SOIL ORGANIC MATTER FRACTIONS AND CARBON MANAGEMENT INDEX UNDER INTEGRATED CROP-LIVESTOCK SYSTEM

FRAÇÕES DA MATÉRIA ORGÂNICA DO SOLO E ÍNDICE DE MANEJO DE CARBONO SOB SISTEMA DE INTEGRAÇÃO LAVOURA-PECUÁRIA

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ABSTRACT: The objective of this work was to evaluate the carbon content of the physical, chemical and oxidizable fractions of soil organic matter (SOM) and to calculate the carbon management index (CMI) in an area managed under an integrated crop-livestock system (ICLS) in the western region of Paraná - Brazil. The experiment was carried out at the experimental farm, belonging to the Universidade Estadual do Oeste do Paraná. Seventeen areas, which are managed in different ways, fifteen in ICLS and two areas of controls (Forest and Haymaking), using the design divided with two nested controls, with three replications were evaluated. Deformed and undisturbed soil samples were collected from all the areas to determine the total organic carbon (TOC), carbon stock, the physical, chemical and oxidizable fractions of SOM and the CMI in the layers of 0-0.05, 0.05-0.1 and 0.1-0.2 m. Little significant changes in the fractions were found for the management of the ICLS area in relation to the Forest and the area of Haymaking, although the Forest presented the best values for most of the studied fractions. It is recommended to adopt sustainable practices, such as ICLS, even though the average fractions tend to take time to match reference areas.

KEYWORDS: Carbon stock. Humic substances. Particulate carbon.

INTRODUCTION

Soil organic matter (SOM) is a sensitive indicator of soil changes due to its use and occupation (BALDOTTO et al., 2015), since the anthropic action of replacing natural ecosystems with agroecosystems for food production, often favors a decline in the organic carbon (C) content of the soil, due to the reduction of the contribution, and losses due to erosion and changes in the rate of decomposition of organic matter (HICKMANN; [illegible] throughout the year are usually associated with fallow systems, such as low productivity crops, burning or removal of cultural residues, contributing to low annual deposited C values (PEREIRA et al., 2013).

Besides directly affecting the SOM, causing the decrease of the contribution of C (SILVA et al., 2013), management systems that provide small contributions of cultural residues are not indicated. Therefore, it is recommended the use of conservationist systems, which interfere little in the soil structure, such as the no-tillage system (HICKMANN; COSTA, 2012) or the integrated crop-livestock system (ICLS) are recommended (CASTAGNARA et al., 2015; PIANO et al., 2015). Another important aspect of the use of ICLS is that it provides C cycling promoted by deposition of feces and animal urine at the soil surface (BAYER et al., 2011).

In this way, it is important to maintain the vegetal residues on the soil surface and to reduce its revolving, since they contribute positively to the soil [illegible] 2011). Moreover, the dynamic balance between the addition of cultural residues and loss by decomposition or mineralization represents the C stock of soil (PEREIRA et al., 2013), although the rates of addition and the quality of vegetation C depend heavily on the climate, vegetation type, soil fertility (BERTNER et al., 2011), and the soil management system (BAYER et al., 2011) as soil density has a direct impact on soil C stocks.

There are several ways of studying the dynamics of SOM, among them, the granulometric

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physical fractionation (CAMBARDELLA; ELLIOTT, 1992), the oxidation fractionation (CHAN; BOWMAN; OATES, 2001), the chemical fractionation (SWIFT, 1996; BENITES; MADARI; MACHADO, 2003), and the carbon management index (CMI) (BLAIR; LEFROY; LISLE, 1995). Among these, the form used as an indicator of soil quality, more sensitive to changes in management, is the physical granulometric fractionation of soil in Particulate Organic Carbon (POC) and Organic Carbon Associated with Minerals (OCAM) (BALIN et al., 2017; FACCIN et al., 2016), because they are based on the degree of association of SOM with the soil matrix (GAZOLLA et al., 2015). Carbon is called POC when it is free or weakly associated with soil particles, or OCAM, when C is strongly bound to the mineral particles, forming organic-mineral complexes (GAZOLLA et al., 2015).

Also, by evaluating the SOM granulometric compartments, it is possible to estimate the CMI between cultivated areas and those in equilibrium (native vegetation), increasing the number of soil organic compartment quality indicators (BLAIR; LEFROY; LISLE, 1995). In addition to the physical fraction, the oxidizable fractions of SOM assist in the interpretation of soil C dynamics (CHAN; BOWMAN; OATES, 2001). They are based on the oxidation levels of C and present four fractions (F1, F2, F3, and F4). The first two are related to nutrient availability and the formation and stabilization of macroaggregates (BARRETO et al., 2011); and the last two are related to compounds of greater chemical stability and molecular weight, common in the soil humic fractions of the SOM that remain longer in the soil (CHAN; BOWMAN; OATES, 2001).

Most studies focus on TOC, however, small changes in C totals are difficult to detect in the short term because the natural soil variability is high (SILVA et al., 2011). The largest compartment of SOM, waters, and sediments occurs in the form of Humic Substances (HS), a heterogeneous mixture of organic compounds aggregated by weak hydrophobic interactions and by hydrogen bonds (BALDOTTO et al., 2013). The HS is fractionated as a function of its solubility at different pH values: Humic Acids (HA), Fulvic Acids (FA) and Humic (HUM) (ROSSI et al., 2011).

Changes, such as decreased or increased the SOM, allow calculating the level of conservation of natural ecosystems and the potential impacts on farming systems with different types of soil management (SILVA et al., 2011). Most of the SOM, in tropical environments, is formed by the HS (PARTELLI et al., 2009), which may reflect the changes that have occurred due to anthropic alterations. The characterization of these fractions presents great potential for the evaluation of soil quality (BENITES et al., 2010), through the chemical fractionation of the SOM (LOSS et al., 2010).

The use of different management systems deserves special attention because it can impact the organic matter content of the soil, that is, to influence the carbon cycle of the soil. From the above, our hypothesis is that the use of the soil with crop integration system, using annual grazing winter forages, provides increases of carbon within the physical, chemical and oxidizable fractions of SOM and to calculate the carbon management index. Therefore, this study aimed to evaluate the carbon content of the physical, chemical and oxidizable fractions of soil organic matter (SOM) and to calculate the carbon management index (CMI) in an area managed under an integrated crop-livestock system (ICLS) in the western region of Paraná - Brazil.

MATERIAL AND METHODS

Location of the experiment

The experiment was conducted at the Experimental Station Professor Antônio Carlos dos Santos Pessoa, belonging to the Universidade Estadual do Oeste do Paraná (UNIOESTE), Campus Marechal Cândido Rondon - Paraná - Brazil. The altitude of the site is 400 m, with the coordinates of 24°31'58" S and 54°01'10" W. According to the Köppen classification, the climate of the region is the Cfa type: humid subtropical mesothermic of dry winter, with well-distributed rainfall throughout the year and hot summers (ALVARES et al., 2014). The soil of the area is classified as a Eutrophic Red Latosol, of very clayey texture (SANTOS et al., 2013a), and due to the proximity between the areas the average levels found in the layer of 0.00 to 0.10 m are of 681.0 g kg^{-1} of clay, 266.5 g kg^{-1} of silt and 52.5 g kg^{-1} of sand, and for the layer 0.10 to 0.20 m contents of 751.5 g kg^{-1} clay, 199.1 g kg^{-1} silt and 49.4 g kg^{-1} sand.

Assessed management systems

The evaluated systems comprised seventeen forms of management. In an agricultural area that had been managed for four years under ICLS (soybean in the summer and autumnal forage for grazing of milk cattle in the winter), with no-tillage in consolidation, the forage species tested were: black oats cv. BRS 139 (O 139), black oats cv. IPR 61 (O 61), white oats cv. IPR Esmeralda (OE), Triticale cv. IPR 111 (T) and the triticale consortium with white oats cv. IPR Esmeralda (CON). These forages were managed with different grazing: without grazing (WG), one grazing (1G) and two grazings (2G). Also evaluated were an area of Forest and Haymaking that were considered as controls areas.

For the winter fodder sowing, the area was desiccated thirty days before sowing of the species, using glyphosate-salt of Isopropylamine and Cletodim, at doses of 4 L ha^{-1} and 0.5 L ha^{-1} of the commercial product, respectively, with flow rate of 100 L ha^{-1}. Sowing of forage species was on April 16, 2016, using continuous flow seeder directly on the soybean straw, with a spacing of 0.17 m between rows. Seeding rates were 60 kg ha^{-1}, 140 kg ha^{-1} and 40 ± 120 kg ha^{-1} for oats, triticale, and consortium, respectively. The base fertilization was 25 kg ha^{-1} of N, 38 kg ha^{-1} of P_2O_5 and 38 kg ha^{-1} of K_2O.

During the growth of the forages, cover fertilization was carried out in a Split topdressing piecemeal manner, totaling 120 kg ha^{-1} of N with urea. Regarding phytosanitary treatments, during the forage cycle, there was no need to apply herbicides, insecticides or fungicides.

For grazing, animals of the Dutch breed during lactation were used, with an average weight of 600 kg ± 50 kg. The grazing was started when the plants reached a height between 0.25 to 0.35 m, about 80 days after the emergency. The animals were removed when the plants had reached 0.15 m height, so that there were no damages to the plant apical meristem, being able to grow again to the formation of straw sufficient for the direct tillage of the soybean in succession (FONTANELI; SANTOS; FONTANELLI, 2012).

In order to implant the soybean crop, the area was previously desiccated, 20 days before sowing, using Isopropylamine + Clethodim glyphosate salt at 3.0 L ha^{-1} and 0.40 L ha^{-1} of the product containing 480 g L^{-1} and 240 g L^{-1} of active ingredient respectively. The sowing of soybean was carried out in no-tillage system, on October 21, 2016, using the NIDERA 5909 RR cultivar, 0.50 m row spacing, 4 cm depth and 14 seeds per linear meter. For the basic fertilization, 310 kg ha^{-1} of the commercial formulation 02-20-18 (N, P_2O_5, and K_2O) was used. Due to the development of the crop, applications of fungicides Piraclostrobin + Fluxapiroxade at the dose of 300 mL ha^{-1}, commercial product; and insecticides: Neonicotinoid + Pyrethroid and Benzoylurea, at doses of 250 mL ha^{-1} and 300 mL ha^{-1}, commercial product, respectively, with flow rate of 100 L ha^{-1}. The soybean harvest was performed mechanically on March 03, 2017.

The Haymaking area was being managed with the production of hay for feeding the animals from the experimental farm of the university during the last 10 years, with the cultivation of Tifton 85 grass (*Cynodon* spp.), with periodic fertilization of swine manure from its own university, being located 230 m from the ICLS. The Forest area has been maintained on permanent preservation as a fragment, which is classified as Semidecidual Seasonal Forest (VELOSO; RANGEL FILHO; LIMA, 1991), being located about 1,130 m from the ICLS area.

Collection of soil samples and assessments

Soil collections were carried out in March 2017, almost a year after the sowing of forages in the agricultural area. In order to collect soil samples within the management systems, three plots were chosen at random within each area. In each plot, four samples of deformed soil with an auger Dutch type were collected and homogenized to form a composite sample in the 0-0.05 m, 0.05-0.1 and 0.1-0.2 m layers.

The determination of the TOC was carried out by wet oxidation using 0.116 mol L^{-1} potassium dichromate solution and concentrated sulfuric acid, with digestion block heating (YEOMANS; BREMNER, 1988). The granulometric physical fractionation of the organic matter was carried out according to the methodology proposed by Cambardella and Elliot (1992), and also the determination of the POC and OCAM.

The carbon stocks of TOC, POC and OCAM were calculated using the following equation: Cst= (C x SD x T)/10, where: Cst represents the carbon stock in a given layer expressed in Mg ha^{-1}; C represents the Carbon content in the layer (g kg^{-1}); SD represents the Soil Density (Mg m^{-3}), determined by the average of three points collected within each area by the volumetric ring method (DONAGEMA et al., 2011) for each depth; T represents the thickness of the layer under analysis, in cm (FREIXO et al., 2002).

In order to adequately compare the calculated inventories between the areas, it was necessary to make comparisons between equal masses of soil, adjusting the values of the layers used in the calculations using the method of Ellert and Bettany (1995). For corrections for the equivalent soil mass, the native Forest area was considered the reference area and calculated by the equation: Corrected depth (cm) = (MDref / MDcor) x DEPcor, where: MDref represents the mean density of the reference area (g cm^{-3}); MDcor is the mean density of the area being corrected (g cm^{-3}); and DEPcor is the original depth of the layer being corrected (cm), as suggested by Signor et al. (2014), with small modifications in relation to the average density instead of the weighted one.

Calculation of the Carbon Management Index (CMI) is made considering a Carbon Stock Index (CSI) that relates the content of TOC of the cultivated area under study in relation to the reference area system (native Forest). We calculate CMI by means of the equation: CMI = CSI x LABI x 100, from the results of TOC and each granulometric fraction stocks (BLAIR; LEFROY; LISLE, 1995; CONCEIÇÃO et al., 2014). The lability (LAB) is determined by the relationship between particulate organic carbon stock (POCst) and the organic carbon stock associated with silt and clay minerals (OCAMst). The lability index (LABI) is calculated by the relation between the LAB of the cultivated area and the LAB of the reference area. Because it was a study that used two areas as control (Forest and Haymaking) for the calculations of the indices, the native Forest area was used as a total control, since it deals with the environment without anthropic action.

The oxidizable fractionation was performed by the degrees of oxidation established by Chan, Bowman and Oates (2001), which obtained four fractions with decreasing degrees of lability by the adapted method proposed by Mendonça and Matos (2017), in which the soil is oxidized by a solution of potassium dichromate 0.167 mol L^{-1} in acid medium in three different concentrations (3, 6 and 9 mol L^{-1}) of H_2SO_4, giving four fractions: Very easily labile fraction (F1); Easily labile fraction (F2); Moderately labile fraction (F3); and Fraction resistant (F4). The relationship between (F1/F4) and (F1+F2)/(F3+F4) was used to obtain indexes to facilitate the understanding of the dynamics between these fractions.

For the fractionation of the humic substances (HS), it was used the methodology based on the differential solubility and subsequent determination of carbon of each fraction, being: Humina (HUM), Fulvic Acid (FA) and Humic Acid (HA), established by the International Society of Humic Substances (SWIFT, 1996) and adapted by Mendonça and Matos (2017).

After determining the carbon content in HS, the following relations of interest were calculated: HA/AF (indicates Soil Carbon Mobility) and Alkaline Extract AE/HUM (indicates the organic matter illuviation in the soil profile) to verify the humification processes of SOM (CANELLAS; SANTOS, 2005).

Development and statistical analysis

The experimental design was subdivided with two nested controls, with three replicates, totaling 51 experimental plots. The data were submitted to analysis of variance with R (Core Development Core Team, 2016) and the means, when obtained by F test ($P \leq 0.05$), were compared by the Dunnett test with Genes software (CRUZ, 2013).

RESULTS AND DISCUSSION

For the TOC contents, the Forest area presented the highest content (31.98 g kg^{-1}), in the 0-0.05 m layer. In this layer, the other management systems presented levels that were equal to or smaller than the Haymaking area. In the other layers studied (0.05-0.10 and 0.10-0.20 m), the TOC contents in the Forest zone were higher than all the other management systems studied (Table 1). The low TOC content found in the winter forage areas is due to the short conversion period between the conventional planting system and the ICLS (4 years). Among the factors that can affect the TOC levels, we can find soil, climate, management system, but also changes in the levels of C in areas converted to ICLS can be observed after 10-15 years (CARVALHO et al., 2009).

Similar results were reported by Schiavo et al. (2011) and Dortzbach et al. (2015), which verified differences in TOC levels both between treatments and depths, and found the highest levels in native vegetation areas. Higher TOC values in native vegetation areas occur due to the higher amount of vegetal residues on the soil surface, associated with the absence of anthropic action (GAZOLLA et al., 2015). The TOC content tends to decrease in depth, as observed in this work in the native vegetation, the reduction was of 28% between the superficial layer and the deepest. This result is due to the greater contributions of SOM in the superficial layers (BATISTA et al., 2013; DORTZBACH et al., 2015).

Minor TOC content in the area of ICLS and Haymaking, also show the negative impact that occurred in the soil after conversion of forest to agriculture or livestock (DORTZBACH et al., 2015). Minor TOC values are related to inadequate management or the concurrence of degraded pastures, resulting in lower nutrient cycling in these areas compared to Forest areas (SILVA et al., 2012).

Table 1. Mean values of total organic carbon (TOC), particulate organic carbon (POC), organic carbon associated with minerals (OCAM) and total carbon stock (TOCst)

Management	TOC g kg^{-1}			POC g kg^{-1}		
	0-0.05 m	0.05-0.1 m	0.1-0.2 m	0-0.05 m	0.05-0.1 m	0.1-0.2 m
O 139 WG	19.82	20.45b	17.90b	12.78ab	13.30ab	12.74ab
EO WG	23.23b	21.93b	19.26ab	13.13ab	15.65ab	15.91b
O 61 WG	20.61	22.47b	19.44ab	12.86ab	13.14ab	15.75b
T WG	23.05b	23.47ab	16.97b	11.92ab	13.99ab	12.50ab
CON WG	21.34	20.02b	19.62ab	12.78ab	10.90ab	12.69b
O 139 1G	20.80	20.08b	18.72b	11.26ab	12.41ab	13.96b
EO 1G	21.20	20.12b	16.08b	13.66ab	13.55ab	13.50b
O 61 1G	20.78	19.18b	17.80b	12.99ab	12.95ab	17.09b
T 1G	21.45	21.52b	18.57b	14.92ab	16.86	13.72b
CON 1G	20.39	19.24b	16.88b	9.17b	14.13ab	15.51b
O 139 2G	22.01b	19.54b	17.23b	14.13ab	13.63ab	9.55ab
EO 2G	20.84	18.69b	18.06b	14.58ab	12.52ab	13.11b
O 61 2P	20.90	19.35b	17.87b	11.32ab	13.10ab	11.55ab
T 2G	20.78	22.01b	16.97b	13.28ab	16.49	12.69ab
CON 2G	21.96b	20.82b	17.44b	11.55ab	15.08ab	12.72ab
Forest	31.98a	27.12a	23.15a	16.78a	9.27a	7.13a
Haymaking	25.42b	22.54b	20.40b	9.42b	9.57b	13.41b
	OCAM g kg^{-1}			TOCst Mg ha^{-1}		
O 139 WG	7.05	7.15b	5.16b	6.71	6.05	12.48
EO WG	10.10ab	6.27b	3.35b	6.85	6.65	13.51
O 61 WG	7.75	9.33b	3.70b	7.29	6.74	13.63
T WG	11.12ab	9.49b	4.48b	6.94	6.69	11.76
CON WG	8.56a	9.12b	6.93b	6.49	6.18	13.75
O 139 1G	9.54ab	7.68b	4.76b	6.20	6.03	12.91
EO 1G	7.54	6.58b	2.57b	6.15	6.04	10.78
O 61 1G	7.80	6.23b	0.71b	6.72	5.80	12.82
T 1G	6.52	4.66	4.85b	7.17	6.56	12.91
CON 1G	11.21ab	5.11	1.38b	6.02	5.70	12.35
O 139 2G	7.88	5.91b	7.68b	7.15	5.84	11.85
EO 2G	6.26	6.17b	4.95b	6.56	5.66	12.46
O 61 2P	9.58ab	6.25b	6.32b	6.85	5.97	12.82
T 2G	7.50	5.52	4.28b	6.75	6.96	11.93
CON 2G	10.41ab	5.73b	4.73b	6.75	6.60	12.76
Forest	15.19a	17.85a	16.02a	11.81a	10.68a	21.13a
Haymaking	16.00b	12.97b	6.99b	9.39b	8.88b	18.62b

Note. Means followed by the same lowercase letter in the column do not differ statistically by the Dunnett test (5%), from controls, means without letter are diffrent from controls. O 139: Oat 139; EO: Esmeralda Oat; O 61: Oat 61; T: Triticale; CON: Consortium; WG: Without Grazing; 1G: 1 Grazing: 2G: 2 Grazing.

High values of POC (16.78 g kg^{-1}) were found in the Forest area in the superficial layer, with decreasing values in depth, 44.56% smaller between the layer of 0.05 and 0.1-0.2 m (Table 1). Similar results were found by Batista et al. (2013) and Carmo et al. (2012), in which the authors verified that the levels of POC were decreasing in depth, due to the accumulation of organic matter on the surface. Organic matter has its decomposition on the surface layer of the soil, which means minimum soil disturbance. We observed that the POC was efficient to show differences between the analyzed areas, in comparison with the TOC. Similar results were observed by Loss et al. (2009), Carmo et al. (2012) and Batista et al. (2013). Thus, POC can be used as an indicator of the quality of soil organic matter in relation to management changes in a short-term period (LOSS et al., 2009).

The non-formation of a gradient of POC in depth in the ICLS areas under consolidation is a negative effect of the conventional planting system, which was practiced in the area. The plow and gradation incorporate plant residues in greater depths, promoting lower contents of POC in surface (LOSS et al., 2014). Besides that, POC is the fraction of soil organic matter that can be rapidly decomposed (BATISTA et al., 2013). However, higher POC values were observed , with the exception of the Forest, is due to the use of Poaceae, which has an abundant root system at this depth that contributes to the increase the organic matter (CARMO et al., 2012; LOSS et al., 2014).

It is indicated the use of crops, such as oats, with have a large biomass remaining, both in surface and in depth layers of the soil, in addition to having a high carbon/nitrogen ratio. The contribution of organic material larger than 53 µm, associated with smaller decomposition of the plant residues, contributes to the maintenance or increase of POC (CONCEIÇÃO et al., 2014).

Significant changes were observed for OCAM contents, with the levels that tend to increase in depth and different behavior of the POC. The higher OCAM levels in depth may be associated with the greater stability of subsurface aggregates, which contributes to greater stabilization of SOM (FACCIN et al., 2016) (Table 1). Higher OCAM levels (17.85 and 16.02 kg kg^{-1}) were found in the Forest area because if there is a high OCAM participation in the organic C, it means that in the area there is a great stabilization of the C and probably a decrease of CO_2 emission (BATISTA et al., 2013). In addition, higher carbon contents in the most recalcitrant fractions in Oxisols can be explained by the association of organic matter with the clays, forming organomineral complexes (FACCIN et al., 2016). However, OCAM is not always a good indicator of the effect of management on soil properties, since changes in soil properties may take many years to be detected (CARMO et al., 2012).

Lower levels of OCAM were found in the ICLS area, in the 0-0.05 m layer, in relation to the controls, similar results were found by Loss et al. (2014). This is due to the use of practices such as the plowing and harrowing, that produce breaks in soil aggregates, exposing the organic matter protected in its interior to the attack of microorganisms, which is rapidly mineralized, causing decrease in the contents of OCAM levels.

For TOCst, the highest and significant values were found in the Forest area, followed by the Haymaking area, and the lowest in the ICLS area. These results were similar to the values obtained by other authors (ROZANE et al., 2010; GATTO et al., 2010; DORTZBACH et al., 2015), were the higher contents of TOCst are due to the greater contribution of organic matter material. The smaller stocks are possibly due to the lower contribution of residues of the vegetal biomass and/or consequence of the cultivation of grains (SANTOS et al., 2013b) and little or no grazing of animals.

However, more significant changes were found for POCst, taking into account the TOCst and OCAMst (Table 2). As for this variable, the values found for most of the ICLS area management tend to approach the Forest area. This shows the importance of the quantification of POCst, as an indicator, by the greater sensitivity with different soil management in a short period of time (SCHIAVO et al., 2011; BATISTA et al., 2013). POCst, both positive and negative changes, are due to variations and contributions of plant residues (SCHIAVO et al., 2011; SANTOS et al., 2013b),

Few significant changes in the OCAMst were found for the area of ICLS in relation to the areas of Forest and Haymaking (Table 2). Low values for OCAMst are generally due to changes in soil management, for a short period, result in small changes in the organic matter content associated with the soil minerals that consequently OCAMst (SCHIAVO et al. 2011). Higher OCAMst in the reference areas can also be explained by the advanced stage of humification of organic matter, which becomes highly stable (SCHIAVO et al., 2011) and by the higher clay content in Oxisols, favoring the formation of stable aggregates, which would hamper both decomposition and mineralization of soil organic fractions (GATTO et al., 2010). Results similar to this work were found by Batista et al. (2013), evaluating the OCAMst under ICLS area in the Cerrado, no differences were verified regarding the in-depth.

For the CSI, the highest values observed were for the Forest, because the CSI reflects the relationship between the stocks of the management systems evaluated to the reference system, in this case the native Forest, and only the triticale without grazing in the 0.05-0.1 m was equal to it (Table 2). The CSI in this work follows the behavior of the TOC, being the values of the Forest superior to most of the other managements, a result similar to those obtained by Kunde et al. (2016).

Only in the 0.1-0.2 m layer in relation to the Forest, significant changes were found for LAB in the ICLS area (Table 2). In the 0-0.05 m layer the highest value for LAB (1.20) was found in the Forest area, and at the other depths (0.05-0.1 and 0.1-0.2 m) the highest values (0.75 and 1.98) were to the Haymaking area. C increase in the fraction of soil is desirable, since it is the most dynamic fraction of the SOM, which is reflected in the quality of the soil (CONTE et al., 2011).

The highest levels of C in more labile fractions are directly associated with the higher content of plant residues (LEITE et al., 2013), altering the ratio of labile organic matter to non-labile organic matter (KUNDE et al., 2016).

Table 2. Mean values of particulate organic carbon stock (POCst), carbon stock associated with minerals (OCAMst), carbon stock index (CSI) and lability (LAB) in different management systems

Management	POCst Mg ha^{-1}			OCAMst Mg ha^{-1}		
	0-0.05 m	0.05-0.1 m	0.1-0.2 m	0-0.05 m	0.05-0.1 m	0.1-0.2 m
O 139 WG	4.33ab	3.94ab	8.88a	2.39	2.12	3.60b
EO WG	3.87ab	4.75ab	11.16b	2.98a	1.90	2.35
O 61 WG	4.55ab	3.94ab	11.04b	2.74	2.80b	2.59
T WG	3.59ab	3.99ab	8.66a	3.35ab	2.70b	3.10
CON WG	3.88ab	3.37ab	8.89a	2.60	2.81b	4.86b
O 139 1G	3.36ab	3.73ab	9.62ab	2.85a	2.31b	3.28
EO 1G	3.96ab	4.07ab	9.06a	2.19	1.97	1.73
O 61 1G	4.20ab	3.91ab	12.31b	2.52	1.88	0.51
T 1G	4.99ab	5.14ab	9.54ab	2.18	1.42	3.37
CON 1G	2.71b	4.19ab	11.34b	3.31ab	1.52	1.01
O 139 2G	4.59ab	4.08ab	6.57b	2.56	1.77	5.28b
EO 2G	4.59ab	3.79ab	9.04a	1.97	1.87	3.42
O 61 2P	3.71ab	4.04ab	8.29a	3.14ab	1.93	4.53b
T 2G	4.31ab	5.21ab	8.92a	2.43	1.75	3.01
CON 2G	3.55ab	4.78ab	9.30ab	3.20ab	1.82	3.46
Forest	6.20a	3.65a	6.51a	5.61a	7.03a	14.62a
Haymaking	3.48b	3.77b	12.24b	5.91b	5.11b	6.38b
	CSI			LAB		
O 139 WG	0.62	0.75b	0.76b	0.15	0.19	0.18
EO WG	0.73b	0.81b	0.82b	0.16	0.21	0.22a
O 61 WG	0.65	0.83b	0.83b	0.20	0.21	0.23a
T WG	0.73b	0.87ab	0.72	0.17	0.21	0.21
CON WG	0.67b	0.74b	0.83b	0.18	0.21	0.18
O 139 1G	0.66b	0.74b	0.80b	0.21	0.22	0.19
EO 1G	0.67b	0.74b	0.68	0.25	0.25	0.23a
O 61 1G	0.65	0.71b	0.76b	0.23	0.21	0.27a
T 1G	0.68b	0.79b	0.79b	0.23	0.25	0.24a
CON 1G	0.64	0.71b	0.72	0.26	0.23	0.23a
O 139 2G	0.69b	0.72b	0.73b	0.22	0.23	0.20
EO 2G	0.66b	0.69b	0.77b	0.22	0.20	0.22a
O 61 2P	0.66b	0.71b	0.76b	0.19	0.20	0.19
T 2G	0.65	0.81b	0.72	0.23	0.24	0.23a
CON 2G	0.69	0.77b	0.74b	0.24	0.23	0.21
Forest	1.00a	1.00a	1.00a	1.20a	0.52a	0.45a
Haymaking	0.80b	0.83b	0.87b	0.59b	0.75b	1.98b

Note. Means followed by the same lowercase letter in the column do not differ statistically by the Dunnett test (5%), from controls, means without letter are diffrent from controls. O 139: Oat 139; EO: Emeralda Oat; O 61: Oat 61; T: Triticale; CON: Consortium; WG: Without Grazing; 1G: 1 Grazing: 2G: 2 Grazing.

The labile fractions, besides being a source of nutrients for plants and an energy source for microorganisms (LEAL et al., 2015), they are important for short-term carbon and nutrient cycle, in addition to their remarkable contribution to the formation and transitory stabilization of aggregates (SANTOS et al., 2013b).

Regardless of the management adopted in the ICLS area, the LABI tended to be intermediate between the controls in all layers (Table 3). Conceição et al. (2014), evaluated conservationist systems, among which are no-tillage, and he also found LABI near the reference. This result was found by Leal et al. (2015), who evaluated the LABI in perennial grass areas. They found the LABI higher than that of the Forest (control) in all treatments.

For the CMI, the values found were, for most of the management systems, the same as those of Forest, which was the reference area (100) (Table 3). The importance of CMI, suggested by Blair, Lefroy and Lisle (1995) is that it takes into account aspects of the lability of soil organic matter and allows to compare the changes that occur in TOC and labile carbon (LC) as a consequence of the use and management of the soil. It is an indicator of the quality of soil management and allows to evaluate the process or the gain of soil quality, since the bigger the CMI, the greater it is quality and vice versa (SOUZA et al., 2009). However, the efficiency of a management system to recover soil quality depends, in addition to the characteristics of this management, on the degradation process in which the soil is found (REIS; LIMA; BAMBERG, 2016).

Table 3. Mean values of lability of index (LABI), carbon management index (CMI), and fractions oxidizable organic carbon (F1e F2) in different management systems.

Management	LABI			CMI		
	0-0.05 m	0.05-0.1 m	0.1-0.2 m	0-0.05 m	0.05-0.1 m	0.1-0.2 m
O 139 WG	4.84ab	3.91ab	5.93ab	284.74ab	293.42ab	444.59ab
EO WG	1.36ab	5.26ab	12.38	101.61ab	427.08ab	525.27ab
O 61 WG	1.72ab	3.03ab	6.90ab	110.72ab	250.38ab	580.15ab
T WG	1.10ab	3.18ab	7.89ab	78.03ab	277.43ab	555.62ab
CON WG	1.60ab	2.74ab	3.96ab	106.23ab	205.97ab	330.76ab
O 139 1G	1.15ab	3.58ab	8.02ab	75.57ab	264.41ab	646.82ab
EO 1G	1.91ab	7.25ab	12.28	127.89ab	562.05ab	426.47ab
O 61 1G	2.17ab	4.97ab	19.33	130.89ab	356.10ab	661.31ab
T 1G	3.44ab	8.47ab	6.71ab	227.50ab	705.37b	553.26ab
CON 1G	0.82ab	6.93ab	12.90	52.02ab	506.72ab	444.59ab
O 139 2G	2.25ab	7.97ab	4.59ab	151.29ab	533.10ab	351.48ab
EO 2G	5.90ab	6.01ab	7.17ab	348.31ab	390.31ab	524.25ab
O 61 2P	1.15ab	4.89ab	4.02ab	75.88ab	357.31ab	302.84ab
T 2G	2.15ab	7.13ab	6.90ab	135.36ab	587.98ab	495.03ab
CON 2G	1.31ab	6.59ab	6.21ab	88.07ab	508.94ab	456.53ab
Forest	1.00a	1.00a	1.00a	100.00a	100.00a	100.00a
Haymaking	0.57b	1.55b	4.27b	47.26b	129.76b	369.17b
	F1 g kg^{-1}			F2 g kg^{-1}		
O 139 WG	7.02ab	6.00ab	6.58ab	4.71ab	5.25ab	4.07ab
EO WG	5.20b	4.20ab	3.22a	6.59ab	5.71ab	5.68ab
O 61 WG	7.26ab	7.68ab	7.45ab	4.50ab	3.89b	2.54b
T WG	8.49ab	7.42ab	6.28ab	5.04ab	3.76b	2.54b
CON WG	4.68b	3.79ab	3.62a	5.52ab	5.49ab	5.33ab
O 139 1G	3.81	4.27ab	3.61a	6.53ab	3,74b	4.35ab
EO 1G	5.78b	4.84ab	4.09ab	4.20ab	5.01ab	4.25ab
O 61 1G	5.03b	4.70ab	4.14ab	4,11b	5.55ab	5.28ab
T 1G	5.03b	5.13ab	3.97ab	4.59ab	1.43b	5.28ab
CON 1G	4.77b	5.17ab	4.20ab	5.39ab	4.66ab	4.67ab
O 139 2G	6.41ab	5.17ab	4.92ab	5.42ab	6.65ab	5.00ab
EO 2G	3.46	4.33ab	4.18ab	5.48ab	4.58ab	4.67ab
O 61 2P	5.67b	4.33ab	4.04ab	6.86ab	6.35ab	6.31a
T 2G	5.60b	5.42ab	4.16ab	5.96ab	3.71b	7.32a
CON 2G	5.21b	4.67ab	3.64a	6.40ab	6.52ab	6.22a
Forest	8.24a	5.83a	5.42a	8.64a	9.08a	7.37a
Haymaking	6.67b	6.04b	6.10b	3.93b	2.83b	1.66b

Note. Means followed by the same lowercase letter in the column do not differ statistically by the Dunnett test (5%), from controls, means without letter are diffrent from controls. O 139: Oat 139; EO: Emeralda Oat; O 61: Oat 61; T: Triticale; CON: Consortium; WG: Without Grazing; 1G: 1 Grazing: 2G: 2 Grazing.

For the CMI, the values found were, for most of the same managements as that of Rossi et al. (2012), evaluating CMI as a soil quality indicator, in the area Cerrado Goiano, in a dystrophic Red Latosol, also at high CMI values (905) with soybean and *Brachiaria* under no-tillage, demonstrating that the evaluated systems are being maintenance of carbon stocks. Souza et al. (2009), evaluating CMI in a ICLS in no-tillage, also found high CMI values (256), with the Forest as reference (100), due to the management with greater plant residues.

Corroborating with this work, Gazolla et al. (2015), found the highest values of CMI in the area of ICLS, due to the higher contributions of organic matter by the grass root system (corn and *Brachiaria*), especially the *Brachiaria* crop. However, for Balin et al. (2017), evaluating the

CMI of a Red Latosol under different systems of use, found that LAB, LABI, and CMI values were lower in the ICLS area compared to the reference area (Forest). However, present potential for C preservation and recovery in their compartments compared to more conservationist systems.

The levels of C of the oxidative fractions and their respective ratios are shown in Tables 3 and 4. In the 0-0.05 cm layer, the oats 139, oats 61 and the triticale without grazing together with the oats 139 presented levels of C in the F1 fractions of the LC equal to those of the controls, since the other management of the ICLS area is equal only to the area of Haymaking. For the F1 fraction, in the other depths (0.05-0.1 and 0.1-0.2 m) the mean levels of this fraction tend to be intermediate between the reference areas. For F2 and F4 fractions, at all depths, the studied managements tend to be similar in the reference areas. However, for the F3 levels of managements, in all depths, they tend to resemble the Forest.

Table 4. Mean values of the oxidizable fractions of organic carbon (F3 and F4) and the relation between the oxidizable fractions F1/F4, (F1+F2)/(F3+F4) in the different management systems.

Management	F3 g kg^{-1}			F4 g kg^{-1}		
	0-0.05 m	0.05-0.1 m	0.1-0.2 m	0-0.05 m	0.05-0.1 m	0.1-0.2 m
O 139 WG	4.56a	3.42a	3.43a	3.54ab	5.78ab	3.83ab
EO WG	6.09ab	5.56ab	4.70a	5.34ab	6.46ab	5.65ab
O 61 WG	3.01	3.12a	2.72a	5.84ab	7.78ab	6.73ab
T WG	3.63	4.17a	4.45a	5.89ab	7.80ab	3.71ab
CON WG	6.10ab	5.80ab	5.27ab	5.04ab	4.94ab	5.39ab
O 139 1G	6.02ab	5.66ab	4.27a	4.44ab	6.42ab	6.48ab
EO 1G	5.80ab	3.96a	5.58ab	5.41ab	6.31ab	2.16ab
O 61 1G	6.65ab	3.80a	4.30a	4.99ab	5.13ab	4.08ab
T 1G	5.44ab	6.44ab	5.12ab	6.39ab	8.52a	4.20ab
CON 1G	3.97	3.67a	3.93a	6.26ab	5.74ab	4.09ab
O 139 2G	3.91	2.52a	3.88a	6.26ab	5.21ab	3.44ab
EO 2G	5.38ab	4.64a	5.87ab	6.52ab	5.14ab	3.68ab
O 61 2P	5.72ab	6.58ab	3.89a	2.65b	3.75ab	3.63ab
T 2G	4.21a	5.01a	3.04a	5.01ab	7.86ab	2.58ab
CON 2G	5.15a	4.38a	3.88a	5.20ab	5.24ab	3.70ab
Forest	7.90a	5.66a	6.68a	7.21a	6.54a	3.68a
Haymaking	9.21b	9.43b	8.77b	5.61b	4.02b	3.88b
	F1/F4			(F1+F2)/(F3+F4)		
O 139 WG	1.62ab	1.45ab	1.80ab	1.50ab	1.23ab	1.51ab
EO WG	0.78ab	0.85ab	0.58ab	1.04ab	0.85ab	0.87ab
O 61 WG	1.76ab	2.23b	3.02	1.33ab	1.07ab	1.06ab
T WG	1.85ab	1.73ab	2.54ab	1.45ab	1.13ab	1.14ab
CON WG	0.87ab	0.70ab	0.75ab	0.92ab	0.87ab	0.87ab
O 139 1G	0.73ab	1.15ab	1.63ab	1.02ab	0.66ab	0.78ab
EO 1G	1.47ab	0.97ab	0.99ab	0.90ab	0.96ab	1.09ab
O 61 1G	1.33ab	0.87ab	0.79ab	0.85ab	1.15ab	1.12ab
T 1G	1.28ab	3.66	0.79ab	0.81ab	0.45ab	1.07ab
CON 1G	0.89ab	1.19ab	0.90ab	1.03ab	1.07ab	1.14ab
O 139 2G	1.19ab	0.79ab	1.01ab	1.20ab	1.56ab	1.47ab
EO 2G	0.73ab	0.94ab	0.94ab	0.76ab	0.91ab	1.00ab
O 61 2P	0.84ab	0.73ab	0.66ab	1.54ab	1.09ab	1.39ab
T 2G	1.10ab	1.47ab	0.61ab	1.30ab	0.72ab	3.08
CON 2G	0.89ab	0.77ab	0.62ab	1.15ab	1.18ab	1.41ab
Forest	1.14a	0.95a	1.52a	1.12a	1.22a	1.24a
Haymaking	1.32b	1.51b	1.58b	0.74b	0.66b	0.62b

Note. Means followed by the same lowercase letter in the column do not differ statistically by the Dunnett test (5%), from controls, means without letter are diffrent from controls. O 139: Oat 139; EO: Emeralda Oat; O 61: Oat 61; T: Triticale; CON: Consortium; WG: Without Grazing; 1G: 1 Grazing: 2G: 2 Grazing.

The levels of F1 and F2 in the ICLS area, similar to Forest area, tend to correlate positively with TOC, since, according to Souza et al. (2014), higher levels of LC in the fractions F1 and F2 tend to be found in areas where there is a great contribution of organic matter, from vegetal residues on the soil surface. The labile fractions of organic matter are fundamental for both the cycling of C between the compartments and for the cycling of nutrients in the short term, in addition to its remarkable contribution to the formation and transitory stabilization of aggregates (SANTOS et al., 2013b).

In general, for Rosset et al. (2016), the contents of the fractions F1 and F2 decrease in depth from 52 to 44% in the layers of 0-0.05 and 0.1-0.2 m, and fractions F3 and F4 tend to increase from 48 to 56%, in the above-mentioned layers. Similar results to those of Melo et al. (2016), finding higher levels of C in the oxidizable fractions in the 0.0-0.05 m layer, compared to the 0.05-0.1 m layer, are mainly due to the contribution of residues. The non-formation of layers, mainly in the agricultural area of this work, is due to the short period of transition from conventional system to ICLS. Loss et al. (2014), found lower levels of C in all fractions evaluated in the conventional system area, demonstrating the negative anthropic influence in this type of system in detriment to the Forest and no-tillage.

The fractions F3 and F4 are the most stable fractions of SOM, increasing in depth. Rosset et al. (2016) found the highest levels of C in fractions F3 and F4, in the 0.1-0.2 m layer, in the pasture area, due to the higher levels of HUM, a different result to this work. Melo et al. (2016), evaluating different forms of management, found lower values of C in fraction F1 by reducing soil C and that F3 and F4 fractions were not favored by these activities due to the lower values of these more recalcitrant fractions. Loss et al. (2014), also observed higher levels in the most stable fractions (F3 and F4) for the pasture area, in depth (0.05-0.4 m), due to the root system of the grassland and lower F4 fraction content in conventional system, due to lower OCAM levels, evidencing inadequate management (plowing and grading weeds out).

For the relative distribution between the labile and recalcitrant fractions of SOM, represented by the relations F1/F4 and (F1+F2)/(F3+F4), in this work, the results found in agricultural areas at all depths tend to be intermediate to the reference areas (Table 4). In this work, most of the results, from the F1/F4 ratio, are close to 1, and for Loss et al. (2014), the closer this ratio is, the better the distribution of carbon contents between the more labile fraction (F1) and the more recalcitrant fraction (F4) in the soil.

Similar results to this work were found by Rosset et al. (2016), that when evaluating areas of no-tillage found values for the F1/F4 ratio similar to those of the Forest, which indicates a higher input of plant material of greater lability. Loss et al. (2014) also found the index values of F1/F4 upper 1, for pasture and Forest area in the soil surface layer (0-0.1 m) due to higher levels of C in fraction F1 and area of no-tillage with less than 1, due to the higher concentration of C in fraction 4.

When the four fractions were evaluated together (F1+F2)/(F3+F4), the ICLS area stood out, with values close to the reference units, especially in the first two layers (Table 4). Similar results to this work were found by Rosset et al. (2016), that when evaluating the relationship (F1+F2)/(F3+F4), in areas with no-tillage and ICLS in red eutrophic Latosol, found values lower than 1.20. However, for Martins et al. (2015), the relationship (F1+F2)/(F3+F4) tends to be high in the surface horizon, indicating predominance of the most labile fractions (F1 and F2), and low in the subsurface horizon, indicating greater presence of the most recalcitrant fractions (F3 and F4), a fact not observed in this work.

The levels of C of the humic fractions did not show a wide variation among the management systems, and the levels of FA, HA and HUM tended to be intermediate between the reference areas (Table 5). Among the fractions, the HUM presented the highest levels regardless of management systems and depth, a similar result to that of Pulrolnik et al. (2009), evaluating soils under eucalyptus, pasture, and cerrado and for Gazolla et al. (2015), evaluating areas of pasture, no-tillage, and ICLS. Campos et al. (2013), also observed higher levels of HUM, with higher content (17.60 g kg^{-1}), in the superficial layer of 0.0-0.05 m in the native vegetation area, a result associated with the greater amount of TOC treatment. Higher levels of HUM, in very clayey soils under tropical climate, can be also attributed to the interaction of the organic matter with the mineral fraction of this soil (PULROLNIK et al., 2009; CAMPOS et al., 2013; ROSSET et al., 2016).

Portugal et al. (2008), evaluating agricultural systems implanted in red-yellow argisol, found that the different soil uses altered the C content in the fractions FA, HA, HUM similarly between the systems of use, in the depths of 0-0.1 m and 0.1-0.2 m, a result similar to this work. For Gazolla et al. (2015), the values of the humic substances, HUM (0.2-0.4 m), AF (0.05-0.1, 0.1-0.2

and 0.2-0.4 m) and HA (all depths) were practically similar, between the no-tillage and ICLS areas, mainly due to the similarity of SOM dynamics. However, for Martins et al. (2015), evaluating different types of soil in Forest areas, observed that the C levels of the humic fractions also showed a wide variation among the studied horizons, with FA varying between 0.6 and 3.67 g kg^{-1}, AH of 0.3 to 5.8 g kg^{-1} and the HUM of 3.0 to 40.8 g kg^{-1}.

Table 5. Mean values of humidified fractions of fulvic acid (FA), humic acid (HA) and humin (HUM), humic acid and fulvic acid ratio (HA/FA) in different management systems.

Management	FA g kg^{-1}			HA g kg^{-1}		
	0-0.05 m	0.05-0.1 m	0.1-0.2 m	0-0.05 m	0.05-0.1 m	0.1-0.2 m
O 139 WG	3.09b	2.86ab	3.00ab	2.68b	3.06ab	3.10ab
EO WG	2.79b	2.85b	2.94ab	2.95b	3.69ab	3.85a
O 61 WG	2.98b	3.19ab	3.23ab	3.38ab	3.55ab	3.76a
T WG	3.21b	3.03ab	2.86ab	3.30b	3.78ab	3.41ab
CON WG	3.03b	2.83b	2.97ab	3.21b	3.32ab	3.34ab
O 139 1G	2.98b	3.15ab	3.11ab	3.22b	3.44ab	2.90ab
EO 1G	3.28b	3.38ab	2.94ab	3.41ab	3.35ab	3.19ab
O 61 1G	3.39b	3.03ab	3.05ab	3.71ab	3.29ab	3.48ab
T 1G	2.81b	3.09ab	3.03ab	3.48ab	4.07a	3.88a
CON 1G	2.97b	2.94ab	2.98ab	3.70ab	3.34ab	3.23ab
O 139 2G	3.55b	3.20ab	3.31ab	3.33ab	3.46ab	2.96ab
EO 2G	3.06b	3.20ab	3.27ab	2.98b	2.87ab	3.04ab
O 61 2P	3.40b	3.47ab	3.72a	3.20b	3.44ab	3.28ab
T 2G	3.51b	3.34ab	3.27ab	3.23b	3.48ab	3.12ab
CON 2G	3.34b	3.62ab	3.14ab	3.52ab	3.43ab	3.04ab
Forest	4.53a	3.64a	3.32a	4.39a	3.83a	3.47a
Haymaking	3.15b	2.84b	2.60b	3.25b	2.88b	2.50b
	HUM g kg^{-1}			HA/FA		
O 139 WG	18.09ab	16.08ab	17.25a	0.87ab	1.11ab	1.07ab
EO WG	18.32ab	17.48ab	17.70a	1.07ab	1.40ab	1.45ab
O 61 WG	17.50ab	17.50ab	16.84a	1.17ab	1.14ab	1.22ab
T WG	19.86ab	18.22a	16.51a	1.05ab	1.28ab	1.26ab
CON WG	18.27ab	15.85ab	18.20a	1.09ab	1.32ab	1.19ab
O 139 1G	16.22ab	16.32ab	15.64ab	1.12ab	1.10ab	0.94ab
EO 1G	14.22b	14.02ab	14.33ab	1.06ab	1.01ab	1.14ab
O 61 1G	16.45ab	15.71ab	13.99ab	1.10ab	1.12ab	1.20ab
T 1G	16.43ab	16.57ab	16.21ab	1.30ab	1.45ab	1.40ab
CON 1G	14.84b	14.83ab	14.74ab	1.30ab	1.17ab	1.13ab
O 139 2G	15.44ab	15.44ab	15.45ab	0.94ab	1.09ab	0.88ab
EO 2G	14.21b	14.61ab	13.94ab	0.98ab	0.90ab	0.92ab
O 61 2P	17.25ab	17.60ab	17.43a	0.95ab	1.03ab	0.87ab
T 2G	14.90b	15.09ab	14.36ab	0.92ab	1.04ab	0.96ab
CON 2G	15.25ab	15.54ab	14.79ab	1.05ab	0.96ab	0.97ab
Forest	19.15a	17.84a	13.97a	0.97a	1.07a	1.05a
Haymaking	16.40b	13.71b	11.70b	1.03b	1.02b	0.96b

Note. Means followed by the same lowercase letter in the column do not differ statistically by the Dunnett test (5%), from controls, means without letter are diffrent from controls. O 139: Oat 139; EO: Emeralda Oat; O 61: Oat 61; T: Triticale; CON: Consortium; WG: Without Grazing; 1G: 1 Grazing: 2G: 2 Grazing.

However, when the native vegetation is removed by anthropic action, important changes occur in the humic substances dynamics (PULROLNIK et al., 2009), such as soil plow in the conventional system, that accelerates the decomposition of the SOM, disfavoring the HA and benefiting the FA (LOSS et al., 2010). And the FA fraction represents the intermediate fraction in the stabilization process of the humic compounds (PORTUGAL et al., 2008).

Although agricultural use drastically decreases SOM content, agricultural systems present a different recovery to this organic behavior (PORTUGAL et al., 2008), because for Loss et al. (2010) in no-tillage areas, when there is no soil disturbance, there is an increase in the proportion of HA in relation to surface FA, since HA represents the intermediate fraction in the stabilization process of the humic compounds (SANTOS et al., 2013b).

For the HA/FA ratio, which expresses the degree of evolution of the humification process, in this study, the values found for the management were intermediate between the reference areas, and the ratio ranged from 0.87 to 1.45 (Table 5). In tropical soils, this ratio is lower than 1, because the organic fraction is dominated by humic, indicating soil with intense mineralization of residues, edaphic restrictions and intensely weathered soils (CERRI; VOLKOFF, 1988; CANELLAS et al., 2003). The HA/FA ratio also indicates the degree of conversion of the insoluble organic carbon present in the soil into soluble fractions, whereas in sandy soils presented higher values for the ratio HA/FA, which means the selective loss of the most soluble fraction (MARTINS; CORINGA; WEBER, 2009).

Martins et al. (2015), found for the AH/AF ratio, in different soil types under Seasonal Deciduous Forest, values greater than 1 for most horizons, denoting the predominance of humic acids. For Martins, Coringa and Weber (2009), pasture and agroforestry systems presented the highest values for the AH/AF ratio, which indicates greater carbon mobility in these systems of land use. However, Gazolla et al. (2015), found AH/AF ratio values of the ICLS and Cerrado area close to 2, indicating that in these areas, there is a predominance of HA in relation to FA, presenting a more stable organic material, evidencing more preserved soils, of more conservationist management systems.

The results found for the AE, in the 0-0.05 m layer, were for all management systems lower than Forest, and in the other layers the results were the same or intermediate the reference areas (Table 6). However, Campos et al. (2013), found values of AE, lower in the 0-0.05 m depth layer, for the Forest area and in the other layers the results were the same or intermediate for the management systems in relation to the reference areas. Although AE indicates the degree of conversion of insoluble organic C from soil to soluble fractions, for these authors, lower values of AE, in soils under native vegetation and pastures are due to the composition of plant residues being poor in lignin.

Table 6. Mean values of alkaline extract (AE) and the relation between alkaline extract/humic (AE/HUM), in the different management systems.

Management	AE g kg^{-1}			AE/HUM		
	0-0.05 m	0.05-0.1 m	0.1-0.2 m	0-0.05 m	0.05-0.1 m	0.1-0.2 m
O 139 WG	5.77b	5.92b	6.10ab	0.32b	0.37ab	0.35b
EO WG	5.74b	6.54ab	6.79a	0.31b	0.38ab	0.38ab
O 61 WG	6.35b	6.74ab	6.99a	0.37ab	0.39ab	0.42ab
T WG	6.51b	6.82ab	6.27ab	0.33b	0.38ab	0.38ab
CON WG	6.24b	6.15ab	6.32ab	0.34b	0.39ab	0.35b
O 139 1G	6.20b	6.59ab	6.01ab	0.40ab	0.41ab	0.38ab
EO 1G	6.69b	6.72ab	6.13ab	0.49ab	0.49ab	0.43ab
O 61 1G	7.09b	6.32ab	6.53a	0.44ab	0.40ab	0.49ab
T 1G	6.29b	7.15a	6.91a	0.41ab	0.43ab	0.42ab
CON 1G	6.67b	6.28ab	6.21ab	0.46ab	0.44ab	0.43ab
O 139 2G	6.88b	6.65ab	6.27ab	0.45ab	0.44ab	0.42ab
EO 2G	6.04b	6.07b	6.32ab	0.44ab	0.42ab	0.46ab
O 61 2P	6.60b	6.92ab	7.00a	0.38ab	0,40ab	0.40ab
T 2G	6.74b	6.83ab	6.38ab	0.47ab	0.46ab	0.46ab
CON 2G	6.86b	7.05a	6.17ab	0.46ab	0.47ab	0.43ab
Forest	8.92a	7.47a	6.79a	0.47a	0.42a	0.49a
Haymaking	6.40b	5.72b	5.10b	0.39b	0.42b	0.44b

Note. Means followed by the same lowercase letter in the column do not differ statistically by the Dunnett test (5%), from controls, means without letter are diffrent from controls. O 139: Oat 139; EO: Emeralda Oat; O 61: Oat 61; T: Triticale; CON: Consortium; WG: Without Grazing; 1G: 1 Grazing: 2G: 2 Grazing.

The values of the AE/HUM ratio, in this work, were equal and intermediate the reference areas for all the managements, ranging from 0.31 to 0.49 (Table 6). The quotient between AE/HUM indicates the illuviation of organic matter or organic carbon in the soil, and for Martins, Coringa and Weber (2009), evaluating different management systems, the systems presented the following order: pasture > forest > agroforest > silvopastoril. For Campos et al. (2013), evaluating different management systems in a Yellow Latosol, the highest values of the relation AE/HUM were found for the no-tillage with five years of adoption.

The low values of the AE/HUM ratio in this work are also due to the high levels of HUM found in the evaluated areas, mainly due to the high clay content, a pattern also observed by Rosset et al. (2016). Fontana et al. (2010), found values of the AE/HUM ratio varying between 0.27 and 1.03, which are considered to be low, as they are indicative of the insolubility of the organic matter and high stability between this and the mineral matrix of the soils.

CONCLUSIONS

The native Forest area presented the best values for most of the fractions studied.

Conservation systems such as ICLS can match the soil quality of the reference system, but they require an adequate management system and time.

The POC fraction was more sensitive than TOC to detect variations in a short period of time.

The use of grasses tends to promote carbon increment in depth.

The main alterations of C in the soil are due to the inadequate management system of the area before the beginning of the conversion to the ICLS.

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RESUMO: O objetivo desse trabalho foi avaliar os teores de carbono das frações física, química e oxidável da matéria orgânica do solo (MOS) e calcular o índice de manejo de carbono (IMC) em uma área manejada em sistema de integração lavoura pecuária (ILP) na região Oeste do Paraná - Brasil. O experimento foi realizado na fazenda experimental, pertencente à Universidade Estadual do Oeste do Paraná. Foram avaliadas dezessete áreas, que foram manejadas de diferentes formas, quinze em ILP e duas testemunhas (Mata e Fenação), sendo empregado o delineamento subsubsubdividido com duas testemunhas aninhadas, com três repetições. Em todas as áreas foram coletadas amostras deformadas e indeformadas de solo para serem determinados o carbono orgânico total, estoque de carbono e as frações físicas granulométricas, oxidáveis e químicas da MOS e o IMC nas camadas de 0-0,05, 0,05-0,1 e 0,1-0,2 m. Alterações pouco significativas das frações foram encontradas para os manejos da área em ILP em relação a mata e a área de fenação, entretanto a mata apresentou os melhores valores para a maioria das frações estudadas. Recomenda-se a adoção de práticas sustentáveis, como a ILP, mesmo que os teores médios das frações tendem a demorar tempo para igualar-se a áreas de referência.

PALAVRAS CHAVES: Estoque de carbono. Substâncias húmicas. Carbono particulado.

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