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Soil chemical and microbiological attributes under integrated production system in Oxisol of degraded pasture

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Abstract

The objective of this study was to evaluate the chemical attributes and quality of an Oxisol after one year of conversion of degraded pasture into integrated production system. The evaluated treatments were degraded pasture (PAST-Control); Eucalyptus, clone Urograndis 144 (*Eucalyptus grandis* x *E. urophylla* hybrid) intercropped with cor and marandu grass (*Brachiaria brizantha*) (integration crop-livestock-forest system - ICLFS-M); with maize and perennial horse gram (*Macrotyloma axillare*) (ICLFS-HG); and with maize, java and marandu grass (ICLFS-M+J); Monoculture of marandu grass (MAR) and perennial horse gram (HG); and marandu grass intercropped with Java/ perennial horse gram (H+M). Soil samples were collected in July/2015 and January/2016 in 0-5, 5-10, 10-20 and 20-30 cm soil depth layers. The soil attributes such as pH, organic matter, phosphorus, sum of bases, effective and potential cation exchange capacity and base saturation were evaluated. The implantation of ICLFS system contributed to increase of soil organic matter, sum of bases, effective and potential cation exchange capacity and soil base saturation. The soil biological activity was increased in the rainy season, and the soil microbial carbon increased in ICLFS-HG+M, ICLFS- HG, ICLFS-M and HG+M when compared to monocultures and PAST. Integrated production systems provide improved in soil quality even with a short time implementation.

Keywords: Soil quality, Agrosilvopastoral system, *Eucalyptus urograndis*, *Brachiaria brizantha*, *Macrotyloma axillare*.
Abbreviations: PAST_degraded pasture; ICLFS-M_Eucalyptus, clone Urograndis 144 (Eucalyptus grandis x E. urophylla hybrid) intercropped with cor and marandu grass (*Brachiaria brizantha*); ICLFS-HG _ Eucalyptus, clone Urograndis 144 (Eucalyptus grandis x E. urophylla hybrid) intercropped with maize and perennial horse gram (*Macrotyloma axillare*); ICLFS-M+J _ Eucalyptus, clone Urograndis 144 (Eucalyptus grandis x E. urophylla hybrid) intercropped with maize, java and marandu grass; MAR _ Monoculture of marandu grass; HG _ perennial horse gram; H+M _ marandu grass intercropped with Java/ perennial horse gram; pH _ pH in water; P _ phosphate; K _ potassium; Ca _ calcium; Mg _ magnesium; Al _ aluminum; SB _ sum of bases; H + Al _ potential acidity; ECEC _ effective cation exchange capacity; CEC _ potential cation exchange capacity; m _ aluminum saturation; BS _ base saturation; OC _ organic carbon; SOM _ soil organic matter; SBR _ microbial respiration of the soil; SMB-C _ microbial carbon; TOC _ total organic carbon; qCO_2 _ metabolic quotient.

Introduction

Soil degradation reduces its productive capacity, compromising food production and, consequently, supplying the basic needs of the society. According to Lal (2015), agricultural models based on homogeneous crops of plant species and with high soil mobilization have had detrimental effects on the soil quality, in addition to the loss of fauna and flora biodiversity.

Integrated production systems are considered as alternatives for soil quality recovery, as the integration of agricultural, livestock and forestry components favors the increase of biodiversity, providing the generation of synergistic effects on the environment. In addition, land use is maximized by reducing the need to open new production areas with sustainable intensification (Cordeiro et al., 2015).

In the present study, the processes of nutrient extraction and exportation by the crops contributed to obtain very low and low levels of phosphorus, since fertilizer application was done only in the initial phase of the areas implantation. According to Bastos and Ferreira (2010) and Carvalho et al. (2015), the soils under cerrado vegetation are of low natural fertility and P is highlighted as one of the limiting nutrients for agricultural production in these areas, since phosphorus has the low concentrations and get fixed in the soil.

Azar et al. (2013) showed favorable results for biomass and soil microbial activity under integration of crop-livestock-forest system compared to pasture monoculture, with improvements in the carbon attributes of microbial biomass, organic carbon and soil respiration.

Given the complexity of integrating different components in the same area, research into different soil and climate conditions is necessary, also considering the possible arrangements of species used in integrated production systems. The objective of this study was to evaluate the chemical attributes and quality of Oxisol after one year of conversion of degraded pasture into integrated production systems.

Results

Chemical analysis of the soil

The crop-livestock-forest system (ICLFS) presented an increase in the soil organic matter (SOM) contents (Table 1).
At the depth of 0-5 cm, the SOM contents in the ICLFS treatment were classified as good (40.1 to 70.0 g kg^{-1}), according to the interpretation classes presented by Alvarez et al. (1999) for the soils of Minas Gerais State. Higher SOM contents were found in perennial horse gram (HG) (5-10 and 20-30 cm layers) and ICLFS-M (10-20 cm depth) treatments. The ICLFS systems presented higher SOM contents ($p < 0.05$) than the other treatments in the 0-5 cm and 5-10 cm layers (Table 1).
The clay content observed in the experimental areas was 656 g kg^{-1}. 96.43% of phosphorus (P) values were found to be very low (≤2.7 mg dm^{-3}). There were significant differences ($p < 0.05$) in the P contents only in the 20-30 cm deep layer, and the MAR and HR systems presented higher levels of this nutrient (Table 1).
The pH values were similar between the studied systems, except in the 0-5 cm layer (Table 2).
The ICLFS systems presented higher means for base sum (SB), effective cation exchange capacity (ECEC), potential cation exchange capacity (CEC) and base saturation (V%) compared to the control treatments, where the cultures were cultivated in monoculture (Table 2).
Higher total organic carbon (TOC) contents were observed in the ICLFS systems compared to the monoculture system (Table 3).

Soil microbial analysis

The levels of microbial carbon (SMB-C) in the rainy season were higher than those found in the dry season for all areas and depths evaluated (Table 4).
The average values in the superficial layer and in the subsequent layer (5-10 cm) in the intercropped systems presented higher SMB-C contents compared to monocultures, with MAR exception (5-10 cm), which presented similar average to the intercropped systems (Table 4).
The microbial quotient (qMIC) ranged from 0.40 (dry season) to 2.84% (rainy season). Statistical differences were observed between the studied systems for qMIC only in the rainy season, at all depths evaluated. In the HR + M system, a higher value was observed at a depth of 0-5 cm, while at a depth of 5-10 cm, the MAR, HR + M and PAST systems. The J + M and PAST systems presented higher means of qMIC at a depth of 10-20 cm (Table 4).
In general, Microbial respiration of the soil (SBR) remained constant in both periods for the systems and depths analyzed, except for the monoculture MAR, which presented higher respiration rate in the rainy season, and in PAST, which presented higher RBS in the dry period at depths 5-10 and 10-20 cm. In the dry period, the MAR treatment presented the lowest SBR value different from the other systems in all studied layers. In the rainy season, in the 5-10 cm layer, the PAST and ICLFS + H + M treatments presented lower RBS values compared to H + M, HG, MAR and ICLFS-M (Table 4). There was no significant interaction between the systems and the periods studied for the variable qCO2 at all depths. Comparing the evaluation times, soil qCO2 was higher in the rainy season. No statistical differences were observed between the evaluated systems for all studied layers (Table 4).

Discussion

ICLFS systems provided increase in SOM levels due to the association of more species cultivated in the same area, and the grass pastures developed a root system occupying a large volume of the soil. According to Tonucci et al. (2011) and Torres et al. (2014), the higher production of plant biomass obtained from the integration of different production components favors the increase of SOM contents. Baldotto et al. (2015), evaluated a Dystrophic Yellow Latosol and observed that forest systems integrated with pastures provided increases in SOM contents, corroborating the results obtained in the present study. Bonini et al. (2016) also found an increase in SOM content in dystrophic Red-Yellow Latosol under different crop-livestock-forest integration systems, when compared to monoculture.
The processes of nutrient extraction and exportation by the crops in the present study contributed to obtain very low and low levels of phosphorus, since fertilizer application was done only in the initial phase of the areas implantation. According to Bastos and Ferreira (2010) and Carvalho et al. (2015), the soils under cerrado vegetation are of low natural fertility and P is highlighted as one of the limiting nutrients for agricultural production in these areas.
These results are explained because the correction and fertilization were performed only in the crop implantation phase. According to Alvarez et al. (1999), most of the pH values classified the active soil acidity level as medium, ranging from 5.1 to 6.0.
SB values were classified as medium (from 1.81 to 3.60 $cmol_c$ dm^{-3}) and good (between 3.61 and 6.0 $cmol_c$ dm^{-3}) according to Alvarez et al. (1999).
According to Costa et al. (2015), the larger deposition of vegetal residues in the superficial soil layer in integrated systems, contributes to higher nutrient contents in the system when decomposed. It also promotes biological activity in the environment. In addition, the integration of species with distinct root morphologies optimizes the nutrient cycling process, reducing the losses of these elements in the system.
The higher value of TOC in the ICLFS can be attributed to the input of crop residues resulting from the integration system.
In the last layer evaluated, significant interaction was observed. For this depth, no differences were observed between the averages obtained in the dry period. In the humid period, monocultures MAR and JAVA presented the lowest levels of SMB-C.
This period was marked by intense rainfall and high temperatures, favorable conditions for the increase of soil microbial biomass. These results corroborate those found by Frazão et al. (2010) and Alves et al. (2011) for the Cerrado

Table 1. Soil organic matter (SOM) and phosphorus (P) contents under different management and use systems.

System [(2)]	Depth (cm)			
	0-5	5-10	10-20	20-30
	SOM (g kg^{-1})			
ICLFS-M	49.90a	48.46a	46.23a	35.41a
ICLFS-H	51.96a	46.40a	38.24a	29.95a
ICLFS-H+M	47.41a	46.09a	34.98a	27.63a
MAR	38.85b	35.93b	29.30a	23.08a
HR	38.80b	40.50a	36.20a	51.60a
H+M	36.33b	35.28b	31.70a	24.05a
PAST	39.35b	30.50b	40.00a	25.70a
	P(mgdm^{-3})			
ICLFS-M	2.60a	0.99a	0.81a	0.60b
ICLFS-H	2.10a	1.18a	0.75a	0.56b
ICLFS-H+M	1.53a	1.03a	0.82a	0,55b
MAR	1.73a	0.91a	0.87a	0.78a
HR	3.66a	0.98a	0.68a	0.67a
H+M	1.57a	0.76a	1.93a	0.59b
PAST	0.62a	0.47a	0.37a	0.43b

[1)] Averages followed by the same letter in the column do not differ from each other by the Scott-Knott test at the 5% probability level.
[(2)] Systems: ICLFS-M = Eucalyptus intercropped with corn and marandu grass; ICLFS-H = Eucalyptus intercropped with maize and java; ICLFS-H + M = Eucalyptus intercropped with maize, marandu grass and java; MAR = marandu grass monoculture; HR = perennial horse gram monoculture; H + M = marandu consortium with java; PAST = Pasture in degradation process. P is extracted by Mehlich-1 (0.05 mol L^{-1} HCl + 0.0125 mol L^{-1} H_2SO_4).

Table 2. pH, base sum (SB), effective cation exchange capacity (ECEC), potential cation exchange capacity (CEC) and base saturation (V%) values under different management and use systems [(1)].

ystem [(1)]	Depth (cm)			
	0-5	5-10	10-20	20-30
	pH (H_2O)			
CLFS-M	5.70b	5.84a	5.93a	5.91a
CLFS-H	5.38b	5.40a	5.51a	5.39a
CLFS-H+M	6.34a	6.26a	6.40a	6.35a
AR	5.05b	5.30a	5.35a	5.48a
R	5.28b	5.43a	5.45a	5.53a
+M	4.98b	5.05a	5.25a	5.50a
AST	5.55b	5.33a	5.23a	5.23a
	SB (cmol$_c$dm^{-3})			
CLFS-M	5.57a	5.78a	5.33a	3.92a
CLFS-H	4.43a	4.34a	3.84a	2.57a
CLFS-H+M	5.51a	5.63a	4.94a	3.66a
AR	2.86a	2.53b	2.05b	1.04b
R	3.43a	4.16a	1.81b	0.89b
+M	2.17a	1.56b	2.00b	1.86b
AST	4.35a	2.12b	1.71b	1.04b
	ECEC (cmol$_c$dm^{-3})			
CLFS-M	5.70a	5.88a	5.54a	4.15a
CLFS-H	4.60a	4.58a	4.10a	3.02b
CLFS-H+M	5.65a	5.89a	5.12a	3.99a
AR	3.35a	3.04b	2.55b	1.94b
R	3.62a	4.39a	2.78b	2.14b
+M	3.02a	2.46b	2.56b	2.54b
AST	4.53a	2.81b	2.54b	2.06b
	CEC (cmol$_c$dm^{-3})			
CLFS-M	7.71a	7.80a	7.29a	5.89a
CLFS-H	7.57a	7.55a	6.53a	5.39a
CLFS-H+M	7.66a	7.97a	7.08a	5.74a
AR	5.40b	4.96b	4.48b	3.36b
R	5.57b	6.56a	4.69b	3.73b
+M	4.73b	4.24b	4.27b	4.09b
AST	7.05a	4.94a	4.79b	3.98b
	V(%)			
CLFS-M	70.28a	72.03a	69.35a	62.83a
CLFS-H	58.37a	57.53a	57.81a	48.58a
CLFS-H+M	70.73a	68.44a	67.93a	63.57a
AR	52.44a	50.94b	44.96b	30.84b
R	60.51a	62.34a	38.20b	24.19b
+M	44.99a	36.21b	45.22b	39.56b
AST	59.60a	42.77b	35.54b	26.44b

[(1)] Averages followed by the same letter in the column do not differ from each other by the Scott-Knott test at the 5% probability level.
[(2)] Systems: ICLFS-M = Eucalyptus intercropped with corn and marandu grass; ICLFS-H = Eucalyptus intercropped with maize and java; ICLFS-H + M = Eucalyptus intercropped with maize, marandu grass and perennial horse gram; MAR = marandu grass monoculture; HR = perennial horse gram; H + M = marandu consortium with java; PAST = Pasture in degradation process.

Table 3. Total organic carbon (TOC) content under different management and use systems [(1)].

System [(2)]	Depth (cm)		
	0-5	5-10	10-20
	TOC (mg kg^{-1} de solo)		
ICLFS-M	2.82a	2.94a	2.68a
ICLFS-H	3.01a	2.69a	2.22b
ICLFS-H+M	2.75a	2.67a	2.03b
MAR	2.25b	2.08b	1.70c
HR	2.23b	2.32a	2.10b
H+M	2.11b	1.92b	1.84c
PAST	2.34b	1.77b	1.76c

(1) Averages followed by the same letter in the column do not differ from each other by the Scott-Knott test at the 5% probability level.
(2) Systems: ICLFS-M = Eucalyptus intercropped with corn and marandu grass; ICLFS-J = Eucalyptus intercropped with maize and java; ICLFS-H + M = Eucalyptus intercropped with maize, marandu grass and java; MAR = marandu grass monoculture; HR = perennial horse gram monoculture; H + M = marandu consortium with perennial horse gram; PAST = Pasture in degradation process. P extracted by Mehlich-1 (0.05 mol L^{-1} HCl + 0.0125 mol L-1 H_2SO_4)

Table 4. Carbon microbial biomass (SMB-C), microbial quotient (qMIC), soil basal respiration (RBS) and metabolic quotient (qCO2) under different periods, management systems and use [(1)].

System[(2)]	Depth (cm)								
	0–5			5–10			10–20		
	Dry	Rainy	Aver	Dry	Rainy	Ave	Dry	Rainy	Aver
	SMB-C (mg kg^{-1})								
ICLFS-M	216	438	327a	163	499	331a	107aB	409bA	258
ICLFS-H	244	478	361a	222	479	351a	124aB	405bA	265
ICLFS-H+M	199	489	344a	153	503	328a	102aB	396bA	249
MAR	200	418	309b	111	512	312a	113aB	324cA	219
HR	154	412	283b	96	454	275b	91aB	317cA	204
H+M	206	598	402a	95	522	309a	92aB	489aA	291
PAST	171	438	305b	79	424	252b	112aB	420bA	266
Average	199B	467A		131B	484A		106	394	
	qMIC (%)								
ICLFS-M	0.76aB	1.55bA	1.16	0.56aB	1.70bA	1.13	0.40aB	1.54bA	0.97
ICLFS-H	0.81aB	1.59bA	1.20	0.83aB	1.78bA	1.31	0.56aB	1.83bA	1.20
ICLFS-H+M	0.73aB	1.79bA	1.26	0.57aB	1.88bA	1.23	0.50aB	1.96bA	1.23
MAR	0.90aB	1.86bA	1.38	0.53aB	2.46aA	1.50	0.66aB	1.91bA	1.29
HR	0.71aB	1.89bA	1.30	0.42aB	1.97bA	1.20	0.44aB	1.53bA	0.99
H+M	0.98aB	2.84aA	1.91	0.50aB	2..73aA	1.62	0.50aB	2.71aA	1.61
PAST	0.73aB	1.88bA	1.31	0.45aB	2.41aA	1.43	0.64aB	2.41aA	1.53
Average	0.80	1.91		0.55	2.13		0.53	1.98	
	RBS (mg C-CO_2 kg^{-1} solo $hora^{-1}$)								
ICLFS-M	0.16aA	0.14aA	0.15	0.17aA	0.14aA	0.16	0.13aA	0.12aA	0.13
ICLFS-H	0.12bA	0.10aA	1.11	0.12bA	0.10bA	0.11	0.11aA	0.09aA	0.10
ICLFS-H+M	0.12bA	0.12aA	0.12	0.12bA	0.12bA	0.12	0.10aA	0.11aA	0.11
MAR	0.05cB	0.13aA	0.09	0.05cB	0.13aA	0.09	0.05bB	0.13aA	0.09
HR	0.15aA	0.12aA	0.14	0.17aA	0.15aA	0.16	0.15aA	0.14aA	0.15
H+M	0.13bA	0.11aA	0.12	0.15aA	0.15aA	0.15	0.14aA	0.09aB	0.12
PAST	0.16aA	0.13aA	0.15	0.15aA	0.07bB	0.11	0.15aA	0.09aB	0.12
Average	0.13	0.12		0.13	0.12		0.12	0.11	
	qCO_2 (mg C-CO_2 g^{-1} SMB-C h^{-1})								
ICLFS-M	0.77	0.32	0.55a	1.06	0.28	0.67a	1..25	0.29	0.77a
ICLFS-H	0.52	0.21	0.37a	0.53	0.20	0.37a	0.90	0.23	0.57a
ICLFS-H+M	0.62	0.25	0.44a	0.78	0.23	0.51a	1.06	0.29	0.68a
MAR	0.25	0.31	0.28a	0.50	0.26	0.38a	0.42	0.39	0.41a
HR	1.00	0.30	0.65a	1.75	0.35	1.05a	1.70	0.46	1.08a
H+M	0.64	0.19	0.42a	1.60	0.29	0.95a	1.63	0.19	0.91a
PAST	0.98	0.30	0.64a	2.03	0.18	1.11a	1.39	0.22	0.81a
Average	0.68A	0.27B		1.18A	0.26B		1.19A	0.30B	

(1) Averages followed by the same uppercase letter in the row (between periods) and lowercase in the column do not differ from each other by the Scott-Knott test at the 5% probability level. There was no significant interaction in comparisons made only between general averages. (2) Systems: ICLFS-M = Eucalyptus intercropped with corn and marandu grass; ICLFS-H= Eucalyptus intercropped with maize and java; ICLFS-H + M = Eucalyptus intercropped with maize, marandu grass and perennial horse gram; MAR = marandu grass monoculture; HR = perennial horse gram monoculture; J + M = marandu consortium with java; PAST = Pasture in degradation process.

region. Araújo Neto et al. (2014) observed higher levels of SMB-C in soil with higher plant diversity, as it promotes greater regularity in substrate input. Azar et al. (2013) reported that increasing the diversity of plant species in integrated systems can modify the microclimate and favor the increase of soil microbial biomass. Chaudhary et al. (2018) also observed higher SMB-C values in integrated systems compared to monocultures and conventional plantings, and according to the authors, the presence of residues on the soil surface in conservation systems favors the development of soil microorganisms. The lowest qMIC values were found in the dry period demonstrating that a small amount of C was immobilized in microbial tissues. Mercante et al. (2008) found qMIC values below 1% and attributed this result to the presence of low nutritional quality organic matter, leading the microbial biomass to stress conditions and not total utilization of organic soil C.

The highest qMIC values observed in the HR + M 0-5 cm, MAR, J + M and PAST at 5-10 cm and HR + M and PAST at 10-20 cm treatments indicate higher nutrient cycling and also higher availability of organic C for soil microorganisms

(Padilha et al., 2014). The 2.41% qMIC value observed in PAST at depth 10-20 cm in the rainy season, demonstrates that pasture still has the ability to incorporate C into microbial tissues, possibly due to the input of feces and urine into this system over time.

Diniz et al. (2014) reported that in lower SBR values in the dry and cold period the microbial biomass can act as a nutrient reserve compartment, thus avoiding losses and promoting better substrate utilization.

The higher respiration rates found in the other systems may be related to a greater biological activity, resulting from the increase of local diversity (Azar et al., 2013; Santos et al., 2015), with the presence of java legume and weeds in some of the analyzed systems contributed to the observed results.

Low qCO2 values indicate that microbial biomass was more efficient in the use of organic compounds, releasing less carbon as CO_2 and incorporating more carbon into microbial tissues (Anderson and Domsch, 1993). These results corroborate those found by Alves et al. (2011), indicating that there is an inverse relationship between SMB-C and qCO2. According to Ribeiro (2014), higher qCO2 values indicate little incorporation of microbial carbon.

Materials and Methods

Locality

The experiment was conducted at the Experimental Farm of the Universidade Federal dos Vales do Jequitinhonha e Mucuri (UFVJM), in Curvelo (MG) (18 ° 44'52,03 "S 44 ° 26'53,56" O). The altitude of the area is approximately 644 m, with flat topography and Cerrado vegetation.

According to the Köppen classification, the region's climate is Aw, with concentrated rainfall in the summer (October to April). The average annual rainfall of the region of Curvelo in the last 15 years was 1064 mm, with an average temperature of 22ºC (INMET, 2016).

Soil analysis

The soil of the experimental area was classified as typical Oxisol (soil classification reference), with clay texture, being the contents of sand, silt and clay, respectively: 94.8, 249.2 and 656 g kg^{-1}. The chemical attributes of the soil had the following initial values: pH in water = 5.32; P Mehlich 1 = 0.47 mg dm^{-3}; K = 0.16 cmolc dm $^{-3}$; Ca = 1.54 $cmol_c$ dm^{-3}; Mg = 0.59 $cmol_c$ dm^{-3}; exchangeable acidity (Al) = 0.67 $cmol_c$ dm^{-3}; sum of bases (SB) = 2.30 $cmol_c$ dm^{-3}; potential acidity (H + Al) = 2.88 $cmol_c$ dm^{-3}; effective cation exchange capacity (ECEC) = 2.97 $cmol_c$ dm^{-3}; potential cation exchange capacity (CEC) = 5.18 $cmol_c$ dm^{-3}; aluminum saturation (m) = 27.95%; base saturation (BS) = 41.08%; and organic carbon (OC) = 19.62 g kg^{-1}.

Experimental design and crop-livestock-forest system

The experiment started in December 2014 and was conducted for a year in an area previously occupied by low yielding and degrading *Urochloa decumbens* pasture. Seven treatments and four replications were evaluated in a completely randomized design: Crop-Livestock-Forest integration systems, cultivated with eucalyptus intercropped with Marandu grass (*Urochloa brizantha*) (ICLFS-M) and perennial horse gram legume (*Macrotyloma axillare*) (ICLFS-HG) and with marandu and perennial horse gram (ICLFS-J + M); monocultures of marandu grass (MAR) and perennial horse gram (JAVA/HG); marandu consortium with java (H + M); and pasture in degradation process (PAST), used as a reference of the original soil condition before the systems implementation and with a history of use for 20 years for dairy and beef cattle.

Experiment setup and fertilization

The experimental units of the systems comprised of 12 m wide by 36 m long, and, when in the presence of eucalyptus, consisting of simple rows of tree species spaced 12 m apart. Soil acidity correction was performed with limestone application 90 days before the implantation of the experimental units. Then, the conventional tillage was done with plowing and harrowing.

Eucalyptus was planted using the clone Urograndis 144 (*Eucalyptus grandis* x *E. urophylla* hybrid). In the planting fertilization of the tree species, 0.2 kg of reactive phosphate and 0.125 kg of NPK (8-28-16) were used per pit, whose size was 40x40x40 cm. The transplantation took place along with the sowing of maize (SHS 7920 hybrid) and the studied forages (*Urochloa brizantha* cv. Marandu) (marandu) and *Macrotyloma axillare* (perennial horse gram)). In the eucalyptus planting, the 12x3 m spacing was adopted, and the eucalyptus cover fertilization was performed after 60 days of transplanting. For this purpose, 0.125 kg of potassium chloride, 0.05 kg of ammonium sulfate, 0.010 kg of borax and 0.005 kg of zinc sulfate per plant were used.

The forages, implanted in ICLFS system, were intercropped with corn in the first year of cultivation. The planting of this crop was carried out between the rows of eucalyptus, distributing seven seeds per linear meter, with row spacing of 0.8 m. The forage seeds were mixed with planting fertilization and sowed in consortium with corn, using 4 kg ha^{-1} of viable pure seeds and 0.4 m row spacing. For the marandu and java forage consortium, the amount of viable pure seeds of each species corresponded to 2 kg ha^{-1}, totaling 4 kg ha^{-1}. In the planting fertilization of these crops 400 kg ha $^{-1}$ of NPK (8-28-16) was used. Top dressing was performed 30 days after sowing, 100 kg ha^{-1} of N were supplied, whose sources corresponded to 50% urea and 50% ammonium sulfate.

Soil samples

Soil samples were collected in mini-trenches (4 replicates per treatment) allocated in the center of the experimental units, so that in the ICLFS systems allocated between eucalyptus planting lines. Soil collections for chemical analysis were performed in January 2016, at depths of 0-5, 5-10, 10-20 and 20-30 cm depth.

For microbiological analyzes, the samples were collected in winter (July 2015) and summer (January 2016), in the 0-5, 5-10 and 10-20 cm layers.

Chemical analysis of the soil

For chemical analysis of the soil, the samples were air dried and then passed through a 2 mm sieve to remove plant and animal residues. The chemical attributes of soil organic matter (SOM), pH (active acidity), P, K, Ca, Mg, Al (exchangeable acidity) and soil H + Al (potential acidity) were obtained following Embrapa's methodology (1997). From these analyzes, we calculated the saturation of bases (SB), the effective cation exchange capacity (ECEC), the potential cation exchange capacity (CEC) and the soil base saturation (SBS).

Soil microbial analysis

Microbial respiration of the soil (SBR) was estimated by the amount of CO_2 evolved, which was captured in flasks containing 100 mL of NaOH (0.25 mol L^{-1}), in a continuous air flow system (free of CO_2 and moisture, by prefiltration, and passage of air in columns containing NaOH Indirect titration of sodium hydroxide with HCl (0.25 mol L^{-1}); Excess unreacted NaOH with evolved CO_2 was quantified.
Additionally, in the samples for microbiological evaluation, the samples were corrected to 60% of field capacity and pre-incubated for a period of seven days for subsequent determination of microbial carbon (SMB-C).
Extraction of soil microbial biomass was performed by the Fumigation-Extraction method (Reis Junior and Mendes, 2007; Silva et al., 2007) and the determination of SMB-C by wet oxidation (Walkley and Black, 1934). Soil microbial respiration determined by evolved CO2 and NaOH sodium hydroxide extraction (Jenkinson and Powlson, 1976). Total organic carbon (TOC) was determined according to Embrapa's methodology (1997). Subsequently, we calculated the metabolic quotient (qCO2), which is the ratio between SBR and SMB-C, and the microbial quotient (qMIC), obtained by the ratio between SMB-C and COT (Anderson and Domsch, 1993). Reis Junior and Mendes, 2007).

Statistical analysis

Data were submitted to analysis of variance (ANOVA) and for the microbiological attributes, time subdivided plots were used (two evaluation periods). Means were compared by Scott-Knott test ($p < 0.05$). To perform the analyzes, the program Program R, version 3.3.0 was used. (R Development Core Team, 2016).

Conclusion

Crop-Livestock-Forest integration systems promoted improvement in soil quality, expressed by the indicators soil organic matter, base sum, CTC and base saturation. The crop-livestock-forest integration promotes SMB-C increase in the first year of cultivation.

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