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Chemical characterization of soil organic matter in differents management practices in the Cerrado-Pantanal ecotone

Caracterização química da matéria orgânica do solo em diferentes sistemas de manejo no ecótono Cerrado-Pantanal

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Different land uses and occupations have a direct impact on edaphic attributes, which can be identified by soil quality indicators, with organic matter being an excellent edaphic quality indicator. The objective of the work was to chemically characterize soil organic matter (SOM) in different management systems in the municipality of Aquidauana, Mato Grosso do Sul, Brazil. Soil samples were collected in five areas with different management practices, in addition to an area of native Cerrado forest (NF), and the managed areas were: exposed soil (ES), conventional tillage system (CTS), no-tillage (NTS), permanent pasture (PP) and sugarcane (SC). In addition to the determination of bulk density (Bd), total organic carbon (TOC) contents and stocks were quantified, as well as carbon (C) contents and stocks of the humified fractions: humic acid (AH), fulvic acid (AF) and humin (HUM), with subsequent calculation of HA/FA and alkaline extract/humin (AE/HUM) and TOC stratification index (SI). There were no significant changes for Ds after six years of implementation of management systems. TOC levels and stocks were higher in PP and NTS areas. The HUM fraction was predominant, with higher contents and stocks of all fractions for the PP and NTS areas, demonstrating the greater intensity of the humification process in these management systems, with greater stability of C in the soil after six years of experiment. The PCA indicated a difference between the areas that present conservation practices in the ES and CTS areas. The NF, NTS, PP and SC areas contribute to SOM stabilization.
Key words: sustainability, edaphic quality, humic substances.

Os diferentes usos e ocupações do solo impactam diretamente nos atributos edáficos, que podem ser identificados pelos indicadores de qualidade do solo, sendo a matéria orgânica um excelente indicador de qualidade edáfica. O objetivo do trabalho foi caracterizar quimicamente a matéria orgânica do solo (MOS) em diferentes sistemas de manejo no município de Aquidauana, Mato Grosso do Sul, Brasil. Amostras de solo foram coletadas em cinco áreas com diferentes práticas de manejo, além de uma área de floresta nativa de Cerrado (NF), e as áreas manejadas foram: solo exposto (ES), sistema de preparo convencional (SPC), plantio direto (SPD), pastagem permanente (PP) e cana-de-açúcar (SC). Além da determinação da densidade do solo (Ds), foram quantificados os teores e estoques de carbono orgânico total (COT), bem como os teores e estoques de carbono (C) das frações humificadas: ácido húmico (AH), ácido fúlvico (AF) e humina (HUM), com posterior cálculo de HA/FA e extrato alcalino/humina (AE/HUM) e índice de estratificação TOC (SI). Não houve mudanças significativas para Ds após seis anos de implantação dos sistemas de gestão. Os níveis e estoques de COT foram maiores nas áreas de PP e SPD. A fração HUM foi predominante, com maiores teores e estoques de todas as frações para as áreas de PP e SPD, demonstrando a maior intensidade do processo de humificação nesses sistemas de manejo, com maior estabilidade do C no solo após seis anos de experimento. O PCA indicou uma diferença entre as áreas que apresentam práticas conservacionistas nas áreas do ES e CTS. As áreas NF, CTS, PP e SC contribuem para a estabilização do MOS.
Palavras-chave: sustentabilidade, qualidade edáfica, substâncias húmicas.

1. INTRODUCTION

The adoption of management systems aimed at sustainability in agricultural production becomes increasingly essential to maintain the quality of production systems, in order to improve soil quality (SQ) and, consequently, crop yield. The replacement of management systems with intense soil revolving, such as the conventional tillage system (CTS), for conservation systems such as the no-tillage system (NTS) and pastures, when well-handled, allow the maintenance of the intake of residues on the soil surface and, added to the non-revolving of it, provides greater accumulation and storage of carbon (C), contributing to the maintenance of edaphic quality and productive capacity [1-5].

Among the components responsible for maintaining the SQ, there is the soil organic matter (SOM) [6-8]. It integrates three main components, comprising the remains of dead roots and other residues with a particle size sufficient for recognition, the living biomass that includes tissues of plants, animals, and microorganisms, and, finally, a combination of organic substances whose chains are complex and not recognizable as tissues, also called soil humus [9, 10].

Humus represents the decomposed part of SOM, in which the structure of the material that originated it cannot be identified, due to the advanced state of decomposition. It is separated into three types of humic substances (SH), namely fulvic acids (AF), humic acids (AH), and humine (HUM) [11]. Its effects reflect directly on agricultural production, as in addition to increasing the aggregation capacity and water retention in the soil, they improve soil fertility by increasing the cation exchange capacity (CEC) of the soil [12].

The expansion of the agricultural sector has caused the replacement of areas with pasture for crops, especially for the production of soybeans, corn and cotton [13]. Studies are being done intensively to improve the technologies applied to plant resistance to pests and diseases, however, the crop change adopted and the treatment that the soil receives causes changes in its properties, which vary for soil type and region. In addition, there is a lack in studies that clarify the changes in the edaphic system instigated by the different management systems at the interface of the transition of the Cerrado and Pantanal biomes.

The degradation that occurs in productive areas is notorious when management systems that do not use conservation techniques are adopted. The transition region between the Cerrado and the Pantanal has potential for agricultural use, therefore, management systems that contribute to environmental sustainability must be sought, considering the weaknesses found in the Pantanal. In view of the above, due to several management practices adopted in different climate and soil conditions at the country level, it is important to characterize not only the amount of C, but also the quality of this C to the soil due to the adoption of different management systems. Thus, with the intention of verifying which management practices play a role in maintaining/improving the quality of the soil organic fraction and, consequently, of the other edaphic attributes, with the goal of increasing the productive capacity and sustainability of the cultivation areas, the study aimed to chemically characterize the soil organic matter in different management systems conducted over time in the Cerrado-Pantanal ecotone region.

2. MATERIAL AND METHODS

Soil samples were collected in five different management systems, and also in an area under native Cerrado vegetation in the municipality of Aquidauana, Mato Grosso do Sul, Brazil (Figure 1) [14]. The study region is located in a transition area of the Cerrado-Pantanal biomes, and the climate is classified by the international system of Köppen [15], as sub-humid hot tropical, with records of average annual precipitation of 1,250 mm and average annual temperature of 26ºC.

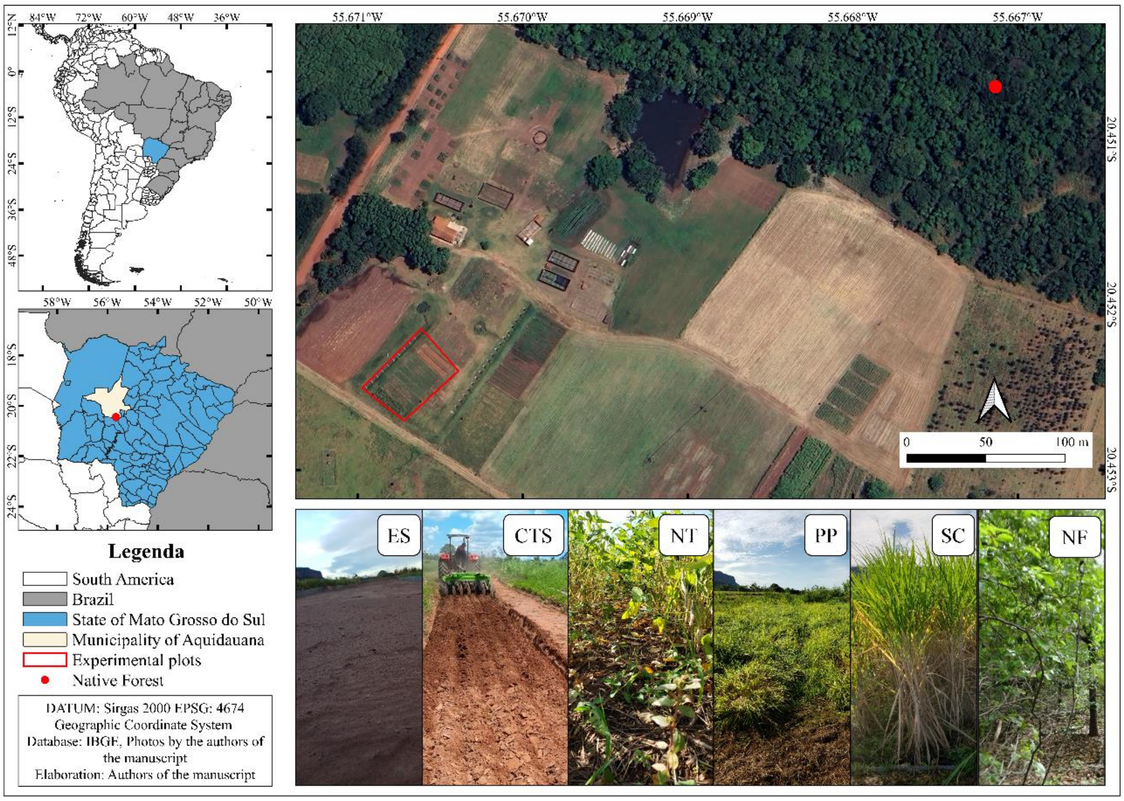

Figure 1. Map of location of the municipality of Aquidauana, state of Mato Grosso do Sul. (Source: QGIS, version 3.26.0 Buenos Aires).

Five managed areas and an adjacent reference area (Native Forest - NF - Cerrado Stricto sensu vegetation with variations of Cerradão) without anthropic action were evaluated, making up six different systems. The five managed areas comprise exposed soil without any cultivation with annual revolving in the direction of slope (ES), conventional tillage system with annual revolving towards the slope (CTS), no-tillage system (NTS), permanent pasture (PP) and sugarcane (SC), all with a history of six years of management. The physical and chemical attributes of the managed areas of the study are shown in Table 1, and the history of use of the respective managed areas is shown in Table 2.

Table 1. Physical and chemical attributes of the dystrophic Red Ultisol of the experimental area prior to the implementation of the experiment.

Layer (m)	Sand	Silt	Clay	pH	C	OM	P	Ca	Mg	K	Al	m	V
	--------g.kg^{-1}--------				----%---		Mg.dm^{-3}	-----cmol$_c$.dm^{-3}-----				-----%-----	
0.0-0.2	815	124	61	5.69	0.73	1.26	47.23	2.40	0.54	0.39	0.00	0.00	54.01
0.2-0.4	785	138	77	5.67	0.57	0.98	38.97	2.41	0.37	0.31	0.00	0.00	54.53

pH: Hydrogenionic potential. C: Carbon. OM: Organic matter. P: Phosphorus. Ca: Calcium. Mg: Magnesium. K: Potassium. Al: Aluminum. m: Aluminum Saturation. V: Base saturation.

The experimental plots were installed in 2014. Before the installation of the different management systems, the soil in the experimental areas had been cultivated for 20 years with a succession of pastures and annual crops. During this period, the crops were carried out in CTS, in which, before the installation of annual crops alternated with pastures, a soil disturbance operation was carried out with harrowing to a depth of 0.2 m and two operations with leveling harrows to a depth of 0.1 m.

Table 2. History and description of the different management systems installed.

MS	Management history
ES	Managed with two plows using a disc plow up to a depth of 0.2 m and two leveling harrows at a depth of 0.1 m in the direction of the slope, without any cultivated plant species.
CTS	Managed with two plows using disc plows to a depth of 0.2 m and two leveling harrows at a depth of 0.1 m in the direction of the slope, with the alternating cultivations of soybean, corn, turnip, sunn hemp and fallow in summer and winter crops.
NTS	Managed without soil revolving, with alternating crops of soybean, corn, turnip, sunn hemp, millet and fallow in summer and winter seasons.
PP	Managed continuously with *Brachiaria ruziziensis* without grazing with beef or dairy cattle.
SC	Managed continuously with sugarcane using the RB 855536 variety with annual cuts, without the practice of burning in pre-harvest.
NF*	Area adjacent to the experimental plots with vegetation of Native Forest of Cerrado *Stricto sensu*. Used as a reference for the original soil condition.

Source: Farias et al. (2022) [16]. MS: management systems; ES: exposed soil, CTS: conventional tillage system, NTS: no-tillage system, PP: permanent pasture, SC: sugarcane and NF*: native forest (area adjacent to experimental plots with straight distance of 400 m).

In the year 2018, in each study area, four replicates were collected for both disturbed and undisturbed samples, and each disturbed composite sample was represented by five simple samples in the 0-0.05, 0.05-0.1 and 0.1-0.2 m layers, thus comprising 72 sample units.

The disturbed samples were disaggregated and sieved in a 2 mm mesh sieve, constituting the Thin Air-Dried Soil (TADS). Bulk density analysis (Bd) was performed according to Claessen (1997) [17]. TOC analyses were performed by oxidation of carbon by potassium dichromate under heating and titrated with ammoniacal ferrous sulfate in the presence of Ferroin, according to a methodology adapted from Yeomans and Bremner (1988) [18].

The chemical fractionation of SOM was performed according to a differential solubility technique established by the International Society of Humic Substances [19], according to the adaptation of Benites et al. (2003) [20], by separating the fractions in fulvic acid (FA), humic acid (HA) and humin (HUM), with subsequent determination of the carbon content (C) of each fraction by oxidation of C by potassium dichromate in sulfuric medium under heating, and ammoniacal ferrous sulfate titration with Ferroin indicator.

From the analyses of C, HA, FA, alkaline extract (AE) (AE = HA+FA) and HUM, the following ratios were calculated: HA/FA and AE/HUM to verify the humification processes of SOM, and the relative proportion of each fraction in relation to the TOC was also calculated. In addition, the stocks of TOC (StockC) and C of the humic substances (HS) were calculated according to the equivalent mass method [21, 22].

After all the analyses performed, the results obtained were analyzed in a completely randomized design, being subjected to variance analysis with F-test application, and the mean values compared to each other by the 5% Tukey test with the aid of the GENES program [23]. In addition, a Principal Component Analysis (PCA) was generated with the help of the R Core Team program (2019) [24], using the "prcomp" command of the vegan package [25], with the variables TOC, StockC, Ds and SI.

3. RESULTS AND DISCUSSION

Higher bulk density values (Bd) can be observed for the ES management system in all evaluated layers, with values ranging from 1.47 to 1.71 $Mg.m^{-3}$, differing from the PP area in the layers of 0-0.05 and 0.05-0.1 m, with 1.19 and 1.37 $Mg.m^{-3}$, respectively, and the NF area in the 0.1-0.2 m layer, 1.42 $Mg.m^{-3}$. In general, for the other systems evaluated, there were no differences (Table 3). After six years of cultivation, no significant changes were observed in Sd in most of the studied areas.

In all areas evaluated, Sd values were below the critical limit presented for plant development, which now have difficulty in penetrating soils with Sd above 1.75 $Mg.m^{-3}$ [26, 27]. It is also noteworthy that there were no differences in Sd between the areas of CTS and NTS after six years of practice in the areas.

Higher TOC contents were observed for the NTS and PP areas in the 0-0.05 m layer, with 36.38 and 37.37 $g.kg^{-1}$, respectively, being similar in this layer, with the PP area higher than the NTS in the other layers (Table 3). The highest TOC contents presented in these areas are related to the frequent deposition of plant material in the soil over time, and the development of the root system of the different plant species in the crop rotation system in NTS and grass in PP, in addition to the absence of grazing and soil revolving [28-32].

It is also worth noting the difference in the accumulation of TOC between the areas of CTS and NTS with only six years of cultivation, with contents of 11.52, 16.05 and 12.79 $g.kg^{-1}$ in CTS and 36.38, 27.99 and 23.13 $g.kg^{-1}$ in NTS, respectively for the 0-0.05, 0.05-0.1 and 0.1-0.2 m layers (Table 3), consequently reflecting in the StockC (Table 3). On average, for the profile of 0-0.2 m, the CTS area presented a TOC content of 13.45 $g.kg^{-1}$, and the NTS area of 29.17 $g.kg^{-1}$, that is, the CTS in six years accumulated only 46.11% of the TOC in relation to the NTS. This represents an accumulation of TOC of 7.85 $g.kg^{-1}$ $year^{-1}$ for the NTS area in relation to the NTS, a fact also reported in the studies of Loss et al. (2017) [33] and Assunção et al. (2019) [34].

As well as for TOC levels in relation to conservation practices and pasture management, the highest StockC were observed for the PP area in all layers evaluated, with values ranging from 50.87 $Mg.ha^{-1}$ in the 0.05-0.1 m and 47.32 $Mg.ha^{-1}$ in the 0.1-0.2 m layer, and the NTS area was similar to PP only in the 0-0.05 m layer with C storage of 48.79 $Mg.ha^{-1}$ (Table 3). The same similarity between StockC in surface layer between PP area with 41 years of management and NTS with 17 years of cultivation was also found by Assunção et al. (2019) [34]. Several authors, in the most diverse regions, soil and climate, have demonstrated in their studies how management is capable of interfering in the StockC [7, 30, 32, 34-37].

It is also worth mentioning the C storage potential that the NTS had in relation to the CTS after six years of conducting the experiment. The CTS area presented StockC of 15.44, 23.18 and 18.23 $Mg.ha^{-1}$, and the NTS showed values of 48.79, 40.42 and 32.99 $Mg.ha^{-1}$, respectively, for the layers of 0-0.05, 0.05-0.1 and 0.1-0.2 m (Table 3). Considering the 0.2 m profile, the areas of CTS and NTS stocked 56.85 and 122.20 $Mg.ha^{-1}$ of C. That is, the CTS area stocked 46.52% of the C of the NTS area. This difference also represents that the area of NTS stocked 10.89 $Mg.ha^{-1}$ $year^{-1}$ of C plus in relation to the CTS area for the 0-0.2 m layer. This fact is probably due to the constant soil revolving adopted by the NTS, which accelerates the process of decomposition of SOM present inside soil aggregates, further preventing soil stabilization, unlike the NTS [37, 38]. Several studies in the literature show the advantages of adopting the NTS in relation to CTS regarding the potential for C accumulation over the years of cultivation [27, 39-41].

The areas with the highest C-FA contents were ES and CTS, being similar to the PP area in the 0-0.05 and 0.1-0.2 m layers, reaching 1.33 $g.kg^{-1}$ in the 0.05-0.1 m layer in CTS (Table 3). This result is mainly due to the annual revolving of the soil that these two areas have, a fact that provides the non-evolution of the stages of humification of SOM, causing the FA to take a longer period to stabilize in the most recalcitrant fractions of HA and, mainly of HUM [41, 42]. Results found by Melo et al. (2016) [28] in a study with NTS, CTS and PP in the Cerrado region, demonstrated that there were lower levels of C-FA for the areas of PP and CTS compared to the NTS, diverging from those found in this study.

The PP area presented higher levels of C-HA in all layers, with higher content in layer 0-0.05 m, 3.07 $g.kg^{-1}$, differing from the other assessed areas, including NF. However, the PP area presented levels similar to those found for the NTS area with 2.37 and 2.45 $g.kg^{-1}$ in the layers 0.05-0.1 and 0.1-0.2 m, respectively. Management systems that adopt less soil revolving preserving surface-based plant residues contribute to the increase of HA levels over the years of cultivation [42, 43], resulting in fractions with greater stability of C in the soil [43, 44].

Table 3. Bulk density (Bd), total organic carbon contents (TOC), carbon contents of the humified fractions of MOS fulvic acid (C-FA), humic acid (C-HA) and humin (C-HUM), HA/FA, alkaline extract/HUM ratio (AE/HUM), carbon stock (Stock C) and carbon stock of the humified fractions fulvic acid (Stock-FA), humic acid (Stock-HA) and humin (Stock-HUM) in the different management systems.

MS	Bd	TOC	Stock C	C – FA	C – HA	C – HUM	HA/FA	AE/HUM	Stock-FA	Stock-HA	Stock-HUM
	$Mg.m^{-3}$	$g.kg^{-1}$	$Mg.ha^{-1}$	--------- $g.kg^{-1}$ ------------					------------------ $Mg.ha^{-1}$ ------------------		
					0 - 0.05 m						
ES	1.47a	6.31d	8.46d	1.28a	1.14c	3.65d	0.89b	0.66a	1.72a	1.53c	4.89d
CTS	1.40ab	11.52c	15.44c	1.25a	1.16c	8.71c	0.93b	0.28b	1.68a	1.56c	11.68c
NTS	1.42a	36.38a	48.79a	0.66b	2.29b	20.18b	3.56a	0.14c	0.89b	3.07b	27.06b
PP	1.19b	37.37a	50.11a	0.94ab	3.07a	25.27a	3.33a	0.16c	1.26ab	4.12a	33.88a
SC	1.53a	27.26b	36.55b	0.81b	1.72bc	19.87b	2.18ab	0.13c	1.09b	2.30bc	26.65b
NF	1.34ab	27.55b	36.95b	0.58b	2.05b	19.38b	3.63a	0.13c	0.77b	2.74b	25.99b
CV%	6.46	5.12	8.02	17.97	15.23	7.94	26.90	20.99	17.86	15.13	7.94
					0.05 – 0.1 m						
ES	1.60a	7.00 e	10.10e	1.25a	1.33c	3.89e	1.04c	0.67a	1.80a	1.92c	5.62e
CTS	1.51ab	16.05d	23.18d	1.33a	1.14c	9.98d	0.87c	0.25b	1.92a	1.65c	14.41d
NTS	1.53ab	27.99b	40.42b	0.48b	2.37ab	20.22b	5.63a	0.14b	0.70b	3.42ab	29.21b
PP	1.37b	35.23a	50.87a	0.79b	2.79a	24.90a	3.50b	0.14b	1.15b	4.03a	35.97a
SC	1.52ab	25.27bc	36.50bc	0.56b	1.24c	19.43b	2.20bc	0.09b	0.81b	1.80c	28.06b
NF	1.44ab	22.80c	32.93c	0.65b	2.09b	16.36c	3.44b	0.17b	0.94b	3.01b	23.63c
CV%	4.98	8.02	8.02	20.82	12.38	6.30	33.93	33.47	20.82	12.30	6.30
					0.1 – 0.2 m						
ES	1.71a	6.38f	9.10e	1.13a	1.06c	3.81e	0.95c	0.58a	1.61a	1.51c	5.43e
CTS	1.56ab	12.79e	18.24d	1.21a	1.27c	9.03d	1.10bc	0.27b	1.73a	1.82c	12.88d
NTS	1.52ab	23.13c	32.99b	0.42c	2.45ab	20.21b	6.36a	0.14c	0.60c	3.49ab	28.81b
PP	1.48ab	33.19a	47.32a	1.04ab	2.85a	24.53a	2.81bc	0.16c	1.48ab	4.06a	34.98a
SC	1.56ab	25.36b	36.15b	0.48c	1.39c	19.21b	2.88bc	0.09c	0.69c	1.99c	27.38b
NF	1.42b	19.86d	28.31c	0.67bc	2.17b	15.79c	3.44b	0.18c	0.95bc	3.09b	22.51c
CV%	7.62	6.55	6.56	23.65	14.97	3.95	36.03	16.86	23.80	14.93	3.95

Means followed by the same lowercase letter in the column for each system and layer do not differ statistically by the Tukey test (5%). MS: Management system; ES: Exposed soil; CTS: Conventional preparation system; NTS: No-tillage system; PP: Permanent pasture; SC: Sugarcane; NF: Native forest. CV%: coefficient of variation.

The PP area presented higher C-HUM content in all evaluated layers, differing from the other areas, representing 19% and 31% more C in this fraction compared to the areas of NTS and NF, respectively, considering the profile of 0-0.2 m. This can be explained by the contribution of plant material with higher carbon/nitrogen (C/N) ratio added to higher microbial activity [44, 45], because plant residues (straw and roots) of grasses have higher lignin content, promoting the increase of HA content [46] due to the low intensity of the decomposition of plant materials [45], forming more stable substances in the soil, such as HUM [43]. A common fact in areas where there is no constant soil revolving, which favors the processes of humification and stabilization of the SOM [34, 42].

It is observed, in general, that in conservation systems, such as NTS, SC and PP, there are fractions of greater stability and greater degree of humification of SOM, differently from the observed in the areas of ES and CTS, which, when presenting higher levels of C-FA, show the stagnation of the humification of SOM in the phase of lower stability, preventing C stabilization in more recalcitrant fractions such as HUM [33, 46, 47]. This is evident when comparing the areas of CTS and NTS, because even though the NTS area had higher levels of TOC, it presented lower levels of C-FA in relation to the CTS area, differently from the observed for the fractions of C-HA and C-HUM (Table 3).

Regarding the HA/FA ratio, in which values higher than one determine the predominance of HA in relation to FA, values lower than the unit were found only for the ES and CTS areas, reaching 0.89 and 0.93, respectively in the 0-0.05 m layer, being similar to each other in all layers. For the other areas and layers evaluated, values above the unit were observed, with the NTS area standing out with higher values, ranging from 3.56 to 6.36 in the layers of 0-0.05 and 0.1-0.2 m, respectively, being similar to the areas of PP, SC and NF only in the 0-0.05 m layer (Table 3), again indicating greater stability of the C. In addition, the greater presence of HA in relation to FA benefits the chemical attributes of the soil, since the HA is responsible for the higher cation exchange capacity of organic soil origin, especially in sandy soils [20].

Farias et al. (2022) [16] determined soil quality using physical fractions as an indicator of its quality in the same cultivated areas of this research. They noted higher levels of C in particulate organic matter (C-POM) in the PP, SC and NF systems, indicating a greater input of plant material in these areas. As for C from organic matter associated with minerals (C-MOM), the highest levels were in the areas of PP and NTS. The fact that the PP area has the highest levels both in the physical and chemical fractions of SOM, indicates a greater SOM stabilization capacity at all levels of mineralization, and C storage capacity in the edaphic system both on the surface and in depth.

Lopes et al. (2022) [48], evaluated the soil quality of managed systems such as NTS with 10 year soybean and corn rotation, permanent pasture area with signs of degradation, an area of Private Natural Heritage Reserve (PNHR) in state of recovery for 2 years and a reference area of native forest in sandy soil. The results showed that despite the ability of pastures to improve soil quality, if the management adopted is inappropriate, this capacity decreases significantly, equaling a degraded area undergoing environmental regeneration, preventing the advancement of SOM stabilization.

The benefits of adopting conservation systems of soil management in relation to the quality/stability of the organic fraction can be observed comparing the HA/FA ratio between the areas of CTS and NTS, in which the values of this relationship between these two areas were different in all layers, ranging from 0.87 to 1.10 in CTS and 3.56 to 6.36 in NTS (Table 3). Melo et al. (2016) [28], compared cultivation areas in NTS and CTS analyzing the humic fractions, reaching the conclusion that the NTS improves the edaphic quality, presenting values similar to the native Cerrado area.

Other data that prove the benefits of conservation systems in the SOM humification process is the AE/HUM ratio, in which the ES and NTS areas presented higher values in all layers, reaching 0.67 for the ES area in the 0.05-0.1 m layer. Differently from what was observed in areas managed with conservation systems and NF, where the values of this relationship were no more than 0.18 (Table 3). Rosa et al. (2017) [49] in a study evaluating alterations in MO and HS contents in cultivation with cover crops in rotation with corn and soybean in NTS, found values of the AE/HUM ratio lower than the unit in all treatments.

According to the results of the C contents of the humified fractions of the SOM, the highest StockC-FA were observed for the CTS area followed by the ES area with 1.92 and 1.80 $Mg.ha^{-1}$, respectively in the 0.05-0.1 m layer, a pattern also observed in all evaluated layers (Table 3). Soil revolving in the CTS area subjects it to solar radiation exposure, as it is happens in the ES area, reducing the moisture present in the soil. Fernandes et al. (1999) [50] reports that the low availability of water in surface layers restricts the polymerization process of these HS, which causes greater accumulation of C in less stable fractions.

The highest StockC-HA were verified for the PP area, with C storage above 4.00 $Mg.ha^{-1}$ in all layers, reaching 4.12 $Mg.ha^{-1}$ in the 0-0.05 m layer, while in the other layers the results found for PP in relation to NTS were similar (Table 3). Humic acids play an important role in the stabilization of organic compounds in the soil, being considered natural markers of the humification process and reflecting both the condition of genesis and soil management [11].

Because of the higher levels of C-HUM in the PP area, there was also a higher StockC-HUM in all layers, reaching 35.97 $Mg.ha^{-1}$ in the 0.05-0.1 m layer (Table 3). This result corroborates with several studies in the literature that also verified higher C storage of the HUM fraction in relation to the other fractions, especially in systems with a higher degree of soil conservation [37, 42, 45, 50, 51].

The values of the stratification index (SI) of the TOC varied between 0.91 and 1.57 for the areas of CTS and NTS, respectively, and the NF area presented a value similar to that found for the NTS area. The high values of SI found for the NTS and NF areas, when compared to the other treatments evaluated, showed greater accumulation of C in the soil surface layer. Since the treatments that presented values lower than 1.0 were the ES and CTS, and the area of ES was similar to the areas of CTS, PP and SC (Figure 2).

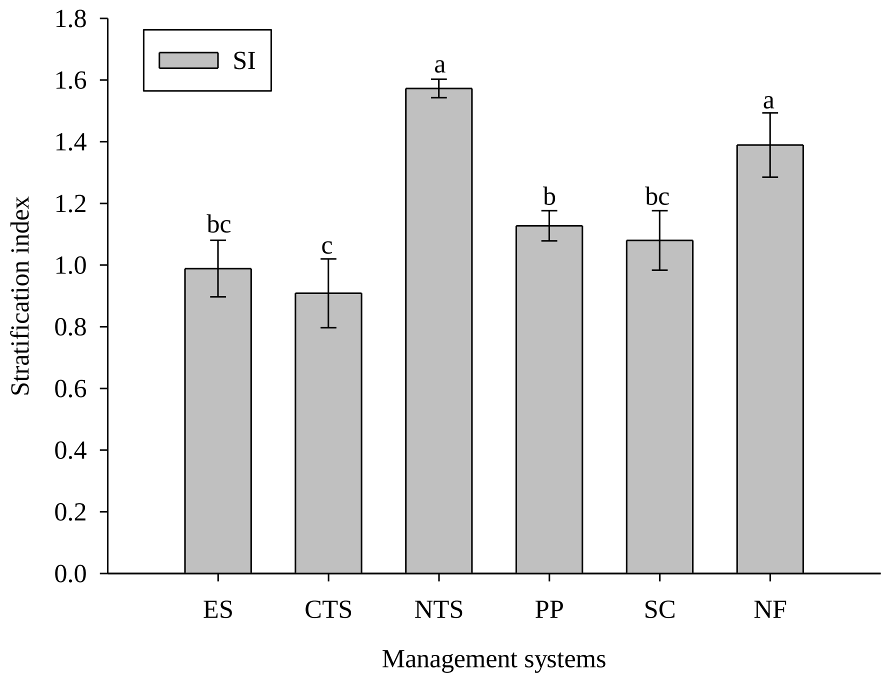

Figure 2. Total organic carbon stratification index (SI) as a function of different management systems. ES: Exploded Soil, CTS: Conventional Tillage System, NTS: No-till System, PP: Permanent Pasture, SC: Sugarcane and NF: Native Forest.

Franzluebbers (2002) [52] working with CTS and NTS, highlighted that management systems that adopt constant soil revolving presented SI variation from 1.1 to 1.9. In more conservationist management systems such as the NTS, they can present values that reach from 2.1 to 4.1 [52, 53]. Troian et al. (2020) [32] assessing areas managed with pasture, eucalyptus and crops, found values between 1.01 and 1.22.

Figure 3 shows the principal component analysis (PCA) with the variables Sd, TOC, FA, HA, HUM, HA/FA, AE/HUM, StockC, StockC-FA, StockC-HA, StockC-HUM and stratification index, evaluated in the section 0-0.20 m of the different management systems evaluated. The variation of axis 1 explains 70.7% of the total variation of the data. This axis separated the CTS and ES areas from the other areas (Figure 3). The fact that these areas are isolated from the other areas evaluated is related to the difference presented for the variables studied between the areas of CTS and ES in the areas of NF, PP, NTS and SC (Table 3).

The variables Sd and FA, StockC-FA and AE/HUM evaluated were correlated with the areas of CTS and SE (Figure 3). This demonstrates that the absence of conservation practices, and the intense soil revolving can negatively affect soil attributes, with increased Sd [3] and predominance of levels and stock of FA and AE/HUM ratio, showing difficulty in advancing the humification process of soil C [1, 34, 42].

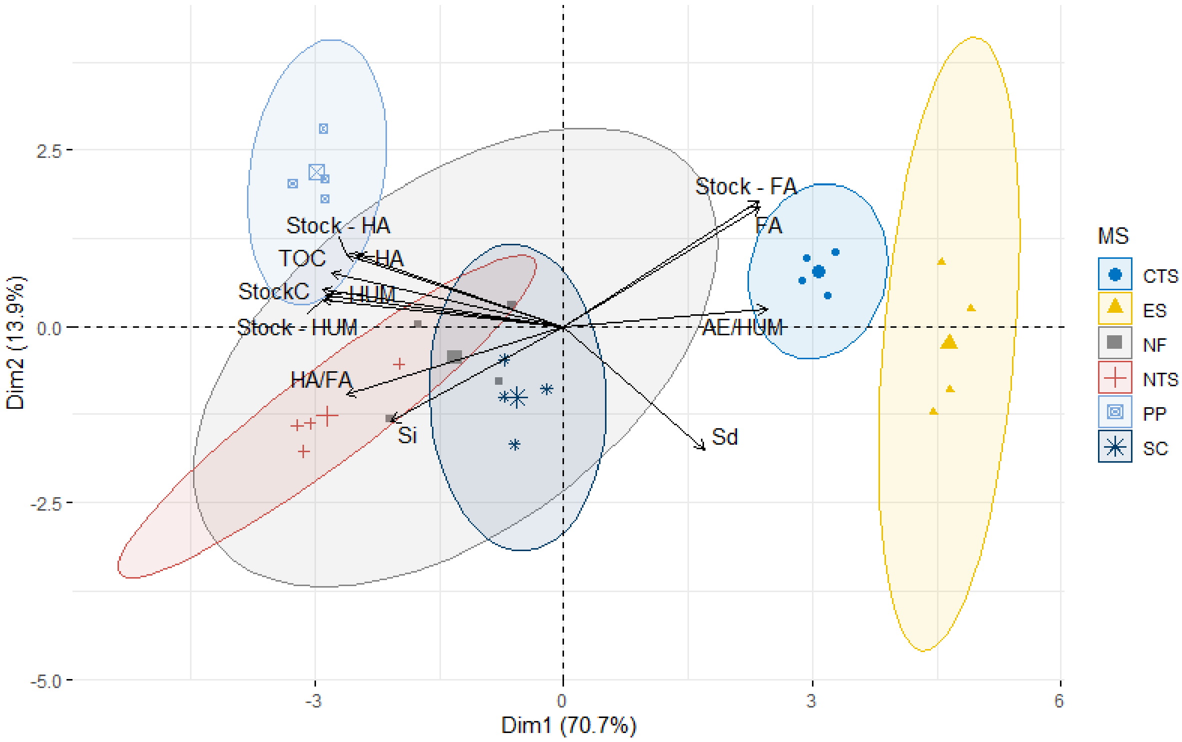

Figure 3. Principal component analysis of Sd, TOC, FA, HA, HUM, HA/FA, AE/HUM, StockC, StockC - FA, StockC - HA, StockC - HUM and Si, in the section 0-0,2 m, of the different management systems (MS), CTS: Conventional Tillage System; ES: Exploded Soil; NF: Native Forest; NTS: No-till System; PP: Permanent Pasture; SC: Sugarcane.

The areas of NF, NTS, PP and SC, present similarity with the contents and stocks of TOC, HA, HUM and with the SI (Figure 3). The association of these variables with these areas occurs due to the absence of intense soil revolving activity, which promote the stabilization of C [3, 7, 54, 55].

The results of the PCA indicate the importance of management without annual soil revolving, since C stabilization benefits the edaphic quality, acting directly in the maintenance of soil aggregates [3, 55, 56], reducing Sd and soil resistance penetration [57-59], increasing levels and stocks of C [55], mitigating the emission of greenhouse gases [4] reducing the occurrence of erosive processes [60-62] and, consequently lowering production costs [63, 64].

4. CONCLUSIONS

After six years of cultivation, no significant changes in bulk density were observed among the studied areas.

The areas of permanent pasture and no-tillage system contributed to the increase of the carbon content sums and stock in the soil.

There was a predominance of the humin fraction in relation to fractions of fulvic acid and humic acid, and the area of permanent pasture showed predominance of fractions of greater stability and greater degree of humification of SOM.

The exposed soil areas and conventional tillage system, both with annual soil revolving, showed lower carbon stabilization, being represented by higher levels and stocks of fulvic acid, lower HA/FA ratio and higher AE/HUM ratio.

Conservation management practices are the main factor that differed the areas evaluated in the PCA, where one group comprised the areas of SC, NTS, PP and NF and another one comprised the areas of ES and CTS, with the first group being associated with the main variables of edaphic quality.

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6. REFERENCES

1. Lal R. Digging deeper: A holistic perspective of factors affecting soil organic carbon sequestration in agroecosystems. Global Chang Biol. 2018 Jan;24(8):3285-01. doi: 10.1111/gcb.14054
2. Samson ME, Chantigny MH, Vanasse A, Menasseri-Aubry S, Royer I, Angers DA. Management practices differently affect particulate and mineral-associated organic matter and their precursors in arable soils. Soil Biol Biochem. 2020 Sep;148:1-32. doi: 10.1016/j.soilbio.2020.107867
3. Falcão KS, Monteiro FN, Ozório JMB, Souza CBS, Farias PGS, Menezes RS, et al. Estoque de carbono e agregação do solo sob diferentes sistemas de uso no Cerrado. Braz J Environ Sci. 2020 Jun;55(2):242-55. doi: 10.5327/Z2176-947820200695
4. Lal R. Managing soils for resolving the conflict between agriculture and nature: The hard talk. Eur J Soil Sci. 2019 Jun;71(1):1-9. doi: 10.1111/ejss.12857
5. Almeida LLS, Frazão AA, Lessa TAM, Fernandes LA, Veloso ALC, Lana AMQ, et al. Soil carbono and nitrogen stocks and the quality of soil organic matter under silvopastoril sistems in the Brazilian Cerrado. Soil & Tillage Res. 2021 Jan;205:1-10. doi: 10.1016/j.still.2020.104785
6. Felicianno CA, Lopes AWP, Silva MC, Costa MBB, Ferrante VLSB. Qualidade do solo em sistemas de manejo convencional e orgânico na propriedade da agricultura familiar. Rev Interdiscipl Tecnol Educ. 2018;4(1):1-22.
7. Ozorio JMB, Rosset JS, Schiavo JA, Souza CBS, Farias PGS, Oliveira NS, et al. Physical fractions of organic matter and mineralizable soil carbon in forest fragments of the Atlantic Forest. Rev Ambient Água. 2020 Nov;15(6):1-19. doi: 10.4136/ambi-agua.2601
8. Wulanningtyas HS, Gong Y, Li P, Sakagami N, Nishiwaki J, Komatsuzaki M. A cover crop and no-tillage system for enhancing soil health by increasing soil organic matter in soybean cultivation. Soil Tillage & Res. 2021 Jan;205:1-14. doi: 10.1016/j.still.2020.104749
9. Brady NC, Weil RR. Elementos da natureza e propriedades dos solos. 3. ed. Porto Alegre (RS): Bookman; 2013.
10. Pausch J, Kuzyakov Y. Carbon input by roots into the soil: Quantification of rhizodeposition from root to ecosystem scale. Global Chang Biol. 2017 Jul;24(1):1-12. doi: 10.1111/gcb.13850
11. Canellas LP, Velloso ACX, Marciano CR, Ramalho JFGP, Rumjanek VM, Rezende CE, et al. Propriedades químicas de um Cambissolo cultivado com cana-de-açúcar, com preservação do palhiço

e adição de vinhaça por longo tempo. Rev Bras Ciênc Solo. 2004 jan;27(5):935-44. doi: 10.1590/S0100-06832003000500018

12. Tan KH. Humic matter in soil and the environment: Principles and controversies. 2. ed. Boca Raton (US): CRC Press; 2014.
13. Chaddad F. The economics and organization of brazilian agriculture. recent evolution and productivity gains. London: Elsevier Academic Press; 2016. Chapter 5, Agriculture in the Cerrado: Large-scale farming and new-generation cooperatives; p. 111-45.
14. Governo do Estado de Mato Grosso do Sul, Secretaria de Estado de Meio Ambiente e Desenvolvimento Econômico (SEMADE). Estudo da dimensão territorial do Estado de Mato Grosso do Sul: Regiões de planejamento. Campo Grande (MS): Governo do Estado de Mato Grosso do Sul; 2015. Available from: https://www.semadesc.ms.gov.br/estudo-da-dimensao-territorial-do-estado-de-ms-regioes-de-planejamento/
15. Peel MC, Finlayson BL, Mcmahon TA. Updated world map of the Köppen-Geiger climate classification. Hydrol Earth Syst Sci. 2007 Oct;11(5):1633-44. doi: 10.5194/hess-11-1633-2007
16. Farias PGS, Souza CBS, Rosset JS, Ozorio JMB, Panachuki E, Schiavo JA, et al. Physical fractions of organic matter and mineralizable soil carbon as quality indicators in areas under different forms of use in the Cerrado-Pantanal Ecotone. Environ Monit Assess. 2022 Jun;194:517. doi: 10.1007/s10661-022-10163-z
17. Claessen MEC. Manual de métodos de análise de solo. 2. ed. Rio de Janeiro (RJ): Embrapa; 1997.
18. Yeomans A, Bremner JM. A rapid and precise method for routine determination of organic carbon in soil. Commun Soil Sci Plant Anal. 2008 Nov;19(13):1467-76. doi: 10.1080/00103628809368027
19. Swift RS. Organic matter characterization. In: Sparks DL, Page AL, Helmke PA, Loeppert RH, Soltanpour PN, Tabatabai MA, et al., editors. Methods of soil analysis: Part 3 Chemical methods. SSA Book Series [Online]; 1996. p. 1011-20. doi: 10.2136/sssabookser5.3.c35
20. Benites VM, Madari B, Machado PLOA. Extração e fracionamento quantitativo de substâncias húmicas do solo: um procedimento simplificado de baixo custo. Rio de Janeiro (RJ): Embrapa Solos; 2003.
21. Ellert BH, Bettany JR. Calculation of organic matter and nutrients stored in soils under contrasting management regimes. Can J Soil Sci. 1995 Nov;75(4):529-38. doi: 10.4141/cjss95-075
22. Sisti CPJ, Santos HP, Kohhann R, Alves BJR, Urquiaga S, Boddey RM. Change in carbon and nitrogen stocks in soil under 13 years of conventional or zero tillage in southern Brazil. Soil & Tillage Res. 2004 Mar;76(1):39-58. doi: 10.1016/j.still.2003.08.007
23. Cruz CD. Programa genes - Biometria. 1. ed. Viçosa (MG): Editora UFV; 2006. Available from: www.ufv.br/dbg/genes/genes.htm
24. R Core Team. R: A language and environment for statistical computing. Viena (AT): R Foundation for Statistical Computing; 2019. Available from: https://www.R-project.org/
25. Oksanen JF, Blanchet G, Friendly M, Kindt R, Legendre P, Mcglinn D, et al. vegan: Community Ecology Package. R Package Version 2.5-5. R Core Team; 2019. Available from: https://CRAN.R-project.org/package=vegan
26. Reinert DJ, Albuquerque JA, Reichert JM, Aita C, Andrada MMC. Limites críticos de densidade do solo para o crescimento de raízes de plantas de cobertura em Argissolo Vermelho. Rev Bras Ciênc Solo. 2009 jan;32(5):1805-16. doi: 10.1590/S0100-06832008000500002
27. Sales RP, Portugal AF, Moreira JAA, Kondo MK, Pegoraro RF. Qualidade física de um Latossolo sob plantio direto e preparo convencional no semiárido. Rev Ciênc Agron. 2016 jul-set;47(3):429-38. doi: 10.5935/1806-6690.20160052
28. Melo GB, Pereira MG, Perin A, Guareschi RF, Soares PFC. Estoques e frações da matéria orgânica do solo sob os sistemas plantio direto e convencional de repolho. Pesqui Agropecu Bras. 2016 set;51(9):1511-9. doi: 10.1590/s0100-204x2016000900050
29. Freitas L, Oliveira IA, Casagrande JC, Silva LS, Campos MCC. Estoque de carbono de latossolos em sistemas de manejo natural e alterado. Ciênc Florest. 2018 abr;28(1):228-39. doi: 10.5902/1980509831575
30. Nanzer MC, Ensinas SC, Barbosa GF, Barreta PGV, Oliveira TP, Silva JRM, et al. Estoque de carbono orgânico total e fracionamento granulométrico da matéria orgânica em sistemas de uso do solo no Cerrado. Rev Ciênc Agrovet. 2019 fev;18(1):136-45. doi: 10.5965/223811711812019136
31. Santos KF, Barbosa FT, Bertol I, Werner RS, Wolschick NH, Mota JM. Teores e estoques de carbono orgânico do solo em diferentes usos da terra no Planalto Sul de Santa Catarina. Rev Ciênc Agrovet. 2019 jun;18(2):222-9. doi: 10.5965/223811711812019222
32. Troian D, Rosset JS, Martins LFBN, Ozório JMB, Castilho SCP, Marra LM. Carbono orgânico e estoque de carbono do solo em diferentes sistemas de manejo. RAMA - Rev Agronegócio e Meio Ambiente. 2020 out;13(4):1447-69. doi: 10.17765/2176-9168.2020v13n4p1447-1469

33. Loss A, Santos Junior E, Schmitz D, Veiga M, Kurtz C, Comin JJ. Soil physical attributes of onion cultivation under no-tillage and conventional tillage systems. Rev Colombiana de Ciênc Hort. 2017 Jun;11(1):105-13. doi: 10.17584/rcch.2017v11i1.6144
34. Assunção SA, Pereira MG, Rosset JS, Berbara RLL, García AC. Carbon input and the structural quality of soil organic matter as a function of agricultural management in a tropical climate region of Brazil. Sci Total Environ. 2019 Mar;658:901-11. doi: 10.1016/j.scitotenv.2018.12.271
35. Rosset JS, Schiavo JA, Atanázio RAR. Atributos químicos, estoques de carbono orgânico total e das frações humificadas da matéria orgânica do solo em diferentes sistemas de manejo de cana-de-acúcar. Semina: Ciênc Agrár. 2014 nov;35(5):2351-66. doi: 10.5433/1679-0359.2014v35n5p2351
36. Corado Neto FCC, Sampaio FMT, Veloso MEC, Matias SSR, Andrade FR, Lobato MGR. Variabilidade espacial dos agregados e carbono orgânico total em Neossolo Litólico Eutrófico no município de Gilbués, PI. Rev Ciênc Agrár. 2015 abr;58(1):75-83. doi: 10.4322/rca.1622
37. Gazolla PR, Guareschi RF, Perin A, Pereira MG, Rossi CQ. Frações da matéria orgânica do solo sob pastagem, sistema plantio direto e integração lavoura-pecuária. Semina: Ciênc Agrár. 2015 abr;36(2):693-704. doi: 10.5433/1679-0359.2015v36n2p693
38. Veloso MG, Cecagno D, Bayer C. Legume cover crops under no-tillage favor organomineral association in microaggregates and soil C accumulation. Soil & Tillage Res. 2019 Jul;190:139-46. doi: 10.1016/j.still.2019.03.003
39. Brown V, Barbosa FT, Bertol I, Mafra AL, Luzeka LM. Efeitos no solo e nas culturas após vinte anos de cultivo convencional e semeadura direta. Rev Bras Ciênc Agrár. 2018 Mar;13(1):1-7. doi: 10.5039/agraria. V 13i1a5501
40. Gonçalves VA, Melo CAD, Assis IR, Ferreira LR, Saraiva DT. Biomassa e atividade microbiana de solo sob diferentes sistemas de plantio e sucessões de culturas. Rev Ciênc Agrár. 2019 jan;62:1-8. doi: 10.22491/rca.2019.2611
41. Rosset JS, Lana MC, Pereira MG, Schiavo JA, Rampim L, Sarto MVM. Organic matter and soil aggregation in agricultural systems with different adoption times. Semina: Ciênc Agrár. 2019 Oct;40(6supl3):3443-59. doi: 10.5433/1679-0359.2019v40n6Supl3p3443
42. Rosset JS, Lana MC, Pereira MG, Schiavo JÁ, Rampim L, Sarto MVM. Frações químicas e oxidáveis da matéria orgânica do solo sob diferentes sistemas de manejo, em Latossolo Vermelho. Pesqui Agropecu Bras. 2016 set;51(9):1529-38. doi: 10.1590/S0100-204X2016000900052
43. Loss A, Moraes AGL, Pereira MG, Silva EMR, Anjos LHC. Carbon, light organic matter and oxidizable organic carbon fractions. Comun Sci. 2010 Apr;1(1):57-64. doi: 10.14295/cs. v1i1.10
44. Fontana A, Pereira MG, Loss A, Cunha TJF, Salton JC. Atributos de fertilidade e frações húmicas de um Latossolo Vermelho no Cerrado. Pesqui Agropecu Bras. 2006 ago;41(5):847-53. doi: 10.1590/S0100-204X2006000500018
45. Bezerra RPM, Loss A, Pereira MG, Perin A. Formas de carbono em Latossolo sob sistemas de plantio direto e integração lavoura-pecuária no cerrado, Goiás. Semina: Ciênc Agrár. 2013 dez;34(6):2637-54. doi: 10.5433/1679-0359.2013v34n6p2637
46. Primavesi A. O manejo ecológico do solo. 4. ed. São Paulo (SP): Nobel; 1982.
47. Modak K, Biswas DR, Ghosh A, Pramanik P, Das TK, Das S, et al. Zero tillage and residue retention impact on soil aggregation and carbon stabilization within aggregates in subtropical India. Soil & Tillage Res. 2020 Aug;202:1-9. doi: 10.1016/j.still.2020.104649
48. Lopes GT, Rosset JS, Ozorio JMB, Silva OMM, Santos WV, Santos JVH, et al. Influence of land use and occupation on the chemical and physical fractions of organic matter in cultivated and native areas in the Atlantic Forest biome. Ambiente & Água. 2022 Sep;17(5):1-21. doi: 10.4136/ambi-agua.2814
49. Rosa DM, Nóbrega LHP, Mauli MM, Lima GP, Pacheco FP. Humic substances in soil cultivated with cover crops rotated with maize and soybean. Rev Ciênc Agron. 2017 Apr-Jun;48(2):221-30. doi: 10.5935/1806-6690.20170026
50. Fernandes FA, Cerri AC, Fernandes AHBM. Alterações na matéria orgânica de um podzol hidromórfico pelo uso com pastagens cultivadas no pantanal mato-grossense. Pesqu Agropecu Bras. 1999 out;34(10):1943-51. doi: 10.1590/S0100-204X1999001000022
51. Ferreira CR, Silva Neto EC, Pereira MG, Guedes JN, Rosset JS, Anjos LHC. Dynamics of soil aggregation and organic carbon fractions over 23 years of no-till management. Soil & Tillage Res. 2020 Apr;198:1-9. doi: 10.1016/j.still.2019.104533
52. Franzluebbers AJ. Soil organic matter stratification ratio as an indicator of soil quality. Soil & Tillage Res. 2002 Jul;66(2):95-106. doi: 10.1016/S0167-1987(02)00018-1
53. Salton JC, Mercante FM, Tomazi JA, Concenco G, Silva WM, Retore M. Integrated crop-livestock system in tropical Brazil: Toward a sustainable production system. Agric Ecosyst Environ. 2014 Jun;190:70-9. doi: 10.1016/j.agee.2013.09.023

54. Rosset JS, Pereira MG, Assunção AS, Garcia AC. Qualidade do solo em diferentes sistemas. A Granja. 2019a;75:61-3.
55. Ozorio JMB, Rosset JS, Schiavo JA, Panachuki E, Souza CBS, Menezes RS, Ximenes TS, Castilho SCP, Marra LM. Estoque de carbono e agregação do solo sob fragmentos florestais nos biomas Mata Atlântica e Cerrado. Rev Bras Ciênc Ambient. 2019 dez 30;53:97-116. doi: 10.5327/Z2176-947820190518
56. Kunde RJ, Lima CLRD, Silva SDDA, Pillon CN. Tensile strength, friability, aggregation, and soil organic matter physical fractions of an Oxisol cultivated with sugarcane. Pesqui Agropecu Bras. 2018 apr;53(4):487-494. doi: 10.1590/S0100-204X2018000400010
57. Bonetti JDA, Paulino HB, Souza EDD, Carneiro MAC, Caetano JO. Soil physical and biological properties in an integrated crop-livestock system in the Brazilian Cerrado. Pesqui Agropecu Bras. 2018 nov;53(11):1239-1247. doi: 10.1590/S0100-204X2018001100006
58. Oliveira JT, Oliveira RA, Valente DSM, Ribeiro IS, Teodoro PE. Spatial Relationships of Soil Physical Attributes with Yield and Lateral Shoot Growth of Garlic. HortScience. 2020 may 26;55(7):11053-1054. doi: 10.21273/HORTSCI15082-20
59. Benevenute PA, Morais EG, Souza AA, Vasques IC, Cardoso DP, Sales FR, Severino EC, Homem BGC, Casagrande DR, Silva BM. Penetration resistance: An effective indicator for monitoring soil compaction in pastures. Ecol Indic. 2020 oct;117:1-9, doi: 10.1016/j.ecolind.2020.106647
60. Klik A, Rosner J. Long-term experience with conservation tillage practices in Austria: Impacts on soil erosion processes. Soil & Tillage Res. 2020 sep; 203:1-14. doi: 10.1016/j.still.2020.104669
61. Ricci GF, Jeong J, Girolamo AM, Gentile F. Effectiveness and feasibility of different management practices to reduce soil erosion in an agricultural watershed. Land Use Policy. 2020 jan;90:1-15. doi: 10.1016/j.landusepol.2019.104306
62. Borrelli P, Robinson DA, Panagos P, Lugato E, Yang JE, Alewell C, Wuepper D, Montanarella L, Ballabio C. Land use and climate change impacts on global soil erosion by water. Proc Natl Acad Sci. 2020 aug 24;117(36):21994-22001, doi: 10.1073/pnas.2001403117
63. Teravest D, Wandschneider PR, Thierfelder C, Reganold JP. Diversifying conservation agriculture and conventional tillage cropping systems to improve the wellbeing of smallholder farmers in Malawi. Agric Syst. 2019 may;171:23-35. doi: 10.1016/j.agsy.2019.01.004
64. Perego A, Rocca A, Cattivelli V, Tabaglio V, Fiorini A, Barbieri S, Schillaci C, Chiodini ME, Brenna S, Acutis M. Agro-environmental aspects of conservation agriculture compared to conventional systems: A 3-year experience on 20 farms in the Po valley (Northern Italy). Agric Syst. 2019 jan;168:73-87. doi: 10.1016/j.agsy.2018.10.008