

Soil quality indicators under management systems in a *Quilombola* community in the Brazilian Cerrado

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ABSTRACT: Soil management systems exert different effects on soil attributes, especially on the organic matter content, and, consequently, the soil aggregation. The aim of this study was to evaluate the impact of different land uses practiced by *quilombola* family farmers on water stable aggregates, glomalin and organic carbon in soil aggregates. Soil samples were collected at depths of 0-10 and 10-20 cm from areas cultivated under the following management systems: 1) conventional corn plantation (MA), 2) cultivation of citrus trees intercropped with annual crops (AC) (a conservationist approach), 3) pasture of *Brachiaria* (*Urochloa* spp.) (PA), and, as reference, an area of the Cerrado (CR) free of any anthropogenic interference. The studied areas were evaluated in a completely randomized design, with five replications, in a subplot scheme. The plots were the management systems and the subplots the depths. Soil macro-aggregates were predominant at both depths and the aggregate stability indices were higher than 90 % for all management systems. Total organic carbon in the two aggregate classes (micro and macro-aggregates) correlated with the MWD (mean weight-diameter), but not with the easily extractable glomalin (EEG) related soil protein. Soil micro and macro-aggregates, EEG and MWD discriminated management systems and are important soil quality indicators. The carbon content in both micro-aggregates (C-MIC) and macro-aggregates (C-MAC) of the intercropped system (AC) was higher than in the CR. The soil attributes that best separated the areas were C-MIC, MWD and EEG in macro-aggregates for the depth of 0-10 cm, and EEG in micro-aggregates, together with MWD and C-MAC for the depth of 10-20 cm.

Keywords: Rhodic Hapludox, water-stable aggregates, soil protein, *quilombo*

Introduction

In Brazil, the Cerrado is the second largest biome, after the Amazon, and much of it is located in the Central Plateau, consisting of flat areas, shrub vegetation and marked seasonality with abundant summer rains (Dec to Mar) and dry winters (May to Sept) (Buol, 2009). In the Brazilian Cerrado, there are communities formed by ethnic-racial groups with a presumption of African ancestry, called *quilombolas* (INCRA, 2017). These communities practice family farming, based on giving due esteem to the local and traditional knowledge of farmers in order not to interfere with natural resources and processes. The agricultural management practices applied in *quilombola* communities do not have any technical assistance, which, in time, leads to a decrease in productivity. Thus, it is necessary to evaluate soil quality (SQ) indicators of the areas used by these communities in order to contribute to greater productivity (Nascimento et al., 2017).

SQ is the ability of soil to sustain productivity and biological diversity as well as promoting the health of the organisms that inhabit the area (Doran and Safley, 1997), thus resulting in soil functionality and sustainability of the system consisting of soil, plants, and microorganisms (Cardoso et al., 2013). Soil aggregates and the porous soil system integrated into the soil structure are key components of SQ (Pires et al., 2017).

The formation and stability of aggregates results from the interaction between biotic and abiotic factors (Tisdall and Oades, 1982). Among the factors that affect the formation of aggregates and their stability, are the arbuscular mycorrhizal fungi (AMF) (Rillig et al., 2015) which, together with plant roots, form the symbiotic mycorrhizae. AMF synthesize in their hyphae a compound with a cementing function, consisting of a glycoprotein linked to nitrogen, called glomalin (EEG) (Wu et al., 2014). The other factors that affect SQ are soil organic matter (Kimura and Scotti, 2016), soil texture (Gonçalves et al., 2017), soil fauna (Jouquet et al., 2016), and plant and microorganism diversity (Gould et al., 2016), among others. Conventional management, with intense plowing and tilling, often lead to crop systems with low plant biomass diversity, resulting in changes in the soil physical, chemical and biological attributes (Ahmed et al., 2017).

Thus, the aim of the present study was to evaluate the effect of land uses employed by *quilombola* family farmers on soil properties and finally on soil quality.

Materials and Methods

The study was carried out in a *quilombola* community (*Quilombo Mesquita*) belonging to the municipality of Cidade Ocidental in the eastern region of the state of Goiás, Brazil (16°04'41" S and 47°52'05"

W), at an altitude of 1014 m. The climate of the region, according to Köppen's classification, is type Cwa – high altitude tropical, with well-defined dry and rainy seasons. The mean annual temperature is 21 °C and the mean annual rainfall 1,500 mm (Alvares et al., 2013).

The soil is a Rhodic Hapludox (Soil Survey Staff, 2010), and the physical and chemical soil properties have been described by Nascimento et al. (2017) (Table 1). Distinct historical management systems that were predominantly used by the *quilombola* community were selected (Table 2): 1) conventional corn planting (MA), 2) cultivation of citrus trees intercropped with annual crops (AC) (a conservationist approach), 3) Brachiaria (*Urochloa* spp.) pasture (PA). In addition to the cultivated areas, an area of the Cerrado (CR), free from any anthropogenic interference, was used as a reference.

We took soil samples along an imaginary diagonal line at depths of 0-10 and 10-20 cm in Jan 2016. The localization of the studied areas and the soil sampling points can be found in Figure 1. We obtained five sub-

samples at every 50 m to construct a composite sample. We collected samples in the row and between rows of the conventional corn cultivation system (MA) and in the shadow of treetops in the conservation system of citrus trees intercropped with annual crops (AC). The soil monoliths, collected to analyze the stability of the aggregates in water, were stored in plastic bags to maintain moisture and the stability of their structure. We fractionated all the soil making up the samples, according to points of weakness, so that the total sample volume would pass through an 8.0 mm sieve. Fragments of plants, cuttings and other residues that were retained on the sieve were excluded from the analysis. We used air-dried samples for subsequent analyses.

Stability of the soil aggregates was determined by the vertical wet sieving method in a Yoder device (Yoder, 1936), which consists of separating the aggregates into size classes (Silva et al., 2016a). From the values of the aggregate masses, we calculated the following parameters: (1) the mean weight-diameter (MWD) and (2) the aggregate stability index (ASI).

Table 1 – Soil particle size distribution and chemical characteristics under the investigated management systems at 0-20 cm depth.

Management systems ¹	Granulometry			Chemical properties							
	Sand	Silt	Clay	pH (H ₂ O)	P	K	m	Ca ²⁺	Mg ²⁺	Al ³⁺	H + Al
	g kg ⁻¹			mg dm ⁻³			%	cmol _c dm ⁻³			
CR	40	410	550	5.1	1.3	148	8.7	4.06	1.34	0.55	9.0
AC	40	410	550	5.8	3.7	308	0.6	6.34	1.95	0.06	5.7
PA	120	280	600	4.7	2.1	118	41	0.34	0.28	0.64	5.9
MA	40	410	550	5.9	8.4	353	0.4	4.57	1.28	0.03	4.1

¹CR = Native Cerrado; AC = Cultivation of citrus trees intercropped with annual crops; PA = Pasture of Brachiaria (*Urochloa* spp.); MA = Conventional corn planting; m = aluminum saturation.

Table 2 – Description and history of the management systems.

Management system	Acronym	History
Native Cerrado	CR	Remnant of the Cerradão, with forestry formation, used as a reference and without any exploration or anthropic interference. Presence of species including <i>Anadenanthera macrocarpa</i> (Benth.) Brenan, <i>Lithraea molleoides</i> (Vell.), <i>Hymenaea courbaril</i> L., <i>Handroanthus avellaneda</i> L.
Brachiaria (<i>Urochloa</i> spp.) pasture	PA	Area of approximately 1 ha (10000 m ²) occupied by pastures without soil preparation and fertility management. For 20 years, there was rice/bean/corn/sugarcane rotation. In the last 15 years, there was no management, but area left fallow, a period during which <i>Urochloa decumbens</i> (Stapf) Webster and <i>Urochloa brizantha</i> (Stapf) Webster naturally invaded the location. There was no cattle grazing in the area, and grasses were pulled manually while residues were left on the soil surface and area is not used by farmers.
Conventional corn planting	MA	Area of approximately 1 ha (10000 m ²), managed for 30 years, with planting of grains via conventional practices of minimum soil preparation. For about 20 years, the rice/bean/corn rotation has been used, without fertilization and liming. During the last 10 years, there has been harrowing every two years and cultivation with corn only. Five years ago (2011), liming was applied in the area, with one ton of dolomitic limestone per hectare. The planting and fertilization of corn was manual, while fertilization is performed near the plant row with the NPK formulation 4-30-16 (20 g m ⁻¹) and topdressing potassium nitrate is used (20 g m ⁻¹). Weeds are present, but there is no straw on the soil.
Cultivation of citrus trees intercropped with annual crops	AC	Area of approximately 0.25 ha (250 m ²). For 21 years, the area has been cultivated with <i>Urochloa decumbens</i> (Stapf) Webster, fertilized with cattle manure, and the pasture maintained with continuous cattle grazing. Pasture was removed and for four years the area has been cultivated with tangerine (<i>C. reticulata</i> L.) (4 m × 4 m) intercropped between rows, with the cultures corn/beans/cassava. In the last two years, <i>C. reticulata</i> L. was intercropped only with cassava (<i>Manihot esculenta</i> L.). An initial fertilization was performed with the formulation NPK 4-30-16 (400 g per plant) and with cattle manure (10 L per plant). For two years, the area received coverage fertilization with formula NPK 10-10-10 (400 g per plant). Weeds present in the area were pulled manually four times per year and the residues left near the tree row. Mulching preserved in the area composed of fruit remains, leaves and weeds, so that the soil is permanently covered.

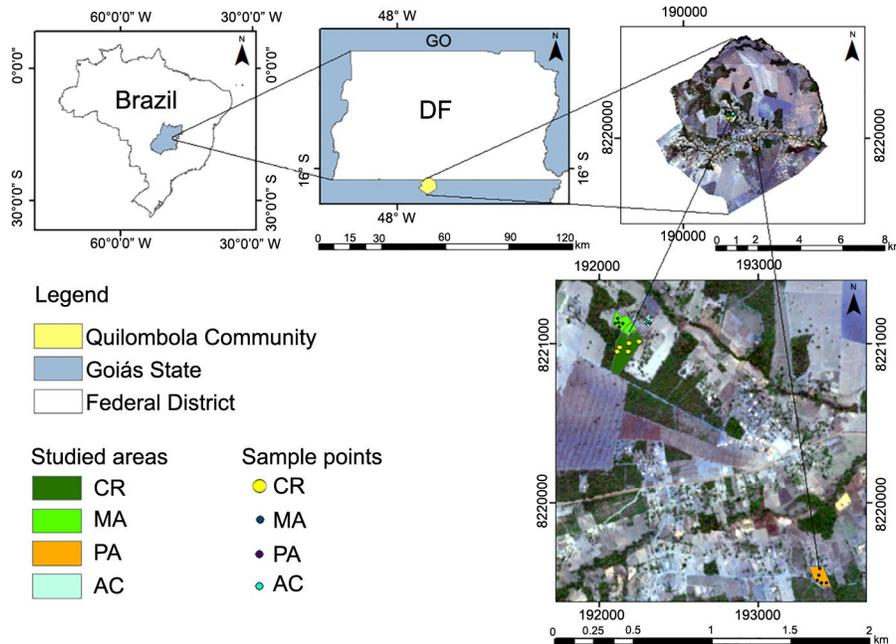


Figure 1 – Localization of studied areas and points of soil collection in *Quilombo Mesquita* (CR = Native Cerrado; AC = Cultivation of citrus trees intercropped with annual crops; PA = Pasture of *Brachiaria* (*Urochloa* spp.); MA = Conventional corn planting).

$$MWD = \sum_{i=1}^n (x_i \cdot w_i) \quad (1)$$

$$ASI = \left(\frac{\text{Dry sample weight} - wp25 - \text{sand}}{\text{Dry sample weight} - \text{sand}} \right) \quad (2)$$

where: w_i = proportion (%) of each class i in relation to the total aggregate weight; x_i = mean diameter of class i , obtained by [(upper mesh + lower mesh):2]; and $wp25$ = weight of aggregates of the class < 250 μm .

The aggregates were subdivided into micro-aggregates (< 250 μm) and macro-aggregates (> 250 μm). The total organic carbon of each class of aggregates was quantified using oxidation by potassium dichromate according to the method of Walkley and Black (1934). Easily extractable glomalin (EEG) related soil protein of each aggregate class was extracted from the soil according to the methodology of Wright and Upadhyaya (1998) and quantified by the Bradford test (Bradford, 1976) using bovine serum albumin (BSA) as standard. We measured absorbance at 595 nm in a colorimeter (Carrizo et al., 2015).

The areas were analyzed in a completely randomized design, with five replications in subplots, where the plots were the management systems and the subplots the depths. The data were submitted to analysis of variance, after having met the normality criteria of the residues and homogeneity of variance, and subsequently multiple comparisons of the means were submitted to Tukey's test ($p \leq 0.05$). We used canonical discriminant analysis (CDA) to separate the studied areas according to

the analyzed variables. In addition, Pearson's correlation was plotted with the use of the program (R Core Team, 2017) and graphs were generated using MS Excel.

Results and Discussion

Distribution of water-stable aggregates

Soil macro-aggregates were predominant (around 90 %) at the depths evaluated in all systems (Figure 2). In areas of native Cerrado, we obtained similar results, with more than 90 % of macro-aggregates stable in water (Bertolin et al., 2016). This may be related to the high clay content found in all management systems (Table 1), because there is a positive correlation of clay content with soil aggregation (Liu et al., 2012). Soils in tropical climates are highly influenced by electrostatic interactions between oxides and clay minerals of the 1:1 type in the aggregation process, forming micro-aggregates, which aggregate again by the action of biological agents, and form macro-aggregates (Costa Júnior et al., 2012).

There was no difference between the relative distribution of micro and macro-aggregates in the analyzed management systems ($p < 0.05$), suggesting that they do not interfere with the distribution of stable aggregates in water (Figure 2). Additionally, there were no changes in the percentage of micro and macro-aggregates in the MA system, where harrowing practices were applied; and this may be related to the effect of lime application in 2011 and continuous crop rotation with rice (*Oryza sativa* L.), beans (*Phaseolus vulgaris* L.),

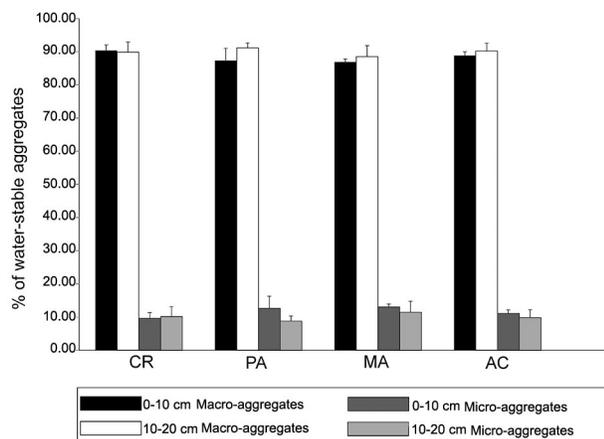


Figure 2 – Relative distribution of stable aggregates in water at depths of 0-10 cm and 10-20 cm submitted to the different management systems. CR = Native Cerrado; PA = Pasture of *Brachiaria (Urochloa spp.)*; MA = Conventional corn planting; AC = Cultivation of citrus trees intercropped with annual crops.

and corn (*Zea mays* L.), for 20 years (Table 2). Silva et al. (2016b) reported that the application of limestone into a Rhodic Hapludox (the same as the one used in our study), increased the growth of root biomass and, consequently, the increase in aggregate stability.

All management systems presented distribution of water-stable aggregates similar to the reference area (CR) (Figure 2), indicating that, after several years of different soil management systems, there was no alteration of aggregate distribution. Soil aggregation seems to be favored by greater soil microbial diversity and active root growth, which allows an increase in interactions between microorganisms, soil and plants (Six et al., 2002; Tivet et al., 2013). Consequently, there may be a greater release of organic exudates that act as cementing agents between soil particles (Wang et al., 2017).

Mean weight-diameter (MWD)

The management system applied to the area with citrus trees intercropped with annual crops (AC) stood out from the other management systems evaluated for promoting significant variation ($p < 0.05$) in the MWD between the depths, with the highest values at 10-20 cm (Figure 3A). For the 0-10 cm depth, the AC, CR and PA systems presented the highest MWD values and did not differ between themselves ($p < 0.05$). For the depth of 10-20 cm, the AC system presented higher MWD and the MA was the management system with the lowest MWD.

For the last 10 years, the MA has been cultivated only with corn. The AC system was cultivated for 21 years with *U. decumbens* and fertilized with cattle manure. This same system was cultivated with *C. reticulata* intercropped with corn/beans/cassava for four years and in the last two years this area was intercropped only with cassava (Table 2). Soil management in AC promoted high-

er MWD, probably due to a higher biodiversity above and below the soil surface, which has the potential to restore soil health (Cardoso et al., 2013).

The addition of plant biomass promotes the entry of easily decomposable carbon into the soil and favors an increase in the MWD. This effect is dependent on the quantity and quality of the organic material being supplied and may exhibit transient effects on the stability of aggregates (Lal, 2015). Moreover, the greater diversity of the planted species, especially grasses, due to their higher root biomass, increases the total organic carbon (TOC) and soil aggregate stability (Pérès et al., 2013). In the case of a Rhodic Hapludox, the organic-mineral interaction between carbohydrates and the mineral surface of clay is one of the most important mechanisms in the formation of soil aggregates (Hanke and Dick, 2017).

We expected that the PA system would present higher MWD than the AC system, since it is known that areas under pasture have a greater tendency to present high levels of soil aggregation because of their fasciculate root system. They produce up to six Mg ha⁻¹ of root biomass in the 0-30 cm layer (McNally et al., 2015), and these are constantly renewed. However, in the present study, the MWD in the PA was lower than in the AC in the 10-20 cm layer (Figure 3A), which could also be associated with lower content of silt and clay in PA in the 0-20 cm layer (Table 2). Soil textures with a higher silt and clay content are capable of binding C to the primary organic-mineral complex into silt-sized aggregates (Tisdall and Oades, 1982).

The MWD is dependent on plant root activity as well as on the quality and amount of metabolites which include organic acids and several other compounds secreted in the rhizosphere (Wang et al., 2017).

Such metabolites also select groups of microorganisms well adapted to the make up of the soil biodiversity thus assisting in the formation of the soil structure (Xiao et al., 2017).

We compared the general distribution of micro and macro-aggregates with the MWD, and found no influence on the distribution of stable macro and micro-aggregates in water (Figure 2). However, the MWD was lower in the MA system (Figure 3A) for both depths. This result may be related to the history of the area (Table 2) and the management system in which plowing and harrowing had been carried out every two years over the last 15 years.

Aggregate stability index (ASI)

There was no influence of ASI by soil use and management system (Figure 3B). Most of the aggregates were larger than 250 μm. However, their size distribution did not differ within management systems. The mineralogy of tropical soils is possibly the factor that results in increased stability of aggregates via the greater organic-mineral interaction (Madari et al., 2005; Hanke and Dick, 2017). A higher ASI was expected in the sys-

tem with greater species diversity (AC), including the reference area (CR), since both could promote a greater diversity of root exudates of different compositions, guaranteeing greater carbon source diversity in the soil system (Silva et al., 2016a). In addition to the biological diversity of natural systems that improves the stability of soil aggregates, another controversial aspect refers to spontaneous burning in the Cerrado that may or may not promote an increase in the stability of these aggregates (Thomaz, 2017; Hobley et al., 2017; Zhang et al., 2017).

Despite this, the ASI value found for the management systems lies within the range commonly found for tropical soils ($82 \pm 6\%$) (Thomaz, 2017). This may also be indicative of high resilience of the soils in these areas, which, according to history, have been cultivated for at least 20 years (Table 2).

The total organic carbon in micro and macro-aggregates

The total organic carbon content (TOC) in both the micro (C-MIC) and macro-aggregates (C-MAC) of the soil differed between the depths ($p < 0.05$) only in the reference area (CR) (Figures 3C and D). At the depth of 0-10

cm, the C-MAC contents presented the following order: $AC > CR > MA > PA$ ($p < 0.05$) (Figure 3D), while at that same depth the concentrations of C-MIC occurred in the following order: $AC > CR = MA > PA$ ($p < 0.05$) (Figure 3C). At the 10-20 cm depth, the contents of C-MAC and C-MIC followed the same trend: $AC > MA > PA = CR$ ($p < 0.05$) (Figures 3C and D).

The AC management system showed higher TOC in the micro and macro-aggregates, possibly due to intercropping with tangerine (*Citrus reticulata* L.) and cassava (*Manihot esculenta* L.), and fertilization with cattle manure and accumulation of plant residues on the soil surface in the AC system. Lack of soil disturbance including the continuous root growth promoted by intercropping are all factors that result in the improvement of aggregation and the supply of carbon (C) to the soil.

Carbon retained within the micro-aggregates seems to be protected physically and chemically as well as a predominance of iron and aluminum oxide in tropical soil. Thus, the micro-aggregates can present high stability and behave like sand particles, and increase the C reserves in the soil (Braida et al., 2011; Silva et al., 2016a). In addition to protection in micro-aggregates,

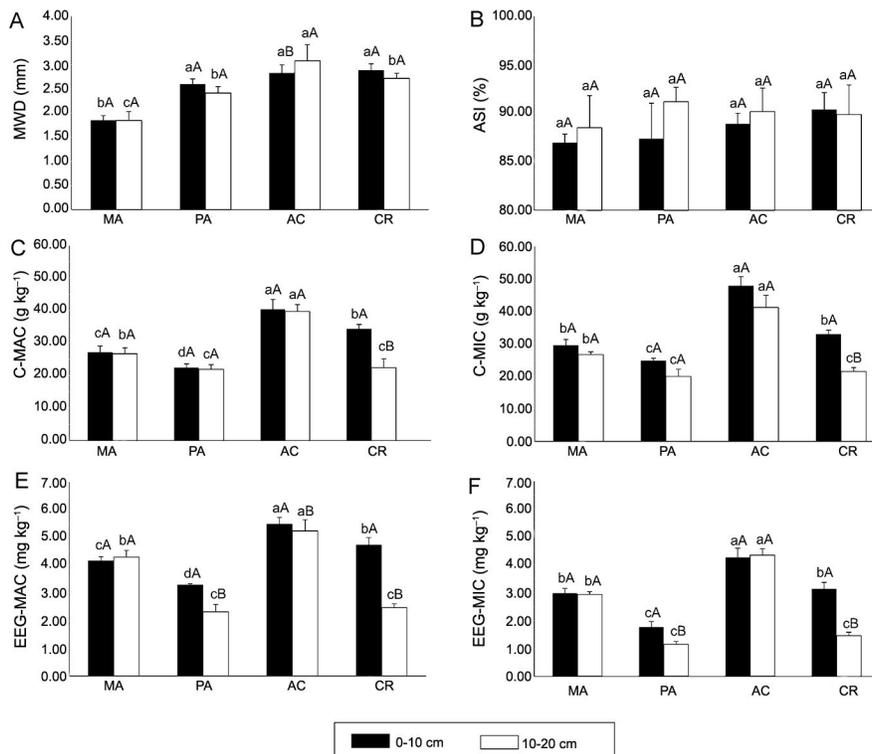


Figure 3 – A) Mean weight-diameter (MWD), B) aggregate stability index (ASI), C) total organic carbon in macro-aggregates (C-MAC), D) total organic carbon in micro-aggregates (C-MIC), E) easily extracted glomalin-related soil protein in macro-aggregates (EEG-MAC), F) and easily extracted glomalin-related soil protein in micro-aggregates (EEG-MIC) of soil submitted to different management systems. MA = Conventional corn planting; PA = Pasture of *Brachiaria* (*Urochloa* spp.); AC = Cultivation of citrus trees intercropped with annual crops; CR = Native Cerrado. Upper-case letters compare the depths within the same management system and lower-case letters compare a given depth among the different management systems by the Tukey's test at 5% ($p < 0.05$) ($n = 5$).

C may have some protection in the macro-aggregates, according to the pore sizes (Kravchenko et al., 2015).

TOC contents in macro and micro-aggregates, obtained in our work, were greater than the contents obtained by Silva et al. (2016a) in a clay-textured Rhodic Hapludox in the Cerrado, with a mean value of 18.94 g C kg⁻¹ and 15.15 g C kg⁻¹ for micro and macro-aggregates, respectively. The authors found no statistical differences in C content in soil cultivated with six cover crops in either micro or macro-aggregates.

It is known that the dynamics of C in soil is affected by different management practices (Nadal-Romero et al., 2016), but it is still unclear which class of soil aggregates is more responsible for the accumulation of C and which soils, depths and management factors are decisive in this process (Fernández et al., 2010). The management systems promoted increases in TOC as compared to levels in the Cerrado (CR) at the 10-20 cm depth (except for PA C-MIC). However, in the 0-10 cm layer, only AC increased TOC when compared with CR (both in micro and macro-aggregates).

Easily extractable glomalin-related to soil protein in micro and macro-aggregates

The EEG content exhibited a behavior similar to the carbon content in micro and macro-aggregates of the soil (Figure 3E and F), which reinforces the concept that EEG is an important source of soil organic carbon (Zhang et al., 2017). The highest EEG levels were found in the AC system, differing between the depths evaluated only in the EEG-MAC ($p < 0.05$), and the systems with the least EEG were the MA and PA (Figure 3E). It has also been reported elsewhere in the literature that conservationist soil management with greater plant species diversity, associated with management practices that minimize degradation of the soil structure, presents a greater tendency to produce high EEG levels (Treseder and Turner, 2007; Vasconcellos et al., 2016).

The AC presented higher EEG than the CR in the micro and macro-aggregates at both depths. The AC system is characterized for being a dynamic system with regard to the input of organic material, as plant residues and manure (Table 2). In addition, the establishment of the AC occurred five years ago as an integrated system and presented the largest accumulation of TOC in different fractions of the soil organic matter (Nascimento et al., 2017).

In the reference area (CR), the contribution of biomass may or may not have a different rate from the intercropped system. In other management systems, which were not evaluated in the present study, without soil disturbance, the EEG content may remain constant over time (Souza et al., 2016), or vary due to the seasonality of precipitation (Buyer et al., 2011).

Macro-aggregates contained higher levels of EEG when compared to micro-aggregates, as had also been found by Vasconcellos et al. (2016), in areas of the Atlantic Forest Recovery in southeastern Brazil.

In macro-aggregates, action of the fungal mycelium network provides greater stability of aggregates in water (Zou et al., 2015) and this may be indicative of greater EEG synthesis (Kohler-Milleret et al., 2013).

Relationship between the analyzed attributes

The Wilks' Lambda multivariate test helps to discriminate between the significance of the studied attributes (Tables 3 and 4). The effect of the management system differed between the depths of 0-10 cm and 10-20 cm (Figures 4A and B). The canonical discriminant analysis (CDA) was selected to determine which attributes (or indicators) differentiate best the effect of the management systems. Contrary to principal component analysis (PCA), the CDA is a confirmatory evaluation whereas PCA is merely an exploratory analysis of the data, with no possibility of precisely determining the attributes that best distinguish the groups (Anderson and Willis, 2003).

For the depth of 0-10 cm (Table 3), the attributes that best discriminated the areas according to the Wilks' Lambda test were MWD ($p < 0.001$), C-MIC ($p < 0.001$), and EEG-MAC ($p < 0.05$). For the depth of 10-20 cm (Table 4), the attributes that best discriminated the areas were MWD ($p < 0.001$), C-MAC ($p < 0.05$) and EEG-MIC ($p < 0.01$). Thus, we observed that the common at-

Table 3 – Wilks' Lambda test between mean weight-diameter (MWD), aggregate stability index (ASI), total organic carbon in macro-aggregates (C-MAC), total organic carbon in micro-aggregates (C-MIC), easily extractable glomalin-related soil protein in macro-aggregates (EEG-MAC) and easily extractable glomalin-related soil protein in micro-aggregates (EEG-MIC) at the depth of 0-10 cm.

Soil attribute	Wilks' Lambda	p-value
MWD	0.001668	0.000132***
ASI	0.000429	0.299248 ^{ns}
C-MAC	0.000484	0.159126 ^{ns}
C-MIC	0.003820	0.000001***
EEG-MAC	0.000740	0.015014*
EEG-MIC	0.000296	0.827494 ^{ns}

Levels of significance: *** $p \leq 0.001$, * $p \leq 0.05$ and ^{ns}non-significant.

Table 4 – Wilks' Lambda test between mean weight-diameter (MWD), aggregate stability index (ASI), total organic carbon in macro-aggregates (C-MAC), total organic carbon in micro-aggregates (C-MIC), easily extractable glomalin-related soil protein in macro-aggregates (EEG-MAC) and easily extractable glomalin-related soil protein in micro-aggregates (EEG-MIC) at the depth of 10-20 cm.

Soil attribute	Wilks' Lambda	p-value
MWD	0.002901	0.000300***
ASI	0.000806	0.407076 ^{ns}
C-MAC	0.001319	0.028746*
C-MIC	0.000578	0.769238 ^{ns}
EEG-MAC	0.000939	0.186470 ^{ns}
EEG-MIC	0.002228	0.001408**

Levels of significance: *** $p \leq 0.001$; ** $p \leq 0.01$; * $p \leq 0.05$; ^{ns}non-significant.

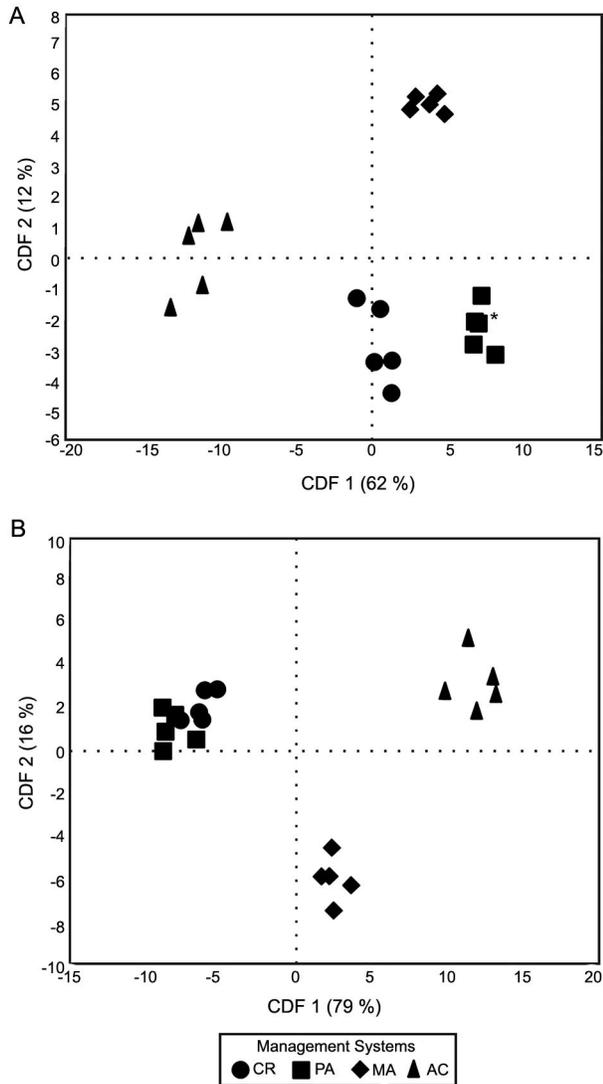


Figure 4 – Relationships between the first and second canonical discriminant functions (CDF1 and CDF2) on the centroids of standardized canonical coefficients (SCC) for the attributes mean weight-diameter (MWD), aggregate stability index (ASI), organic carbon in micro and macro-aggregates (C-MIC and C-MAC) and easily extractable glomalin in micro and macro-aggregates (EEG-MIC and EEG-MAC) at depths of 0-10 cm (A) and 10-20 cm (B). CR = Native Cerrado; PA = Pasture of *Brachiaria (Urochloa spp.)*; MA = Conventional corn planting and AC = Cultivation of citrus trees intercropped with annual crops; and (n = 5). *There is an overlapping of repetitions of the PA samples at the depth of 0-10 cm (A).

tribute between the two depths that best discriminated the management systems was the mean weight-diameter (MWD). At the depth of 10-20 cm the reference area (CR) and the PA system did not differ ($p \leq 0.05$) in terms of the MWD, C-MIC, C-MAC, EEG-MAC and EEG-MIC (Figures 3A to F). The canonical discriminant function 1

Table 5 – Pearson’s correlation among the attributes studied (MWD = mean weight-diameter, C-MIC = organic carbon in the micro-aggregates, C-MAC = organic carbon in the macro-aggregates, EEG-MIC = easily extractable glomalin-related soil protein in micro-aggregates and EEG-MAC = easily extractable glomalin-related soil protein in macro-aggregates).

	MWD	C-MIC	C-MAC	EEG-MAC
C-MIC	0.42*			
C-MAC	0.48*	0.93**		
EEG-MAC	0.25 ^{ns}	0.90**	0.89**	
EEG-MIC	0.26 ^{ns}	0.92**	0.91**	0.96**

Levels of significance: ** $p \leq 0.001$; * $p \leq 0.01$ and ^{ns}non-significant. Data referring to the depths of 0-10 cm and 10-20 cm.

(CDF₁) explained the greatest total variability of the attributes for both depths, between 0-10 cm (62 %) and 10-20 cm (79 %), while the canonical discriminant function 2 (CDF₂) explained 12 % and 16 %, respectively (Figures 4A and B).

EEG correlated with TOC, regardless of the class of aggregates (Table 5). It represents up to 52 % and 25 % of the total C content in organic and mineral soils, respectively (Schindler et al., 2007). Thus, TOC is directly proportional to the amount of EEG present in the soil (Zhang et al., 2017), and studies have proven this relationship to be true in soil cultivated with crops such as citrus (*Poncirus trifoliata* (L.) Raf.) (Wu et al., 2015) and corn (*Zea mays* L.) (Koide and Peoples, 2013).

The MWD did not correlate with the EEG-MAC or the EEG-MIC (Table 4), indicating that EEG contributed more to carbon storage than MWD in the present study.

Conclusions

Soil macro and micro-aggregates, EEG and MWD discriminated management systems, and are important indicators of soil quality.

The carbon content in macro-aggregates (C-MAC) and micro-aggregates (C-MIC) of the intercropped system (AC) was higher than that of the CR.

The attributes that best separated the areas were C-MIC, MWD and EEG in macro-aggregates at the depth of 0-10 cm, and EEG in micro-aggregates, MWD and C-MAC at the depth of 10-20 cm.

Authors’ Contributions

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