CTS8	6.57a	30.50a	0.42a	0.15b	0.65a	1.20a	4.08b	16.03a
NC	0.35b	6.00d	0.10b	0.10b	0.22b	1.29a	5.30a	4.11b

NTS3: no-tillage system for three years, NTS6: no-tillage system for six years, NTS9: no-tillage system for nine years, PA2: pasture for two years, PA6: pasture for six years, EU6: eucalyptus plantation for six years, EU12: eucalyptus plantation for 12 years, CTS2: conventional tillage system for two years, CTS8: conventional tillage system for eight years, NC: native Cerrado. P and K: extractor Mehlich-1 (0.0125 mol L⁻¹ H₂SO₄ + 0.05 mol L⁻¹ HCl); Ca²⁺ and Mg²⁺: extractant 1.0 mol L⁻¹ KCl. Means followed by different letters in the columns differ from each other by the Scott-Knott test at 5% probability in each depth.

noteworthy to mention that before NTS3 implementation, the area was cultivated under a conventional management for 10 years (Table 1), which also explains the highest levels of K^+ in soil subsurface.

The cultivated soils had higher levels of Ca^{2+} and Mg^{2+} ($p \leq 0.05$) owed to direct liming and/ or fertilizations (Table 4). Regarding Ca^{2+} , NTS and PA2 presented higher contents in surface layer than other treatments did, while in NTS9 the highest values were found in subsurface layers. With respect to Mg^{2+} , NTS9 had the highest contents in surface layer, whereas in EU6, they were higher in deeper layers. Carvalho et al. (2007) found higher levels of both Ca^{2+} and Mg^{2+} in NTS superficial layer after longer times under management, which was due to fertilizer addition along with higher cation retention capacity of this system. Moreover, Andrade et al. (2012) attributed the higher contents of Ca^{2+} and Mg^{2+} in topsoil under NTS to OM content, which favours cation adsorption by soil constituents what consequently reduces losses by erosion and leaching.

As a consequence, sum of bases values (SB) and V ($p \leq 0.05$) reflected Ca^{2+} , Mg^{2+} and K^+ behavior, in particular Ca^{2+} , which were larger in surface layer for areas under NTS and PA2 (Table 4) (Leite et al., 2010a), these values confirm a major concentration of exchangeable bases within topsoil, mainly between 0.0 and 0.10 m depth in a NTS. In this management system, fertilizers and correctives are applied without incorporation, a fact that contributes both to reduce the contact surface between soil particles and products (corrective and/ or fertilizers) as to restrict the effect of these practices on most superficial layers. Similar results were reported by Campos et al. (2011), who detected the accumulation of exchangeable bases within 0.0-0.10 m layer soil under NTS when assessing changes in chemical attributes of a Xanthic Ferralsol under different management systems in the Cerrado of Piauí State. Larger V values in the surface layer of a soil under NTS had also reported by Carvalho et al. (2007). It was observed that increases in V values of surface layer is not always associated with base saturation by liming, but also is related to the complexation of Al^{3+} by stable organic compounds (Campos et al., 2011), which may have happened in this study. In depth, the largest V values occurred in soil under EU6 and NTS9 at 0.10-0.20 and 0.20-0.30 m depths, respectively. In the depth of 0.30-0.40 m, NC showed the largest t values due to the high amount of exchangeable Al^{3+} , whilst the NTS9 had the largest V values.

The T values were the highest in soil under NC at all depth (Table 4). Such result is directly related to the potential acidity and OM content encountered in these soils. Amounts similar to those for NC were observed for NTS, NTS9, PA2, PA6, and EU6 at 0.10-0.20 m depth; for NTS9 and EU6 at 0.20-0.30 m depth; and for EU6 and EU12 at 0.30-0.40 m depth, which stems from the higher levels of SOM in these layers (Campos et al., 2011). Mineral fraction of Typic Haplustox has a low amount of electric charges, of which most of them are added by OM (Pignataro Netto et al., 2009).

Micronutrients and sulfur levels of in the soil

The micronutrients and sulfur (S) levels were affected by the treatments, with an increased intensity in areas under

cultivation (Table 5). The treatments NTS3, NTS9, PA2, PA6, and CTS2 presented noteworthy amounts of Zn, which did not differ from each other. Such available Zn amounts are considered high ($>1.6 \text{ mg dm}^{-3}$) for Cerrado soils according to Sousa & Lobato (2004). These values might be due to either high content of OM observed in the systems, as well as fertilizers via seed treatment, mainly in areas grown with grasses (Silva, 2012).

Although the soil under CTS2 showed the highest content of iron (Fe) (Table 5), all treatments had Fe levels considered high for Cerrado areas (Abreu et al., 2007). As verified by Vendrame et al. (2007), iron deficiency has not been reported for soils in Cerrado areas lately. Therefore, such availability of Fe encountered in the soils studied here is considered adequate. In addition, we observed high levels of available manganese (Mn) in areas under NTS3, NTS9, PA2, EU6, EU12 and CTS8. Regarding available copper (Cu), the highest averages were observed in soils under NTS3, NTS9 and PA2 treatments (Table 5). These Mn and Cu contents are regarded as medium (Sousa & Lobato, 2004).

Among the micronutrients, available boron (B) showed the lowest concentration in the soil. This element had higher contents in the treatments NTS, PA6, EU12 and CTS8 (Table 5). According to values stated by Sousa & Lobato (2004), the B content found in this research are considered low for a Cerrado environment. Once this element is found in OM, it is expected that conservation management systems will increase its availability to plants; in contrast, there was little evidence of that at the current study. Additionally, PA2 had a higher available S level than the other management systems studied (Table 5).

Overall, except for Fe, the levels of micronutrients and S were low in NC. On the other hand, we noted increasing contents of these elements except for B in areas under cultivation. Nonetheless, levels of micronutrients were still insufficient to be rated as medium or high. This becomes evident in the case of B, which had low availability after years of cultivation under different uses and management systems, indicating the

Table 5. Mean of available zinc (Zn^{2+}), iron (Fe^{2+}), manganese (Mn^{2+}), copper (Cu^{2+}), boron (B), and sulphur (S) values at a depth of 0.0-0.40 m of an Oxisol under Cerrado in the Piauí State after various years of cultivation under different soil uses and management systems.

System	Zn^{2+}	Fe^{2+}	Mn^{2+}	Cu^{2+}	B	S
	mg dm ⁻³					
0.0-0.40 m Depth						
NTS3	3.36a	100.00c	3.48a	0.44a	0.20a	11.74b
NTS6	0.65b	109.47c	2.44b	0.29b	0.19a	11.60b
NTS9	2.76a	100.11c	4.19a	0.57a	0.19a	10.24b
PA2	6.71a	104.43c	3.26a	0.44a	0.15b	17.38a
PA6	4.21a	125.53b	1.93b	0.26b	0.18a	5.97c
EU6	1.33b	84.08d	3.58a	0.30b	0.12b	6.80c
EU12	1.47b	112.14c	3.50a	0.30b	0.20a	6.18c
CTS2	5.16a	147.78a	1.65b	0.19b	0.15b	10.62b
CTS8	1.33b	99.55c	2.91a	0.18b	0.22a	10.98b
NC	0.87b	82.54d	0.61c	0.12b	0.16b	5.87c

NTS3: no-tillage system for three years, NTS6: no-tillage system for six years, NTS9: no-tillage system for nine years, PA2: pasture for two years, PA6: pasture for six years, EU6: eucalyptus plantation for six years, EU12: eucalyptus plantation for 12 years, CTS2: conventional tillage system for two years, CTS8: conventional tillage system for eight years, NC: native Cerrado. Means followed by different letters in the columns differ from each other by the Scott-Knott test at 5% probability in each depth.

need for more-specific management of fertilization, combined with a more effective strategy to increase B is to increase OM.

Multivariate statistical analysis of the chemical properties and organic matter

The main components (MC1, MC2, and MC3) made up 74.41 % of the total variance (Table 6). The results indicate that the variables pH, Ca²⁺, Mg²⁺, Al³⁺, SB, t and V play an important role in the soil changes within the depth of 0.0 to 0.40 m, varying with the use and management. Concerning

Table 6. Factor loadings by principal components analysis for the combination of factors after Varimax rotation, for depths of 0.0-0.40 m.

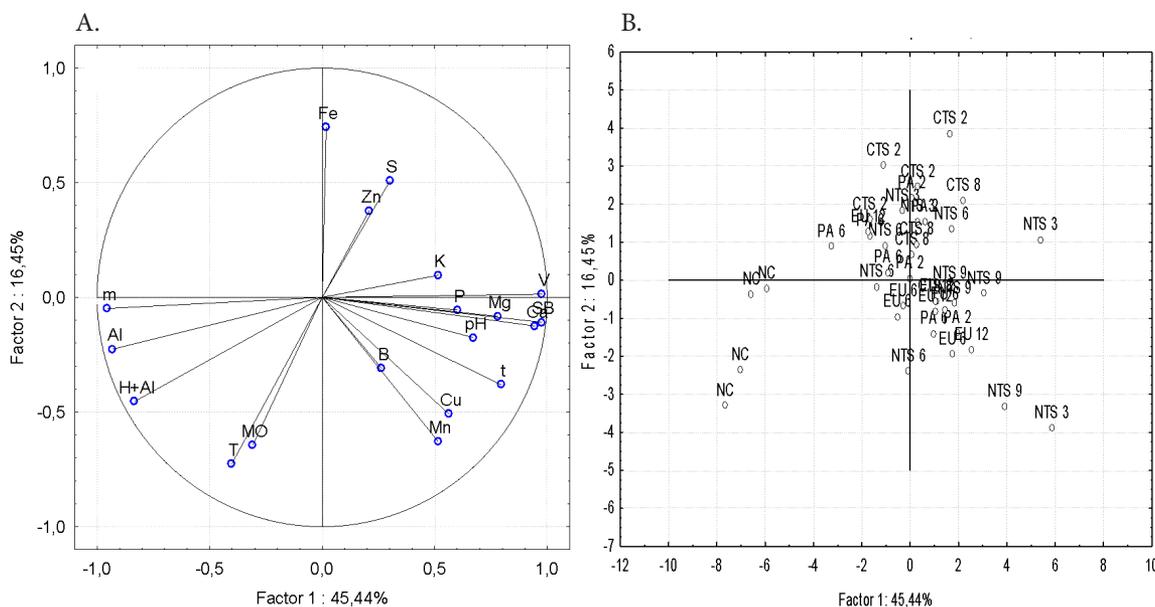
Variables	MC1	MC2	MC3
pH	0.87	0.11	0.26
K ⁺	0.16	0.19	-0.87
P	0.29	0.01	-0.87
Ca ²⁺	0.85	0.02	-0.38
Mg ²⁺	0.91	0.05	0.15
Al ³⁺	-0.83	-0.43	0.14
H ⁺ +Al ³⁺	-0.66	-0.70	0.18
SB	0.92	0.05	-0.29
t	0.79	-0.30	-0.36
T	-0.20	-0.94	0.01
V	0.92	0.22	-0.23
M	-0.90	-0.28	0.14
OM	-0.01	-0.57	0.33
Zn ²⁺	0.12	0.06	0.03
Fe ²⁺	-0.01	0.28	0.03
Mn ²⁺	0.35	0.01	-0.08
Cu ²⁺	0.33	-0.07	-0.17
B	0.06	0.01	0.30
S	0.18	0.10	-0.24
Variance Explained	6.98	2.27	1.08
Total	0.37	0.12	0.12
Total Variance %	45.44	16.45	12.53

MC: main components; pH: hydrogen potential; K⁺: potassium; P: phosphorus; Ca²⁺: calcium; Mg²⁺: magnesium; Al³⁺: aluminium; H+Al: hydrogen plus aluminium; SB: sum of bases; t: effective CTC; T: potential CTC; V: base saturation; m: aluminium saturation; OM: organic matter; Zn²⁺: zinc; Fe²⁺: iron; Mn²⁺: manganese; Cu²⁺: copper; B:boron; S: sulphur.

the OM level, the factorial load was negative for the first two components and positive, however low, for the MC3. We notice that use and management systems were not efficient in increasing OM content in the 0.0-0.40 m depth at levels similar to or higher than NC. These negative correlations are different from those observed by Magalhães et al. (2013), who evaluated nutrient stocks under different soil uses in Colorado do Oeste-RO; these authors concluded that the principal component analysis reduced the original variables to two main components, and the OM content was one of the variables that most contributed to the formation of MC1.

For the PCA of the chemical attributes, OM and soil use and management systems in the 0.0-0.40 m soil layer, the two first principal components explained 61.89 % of the total variation (Figures 2a and 2b). It is worth noting that reducing from nineteen original variables to two main components was very reasonable, because it simplified the analysis in a smaller number of variables without loss of information. These common and independent factors (main components) might reduce the amount of interrelated variables to explain original data variability (Andrade et al., 2007). The Figure 2a indicated that the variable Ca²⁺ and SB were overlapped, since they had the same graphical representation. Thus, these variables have the same degree of importance in soil changes, depending on management and use. The Ca²⁺, SB, H⁺+Al³⁺, Al³⁺, m, and V variables are closer to the unit circle and thus have greater contribution than those farther from it.

The soil use and management systems were distributed according to the degree of influence by variables on their characteristics (Figure 2b). We observed that the variables H⁺+Al³⁺, Al³⁺, m, T, and OM were crucial to separate the land uses in two groups, NC and agricultural land uses (Figure 2a), facilitating the distinction from the other treatments. This acidic condition found in NC can be accounted for non-use of



pH: hydrogen potential; K⁺: potassium; P: phosphorus; Ca²⁺: calcium; Mg²⁺: magnesium; Al³⁺: aluminium; H+Al: hydrogen plus aluminium; SB: sum of bases; t: effective CTC; T: potential CTC; V: base saturation; m: aluminium saturation; OM: organic matter; Zn²⁺: zinc; Fe²⁺: iron; Mn²⁺: manganese; Cu²⁺: copper; B: boron; S: sulfur. NTS3: no-tillage system for three years, NTS6: no-tillage system for six years, NTS9: no-tillage system for nine years, PA2: pasture for two years, PA6: pasture for six years, EU6: eucalyptus plantation for six years, EU12: eucalyptus plantation for 12 years, CTS2: conventional tillage system for two years, CTS8: conventional tillage system for eight years, NC: native Cerrado.

Figure 2. Diagrams of the distribution of chemical properties and soil organic matter in the 0.0-0.40 m soil layer (A) and of the management systems analyzed (B).

products such as limestone, which is responsible for neutralizing such acidic status. The pH, P, Ca²⁺, SB, t, B, Cu and Mn are more clustered within the fourth quadrant (Figure 2a), representing a clustering trend of NTS9 and EU12 (Figure 2b). It was not possible to see a clear separation between the remaining use and management systems that would influence the behavior of other variables in the assessed depth.

Soil use and management systems presented varied behavior depending on the variable evaluated. Nevertheless, soil under cultivation promoted several changes in the studied attributes compared to NC. These changes were positive because they increased the levels of Ca²⁺, K⁺, P, SB, and V as well as decreased the levels of Al³⁺, m, and H⁺+Al³⁺, which at high values can reduce further crop yields.

Conclusions

Use and management systems provided significant effects on the availability of soil macronutrients and organic matter contents, but have inadequate levels of micronutrients in the soil, especially available B.

In areas under tillage, there is an increase in pH, availability of nutrients and organic matter in the surface layer, especially during the first six years of adoption of the system, while in the areas with nine years; there were an increase in phosphorus levels in subsurface. The areas under cultivation with eucalyptus show higher potential in increasing the organic matter levels in soil subsurface layers.

No-tillage (surface layer) system and areas under cultivation of eucalyptus (subsurface layer) promoted an increase in the organic matter levels, but a more efficient management system would be necessary, in order to increase organic matter levels in the 0-0.40 m depth to reach similar levels of the native Cerrado.

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