

Impact of management systems on chemical attributes of an Oxisol from MATOPIBA region, Brazil

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Abstract: The MATOPIBA region, in the Cerrado, has been considered a promising new frontier of Brazilian agriculture. However, inadequate management of Cerrado soils has caused its fertility depletion, reducing crop productivity. This work aimed to evaluate the effect of soil management systems on chemical attributes of an Oxisol from MATOPIBA in the Cerrado. The studied areas, located in Piauí State, where: i) conventional tillage (three years) (CT); ii) no-tillage (16 years) + crop-livestock integration system (two years) (NT+CLI) and; iii) Cerrado native vegetation (NCV). Soil samples were collected (four replicates) from 0.00-0.10 and 0.10-0.20 m depths and soil chemical attributes were evaluated. Overall, the natural acidic and low fertility of the Oxisol as well as the available P, exchangeable K, Ca+Mg and Al contents, potential acidity and base saturation were improved in the agricultural areas compared to NCV, especially when NT+CLI was adopted. Decrease of soil organic matter content in NT+CLI compared to NCV was not observed, evidencing the potential of this system for maintaining carbon levels in the soil. In our study, soil organic matter content in CT and NCV did not differ, probably due to the recent implementation of CT, which generally contributes to organic matter depletion. Monitoring effects of NT+CLI on attributes and quality of MATOPIBA Oxisols is crucial to elucidate the potential of this region to sustain intensive agriculture, the main purpose for opening this agricultural frontier.

Keywords: Conventional tillage, No-tillage, Crop-livestock integration.

Impacto de sistemas de manejo sobre atributos químicos de um Latossolo da região de MATOPIBA, Brasil

Resumo: A região de MATOPIBA, no Cerrado, tem sido considerada uma nova fronteira agrícola promissora no Brasil. Entretanto, sistemas inadequados de manejo dos solos do Cerrado podem levar à exaustão da sua fertilidade, reduzindo a produtividade das culturas. Este trabalho objetivou avaliar o efeito de sistemas de manejo do solo sobre atributos químicos de um Latossolo da região do MATOPIBA no Cerrado. As áreas estudadas, situadas no estado do Piauí, foram: i) plantio convencional: (três anos) (PC); ii) plantio direto (16 anos) + integração lavoura pecuária (dois anos) (PD+ILP), e; iii) Cerrado com vegetação nativa (CVN). Amostras de solo foram coletadas (quatro repetições) nas camadas de 0,00-0,10 e 0,10-0,20 m e atributos químicos do solo foram avaliados. Em geral, a acidez e baixa fertilidade natural do Latossolo bem como teores de P disponível, K, Ca+Mg e Al trocáveis, acidez potencial e saturação de bases foram melhorados nas áreas agrícolas comparado a CVN, principalmente com adoção de PD+ILP. Diminuição do teor de matéria orgânica do solo em PD+ILP em comparação a CVN não foi observada, indicando o potencial desse sistema para manter os níveis de carbono no solo. Em nosso estudo o teor de matéria orgânica do solo não diferiu entre PC e CVN, provavelmente em virtude da recente implantação do PC, o qual geralmente promove perdas de matéria orgânica. O monitoramento dos efeitos do sistema PD+ILP sobre os atributos e qualidade dos Latossolos de MATOPIBA é crucial para elucidar o potencial dessa região para promover agricultura intensiva, a principal razão para abertura dessa fronteira agrícola.

Palavras chave: Plantio convencional, Plantio direto, Integração lavoura-pecuária.

Introduction

The increasing global population and therefore demand for food production have led to the conversion of native vegetation areas into pasture and croplands, and particularly to the need of opening new agricultural frontiers, as in the Cerrado region, Brazil. Generally, the soil management adopted in these converted areas is deficient in terms of soil conservation practices and consequently causes depletion of soil quality and sustainability (Souza, 2013).

The MATOPIBA region, in the Cerrado, has approximately 73 million ha and is composed by administrative regions of four Brazilian States, Maranhão - MA (33%), Tocantins - TO (38%), Piauí - PI (11%) and Bahia - BA (18%) (Brasil, 2017). Recently, special attention has been given to this region as one of the last agricultural frontiers of Brazil (Evangelista et al., 2017).

The major crop production in MATOPIBA is performed under *Latossolos* (Oxisols), which, in this region, generally contain less than 20% of clay within 0.00 - 0.50 m depth (Santos et al., 2013). About 95% of the area of *Latossolos* in MATOPIBA has dystrophic character, acidic pH, usually between 4.8 and 5.2 (Cruz, 2016 & Azevedo et al., 2007), high weathering levels, low content of available phosphorous (P) and high P adsorption capacity, causing fertility limitations for crop production (Soares & Alleoni, 2008). However, these soils can deliver great productivity after pH correction and fertilization. Additionally, great water availability, favorable soil physical structure and climate conditions for crop production in MATOPIBA, with long day periods and high light intensity, are essential characteristics that can boost large scale crop production in this region. In fact, crop production in MATOPIBA is expected to increase about 15% in the next decade, reaching 26.5 million tons in 2026/2027 crop season, corresponding to approximately 8.5 - 11 million ha of planted area (Brasil, 2017), bringing economical and social development to the region (Cruz, 2016) and helping to overcome the global increasing demand for food production.

The potential of Cerrado soils for crop production has, on the other hand, motivated conversion of native Cerrado vegetation areas to croplands, pasturelands and, more recently, reforestation activities, aiming especially food, fiber and energy production (Leite et al., 2010 & Lourente et al., 2011).

The intensification of agriculture and anthropogenic activities in the Cerrado has raised a concern about the preservation of soil and water, which are crucial resources for plant development and moreover for conservation of Cerrado biome (Araújo et al., 2010). In this direction, literature has reported degradation of chemical properties of Cerrado soils, mostly due to improper pasture management and intensive agriculture in areas previously under native vegetation. Soil degradation is accentuated especially when conventional instead of conservation soil tillage systems is adopted (Iwata et al., 2012). Consequently, crop yields and pasture quality tend to decline along the years. Usually, farmers abandon these converted areas searching for more productive (undisturbed) Cerrado soils, contributing thus to the expansion of the Cerrado degraded area (Costa et al., 2015).

From the strategic perspective, expansion of agriculture in the Cerrado, particularly in MATOPIBA, should be considered carefully, not only because of the high potential of the soils for crop production, but mainly due to their vulnerability to degradation when improper soil management systems are preferentially adopted. In this case, the agricultural potential of MATOPIBA region would be limited in short or long-term, since recovery of degraded soils is a slow process. Therefore, implantation of conservation tillage systems, as no-tillage system, is a key to potentialize the promising properties of MATOPIBA soils, thus providing conditions to plants to take advantage of the favorable climate conditions and water availability, consolidating this region as a new agricultural frontier.

In this context, studies dedicated to investigate the dynamics of nutrients and the fertility of Cerrado soils under contrasting soil and plant management systems are crucial to identify strategies of how to optimize fertilizers, correctives of soil acidity and other agricultural inputs and finally boost agriculture in the Cerrado in a more sustainable basis (Goedert, Oliveira, 2007 & Campos et al., 2011). In this way, our study aimed to investigate how the conversion of native Cerrado vegetation to agriculture impacts chemical attributes and the fertility of an Oxisol in MATOPIBA region.

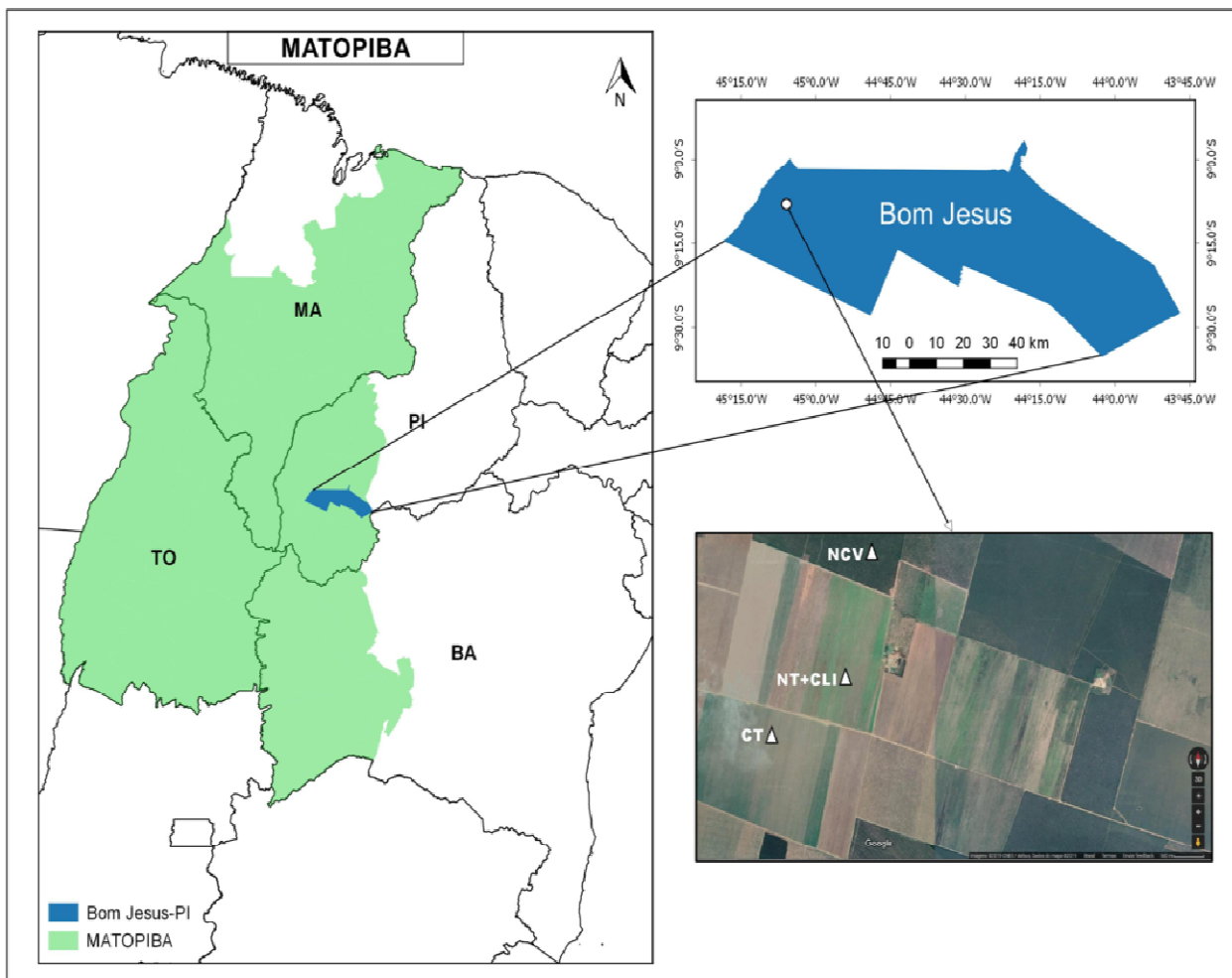
Materials and methods

Experimental site and soil sampling

The study was conducted at São Marcos Farm, Bom Jesus municipality, located at 09°09'59" S, 45°06'43" W, 481 m above sea level, Cerrado region at Serra do Quilombo, MATOPIBA region, southwest of Piauí state (Figure 1). The climate of the region is hot and semi-humid, classified as Aw according to Köppen's classification. The mean annual temperature is 27 °C and the mean annual rainfall rate is 1,000 mm. The rainy season is from October to April, mainly between January and March, with short summer

events, known as "veranicos". The soil is classified as Oxisol (Soil Survey Staff, 2014) and according to the Brazilian soil classification system as *Latossolo Amarelo distrófico típico* (Santos et al., 2013), with loam sandy clay texture. Sand, silt and clay contents of the 0.00 - 0.20 m soil depth determined according to Donagema et al. (2011) are 688, 67 and 246 g kg⁻¹, respectively.

Figure 1 - Extent of MATOPIBA region over Maranhão (MA), Tocantins (TO), Piauí (PI) and Bahia (BA) states in Brazil and localization of experimental sites within Bom Jesus municipality. NCV = native Cerrado vegetation; CT = conventional tillage; NT+CLI = no-tillage + crop-livestock integration.



Source: Research data.

The soil samples were collected at two areas with different soil management systems: i) conventional tillage system (three years) (CT): soil managed with heavy, intermediate and leveling harrow; and ii) no-tillage system (16 years) +

crop-livestock integration system (two years) (NT+CLI). Chronologies of soil use and management and plant species are presented in Table 1. As a reference site, soil samples were collected at an adjacent area under Native

Cerrado Vegetation (NCV) (Figure 1). Sizes of NCV, CT and NT+CLI areas are 105.6, 12.3 and 8.5 ha, respectively. Soil samples were collected in October 2014 from 0.00 - 0.10 and 0.10 - 0.20

m depth, with four replicates, totalizing 24 samples (eight samples/area). The samples were air-dried and the soil chemical attributes were evaluated.

Table 1 - Chronologies of soil use and management, cultures and agricultural practices of the areas under conventional tillage (CT) and no-tillage + crop-livestock integration (CLI) at MATOPIBA region, Piauí state, Brazil, until soil sampling in 2014.

Area	Deforestation	Implantation	Cultures (chronology)	Lime and gypsum	Fertilization (per ha)
CT	2012	2012	-Rice - 2 yr -Soybean - 1yr	-Lime: 2 Mg ha ⁻¹ (2012) 5 Mg ha ⁻¹ (2015) -Gypsum: no	-2012 100 kg N; 100 kg P; 100 kg K -2014 30 kg P; 100 kg K
NT+CLI	1994	NT - 1998 CLI - 2012	-Rice - 3 yr -Soybean - 4 yr -Maize - 4 yr -Soybean - 4 yr -Maize - 1yr - <i>Urochloa. Brizantha</i> (pasture) - 2 yr -Millet (cover crop)	-Lime: 2 Mg ha ⁻¹ (1998, 1999, 2000) -Gypsum: 0.5 Mg ha ⁻¹ (2010) 1 Mg ha ⁻¹ (2013)	-1998 80 kg N; 80 kg P; 80 kg K -2003 40 kg P; 50 kg K -2009-2014 (annually) 70 kg N; 70 kg P; 100 kg K

Source: Research data.

Soil chemical attributes

The soil chemical attributes were determined according to Donagema et al. (2011) as follows: pH-H₂O (1:2.5, soil:water); exchangeable aluminum (Al) content (extracted with KCl 1 mol L⁻¹ and determined by titulometry with NaOH 0.025 mol L⁻¹); exchangeable calcium (Ca) + magnesium (Mg) (extracted with KCl 1 mol L⁻¹ and determined by titulometry with Ethylenediamine tetraacetic acid 0.0125 mol L⁻¹); available phosphorous (P) and exchangeable potassium (K) (extracted by Mehlich-1 method with HCl 0.05 mol L⁻¹ + H₂SO₄ 0.0125 mol L⁻¹ and determined by calorimetry and flame photometry, respectively); potential acidity (H+Al) (extracted with calcium acetate at pH 7.0 and determined volumetrically with NaOH solution, using phenolphthalein as indicator).

The sum of bases (SB) was calculated as SB = Ca + Mg + K, the effective cation exchange capacity (ECEC) as ECEC = SB + Al and the base saturation (V%) as V% = ((SB/T) x 100), where T = SB + (H+Al).

The organic matter (OM) content was determined indirectly by quantifying the organic carbon content using the Walkley & Black combustion method with external heating (Yeomans & Bremner, 1988).

Statistical analyses

The data was subjected to analysis of variance and the means were compared by the Tukey's test at 5% probability. The statistical analyses were performed using the ASSISTAT software (Silva & Azevedo, 2016).

Results and discussion

Soil pH-H₂O, available P, exchangeable K, and Ca+Mg contents, SB and V% were affected by the management systems at both 0.00 - 0.10 and 0.10 - 0.20 m soil depths. Differences regarding OM and Al contents, H+Al and ECEC were not observed (Table 2).

Table 2 - pH-H₂O, exchangeable potassium (K) and available phosphorous (P) content of an Oxisol under different management systems at MATOPIBA region, Piauí state - Brazil.

Management system	pH-H ₂ O	K		P
		-----mg dm ⁻³ -----		
		0.00 - 0.10 m		
NCV	4.4 c	11 c		0.1 b
CT	5.5 a	43 b		0.9 b
NT+CLI	4.8 b	123 a		9.2 a
		0.10 - 0.20 m		
NCV	4.5 b	11 c		0.1 b
CT	4.8 a	32 b		0.7 b
NT+CLI	4.4 b	67 a		4.1 a

Means followed by the same letter in the column within soil depth do not differ significantly according to the Tukey test at 5% probability. NCV = native Cerrado vegetation; CT = conventional tillage; NT+CLI = no-tillage + crop-livestock integration.

Source: Research data.

In general, higher content of nutrients was observed under NT+CLI. These results can be assigned to the non-disturbance of the soil together with the protection of the soil surface with millet or pasture against raindrop impacts, preventing erosion processes and therefore reducing loss of soil and nutrients (Falleiro et al., 2003 & Lourente et al., 2011). Additionally, the improvement of nutrients cycling due to the cultivation of different crops, soil fertilization, and the release of nutrients from the livestock manure and from the plant residues remaining onto the soil, may have contributed to these results.

In both 0.00 - 0.10 and 0.10 - 0.20 m depths the highest pH-H₂O value was observed in CT (Table 2). At 0.00 - 0.10 m, the soil pH-H₂O in CT was 20 and 12 % higher than that observed in NCV and NT+CLI, respectively. At 0.10 - 0.20 m depth, these values were 7 and 10 %. The more recent liming and the higher dose of lime application in CT compared to NT+CLI (Table 1) explain these results. In the 0.00 - 0.10 m depth the pH-H₂O value observed in NT+CLI was 9% higher than that observed in NCV, while in the 0.10 - 0.20 m depth these areas did not differ significantly regarding pH-H₂O. The higher pH-H₂O values observed in CT and NT+CLI compared to NCV (Table 2) can be also attributed to the higher concentration of exchangeable bases, especially at 0.10 - 0.20 m depth (Table 4) as a result of soil pH correction and fertilization. The Oxisols are normally deficient regarding fertility, usually presenting dystrophic character and acidic pH (Azevedo et al., 2007 & Ensinas et al., 2014). The pH of the soil in NCV, irrespective to the soil depth, reinforces the acidic character of

Cerrado Oxisols (Table 2). Therefore, soil pH

correction and fertilization are crucial practices to promote satisfactory plant growth in these soils.

The soil exchangeable K contents observed in NT+CLI were substantially higher than the contents observed in NCV and CT (Table 2). At 0.00 - 0.10 m depth, the K content in NT+CLI was 91 and 65 % higher than that of NCV and CT, respectively. At 0.10 - 0.20 m depth, these values were 84 and 53 %. According to Alvarez et al. (1999), the K contents observed in 0.00 - 0.10 and 0.10 - 0.20 m depth in NT+CLI (Table 2), are considered as "good" and "very good", respectively, in terms of K supply to plants. These results can be attributed to the annual K fertilization in NT+CLI in the last five years before soil sampling (Table 1). Also, the input of organic residues via cover crop (millet) to the soil in NT+CLI may have contributed to the results. Once these residues are decomposed K is released to the soil and can be retained by the cation exchange complex of the soil, especially after soil pH correction. Additionally, NT promotes soil conservation and prevents erosion processes, favoring nutrients accumulation in the soil, such as K, especially within 0.00 - 0.20 m soil depth (Barreto et al., 2008). According to Santos et al. (2009), NT promotes accumulation of P and K near to the soil surface, especially if associated with crop-livestock integration systems.

The P contents observed in NT+CLI were 9.2 mg dm⁻³ at 0.00 - 0.10 m and 4.1 mg dm⁻³ at 0.10 - 0.20 m (Table 2). At 0.00 - 0.10 m depth, the P content in NT+CLI was 99 and 90 % higher than that of NCV and CT, respectively, while at

0.10 - 0.20 m depth these values were 97 and 93 %, most probably due to recent and often P fertilization in NT+CLI (Table 1). Even though the NT+CLI promoted higher P contents in comparison to the other areas, the P availability is considered "low". Increment in available P content in an Oxisol from Cerrado conducted under no-till agriculture compared to a native vegetation and a conventional tillage area was also reported by Lourente et al. (2010). Differently from the P distribution within 0.00 - 0.20 m depth in CT and NCV, the P content value in NT+CLI was about 55 % higher at 0.00 - 0.10 m than in 0.10 - 0.20 m depth. The accumulation of P in 0.00 - 0.10 m soil depth under NT system, can be attributed to the low mobility of P in the soil, especially in highly weathered soils, as Cerrado Oxisols, and to the deposition of fertilizers and organic residues (plants and animals) on the soil surface together with the non-incorporation of these materials into the soil (Santos et al., 2008). Under CT conditions, the lower input of organic residues to the soil and the intensive mechanical mobilization of the soil lead to lower addition and maintenance of P in the soil and furthermore dilute the P content along the soil profile (Santos & Tomm,

2003).

The Ca+Mg contents in CT and NT+CLI did not differ statistically, regardless the soil layer (Table 3). According to Alvarez et al. (1999) these values are considered "regular" and "good", whilst the Ca+Mg contents in NCV are classified as "low". The fertilization and soil acidity corrections in CT and NT+CLI probably contributed to increase Ca and Mg soil content. Similar results were observed by Leite et al. (2010) comparing K, P and Ca+Mg contents of a Cerrado Oxisol from MATOPIBA region under conventional tillage, no-tillage and a native Cerrado forest soil. In general, the authors observed that both conventional tillage and no-tillage systems increased the soil nutrients content compared to the Cerrado forest area, and that these increases were more pronounced under no-tillage, especially within 0.00 - 0.20 m depth. At deeper depths (0.20 - 0.40 m) differences between conventional tillage and no-tillage were less remarkable, reinforcing that the greater deposition of organic residues on the soil surface under no-tillage conditions, together with fertilization and liming lead to greater accumulation of nutrients in the soil, especially near to the soil surface, as discussed before.

Table 3 - Calcium+magnesium content (Ca+Mg), exchangeable aluminum (Al) and potential acidity (H+Al) of an Oxisol under different management systems at MATOPIBA region, Piauí state - Brazil.

Management system	Ca+Mg	Al	H+Al
	-----cmol _c dm ⁻³ -----		
		0.00 - 0.10 m	
NCV	1.1 b	1.5 a	8.1 a
CT	4.2 a	0.3 b	4.5 b
NT+CLI	4.5 a	0.4 b	6.8 ab
		0.10 - 0.20 m	
NCV	1.5 b	1.2 a	7.1 a
CT	2.7 ab	0.5 b	5.4 a
NT+CLI	3.1 a	0.5 b	7.3 a

Means followed by the same letter in the column within soil depth do not differ significantly according to the Tukey test at 5% probability. NCV = native Cerrado vegetation; CT = conventional tillage; NT+CLI = no-tillage + crop-livestock integration.

Source: Research data.

In CT and NT+CLI areas the exchangeable Al contents did not differ, but were lower than in NCV, regardless the soil depth (Table 3). These results are attributed to the soil pH-H₂O and basic cations content increase observed in the agricultural areas compared to NCV (Table 3), specially at 0.00 - 0.10 m depth, as result of soil liming and fertilization, promoting greater Al³⁺

neutralization (Souza & Alves, 2003). These findings corroborate Azevedo et al. (2007), who also observed higher exchangeable Al contents up to 0.20 m depth of a Cerrado Oxisol under native vegetation compared to neighboring soils under conventional and no-tillage systems. In our study, complexation of Al by soil organic matter apparently had a minor effect on Al activity, since

OM contents in NCV, CT and NT+CLI at both 0.00 - 0.10 and 0.10 - 0.20 m depth did not differ (Table 4).

Table 4 - Effective cation exchange capacity (ECEC), sum of bases (SB), base saturation (V) and organic matter (OM) content of an Oxisol under different management systems in the MATOPIBA region, Piauí state – Brazil.

Management system	ECEC	SB	V	OM
	-----cmol _c dm ⁻³ -----		-----%-----	
	0.00 - 0.10 m			
NCV	9.2 a	1.1 b	13.3 b	2.2 a
CT	8.8 a	4.3 a	50.7 a	2.2 a
NT+CLI	11.6 a	4.8 a	41.3 a	2.7 a
	0.10 - 0.20 m			
NCV	8.6 a	1.5 b	18.6 b	2.1 a
CT	8.1 a	2.7 ab	32.8 a	1.8 a
NT+CLI	10.5 a	3.2 a	30.9 ab	2.0 a

Means followed by the same letter in the column within soil depth do not differ significantly according to the Tukey test at 5% probability. NCV = native Cerrado vegetation; CT = conventional tillage; NT+CLI = no-tillage + crop-livestock integration.

Source: Research data.

The H+Al value in CT at 0.00 - 0.10 m depth did not differ from NT+CLI and was 44% lower than that in NCV. At this same soil depth H+Al value in NT+CLI did not differ from that in NCV. Differences were not observed at 0.10 - 0.20 m depth. Most probably, the recent liming in CT before soil sampling (Table 1), increasing soil pH-H₂O at 0.00 - 0.10 m depth in comparison to NCV and NT+CLI (Table 2), decreased the potential acidity of the soil near to the surface.

The ECEC values did not differ between CT, NT+CLI and NCV regardless of soil layer (Table 4). The similar OM content observed in these areas at both soil depths may be related to these results. Usually, soils with higher OM content have greater ECEC values, due to the contribution of OM functional groups (negatively charged after H⁺ dissociation), which increase the cation retention capacity of the soil (Soares, Alleoni, 2008 & Dick et al., 2011).

Generally, when compared to a reference site under natural conditions, CT tends to decrease soil OM content over time due to soil mobilization, which leads to soil oxygenation, breakdown of organic materials and aggregates disruption turning occluded (protected) OM more

easily degradable (Pinheiro et al., 2003, Chaves et al., 2012 & Conceição et al., 2015). Additionally, low inputs of plant residues to the soils is frequently observed in areas managed under CT, also accentuating soil OM loss over time (Araújo, 2007 & Andraus et al., 2013). Therefore, considering that in our study the native vegetation area was converted to CT only 3 years before soil sampling, the soil OM seems to have been considerably preserved within this short period after CT implementation. However, soil OM depletion in CT could be expected to increase in the next years (Cunha et al., 2001). On the other hand, the similar soil OM content in NT+CLI and NCV indicates that conservation agriculture systems in MATOPIBA can maintain organic matter levels similar to that of reference native sites, at least within the first soil depths. Nevertheless, it is important to highlight that investigation of soil OM contents over time and at deeper depths must be monitored in the long-term to elucidate such comparison. Utilization of more complex crops rotation (greater plant diversity) and polyculture of cover crops could increase OM contents considerably (Bayer et al., 2006 & Almeida et al., 2008).

The SB values at 0.00 - 0.10 m depth in CT and NT+CLI were similar and in the mean were 303% higher than that in NCV (Table 4). The soil liming and fertilization in CT and NT+CLI notably contributed to the increase of SB values in comparison to NCV, where no soil chemical correction was performed. In fact, Cerrado soils are naturally of low fertility, but can be potentially improved if fertilization and conservation tillage systems are properly performed (Azevedo et al., 2007, Freitas & Landers, 2014). At 0.10 - 0.20 m depth SB in NT+CLI was 106% higher than in NCV. The SB value in CT did not differ from NCV and NT+CLI values (Table 4). In NT+CLI, gypsum application (2010 and 2013) and mineralization of OM deposited at 0.10 - 0.20 m depth via root system of millet, *U. Brizantha* and main crops may have contributed to the increase of SB content at this depth. Additionally, the root channels created in NT+CLI due to the permanent plants cultivation either with cover crops, pasture or main crops possibly favored gypsum effects and downward movements of cations and its deposition at deeper depths.

The V% values in CT and NT+CLI at 0.00 - 0.10 m depth were similar and approximately 280 and 210% higher than in NCV, respectively (Table 4). At 0.10 - 0.20 m depth SB value in CT was 77% higher than in NCV, while SB value in NT+CLI did not differ from CT and NCV areas (Table 4). These data reinforce that the Oxisol investigated in this study is naturally of limited fertility under native vegetation and without anthropogenic interference. Therefore, expansion of intensive agriculture in MATOPIBA should be considered carefully due to the vulnerability of these soils to degradation. In this way, soil conservation practices and complex managements, as NT+CLI, are crucial to allow MATOPIBA progress as a new agricultural frontier in a sustainable basis.

Conclusions

Conduction of Cerrado Oxisol from MATOPIBA under conservation agriculture practices (no-till 16 years + crop-livestock integration two years) improved important soil agronomical chemical attributes as pH-H₂O, exchangeable Al, SB and V%, and increased available P and exchangeable K and Ca+Mg contents, which are usually limiting factors for local crop production, and maintained soil organic

matter levels compared to the soil under native Cerrado vegetation. Similar benefits on soil attributes were noticed when conventional tillage (three years) was adopted after conversion of native vegetation to agriculture, however benefits occurred in a lower magnitude compared to conservation agriculture and conventional tillage did not increase soil available P contents compared to the native area. Although organic matter levels in the conventional tillage area were comparable to that of the native Cerrado vegetation area, this result was preferentially attributed to the contribution of the native Cerrado vegetation (remaining organic matter) to organic matter contents rather than to the quality or contribution of the conventional tillage to the accumulation of organic matter into the soil.

Monitoring effects of management systems on soil chemical attributes as well as on soil quality in the long-term is crucial to elucidate the potential of Oxisols from the Cerrado (MATOPIBA) region to sustain intensive agriculture, which is the main purpose for opening MATOPIBA as a new agricultural frontier.

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References

- Andraus, M. P., Cardoso, A. A., Leandro, W. M., & Brasil, E. P. F. (2013). Matéria orgânica e características químicas de solos sob sistema de plantio convencional, plantio direto e mata nativa. *Cadernos de Agroecologia*, 8 (2), 1-5.
- Almeida, V. P., Alves, M. C., Silva, E. C., & Oliveira, S. A. (2008). Rotação de culturas e propriedades físicas e químicas em Latossolo Vermelho de Cerrado sob preparo convencional e semeadura direta em adoção. *Revista Brasileira de Ciência do Solo*, 32 (3), 1227-1237. DOI: 10.1590/S0100-06832008000300031.
- Alvarez, V. V. H., Novais, R. F., Barros, N. F., Cantarutti, R. B., & Lopes, A. S. (1999). Interpretação dos resultados das análises de solos. In: Ribeiro, A.C., Guimarães, P. T. G., & Alvarez, V. V. H. *Recomendações para o uso de corretivos e fertilizantes em Minas Gerais – 5ª*

- Aproximação*. (Cap. 5, pp. 25-32). Viçosa: Comissão de Fertilidade do Solo do Estado de Minas Gerais.
- Araújo, F. S., Salviano, A. A. C., Leite, L. F. C., Souza, Z. M., & Sousa, A. C. M. (2010). Physical quality of a yellow Latossol under integrated crop-livestock system. *Revista Brasileira de Ciência do Solo*, 34 (3), 717-723. DOI: 10.1590/S0100-06832010000300013.
- Araújo, R., Goedert, W. J., & Lacerda, M. P. C. (2007). Qualidade de um solo sob diferentes usos e sob cerrado nativo. *Revista Brasileira de Ciência do Solo*, 31 (5), 1099-1108. DOI: 10.1590/S0100-06832007000500025.
- Azevedo, D. M. P., Leite, L. F. C., Teixeira Neto, M. L., & Dantas, J. S. (2007). Atributos físicos e químicos de um Latossolo Amarelo e distribuição do sistema radicular da soja sob diferentes sistemas de preparo no cerrado maranhense. *Revista Ciência Agrônômica*, 38 (1), 32-40.
- Barreto, P. A. B., Gama-Rodrigues, E. F., Gama-Rodrigues, A. C., Barros, N. F., & Fonseca, S. (2008). Atividade microbiana, carbono e nitrogênio da biomassa microbiana em plantações de eucalipto, em sequência de idades. *Revista Brasileira de Ciência do Solo*, 32 (2), 611-619. DOI: 10.1590/S0100-06832008000200016.
- Brasil. Ministério da Agricultura, Pecuária e Abastecimento. (2017). *Projeções do agronegócio: Brasil 2016/17 a 2026/27* (103p). Brasília, DF: MAPA/SPA.
- Bayer, C., Lovato, T., Dieckow, J., Zanatta, J. A., & Mielniczuk, J. (2006). A method for estimating coefficients of soil organic matter dynamics based on long-term experiments. *Soil and Tillage Research*, 91, 217-226. DOI: 10.1016/j.still.2005.12.006.
- Campos, L. P., Leite, L. F. C., Maciel, G. A., Iwata, B. F., & Nóbrega, J. C. A. (2011). Atributos químicos de um Latossolo Amarelo sob diferentes sistemas de manejo. *Pesquisa Agropecuária Brasileira*, 46 (12), 1681-1689. DOI: 10.1590/S0100-204X2011001200014.
- Chaves, A. A. A., Lacerda, M. P. C., Goedert, W. J., Ramos, M. L. G., & Kato, E. (2012). Indicadores de qualidade de Latossolo Vermelho sob diferentes usos. *Pesquisa Agropecuária Tropical*, 42 (4), 446-454. DOI: 10.1590/S1983-40632012000400002.
- Conceição, P. C., Boeni, M., Bayer, C., Dieckow, J., Salton, J. C., & Reis, C. E. S. (2015). Eficiência de soluções densas no fracionamento físico da matéria orgânica do solo. *Revista Brasileira de Ciência do Solo*, 39 (2), 490-497. DOI:10.1590/01000683rbcs20140447.
- Costa, N. R., Andreotti, M., Lopes, K. S. M., Yokobatake, K. L., Ferreira, J. P., Pariz, C. M., Bonini, C. S. B., & Longhini, V. Z. (2015). Atributos do Solo e Acúmulo de Carbono na Integração Lavoura-Pecuária em Sistema Plantio Direto. *Revista Brasileira de Ciência do Solo*, 39 (3), 852-863. DOI: 10.1590/01000683RBCS20140269.
- Cruz, N. N. L. (2016). *Dependência espacial de atributos químicos, físicos e suscetibilidade magnética na região piauiense do MATOPIBA*. Dissertação de Mestrado. Universidade Federal do Piauí, Bom Jesus, PI, Brasil.
- Cunha, T. J. F., Macedo, J. R., Ribeiro, L. P., Palmieri, F., Freitas, P. L., & Aguiar, A. C. (2001). Impacto do manejo convencional sobre propriedades físicas e substâncias húmicas de solos sob cerrado. *Ciência Rural*, 1 (1), 27-36. DOI: 10.1590/S0103-84782001000100005.
- Dick, D. P., Leite, S. B., Dalmolin, R. L. S., Almeida, H. C., & Knicker, H. (2011). *Pinus* afforestation in South Brazilian highlands: soil chemical attributes and organic matter composition. *Scientia Agrícola*, 68 (2), 175-181. DOI: 10.1590/S0103-90162011000200007.
- Donagema, G. K., Campos, D. V. B., Calderano, S. B., Teixeira, W. G., & Viana, J. H. (2011). *Manual de métodos de análise de solos* (230p). Rio de Janeiro: Embrapa Solos.
- Ensinas, S. C., Marchetti, M. E., Silva, E. F., Potrich, D. C., & Martinez, M. A. (2014). Atributos químicos, carbono e nitrogênio total em latossolo submetido a diferentes sistemas de uso do solo. *Global Science and Technology*, 7 (2), 24-36. DOI: 10.14688/1984-3801/GST.V7N2P24-36.
- Evangelista, B. A., Silva, F. A. M., Simon, J., Campos, L. S. M., & Vale, T. M. (2017). *Zoneamento de risco climático para determinação*

de épocas de semeadura da cultura da soja na região MATOPIBA (Boletim de Desenvolvimento e Pesquisa, n. 18). Palmas, TO: Embrapa Pesca e Aquicultura.

Falleiro, R. M., Souza, C. M., Silva, C. S. W., Sedyama, C. S., Silva, A. A., & Fagundes, J. L. (2003). Influência dos sistemas de preparo nas propriedades químicas e físicas do solo. *Revista Brasileira de Ciência do Solo*, 27(9), 1097-1104. DOI: 10.1590/S0100-06832003000600014.

Freitas, P. L., & Landers, J. N. (2014). The transformation of agriculture in Brazil through development and adoption of zero tillage conservation agriculture. *International Soil and Water Conservation Research*, 2 (1), 35-46. DOI: 10.1016/S2095-6339(15)30012-5 .

Goedert, W. J., & Oliveira, S. A. (2007). Fertilidade do solo e sustentabilidade da atividade agrícola. In: Novais, R. F., Alvarez, V. H. V., Barros, N. F., Fontes, R. L., Cantarutti, R. B., & Neves, J. C. *Fertilidade do solo* (Cap 18, pp.991-1017). Viçosa: Sociedade Brasileira de Ciência do Solo.

Iwata, B. F., Leite, L. F. C., Araújo, A. S. F., Nunes, L. A. P. L., Gehring, C., & Campos, L. P. (2012). Sistemas agroflorestais e seus efeitos sobre os atributos químicos em Argissolo Vermelho-Amarelo do Cerrado piauiense. *Revista Brasileira de Engenharia Agrícola e Ambiental*, 16 (7), 730-738. DOI: 10.1590/S1415-43662012000700005.

Leite, L. F. C., Galvão, S. R. S., Holanda Neto, M. R., Araújo, F. R., & Iwata, B. F. (2010). Atributos químicos e estoques de carbono em Latossolo sob plantio direto no cerrado do Piauí. *Revista Brasileira de Engenharia Agrícola e Ambiental*, 14 (12), 1273-1280. DOI: 10.1590/S1415-43662010001200004.

Lourente, E. R. P., Mercante, F. M., Marchetti, F. M., Souza, L. C. F., Souza, C. M. A., Gonçalves, M. C., & Silva, M. A. G. (2010). Rotação de culturas e relações com atributos químicos e microbiológicos do solo e produtividade do milho. *Semina: Ciências Agrárias*, 31 (4), 829-842. DOI: 10.5433/1679-0359.2010v31n4p829.

Lourente, E. R. P., Mercante, F. M., Alovisi, A. M. T., Gomes, C. F., Gasparini, A. S., & Nunes, C. M. (2011). Atributos microbiológicos, químicos e

físicos de solo sob diferentes sistemas de manejo e condições de Cerrado. *Pesquisa Agropecuária Tropical*, 41 (1), 20-28. DOI: 10.5216/PAT.V41I1.8459.

Pinheiro, E. F. M., Pereira, M. G., Anjos, L. H. C., Palmieri, F., & Souza, R. C. (2003). Matéria orgânica em Latossolo Vermelho submetido a diferentes sistemas de manejo e cobertura do solo. *Revista Brasileira de Agrociência*, 9 (1), 53-56. DOI: 10.18539/CAST.V9I1.493.

Santos, H. P., & Tomm, G. O. (2003). Disponibilidade de nutrientes e teor de matéria orgânica em função dos sistemas de cultivo e manejo do solo. *Ciência Rural*, 33 (3), 477-486. DOI: 10.1590/S0103-84782003000300013.

Santos, D. R., Gatiboni, L. C., & Kaminski, J. (2008). Fatores que afetam a disponibilidade do fósforo e o manejo da adubação fosfatada em solos sob sistema plantio direto. *Ciência Rural*, 38 (2), 576-586. DOI: 10.1590/S0103-84782008000200049.

Santos, H. P., Fontaneli, R. S., Spera, S. T., & Tomm, G. O. (2009). Efeito de sistemas de produção integração lavoura-pecuária (ILP) sobre a fertilidade do solo em plantio direto. *Acta Scientiarum Agronomy*, 31 (4), 719-727. DOI: 10.4025/ACTASCIAGRON.V31I4.925.

Santos, H. G., Jacomine, P. K. T., Anjos, L. H.C., Oliveira, V. A., Lumberras, J. F., Coelho, M. R., Almeida, J. A., Cunha, T. J. F., & Oliveira, J. B. (2013). *Sistema brasileiro de classificação de solos* (3 ed. rev. e ampl., 353p). Brasília: Embrapa Solos.

Silva, F. A. S., & Azevedo, C. A. V. (2016). The Assistat and its use in the analysis of experimental data (Version 7.7) [Software]. *African Journal of Agricultural Research*, 11 (39), 3733-3740. DOI: 10.5897/AJAR2016.11522.

Soares, M. R., & Alleoni, L. R. F. (2008). Contribution of soil organic carbon to the ion exchange capacity of tropical soils. *Journal of Sustainable Agriculture*, 32 (3), 439-462. DOI: 10.1080/10440040802257348.

Soil Survey Staff. (2014). *Keys to Soil Taxonomy* (360 p). Washington: United States Department of Agriculture.

Sousa Neto, O. N. (2013). *Análise multivariada dos atributos físicos e químicos de um Cambissolo cultivado sob práticas de manejo sustentável da caatinga*. Dissertação de Mestrado, Universidade Federal Rural do Semiárido, Mossoró, RN, Brasil.

Souza, Z. M., & Alves, M. C. (2003). Propriedades químicas de um Latossolo vermelho distrófico de cerrado sob diferentes usos e manejos. *Revista Brasileira de Ciência do Solo*, 27, 133-139. DOI: 10.1590/S0100-06832003000100014.

Yeomans, J. C., & Bremner. J. M. (1988). A rapid and precise method for routine determination of organic carbon in soil. *Communications in Soil Science and Plant Analysis*, 19 (13), 1467- 1476. DOI: 10.1080/00103628809368027.

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