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Soil use and management systems, time since adoption, and their impacts over aggregation

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ABSTRACT: The Cerrado biome is of notable territorial relevance in the state of Piaui, Brazil. This region is an area of reference for food production. The aim of this work was to evaluate the stability of soil aggregates in water, in function of different soil use and management systems, as well as of the time since adopting these systems in Cerrado areas in the southwest region of Piaui. In this study, nine soil use and management systems were evaluated, arranged in the following manner: no-tillage system of three and six years of use, pasture of two and six years, eucalypt of six and twelve years, conventional tillage of two and eight years, and native Cerrado (Savana). The analyzed variables were: organic carbon, mean geometric diameter, mean weight diameter, aggregate stability index and aggregate diameter classes. Aggregation in Ferralsol is favored by clay and organic carbon contents. The longer adoption time in the no-till, pasture and eucalypt systems favored soil aggregation, while in conventional tillage there was a reduction of the aggregates.

Key words: conventional tillage; eucalypt; no-tillage system; pasture; soil conservation; water

Sistemas de uso e manejo do solo, tempo de adoção e seus impactos sobre a agregação

RESUMO: O bioma Cerrado é de notável relevância territorial no estado do Piauí, Brasil. Esta região é uma área de referência para a produção de alimentos. O objetivo nesse trabalho foi avaliar a estabilidade de agregados do solo em água, em função dos diferentes sistemas de uso e manejo do solo, bem como do tempo decorrido desde a adoção desses sistemas em áreas de cerrado na região sudoeste do Piauí. Neste estudo, foram avaliados nove sistemas de uso e manejo do solo, organizados da seguinte forma: sistema plantio direto de três e seis anos de uso, pastagem de dois e seis anos, eucalipto de seis e doze anos, plantio convencional de dois e oito anos e Cerrado nativo. As variáveis analisadas foram: carbono orgânico, diâmetro geométrico médio, diâmetro médio ponderado, índice de estabilidade agregada e classes de diâmetro agregado. A agregação em Latossolo Amarelo é favorecida pelos teores de argila e carbono orgânico. O maior tempo de adoção nos sistemas de plantio direto, pastagem e eucalipto favoreceu a agregação do solo, enquanto no plantio convencional houve redução dos agregados.

Palavras-chave: plantio convencional; eucalipto; plantio direto; pastagem; conservação do solo; água

Introduction

The *Cerrado* (Brazilian tropical savanna) of Piaui, Brazil, occupies 46% of the state territory, which corresponds to nearly 11.8 million hectares (Aguiar & Monteiro, 2005). According to the crop and livestock census (IBGE, 2006), in Piaui, the areas occupied by seasonal crops, pastures, and planted forests increased by 224%, 618%, and 454%, respectively, from 1970 to 2006. Grain production, especially soybean, maize, and rice, showed the greatest increase in area when compared to the 2016/2017 crop season (Conab, 2017).

Despite evident economic gains, this advance of agriculture in relation to natural systems can result in soil degradation. In most cases, intensive agricultural practices reduce aggregate stability, leaving soils more susceptible to erosive processes. Thus, different management practices can have a different effect on its properties of a same soil, including aggregation processes (Castro Filho et al., 1998; Brandão & Silva, 2012; Almeida et al., 2014).

Within this context, soil physical quality has received special emphasis by some authors (Pragana et al., 2012; Almeida et al., 2014; Silva et al., 2017) since it considerably affects soil chemistry and biology, due to their interdependence. Thus, the physical quality of soils indirectly contributes to improving its biological and chemical conditions (Cunha et al., 2012).

Among the properties that constitute its physical quality, soil aggregates, being the main structural components of the soil, are crucial in maintaining its adequate operation (Pragana et al., 2012; Safadoust et al., 2014). The existence of aggregates that resist the action of water are important and significant for soil performance under agricultural use conditions (Safadoust et al., 2014), and has attracted the attention of researchers concerning this parameter (Pragana et al., 2012; Wilson et al., 2013; Safadoust et al., 2014).

Furthermore, changes caused by soil management regarding aggregation in function of different periods of use, under soil and climatic conditions of southwest Piaui, can influence agricultural sustainability in this region. Therefore, the aim of this study was to evaluate the impacts of use and management systems and of time since adoption over soil aggregation in Cerrado areas in the southwest region of Piaui.

Materials and Methods

The study area was located in Serra Branca, Nova Santa Rosa district, in the municipality of Uruçuí (Latitude 7° 14’ 2”S, Longitude 44° 33’ 14”W), in the southwest region of the state of Piaui, Brazil. The study was conducted between October and November 2013. The predominant soil in the study areas is Ferralsol (Oxisol in Soil Taxonomy; Latossolo Amarelo Distrófico típico caulinítico in Santos et al., 2013) (FAO, 2015). According to the Köppen classification, the climate in the region is tropical Aw, hot and humid, with average rainfall of 1,100 mm year^{-1}, and average temperature of 29 °C (Sousa et al., 2013).

In this study, nine systems with different use and management histories were evaluated (Table 1), arranged in the following manner: area under native Cerrado, representing a balanced condition; areas under eucalypt planting (with six

Table 1. History of the use and management systems, and time since they were adopted in a Ferralsol.

Treatment	Use and management history
NC	Native Cerrado vegetation, without a history of human interference for agricultural use. Geographical coordinates: 08° 17' 10.8" S. 44° 33' 59.4’’ W and altitude of 569 m.
EU 6	Cerrado area cleared in the 2007/2008 season; in the first year, rice was sown, and in subsequent years, a eucalyptus plantation was established. Geographical coordinates: 08° 17' 27.7" S. 44° 39' 55.4’’ W and altitude of 578 m.
EU 12	Cerrado area cleared in the 2000/2001 season; in the first year, rice was sown, and in subsequent years, a eucalyptus plantation was established. Geographical coordinates: 08° 15' 50.3" S. 44° 39' 16.3’’ W and altitude of 580 m.
PA 2	Area converted to an agricultural system in the 2001/2002 season. Rice was sown in the first two years, and then soybean was sown. In the 2009/2010 and 2010/2011 crop years, maize was sown. In the last two years, pasture was established with *Urochloa brizantha*; the soil has not been tilled since 2009. Geographical coordinates: 08° 28' 32.6" S. 44° 57' 82’’ W and altitude of 550 m.
PA 6	Area converted to an agricultural system in the 2000/2001 season. Rice was sown in the first two years, and then soybean was sown. In the last six years, pasture was established with *Urochloa brizantha*. Geographical coordinates: 08° 17' 26.8" S. 44° 35' 03’’ W and altitude of 553 m.
CT 2	Area with use and management history with conventional tillage – rice monoculture in the 2011/2012 crop year. Geographical coordinates: 08° 12' 25" S. 44° 34' 35.3’’ W and altitude of 500 m.
CT 8	Cerrado area cleared in the 2006/2007 season, managed under a conventional tillage system with intense soil turnover. System under soybean monoculture every year, except for the 2012/2013 season, which was with maize. Geographical coordinates: 08° 17' 49.7" S. 44° 29' 47.9’’ W and altitude of 572 m.
NT 3	Area converted to an agricultural system in 1999/2000. In the first season, rice was sown and then soybean, using millet as a second crop or straw cover in most season, up to 2008/2009. In the 2009/2010 season, the no-tillage system was introduced, using millet in the formation of straw cover and alternating maize and soybean crops up to the 2012/2013 season. Geographical coordinates: 08° 18’ 16” S. 44° 35' 17’’ W and altitude of 572 m.
NT 6	Area converted to an agricultural system in the 2002/2003 season, being cleared and then used under a conventional tillage system. Rice was sown in the first season. Soybean was sown in the following years, up to the 2006/2007 season. From the 2007/2008 to 2012/2013 season, three maize crops were alternated with soybean crops. In the 2007/2008 season, the no-tillage system was introduced, using millet in the formation of straw cover. Geographical coordinates: 08° 30' 68.1" S. 44° 58' 81.1" W and altitude of 572 m.

and twelve years of growth); areas under pasture (with two and six years of growth), areas under conventional growing system (with two and eight years); and areas under no-tillage system (with three and nine years of growth).

For soil sampling in each cultivated area, a point was defined in the middle of the field and then an area equivalent to one hectare was marked off with the aid of a GPS and measuring tape. Within this area, 25 points were defined at a distance of 25 meters from one to another. Subsequently, four of the 25 points were randomly selected to compose four replicates within each area. In the area under native Cerrado, a border area of 15 meters was established from the margin of the legal reserve (conservation) area, later conducting the previously described procedure.

The methodology proposed by Donagema et al. (2011) was used for chemical determinations, while sulfuric acid digestion was determined in soil samples derived from the native Cerrado area according to Resende et al. (1987). The Ki and Kr molecular ratios were calculated according to IBGE (2015) (Table 2). The soil was classified as kaolinitic (Ki > 0.75; Kr > 0.75), of medium texture (clay contents of 150 to 350 g kg^{-1}) (Santos et al., 2013).

Soil particle size was determined by the pipette method (Donagema et al., 2011), while the particle size fractions were obtained according to the Brazilian Soil Classification System (Santos et al., 2013) (Table 2). Organic carbon was determined by the dry combustion method, using Organic Carbon Analyzer, Vario ®TOC Cube (Elementar brand). For such purpose, samples (2 mg) were weighed, macerated (mortar), sieved (0.25 mm mesh), and dried (65 °C) for 48 h. They were then placed and sealed in tin capsules and incinerated (950 °C) for 5 min. After combustion, an infrared sensor detected the amount of carbon in the sample.

An analysis of aggregate stability was performed on 144 samples collected at the following depths: 0.00-0.10 m, 0.10-0.20 m, 0.20-0.30 m and 0.30-0.40 m, with the aid of a spade in the four replicates of each area. Subsequently, in laboratory, clumps of sod were selected and, to avoid induced disaggregation and compaction, soon after the samples had been completely air dried at ambient temperature, they were carefully manually broken up until the aggregates could pass through an 8-mm sieve and remain in a 2-mm sieve.

For determining aggregate stability in water (Kemper & Chepil, 1965), 25-g aggregate samples were taken from the part remaining in the 2-mm sieve and subjected to slow wetting by capillarity on wetted filter paper for 24 h. The aggregate samples were then placed in a set of sieves with meshes of 2.00 mm, 1.00 mm, 0.50 mm, 0.25 mm, and 0.105 mm diameters, immersed in water, and shaken by a Yoder type wet sieve shaker using a frequency of 30 cycles min^{-1}, and 3.5 cm vertical amplitude for 15 min, to obtain aggregate class proportions with sizes of 8.00-2.00 (AG1), 2.00-1.00 (AG2), 1.00-0.50 (AG3), 0.50-0.25 (AG4), 0.25-0.105 (AG5), and < 0.105 (AG6) mm diameters.

Posteriorly, the material retained in each sieve was placed in containers for drying in oven at 105°C for 24 h. The values of mean weight diameter “MWD” (Eq. 1) (Kemper & Rosenau, 1986), mean geometric diameter “MGD” (Eq. 2) (Mazurak, 1950), and aggregate stability index “ASI” (Eq. 3) (Castro Filho et al., 1998) were determined according to the following equations:

$$\mathrm{MWD} = \sum_{i=1}^{n} (\mathrm{wi\ xi}) \quad (1)$$

$$\mathrm{MGD} = \frac{\sum_{i=1}^{n} \mathrm{wp} \log \mathrm{xi}}{\sum_{i=1}^{n} \mathrm{wi}} \quad (1)$$

$$\mathrm{ASI} = \left(\frac{\mathrm{Ps} - \mathrm{Wp}_{25} - \mathrm{Sand}}{\mathrm{Ps} - \mathrm{Sand}} \right) \quad (3)$$

Table 2. Characterization of the soil (0-0.40 m deep) under different use and management systems and periods of time since adoption in the Cerrado of Piauí, Brazil.

Management system [1]	pH [2] 1:2.5	P (mg dm^{-3})	K^+ (mg dm^{-3})	Ca^{2+}	Mg^{2+}	Al^{3+}	H+Al	t [3]	T [4]	CS [5]	FS [6]	silt	clay
				cmol$_c$ dm^{-3}						g kg^{-1}			
NC	4.8	0.5	8.0	0.1	0.1	1.3	6.9	1.5	7.1	240	473	58	229
EU6	5.3	1.8	9.9	0.8	0.7	0.4	4.6	1.9	6.1	174	629	26	171
EU12	5.1	3.6	15.1	1.0	0.5	0.4	4.2	1.9	5.7	208	582	37	173
PA2	4.9	10.1	35.0	1.0	0.5	0.5	4.5	1.9	6.0	214	572	24	190
PA6	5.0	5.3	18.5	0.8	0.4	0.6	5.0	1.8	6.2	177	611	47	165
CT2	5.0	5.5	23.3	0.7	0.5	0.5	3.7	1.6	4.9	231	543	43	183
CT8	4.9	17.2	52.4	0.9	0.3	0.4	4.0	1.8	5.4	405	381	59	155
NT3	5.1	18.0	56.1	1.3	0.5	0.4	3.8	2.2	5.7	245	524	32	199
NT6	4.9	16.6	48.3	1.0	0.3	0.6	4.7	2.0	6.1	205	554	41	200

Native Cerrado

Sulfuric acid digestion	P_2O_5	%SiO_2	%Al_2O_3	%Fe_2O_3	%TiO_2	%P_2O_5	[7] Ki	[8] Kr	Al_2O_3/Fe_2O_3
	0.01	9.19	8.99	4.43	0.49	0.01	1.74	1.32	3.18

[1] Soil management system: NC – Native Cerrado, EU6 – Eucalyptus for 6 years, EU12 – Eucalyptus for 12 years, PA2 – Pasture for 2 years, PA6 – Pasture for 6 years, CT2 – Conventional tillage for 2 years, CT8 – Conventional tillage for 8 years, NT3 – No-tillage for 3 years, NT6 – No-tillage for 6 years. [2] pH in water; [3] t: effective cation exchange capacity [4] T: cation exchange capacity at pH 7.0; [5] CS: coarse sand; [6] FS: fine sand; [7] Ki [(% SiO_2 x 1.697) / % Al_2O_3]; [8] Kr (% SiO_2 x 1.697) / [% Al_2O_3) + (% Fe_2O_3 x 0.64)].

in which wi is the proportion of each class of aggregates in relation to the total; xi is the mean diameter of the classes (mm); wp is the weight of aggregates of each class (g); Ps is the weight of the dry sample (g); and Wp_{25} is the weight of the aggregates of the class < 0.25 mm (g).

After this step, we verified the statistical assumptions, activity and error independence by graph analysis, variance homogeneity by the Bartlett test, and error normality by the Shapiro-Wilk test. After these assumptions were met, simple analyses of variance were conducted according to depth in a completely randomized design, which, according to Ferreira et al. (2012), is viable since the requirements for conducting the analysis of variance were met. The mean values were compared by the Scott-Knott test ($p \leq 0.05$) (Borges & Ferreira, 2003). The cluster analysis was performed by the *Ward* method (Ward, 1963), using the mean Euclidean distance as dissimilarity measure (Hair Júnior et al., 2010). The Bartlett sphericity test ($p < 0.05$) was conducted for applying the principal component analysis and, after which, the Kaiser Meyer Olkin test (KMO) was performed. Statistical analyses were doen using the R 3.3.2 statistical software.

Results and Discussion

The use and management systems showed significant effects concerning the parameters related to soil aggregation: mean geometric diameter, mean weight diameter, and aggregate stability index at different depths. The differences were more evident near the soil surface (Table 3). Other studies also emphasized the influence of use and management over the size and distribution of aggregates in a Ferralsol (Almeida et al., 2014) in different soil layers (Santos et al., 2012) and especially near the soil surface (Castro Filho et al., 1998), corroborating the data found in this study.

The values of mean geometric diameter, mean weight diameter, and aggregate stability index generally followed the decreasing order: native Cerrado > 6-year pasture > 2-year conventional tillage > 6-year no-tillage > 2-year pasture > 3-year no-tillage > 12-year eucalypt > 6-year eucalypt > 8-year conventional tillage (Figure 1).

Table 3. Analysis of variance (F values) for aggregate stability under different layers of soil use and management systems.

Source of variation [1]	MGD	MWD	ASI
0.0-0.10 m			
Management	17.32**	12.92**	36.67**
CV [2]	14.30	7.08	10.28
Shapiro-Wilk test[3]	0.96^{ns}	0.97^{ns}	0.97^{ns}
Bartlett test[4]	9.40^{ns}	12.26^{ns}	12.87^{ns}
0.10-0.20 m			
Management	12.63**	10.08**	11.37**
CV	14.67	8.26	13.05
Shapiro-Wilk test	0.97^{ns}	0.95^{ns}	0.98^{ns}
Bartlett test	11.84^{ns}	11.24^{ns}	10.81^{ns}
0.20-0.30 m			
Management	3.71*	1.37^{ns}	5.79**
CV	18.83	8.31	13.28
Shapiro-Wilk test	0.95^{ns}	0.94^{ns}	0.94^{ns}
Bartlett test	11.17^{ns}	10.95^{ns}	14.58^{ns}
0.30-0.40 m			
Management	2.09^{ns}	2.13^{ns}	4.90*
CV	15.28	8.27	11.94
Shapiro-Wilk test	0.95^{ns}	0.97^{ns}	0.97^{ns}
Bartlett test	5.19^{ns}	13.39^{ns}	8.58^{ns}

[1] ns: F not significant; *: F significant at 5%; **: F significant at 1%; [(1)] variables analyzed: MWD = mean weight diameter; MGD = mean geometric diameter; ASI = aggregate stability index; [(2)] coefficient of variation in %. [(3)] Shapiro-Wilk normality test. [(4)] Bartlett homogeneity test.

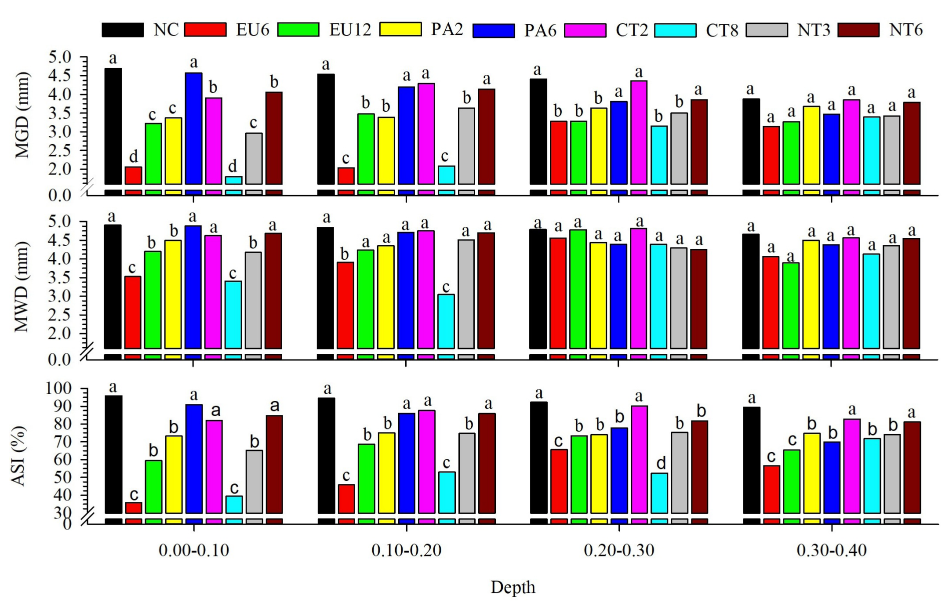

Figure 1. Mean geometric diameter (MGD) and mean weight diameter (MWD) and aggregate stability index (ASI) in the 0.0-0.40m depth layer under different use and management systems: NC – native Cerrado, EU6 – eucalyptus at 6 years, EU12 – eucalyptus at 12 years, PA2 – pasture at 2 years, PA6 – pasture at 6 years, CT2 – conventional tillage at 2 years, CT8 – conventional tillage at 8 years, NT3 – no-tillage at 3 years, NT6 – no-tillage at 6 years.

Thus, evaluation of mean geometric diameter, mean weight diameter, and aggregate stability index at different depths showed that use and management systems 6-year pasture, 6-year no-tillage, and 2-year conventional tillage resulted in larger aggregates from 0.20 m of depth. Systems 6-year no-tillage and 2-year conventional tillage showed more stable aggregates from 0.40 m of depth when compared to the other cultivating systems. This result can be attributed to the higher values of organic carbon at the surface provided by systems 6-year pasture, 6-year no-tillage, and 2-year conventional tillage (Figure 2). The short time of conversion into agricultural system of 2-year conventional tillage and crop rotation, as well as the different root systems for 6-year no-tillage may have led to more stable aggregates at depths greater than 0.30 m when compared to the other systems, which were similar to the native Cerrado.

The similarity in soil aggregation indexes (mean geometric diameter, mean weight diameter, and aggregate stability index) of the 6-year pasture systems and native Cerrado found in this study agree with the results obtained by Pagliarini et al. (2012) in a Ferralsol, in which the cultivation of pasture decreased soil aggregation in comparison to the area under natural vegetation. However, other studies showed that conversion of *Cerradão* (Cerrado with substantial canopy cover) to pasture does not change soil aggregation (Costa Junior et al., 2011) given that planting species such as Urochloa (Brandão & Silva, 2012), associated with the absence of soil turnover, contributes to the formation of stable macroaggregates (Salton et al., 2008) due to the bonds of the points of contact between mineral particles and aggregates, which, over time, favor soil aggregation in pasture areas (Conte et al., 2011).

There was no significant reduction in soil aggregation with the introduction of the 6 year no-tillage system in areas of native Cerrado, as shown in Figure 1. This result agrees with specialized literature (Assis & Lanças, 2010; Franchini et al., 2012), which emphasizes the positive effect of no-tillage over soil aggregation indexes due to the lack of mechanical destruction of aggregates by implements and to the protection that straw cover offers to the soil surface (Morais & Cogo, 2001), favoring a better distribution and morphology of the aggregates at surface level, showing that this management system is similar to the original structuring conditions (Hickmann et al., 2011).

The similarity between the values of mean geometric diameter, mean weight diameter, and aggregate stability index between 2-year conventional tillage and native Cerrado may be related to the preservation of the characteristics of native Cerrado given the short time since conversion to agricultural use. A similar situation was observed by Fontenele et al. (2009) upon evaluating the effect of management systems over aggregate stability in a Ferralsol.

The lowest values of mean geometric diameter, mean weight diameter, and aggregate stability index were obtained in 8-year conventional tillage and 6-year eucalypt (Figures 1 and 2). The results obtained for 8-year conventional tillage agree with other studies (Fontenele et al., 2009; Assis & Lanças, 2010), which confirm that adoption of conventional tillage with substantial soil turnover for a long period contributed to reducing the stability of aggregates in water. In this regard, studies show that conventional tillage contributes to the reduction of organic carbon contents in soils (Salton et al., 2008), as well as significantly impairing soil structure (Oliveira et al., 2003).

The low density of the eucalypt root system near the surface and the reduced amount of organic residues deposited by this species in the soil may have contributed to lower the accumulation of organic carbon (Figure 2), which may have been a determining factor in obtaining lower values of mean geometric diameter and mean weight diameter, as well as less stable aggregates in the eucalypt system, given that carbon in the soil is an important constituent of binding agents (Castro Filho et al., 1998; Fonseca et al., 2007). Thus, we noted that the better structure found in the native Cerrado regarding 6 year eucalypt and 12 year eucalypt may be related to the diversity of plant species and the large input of organic matter on the surface, which favors the action of soil organisms, which, in turn, contributes to soil aggregation (Beldini et al., 2010).

Regarding the time since adoption of the soil use and management systems, a significant contribution is observed for the increase in soil aggregation indexes (mean

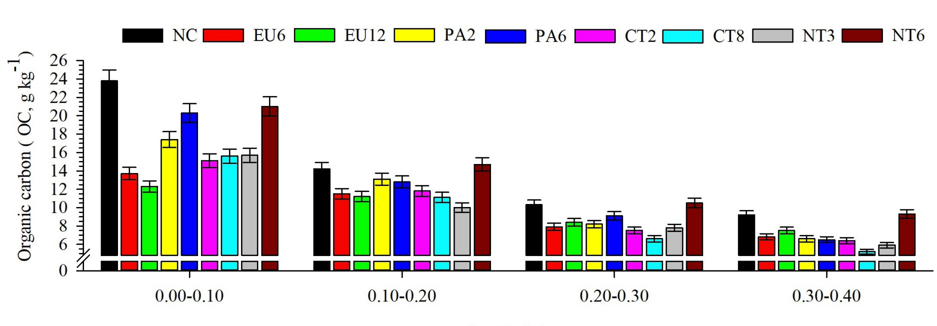

Figure 2. Organic carbon in layers of soil under different use and management systems and periods of time of adoption in the Cerrado of Piauí, Brazil. Management systems: NC – native Cerrado, EU6 – eucalyptus at 6 years, EU12 – eucalyptus at 12 years, PA2 – pasture at 2 years, PA6 – pasture at 6 years, CT2 – conventional tillage at 2 years, CT8 – conventional tillage at 8 years, NT3 – no-tillage at 3 years, NT6 – no-tillage at 6 years.

geometric diameter, mean weight diameter, and aggregate stability index) of the systems under pasture, no-tillage and eucalypt cultivations. However, for the conventional tillage systems, the time of adoption had a negative effect over soil aggregation (Figure 1).

These results indicate that, in the long term, the systems with pasture, no-tillage and eucalypt favor soil structuring, especially in the surface layer. However, conventional tillage leads to destructuring of the soil over time. These results agree with those found by Assis & Lanças (2010) upon observing that the time of adoption of the no-tillage system favored soil aggregation.

Analyzing Figure 3 and Table 4, it can be observed that practically all variables are close to the unit circle, indicating good contribution to the principal components. In relation to the soil use and management systems presented in the Figure 3, a clear tendency of clustering of the native Cerrado plots in the upper left quadrant (Group 1), 8 year conventional tillage in the upper right quadrant (Group 4), and 12 and 6 year eucalypt in the lower right quadrant (Group 3) can be observed.

For the other use and management systems (2 year conventional tillage, 6 year no-tillage, 3 year no-tillage, 6 year pasture and 2 year pasture) (Group 2), there is no clear separation, as they are relatively near the center region of the diagram, where greater homogeneity among them is inferred, revealing lower correlation with the soil aggregation indexes (Figure 3). Moreover, it is observed that Group 1, based on Principal Component 1, obtained strong negative correlation with Group 4 and weak negative correlation with Group 3. However, it was noted that Group 2 was close to

Table 4. Correlation between each principal component and percentage of variance explained by each variable in relation to the management systems studied.

Variables[(1)]	Eigenvalue		Contribution (%)	
	PC 1	PC 2	PC 1	PC 2
MGD	-0.98*	0.07	10.96	0.16
MWD	-0.99*	0.02	11.15	0.01
ASI	-0.89*	0.02	9.09	0.01
AG1	-0.99*	0.01	11.17	0.01
AG2	0.78*	-0.04	4.90	0.05
AG3	0.87*	0.25	6.69	2.26
AG4	0.94*	0.20	10.20	1.45
AG5	0.85*	-0.29	8.34	3.04
AG6	0.79*	0.11	7.11	0.43
CS	0.39	0.84*	0.75	25.08
FS	-0.13	-0.96*	0.19	32.33
TS	0.70*	-0.55	5.30	10.70
SIL	-0.09	0.80*	0.10	22.76
CLY	-0.74*	0.15	6.32	0.78
OC	-0.73*	0.16	7.73	0.93

* More discriminatory values; PC 1 = principal component 1; PC 2 = principal component 2. [(1)] Variables analyzed: coarse sand (CS), fine sand (FS), total sand (TS), silt (SIL), clay (CLY), organic carbon (OC), mean geometric diameter (MGD), mean weight diameter (MWD), aggregate stability index (ASI), and aggregate classes: 8–2 (AG1), 2–1(AG2), 1–0.5 (AG3), 0.5–0.25 (AG4), 0.25–0.105 (AG5), and < 0.105 mm (AG6) diameter.

Group 1. Wendling et al. (2012) observed that conversion of native Cerrado into brachiaria pasture increased the total organic carbon contents, whereas, in the no-tillage system, the contents remain similar to the original.

Furthermore, it was observed that the native Cerrado (Group 1) was more strongly coordinated with variables mean geometric diameter, mean weight diameter, aggregate stability index, AG1, clay, and organic carbon, which confirms the better structural condition of the soil

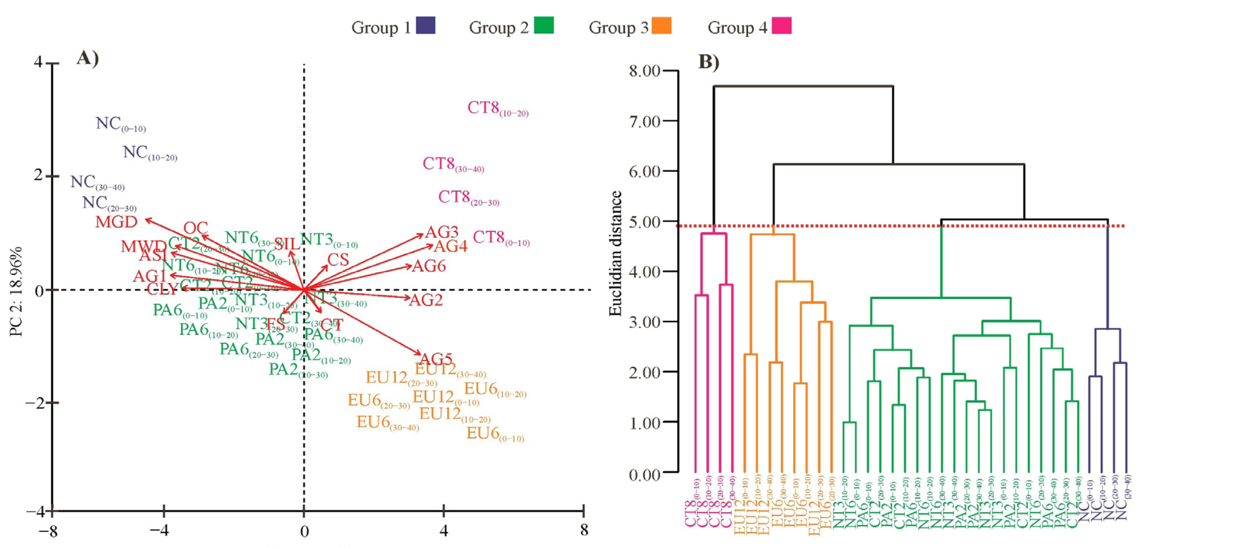

Figure 3. Analysis of principal components (A) and clusters (B) of variables related to stability of soil aggregates for the nine treatments at the four depths. Ellipses: Group 1 = native Cerrado (NC); Group 2 = conventional tillage at 2 years (CT2), no-tillage at 3 years (NT3), no-tillage at 6 years (NT6), pasture at 2 years (PA2), and pasture at 6 years (PA6); Group 3 = eucalyptus at 6 years (EU6) and at 12 years (EU12); Group 4 = conventional tillage at 8 years (CT8). Variables: coarse sand (CS), fine sand (FS), total sand (TS), silt (SIL), clay (CLY), organic carbon (OC), mean geometric diameter (MGD), mean weight diameter (MWD), aggregate stability index (ASI), and aggregate classes: 8–2 (AG1), 2–1(AG2), 1–0.5 (AG3), 0.5–0.25 (AG4), 0.25–0.105 (AG5), and < 0.105 mm (AG6) diameter.

in the area under natural vegetation (Figure 3 and Table 4). The 8-year conventional tillage (Group 4) did not correlate with the previously cited variables. However, it was more associated with coarse sand, AG3, AG4, and AG6 (Figure 3 and Table 4), showing greater fractionation caused by soil turnover in areas under this management system (Oliveira et al., 2003). In a study conducted in a very clayey Ferralsol, Calegari et al. (2006) concluded that the conventional tillage system contributed to reducing soil organic carbon contents, lowering values of aggregate stability index, mean weight diameter and mean geometric diameter, and lowering the percentage of aggregates > 2.00 mm, corroborating the results of this study.

In the same respect, the 6 and 12-year eucalypt systems (Group 3) were more correlated with variables AG2 and AG5 (Figure 3 and Table 4), which may be related to the low quantity of organic carbon in these areas since this property is an important soil cementing agent (Castro Filho et al., 1998, Fonseca et al., 2007). In the areas of 6-year pasture, 6-year no-tillage,2-year conventional tillage, 2-year pasture, and 3-year no-tillage (Group 2), although the analyzed variables have contributed in a similar manner, the systems of this group were those that most drew near the soil condition under natural vegetation (Figure 3 and Table 4), which shows the importance of not turning over the soil (Salton et al., 2008) and of the addition of organic residues to the surface (Castro Filho et al., 1990; Fonseca et al., 2007).

Moreover, we verified a positive correlation between organic carbon, clay and soil aggregation indexes (mean geometric diameter, mean weight diameter, and aggregate stability index), as well as the aggregates with diameter greater than 2 mm (AG1), based on Principal Component 1 (Figure 3 and Table 4). The contribution of the carbon content to soil aggregation indexes has been reported in many studies (Castro Filho et al., 1998; Fonseca et al., 2007). Furthermore, there is high correlation between organic matter and the stability of aggregates in soils with less than 25% of clay (Baver et al., 1972), which is of fundamental importance for agricultural yield since water retention in the surface horizons is positively correlated with the clay and organic carbon contents of the soil (Gomes et al., 2004).

Conclusions

The transition of native Cerrado areas to 2-year conventional tillage, 6-year pasture, and 6-year no-tillage did not promote significant changes in soil aggregation.

Systems of 8-year conventional tillage and 6-year eucalypt led to a reduction in organic carbon content and in the soil aggregation indexes.

The longer time of adoption in no-tillage, pasture and eucalypt favored soil aggregation, whereas conventional tillage led to a reduction in soil aggregation.

Multivariate analysis showed that aggregation in the Ferralsol under the studied management systems is favored by clay and organic carbon contents.

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