

Soil carbon stock in different uses in the southern cone of Mato Grosso do Sul

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Received: 23/07/2020; Accepted: 27/09/2020.

ABSTRACT

This study aimed to assess the soil density (Sd) and the total organic carbon contents and stocks in different management systems and implementation times in the municipality of Iguatemi, MS, Brazil. A completely randomized design with four replications was applied to four areas: conventional tillage (CT), reformed pasture (RP), and degraded pasture (DP), in addition to a native forest (NF) area with no anthropic action. Disturbed and undisturbed soil samples were collected at depths of 0–0.05, 0.05–0.1, and 0.1–0.2 m. The determination of Sd and total organic carbon content (TOC) allowed calculating the carbon stock (Cstock), the stratification index (SI), and the carbon stock variation (Δ Cstock), with subsequent multivariate analysis. The NF area presented the highest TOC contents at all depths compared to the managed areas, with a value of 17.45 g kg⁻¹ at a depth of 0–0.05 m. The RP and NF areas showed similar SI, which was higher in PD, with a value of 2.54. Except for RP, the other managed areas showed a negative Δ Cstock in the soil profile relative to the NF area. The RP and NF areas promoted the maintenance of TOC in the soil, while DP and CT compromised the edaphic quality.

Keywords: soil quality, soil organic matter, principal component analysis, pasture management.

Estoque de carbono do solo em diferentes usos na região cone-sul de Mato Grosso do Sul

RESUMO

O objetivo deste trabalho foi avaliar a densidade do solo (Ds), os teores e estoques de carbono orgânico total em diferentes sistemas de manejo e tempos de implantação no município de Iguatemi, MS. Foi utilizado o delineamento inteiramente casualizado com quatro repetições, sendo estudadas quatro áreas: lavoura em sistema de preparo convencional (PC), pastagem reformada (PR) e pastagem degradada (PD), além da área de mata nativa (MN) sem ação antrópica. Foram coletadas amostras deformadas e indeformadas de solo nas camadas 0-0,05, 0,05-0,1, 0,1-0,2 m. Foram determinadas a Ds e os teores de carbono orgânico total (COT), sendo calculado o estoque de carbono (EstC), o índice de estratificação (IE) e a variação do estoque de carbono (Δ EstC). A área de MN apresentou, em todas as camadas, os maiores teores de COT em relação às áreas manejadas, apresentando teor de 17,45 g kg⁻¹ na camada de 0-0,05 m. As áreas de PR e MN apresentaram IE semelhantes, porém, na área de PD o IE foi superior, com IE de 2,54. Com exceção da área de PR, as demais áreas manejadas apresentaram Δ EstC negativa no perfil do solo em relação à área de MN. A PR e a MN promoveram a manutenção do COT no solo, por outro lado, a PD e o PC comprometeram a qualidade edáfica.

Palavras-chave: qualidade do solo, matéria orgânica do solo, análise de componentes principais, manejo de pastagens.

1. Introduction

Soil quality (SQ) is related to the soil capacity in maintaining ecosystem services, including storing and recycling water, nutrients, and energy (Doran and Parkin, 1994). One of the main soil potentials is to store carbon (C), with direct influence on its chemical, physical, and biological quality (Koven et al., 2017; Assunção et al., 2019; Ferreira et al., 2020; Rosset et al., 2019; D'Abadia et al., 2020; Falcão et al., 2020; Ozório et al., 2020). However, changes in the soil C content are directly related to changes in land use, affecting this important natural C reservoir on the planet (Lal, 2018; Wang et al., 2019).

Possible changes in land use in native or cultivated areas can be studied through quality indicators (Corbeels et al., 2019). Soil organic matter (SOM) is a sensitive indicator of soil changes resulting from its use and occupation. Carbon stock, C fractions, and soil chemical, physical, and biological attributes are closely related (Signor et al., 2018).

Organic C in soils with natural vegetation cover is in dynamic balance, with practically constant contents over time (Borges et al., 2015). The understanding of the dynamics and accumulation or not of C in managed and natural systems allows supporting the establishment of management strategies that guarantee an increase in MOS content and an improvement in the environmental and soil quality over time (Rosset et al., 2016; Assunção et al., 2019; Ferreira et al., 2020; Nijmeijer et al., 2019).

Agricultural cultivation systems managed incorrectly, especially with intense disturbance, such as the conventional tillage (CT) system, provide a reduction in the edaphic quality, with a reduction in carbon contents (Sarker et al., 2018) and stocks (Cstock) (Assunção et al., 2019; Falcão et al., 2020). This reduction in C quality and content in systems with soil disturbance occurs mainly due to the exposure of SOM to the direct action of microorganisms, potentiating C oxidation (Yang et al., 2019; Li et al., 2019).

Systems managed with pastures are important in maintaining soil quality, given the extension of these cultivated areas across the planet (Salton et al., 2008; Santos et al., 2019), especially pastures with adequate management, which present an increase in SOM in surface and subsurface layers due to root decomposition (Coonan et al., 2019; Malcolm et al., 2019). On the other hand, pastures undergoing degradation stages, with low biomass production and soil cover and under the beginning of the emergence of erosive processes, negatively influence soil quality, compromising soil C quality and quantity (Segnini et al., 2019; Zago et al., 2019; Webster et al., 2019).

Thus, the regionalized assessment of soil attributes under different management systems allows identifying management models that contribute significantly to the

maintenance or improvements in the quality of the areas, with consequent lesser environmental impacts.

Thus, this study aimed to assess the soil density and the total organic carbon contents and stocks in different management systems under clayey soil in the municipality of Iguatemi, MS, Brazil.

2. Material and Methods

2.1 Location, climate, and soil of study areas

The experiment was conducted in a native forest area and different management systems exploited commercially in farms located in the municipality of Iguatemi (Figure 1), Southern Cone region of the state of Mato Grosso do Sul, Brazil. The regional climate is subtropical (Cfa), according to the Köppen classification. The native vegetation of the area is the Atlantic Forest, a seasonal semideciduous forest (SEMADE, 2015). The soil is classified as clayey-textured Oxisol (Santos et al., 2018). The studied areas are under the same biome, topography, and soil type and class, and have a particle size distribution at a depth of 0–0.2 m of 402, 96, and 502 g kg⁻¹ of clay, silt, and sand, respectively.

Three managed areas and a reference area with native Atlantic Forest vegetation, that is, a seasonal semideciduous forest with no anthropic action, were assessed, totaling four different systems analyzed in a completely randomized design. The three managed areas consisted of a degraded pasture area (DP), a reformed pasture area (RP), and a cultivated area under the conventional tillage system (CT). The description of the areas is shown in Table 1.

2.2 Soil sample collection

Four 400 m² plots were demarcated in each study area, where soil samples were collected, and each plot represented a replication. Each composite sample was represented by five simple samples within each plot at depths of 0–0.05, 0.05–0.1 and 0.1–0.2 m. After collection, the samples were air-dried, crumbled, and sieved (2 mm openings). Undisturbed samples were also collected using a volumetric ring with a volume of 48.86 cm³, with four replications in all areas and soil depths.

2.3 Soil analyses

Soil density (Sd) analyses were performed according to the method described by Claessen (1997), using the volumetric ring method. Total organic carbon (TOC) was determined by the oxidation of organic matter by potassium dichromate in sulfuric medium and titrated with ammonium ferrous sulfate in the presence of diphenylamine without external heating, according to a method adapted from Yeomans and Bremner (1988). The results allowed the calculation of the total organic carbon stocks (Cstock), according to the equivalent mass method

(Ellert and Bettany, 1995; Sisti et al., 2004). The carbon stock variation (ΔC_{stock}) was calculated to verify trends of TOC accumulation or loss in comparison with the reference system (NF).

The TOC results also allowed the calculation of the carbon stratification index (SI) through the ratio between the TOC contents at depths of 0–0.05 and 0.1–0.2 m (arable layer), as proposed by Franzluebbers (2002).

After all analyses, the results were analyzed for normality and homogeneity of the data using the

Lilliefors and Cochran and Bartlett tests, respectively. Subsequently, the results were subjected to analysis of variance and the F-test, with the means values compared by the Tukey test at 5% probability, using the software GENES (Cruz, 2006).

In addition, a principal component analysis (ACP) was generated using the R Core Team program (2019) through the command *prcomp* from the package *vegan* (Oksanen et al., 2019), with the variables TOC, Cstock, Sd, and SI.

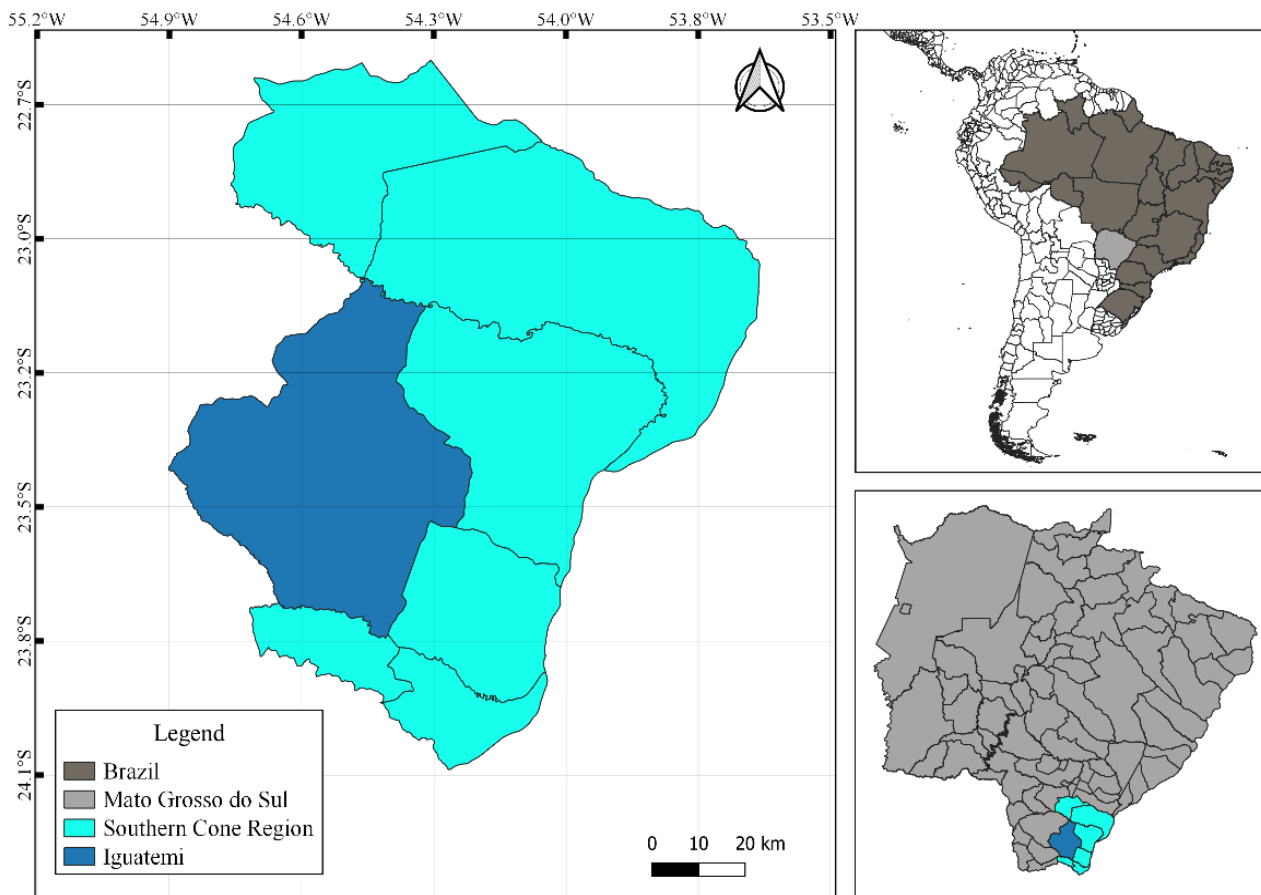


Figure 1. Municipality of Iguatemi, MS, Brazil, where the study areas are located. Mapping software: QGIS 3.14.15 'Pi'.

Table 1. History and description of the study areas (management systems).

Management system	Description
DP	Area of 2.0 ha implanted in 2000 with the species <i>Brachiaria brizantha</i> , with visible signs of degradation (low soil cover, presence of invasive species and erosions in the form of furrows). Capacity of 6 animal units (UA) ha ⁻¹ .
RP	Area of 2.0 ha, pasture with the species <i>Brachiaria brizantha</i> , which in 2008 carried out a reform of the area with soil revolving and application of 1.5 tons of limestone. Capacity of 6 animal units (UA) ha ⁻¹ .
CT	1.7 ha area. Pasture from 1990 until 2010, where the crop was implanted in a conventional tillage system with annual use of plowing and leveling harrow with alternate crops of corn, cassava and watermelon.
NF	Area of 10.0 ha of legal reserve without any anthropic interference, used as a reference for the original condition of the soil.

3. Results and Discussion

The NF area showed the lowest SD values, reaching 1.03, 1.23, and 1.26 Mg m⁻³ at depths of 0–0.05, 0.05–0.1, and 0.1–0.2 m, respectively (Table 2). The lowest Sd values observed in the NF area occurred because this area has not been subjected to any anthropic action, such as soil tillage and grazing, which are carried out in crop and pasture areas, promoting soil compaction and a consequent decrease in macropores and soil water regulation (Colombi et al., 2018; Felde et al., 2018; Furbish et al., 2018).

All managed areas presented similar Sd values at depths of 0–0.05 and 0.1–0.2 m. The TC area showed the highest Sd value at a depth of 0.05–0.1 m, which was similar to DP (Table 2). The Sd values found in the DP, RP, and CT areas at all depth could compromise the physical soil quality and the root growth of crops when considering the critical value of 1.30 Mg m⁻³ proposed by Reichert et al. (2003) for clayey soils.

In general, the results of TOC and Cstock showed a similar pattern between the assessed areas. The NF and RP presented the TOC contents at all assessed layers, reaching values of 17.45, 9.70, and 9.70 g kg⁻¹ in NF and 14.11, 11.18, 9.25 g kg⁻¹ in RP at depths of 0–0.05, 0.05–0.1 and 0.1–0.2 m, respectively. The lowest TOC contents were found in the DP and CT areas, reaching 3.39 g kg⁻¹ at a depth of 0.1–0.2 m in DP. In percentage terms, comparing only the pasture areas, DP presented 60.1, 38.6, and 36.7% of the TOC contents found in RP at depths of 0–0.05, 0.05–0.1 and 0.1–0.2 m, respectively (Table 2).

Table 2. Soil density (Sd), total organic carbon (TOC), and soil carbon stock (Cstock) in different management systems in the municipality of Iguatemi, MS, Brazil.

MS	Sd	TOC	Cstock
	Mg m ⁻³	g kg ⁻¹	Mg ha ⁻¹
0-0.05 m			
DP	1.48a	8.52b	4.41b
RP	1.34a	14.11a	7.34a
CT	1.58a	9.31b	4.83b
NF	1.03b	17.45a	6.98a
CV(%)	8.4	13.0	17.0
0.05-0.1 m			
DP	1.57ab	4.31c	2.63c
RP	1.48b	11.18a	6.86a
CT	1.71a	9.11b	5.59b
NF	1.23c	9.70ab	4.46b
CV(%)	6.3	9.3	11.4
0.1-0.2 m			
DP	1.62a	3.39c	4.26c
RP	1.60a	9.25a	11.62a
CT	1.70a	7.47b	9.38b
NF	1.26b	9.70a	10.44ab
CV(%)	5.7	9.8	10.2

Means followed by the same letter in the column within each depth do not differ from each other by the Tukey test ($p \leq 0.05$). CV = coefficient of variation. MS: Management systems; DP: Degraded pasture; RP: Reformed pasture; CT: Conventional tillage system; NF: Native forest.

The Cstock values varied from 2.63 to 11.62 Mg ha⁻¹. Similar Cstock values could be observed between the NF and RP areas at depths of 0–0.05 and 0.1–0.2 m, with values of 6.98 and 7.34 Mg ha⁻¹, respectively. The Cstock values in the DP area were lower than in RP at all assessed depths, reaching 39.9, 61.7, and 63.3% of the Cstock at depths of 0–0.05, 0.05–0.1, and 0.1–0.2 m, respectively. The TOC and Cstock contents showed that the CT area was not efficient in accumulating C in the soil compared to RP, with values of 4.83, 5.59, and 9.38 Mg ha⁻¹ at depths of 0–0.05, 0.05–0.1, and 0.1–0.2 m (Table 2).

The results of TOC and Cstock demonstrate the negative impact of incorrect pasture management, in which little vegetation cover limits the SOM entry into the soil (Santos et al., 2019; Segnini et al., 2019; Lopes et al., 2020). Segnini et al. (2019) assessed C loss in pastures under different grazing intensities and reported low TOC contents in degraded pasture areas compared to natural vegetation areas. Pasture systems can benefit C inputs in the system when properly managed and, consequently, increase Cstock (Salton et al., 2008; Santos et al., 2019; Falcão et al., 2020), favoring the quality of the edaphic environment and contributing to reducing greenhouse gas emissions (Koven et al., 2017).

The annual soil tillage in the CT areas potentiated the rapid SOM decomposition, which does not undergo all the stages of the humification process, with consequent less TOC stabilization, drastically reducing its soil contents (Assunção et al., 2019; Nijmeijer et al., 2019; Sithole et al., 2019). It is mainly due to the intense tillage that occurs in the system for preparing these areas. Soil tillage, besides fragmenting organic compounds by cutting discs, promotes soil breakdown, which accelerates the mineralization processes of SOM (Assunção et al., 2019; Denardin et al., 2019; Macintosh et al., 2019). Comin et al. (2018) reported high Cstock values in native forest areas compared to areas with soil disturbance.

All studied areas presented the stratification index (SI) of TOC higher than one, with values ranging from 1.25 to 2.54 (Figure 2), which indicates C accumulation on the soil surface (Franzluebbers, 2002). The DP area showed the highest SI value (2.54), differing from the other areas. This result is related to the low TOC contents in the DP area at a depth of 0.1–0.2 m because of the low contribution of the root system in accumulating carbon in the subsurface (Table 2), overestimating the SI values for this area (Figure 2).

The CT and RP areas had the lowest SI values, reaching 1.25 and 1.53, respectively (Figure 2). The stratification of C in the soil is desirable, especially for C storage at deeper subsurface layers (Ozório et al., 2020), favoring the improvement of their quality (Salton et al., 2014). Salton et al. (2014), Ozório et al. (2020), and

Troian et al. (2020) observed SI values of 2.00, 1.85, and 1.08, respectively, in areas of permanent pasture in the state of Mato Grosso do Sul. Moreover, Rosset et al. (2014) found a value of 1.78 in a pasture area managed for 38 years in the state of Paraná.

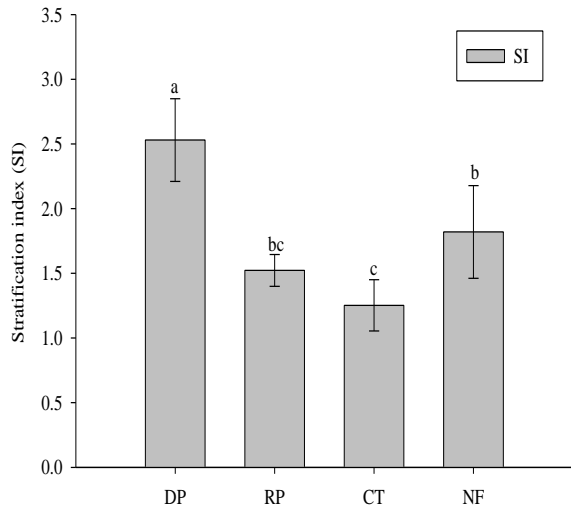


Figure 2. Stratification index (SI) of the total organic carbon as a function of different management systems under a clayey soil. DP: Degraded pasture; RP: Reformed pasture; CT: Conventional tillage system; NF: Native forest.

Negative ΔC_{stock} values were observed at all assessed depths in the DP area (Figure 3), which is in accordance with the low C stock contents of this area (Table 2). Proper management of pasture areas is

essential for the maintenance and improvement of carbon stocks, with consequent improvements in other soil attributes (Ozório et al., 2020; Rosset et al., 2019; Ferreira et al., 2020). Mascarenhas et al. (2017) and Oliveira et al. (2016) reported that the conversion of native areas into pasture systems could significantly compromise the carbon stocks when not managed correctly, mainly due to the low deposition of organic matter on the soil.

The soil depths of 0–0.05 and 0.1–0.2 m in the CT area showed negative ΔC_{stock} compared to the NF area. However, the ΔC_{stock} of the RP area was positive at all depths (Figure 3), which proves the importance of good management of these areas to increase C storage potential and, consequently, decrease CO₂ emissions into the atmosphere (Salton et al., 2008; Assunção et al., 2019).

A negative C stock variation was observed in the entire studied soil profile (0–0.2 m), that is, the three stratified soil layers together, for the CT area and, more accentuated, in the DP area, differently from that observed in RP (Figure 3). The evaluation of changes that have occurred in edaphic attributes due to their use and management is of great practical importance since understanding the changes that have occurred in the most sensitive attributes, such as C stock, could provide elements for sustainable production (Oliveira et al., 2016). Comin et al. (2018) observed similar results, i.e., a system with annual tillage showed lower C stock values in the arable layer than native forest and production systems without soil disturbance.

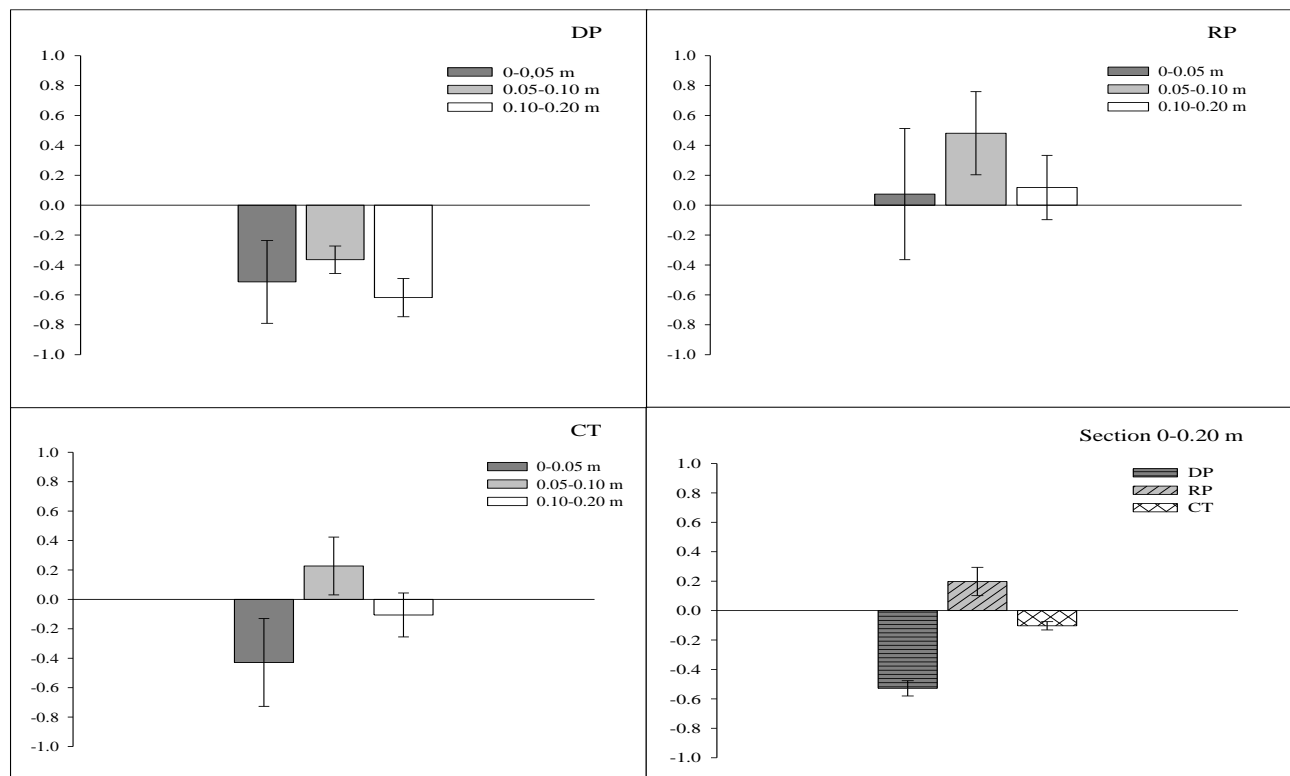


Figure 3. Variation in TOC stock (ΔC_{stock}) of the managed areas relative to the native forest area at different soil depths and in the 0–0.2 m layer of clayey soil. DP: Degraded pasture; RP: Reformed pasture; CT: Conventional tillage system.

Figure 4 shows the principal component analysis involving the variables Sd, TOC, Cstock, and SI under the different assessed management systems. The variation in axis 1 explains 57.0% of the total variation in the data. This axis separated the NF and RP areas, with positive values, from CT and DP, which had negative values. TOC and Cstock contents at a depth of 0–0.05 m were positively correlated in the NF area (Figure 4). It occurs because TOC and Cstock contents at the first soil depth were high due to an intense SOM deposition and the non-soil tillage, allowing the process of humification and accumulation of stabilized organic matter (Lal, 2018; Signor et al., 2018; Assunção et al., 2019).

The values of TOC and Cstock of the subsurface depths (0.05–0.1 and 0.1–0.2 m) were also similar in the RP and NF areas (Figure 4). It shows the potential for C stratification in the soil profile, which is of paramount importance, mainly in improving soil quality and storing C in layers with less interference of soil management (Borges et al., 2015; Muñoz-Rojas et al., 2015). The

ability of well-managed pastures to store C in subsurface layers has been reported by different authors in different Brazilian biomes (Salton et al., 2008; Dortzbach et al., 2015; Mascarenhas et al., 2017; Santos et al., 2017; Campos et al., 2016). On the other hand, Sd is mainly associated with the CT area (Figure 4), which is in line with the highest Sd values observed in this area (Table 2). It occurs because of the management of the area using the conventional tillage system, with an intense traffic of agricultural machinery (Gennaro et al., 2015). Loss et al. (2017) worked with the conventional tillage and no-tillage systems and observed high Sd values in the CT area, which was attributed to the process of intense soil disturbance.

The data assessment allowed verifying the importance of proper soil management, as well as continuous studies that assess their influence on soil quality. This study provided technical information applicable in different regions due to the characteristics of the assessed soil type and systems.

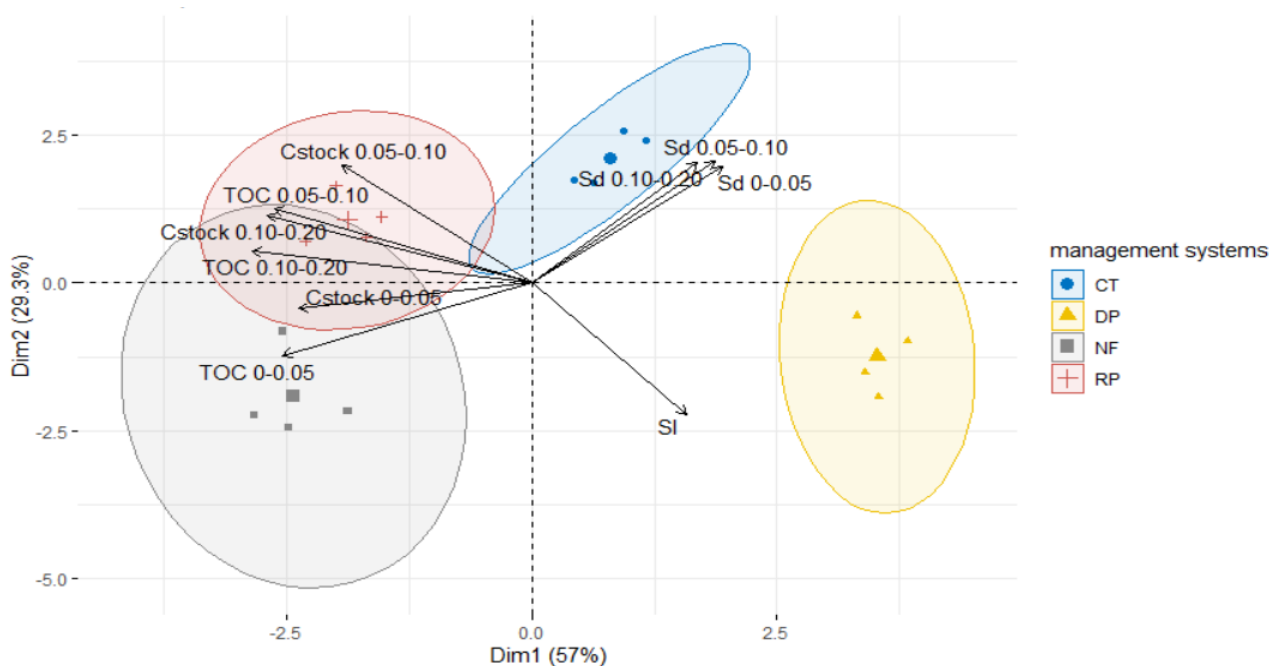


Figure 4. Principal component analysis of TOC, Cstock, Sd, and SI in different management systems: DP: Degraded pasture; RP: Reformed pasture; CT: Conventional tillage system; NF: Native forest.

4. Conclusions

All managed areas had the highest soil density at the three assessed soil depths.

The reformed pasture area showed the same carbon storage potential compared to the native forest area.

The degraded pasture and conventional tillage areas compromised edaphic quality, especially regarding the carbon storage potential.

The principal component analysis showed that the reformed pasture area was similar to the native forest area.

5. Acknowledgments

We thank Fundect (Fundect/UEMS Notice No. 25/2015) for supporting the undergraduate and graduate courses at UEMS; the PIBIC/UEMS notice for granting a scientific initiation scholarship to the undergraduate students; the Coordination for the Improvement of Higher Education Personnel (CAPES) for granting a Postgraduate scholarship; and the farmers for allowing this study to be developed in their areas.

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