Dynamics of soil microbiological attributes under integrated production systems, continuous pasture, and native cerrado

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Abstract – The objective of this work was to evaluate the dynamics of soil microbiological attributes under integrated production systems, continuous pasture, and native cerrado. The study was conducted in a transition area from crop to livestock. Four areas with different land uses were evaluated: an integrated crop-livestock-forestry system (ICLFS), cultivated with *Eucalyptus urograndis* alley cropping, spaced 2x2 m between plants and 22 m between alleys; an integrated crop-livestock system (ICLS); besides two adjacent areas of native cerrado and continuous pasture, used as a reference. For the assessment of microbiological attributes, soil samples were taken in the 0.00–0.10, 0.10–0.20, and 0.20–0.30-m layers, in February 2012 and February 2014 (rainy season), and in July 2012 and September 2013 (dry season). In general, soil under native cerrado had the highest microbial biomass carbon (MBC) levels, while under the ICLFS it had the lowest ones. The ICLS increased MBC and microbial coefficient in the deeper soil layers, after two years of establishment. Basal respiration, microbial biomass nitrogen, and MBC are the soil microbiological attributes better able to differentiate the evaluated systems.

Index terms: integrated crop-livestock-forestry system, soil management, soil microbial biomass, soil quality.

Dinâmica de atributos microbiológicos do solo em sistemas integrados de produção, pastagem contínua e cerrado nativo

Resumo – O objetivo deste trabalho foi avaliar a dinâmica de atributos microbiológicos do solo em sistemas integrados de produção, em pastagem contínua e em cerrado nativo. O estudo foi conduzido em área de transição de lavoura para pecuária. Quatro áreas com diferentes usos da terra foram avaliadas: sistema de integração lavoura-pecuária-floresta (ILPF), cultivado com renques de *Eucalyptus urograndis*, com espaçamento de 2x2 m entre plantas e 22 m entre renques; sistema de integração lavoura-pecuária (ILP); além de duas áreas adjacentes de cerrado nativo e pastagem contínua, usadas como referência. Para a avaliação dos atributos microbiológicos, amostras de solos foram retiradas das camadas de 0,00–0,10, 0,10–0,20 e 0,20–0,30 m, em fevereiro de 2012 e fevereiro de 2014 (estação chuvosa), e em julho de 2012 e setembro de 2013 (estação seca). No geral, o solo sob cerrado apresentou os maiores níveis de carbono da biomassa microbiana (CBM), enquanto sob ILPF apresentou os menores. A ILP aumentou o CBM e o coeficiente microbiano nas camadas mais profundas, após dois anos de estabelecimento. A respiração basal, o nitrogênio da biomassa microbiana e o CBM são os atributos microbiológicos mais adequados para diferenciar os sistemas avaliados.

Termos para indexação: sistema de integração lavoura-pecuária-floresta, manejo do solo, biomassa microbiana do solo, qualidade do solo.

Introduction

The integrated crop-livestock-forestry system (ICLFS) is an innovative strategy for the intensification of sustainable crop production systems, which integrates livestock, agricultural, and forestry practices simultaneously or disjointedly in rotation, succession, or consortium (Moraes et al., 2014). The presence of trees between cropping alleys may result in some limitations to the development of either row crops or pasture grasses, including competition for water, nutrients, and light, as well as less litter production for

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soil cover (Oliveira et al., 2007; Paciullo et al., 2011). As for the integrated crop-livestock system (ICLS), ICLFS has been adopted and arranged in various ways in Brazil and, in general, it is beneficial in terms of soil resilience, fertility, and biology, mostly due to increased soil organic matter and soil fertility. It also has an important role in reducing pasture degradation and the emissions of greenhouse gases, besides increasing livestock performance (Salton et al., 2014).

Total organic carbon (TOC), microbial biomass, and basal respiration of the soils represent some of the most important attributes for soil quality analysis (Hungria et al., 2009). Soil microbial biomass (SMB) is a dynamic labile fraction of soil organic matter that is very sensitive to changes in soil management (Jackson et al., 2003). Highly productive Brazilian Oxisols often have high levels of microbial biomass, associated with higher levels of soil organic matter, resulting in higher soil quality (Lopes et al., 2013).

Muniz et al. (2011) reported that the recovery of degraded pastures by implementing ICLS on Oxisols increased microbial biomass carbon (MBC), even when compared with native cerrado (Brazilian savanna vegetation). Similarly, Frazão et al. (2010) showed that MBC and microbial biomass nitrogen (MBN) values may be higher or equivalent to those of native cerrado, in a Typic Quartzipsamment both under cultivated pasture [*Urochloa decumbens* (Stapf) R.D.Webster] and ICLS. Moreover, the practice of annual crops and pasture grasses in the same area (ICLS) can promote root development and soil organic carbon, providing favorable conditions for SMB (Loss et al., 2012). In this context, the ICLFS may further increase soil organic carbon and microbial biomass, improving soil quality. However, due to the interactions of animal husbandry with annual crops and forest species, this system is dynamic and complex, requiring more study.

The objective of this work was to evaluate the dynamics of soil microbiological attributes under integrated production systems, continuous pasture, and native cerrado.

Materials and Methods

The study was carried out at Embrapa Cerrados, in Planaltina, Brasília, DF (15°36'S, 47°42'W, at 980 m of altitude). The climate of the region is Aw according to Köppen, with 1,500 mm of annual rainfall concentrated between October and April. The average minimum and maximum temperatures are 16.7 and 28.3°C, respectively. Figure 1 shows the mean daily temperature and accumulated rainfall in the experimental areas from February 2012 to April 2014.

Treatments consisted of four areas with different land uses: ICLS, agriculture area, cultivated at full sunlight without tree species, and integrated with animal husbandry in the off-season; ICLFS, integrated system consisting of ICLS + the hybrid *Eucalyptus urograndis* (*Eucalyptus urophylla* x *Eucalyptus grandis*) in alley cropping, with 2x2 m between plants and 22 m between alleys; and two adjacent areas of native cerrado and continuous pasture, used as a reference.

The areas of the ICLS and ICLFS consisted of experimental plots with 1.4 ha, in a randomized complete block design with three replicates. The experiment was implemented in January 2009. The soil in all experimental sites was classified as a clayey Latossolo Vermelho distrófico (Oxisol), according to the Brazilian system of soil classification (Santos et al., 2006). Chemical characteristics of the soil prior to the experiment setup are shown in Table 1. The cropping history of the ICLS and ICLFS, from 2009 to 2014, is presented in Table 2. Fertilizers and lime applications were performed based on soil chemical analysis.

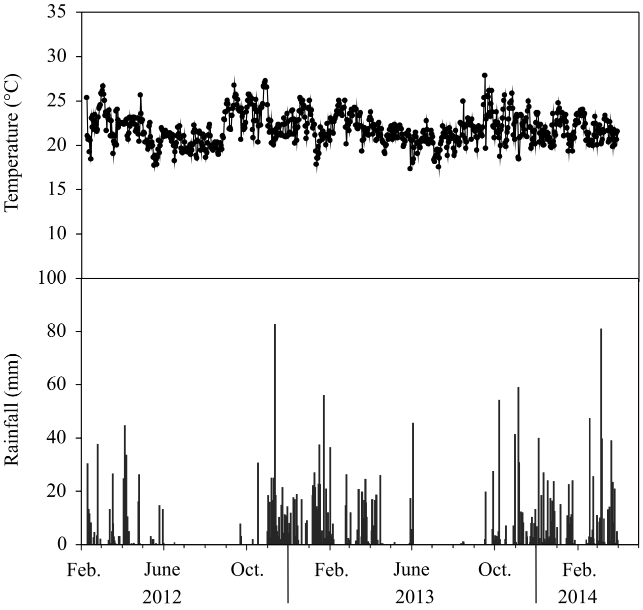

Figure 1. Daily average temperatures and cumulative rainfall values in the experimental field, from February 2012 to February 2014.

Previously to the experimentation, the areas under ICLS and ICLFS were planted with: *Urochloa brizantha* (A.Rich.) R.D.Webster 'Marandu'; *U. brizantha* intercropped with *Stylosanthes guianensis* (Aubl.) Sw.; and *U. brizantha* intercropped with *Leucaena leucocephala* (Lam.) de Wit.

In March 2012, after soybean [*Glycine max* (L.) Merr.] harvest, seeds of *U. brizantha* 'BRS Piatã' were broadcasted (8 kg ha^{-1} viable seeds) immediately before sowing sorghum [*Sorghum bicolor* (L.) Moench] 'BRS 330'. After harvesting sorghum, in July 2012, the pasture of *U. brizantha* was used for cattle husbandry at the beginning of the rainy season, in January 2013, and kept with animals until the end of March 2014, when soil samples were last taken. The pastures of the ICLS and ICLFS were grazed according to forage availability (7–10 kg of forage per 100 kg of animal weight), and the mean carrying capacity of the pasture (AU per hectare) was 2.5 in April 2013 and 1.44 in April 2014.

The native cerrado was characterized by a dense formation of trees up to 4 m tall ("Cerradão" type). In the continuous pasture area, *U. brizantha* 'Piatã' was broadcasted (6 kg ha^{-1} viable seeds) immediately before corn (*Zea mays* L.) sowing, in November 2007. Corn was fertilized at planting with 385 kg ha^{-1} 8-24-12 N-P_2O_5-K_2O and wit 130 kg ha^{-1} urea as side-dressing. After corn harvest, the area was kept with *U. brizantha* – it did not receive any fertilizer or amendments – and was grazed according to forage availability (7–10 kg of forage per 100 kg of animal weight), with mean carrying capacity of 2.06 AU ha^{-1}.

Soil samples were collected at the dry (July 2012 and September 2013) and rainy seasons (February 2012 and February 2014), with soil auger, in three soil layers (0.00–0.10, 0.10–0.20, and 0.20–0.30 m), in the following periods: February 25, 2012, at the end of the soybean cycle, with senescent plants; July 17, 2012, at the end of the sorghum cycle; September 17, 2013, and February 19, 2014, during the continuous pasture with animals in the area. For each layer, period, and replicate (three), three subsamples were collected following an imaginary diagonal line in the plot, to form a composite sample. In areas under the ICLFS, one subsample was taken in the middle distance between tree rows, and the other two were taken next to the trees.

Soil samples were placed inside Styrofoam containers with ice until they reached the laboratory of soil microbiology and biochemistry of Universidade de Brasília. In the laboratory, soil samples were stored under refrigeration, at ±4°C, until analysis. MBN and MBC were determined by the fumigation-extraction method, using the KEN and KEC conversion factors of 0.54 and 0.38, respectively (Brookes et al., 1985; Vance et al., 1987). The basal respiration was estimated by measuring CO_2 released from pre-incubated soil

Table 1. Soil chemical analysis in the 0.00–0.20 and 0.20–0.40-m soil layers, before the establishment of the experiment$^{(1)}$.

Layer (m)	pH (H_2O)	P	K	Al	Ca	Mg	H+Al	CEC	V	OM
		-------- (mg L^{-1}) --------		--------------------- (cmol$_c$ dm^{-3}) ---------------------					---------- (%) ----------	
0.00–0.20	5.55	0.48	67.24	0.14	1.45	0.86	4.41	6.9	35.7	2.86
0.20–0.40	5.47	0.64	33.44	0.23	0.96	0.57	4.19	5.81	27.37	2.32

$^{(1)}$CEC, cation exchange capacity; V, base saturation; and OM, organic matter.

Table 2. Management events in the experimental site from 2009 to 2014.

Plant species	Planting date	Fertilization	N-P_2O_5-K_2O
Eucalyptus urograndis under ICLFS$^{(1)}$	January 2009	150 g per plant	0-20-20
Sorghum bicolor 'BRS 310'	March 2009	350 kg ha^{-1}	8-20-15 + micronutrients
Glycine max 'Baliza RR'	December 2009	400 kg ha^{-1}	0-20-20
Glycine max 'BRS 850'	November 2010	400 kg ha^{-1}	0-20-20
Glycine max 'Favorita'	October 2011	1,500 kg ha^{-1} + 400 kg ha^{-1}	Limestone + 0-20-20
Sorghum bicolor + *Urochloa brizantha*	March 2012	1,500 kg ha^{-1}	08-20-15
Urochloa brizantha	March 2013	200 kg ha^{-1}	45-00-00 (urea)
Urochloa brizantha	February 2014	130 kg ha^{-1}	45-00-00 (urea)

$^{(1)}$ICLFS, integrated crop-livestock-forestry system.

samples, for a period of seven days (Alef & Nannipieri, 1995). TOC and total nitrogen were analyzed according to Claessen (1997). The microbial quotient (qMic) was calculated by dividing MBC by TOC and it was expressed in percentage.

The analysis of variance considered a completely randomized design. To minimize problems from pseudoreplicates in the reference areas, the analysis was done with soil depth nested within treatments (nested design). Means were compared with Tukey's test, at 5% probability. This step was done using the generalized linear mixed model (proc GLIMMIX) of the SAS software, version 9.1.2 (SAS Institute Inc., Cary, NC, USA).

Principal component analysis (PCA) – matrix composed of 36 lines (three treatments, two sampling periods, and six replicates) and of 5 columns (soil attributes) – was used to identify which variable contributed with greater weight to the linear combination of the first two principal components. In order to ease the interpretation, a permutation test (discriminant analysis), based on the Mahalanobis distance or dissimilarity, was applied to compare mathematical distances between samples from treatments and from sampling periods (wet or dry season), in addition to the correlation circle between the eigenvectors of the variables. This analysis uses a permutation test, which calculates the total inertia interclass for each random distribution of individuals and, by association with a statistical probability, it maximizes the discriminating power of the analysis. In this step, only the 0.00–0.10-m depth was considered in the treatments with the same number of observations – i.e., in the ICLS, ICLFS, and native cerrado –, and the analysis was performed using the ADE4 package of the R software (R Core Team, 2013).

Results and Discussions

Values of MBC and MBN ranged from 114.07 to 546.46 mg kg^{-1} and from 14.08 to 50.72 mg kg^{-1}, respectively. In the upper layer, MBC was always the highest for native cerrado, for all sampling periods, but decreased consistently with increasing depths. A reduction of 25 to 57% was observed in MBC with cultivation. On the cerrado, the high diversity of plants, in native areas, and the balanced environment due to the absence of soil perturbation increase soil microbial biomass compared with other management systems and land uses (Stieven et al., 2014). Soil microbiota is stimulated by the continuous supply of plant residues with different chemical compositions and different degrees of susceptibility to decay, which favor the survival and growth of different groups of organisms (Ferreira et al., 2011).

The ICLS had higher MBC in the 0.00–0.10-m layer than the ICLFS, except in the dry season, in July 2012, when both integrated systems were similar. In the 0.10–0.20 and 0.20–0.30-m soil layers, during the rainy season of February 2014, the levels of MBC were also higher in the ICLS, when compared with the ICLFS and native cerrado. This could be a consequence of the increased root development of *Urochloa* sp., which can reach 4 Mg ha^{-1} down to 0.40-m depth (Saraiva et al., 2014). Plant residues from eucalyptus release toxic compounds that can inhibit the growth of microbial biomass and its adaptation to the plant rhizosphere (Behera & Sahani, 2003; Araújo et al., 2010). This, allied to the fact that tree shadows can affect understory growth (Oliveira et al., 2007), can justify the lower values of MBC in the ICLFS. The area under the ICLS received more sunlight and did not suffer any other type of interference to pasture biomass production, leading to higher MBC (Oliveira et al., 2007).

In February 2012, in the rainy season, in the 0.00–0.10-m layer, the ICLFS showed the lowest level of MBC, when compared with the other systems. This result might be attributed to less vegetation cover during the previous season, which lead to lower levels of labile organic matter input to the soil surface (Singh & Ghoshal, 2014). At the beginning of the rainy season, however, the dormant microbial biomass and *U. brizantha* may have had improved their conditions for growth, with strong competition for nutrients (Lourente et al., 2011; Singh & Ghoshal, 2014). Complementarily, during the dry season, the unfavorable conditions of soil moisture at 0.10–0.20 and 0.20–0.30 m lead to minimum competition between microbes and plants, in the continuous pasture. This might be the reason for the higher accumulation of MBC in the continuous pasture, in comparison with the other systems. Furthermore, the microbial biomass in the continuous pasture was less dynamic and more dormant, showing the lowest basal respiration levels (Table 4) (Singh & Ghoshal, 2014).

According to Lopes et al. (2013), the MBC values in the 0.00–0.10-m layer obtained in the present study were adequate for soils under cerrado (>405 mg kg^{-1}), but moderate for those under the ICLS, ICLFS, and continuous pasture (206–405 mg kg^{-1}). It must be highlighted that in the ICLS and deeper soil layers (0.10–0.20 and 0.20–0.30 m), MBC values were considered adequate, according to the same classification, indicating that the ICLS improved soil quality, at least up to 0.20–0.30 m.

MBN in the cerrado system varied from 27.08 to 48.68 mg kg^{-1} (Table 3). Native cerrado had higher values of this variable only in the dry season, in July 2012, at the depths of 0.10–0.20 and 0.20–0.30 m. Differently from MBC, in general, MBN did not decrease with depth. Soil microorganisms only seem to take up N from the soil organic pool (amino acids and peptides, for example) when their C supply is limited (Farrell et al., 2014). Therefore, this may explain the low levels of MBN in the cerrado.

In the rainy season, i.e., in February 2012 and February 2014, MBN values in the ICLS and ICLFS were significantly higher than those in native cerrado. N fertilizer in both integrated systems may have increased these values (Coser et al., 2007). MBN values decreased in depth in the ICLS in July 2012, and in the ICLFS and continuous pasture in February 2014. These results are in alignment with those of Coser et al. (2007), who reported that lower values with increasing depths might be associated with higher amounts of organic N in surface layers, as well as with the quantity and quality of plant residues, temperature, pH, moisture, and aeration.

Five years after the implementation of the ICLS under no-tillage, in February 2014, the MBN values did not change in depth, while MBC increased, revealing a different behavior of these attributes. For most of the sampled periods, native cerrado showed higher basal respiration than the ICLS, ICLFS, and continuous pasture (Table 4). The constant deposition of plant residues, with high levels of labile organic matter, increases microbial biomass and activity, releasing more CO_2 (Lourente et al., 2011). Higher microbial activity, reflected by greater basal respiration, intensifies the mineralization and immobilization of nutrients, increasing the amount of N in the soil microbiota structure (Jarvis et al., 2007).

Table 3. Microbial biomass carbon (MBC) and nitrogen (MBN) in the native cerrado, continuous pasture (CP), integrated crop-livestock (ICLS), and integrated crop-livestock-forestry (ICLFS) systems, in four sampling periods⁽¹⁾.

System	Microbial biomass carbon (mg kg^{-1})			Microbial biomass nitrogen (mg kg^{-1})		
	0.00–0.10 m	0.10–0.20 m	0.20–0.30 m	0.00–0.10 m	0.10–0.20 m	0.20–0.30 m
			February 2012			
Cerrado	546.46aA	384.74aB	224.38aC		28.59b	
CP	-	-	-		-	
ICLS	359.50bA	201.14bB	124.04aB		35.57a	
ICLFS	234.34cA	162.34bA	185.05aA		33.75a	
			July 2012			
Cerrado	552.96aA	216.16aB	180.55aC	32.34aB	48.68aA	47.50aA
CP	-	-	-	-	-	-
ICLS	287.78bA	190.84bB	126.94bC	33.75aA	25.55cB	14.08cC
ICLFS	276.15bA	156.07cB	114.07bC	33.43aA	34.54bA	30.52bA
			September 2013			
Cerrado	512.63aA	145.19bC	247.57aB	30.25aA	27.08aA	22.18bA
CP	297.42bA	235.03aB	249.81aB	25.00bA	30.42aA	25.53bA
ICLS	284.10bA	145.84bB	126.62bB	27.82aB	25.93baA	37.94aA
ICLFS	238.36cA	162.44bB	119.73bC	33.41aA	23.55aB	29.27bAB
			February 2014			
Cerrado	453.45aA	295.05bB	187.10bcC	27.57cA	31.07cA	30.86cA
CP	222.29dA	207.50cAB	193.63bB	49.04aA	30.25cB	20.18dC
ICLS	339.81bC	411.26aB	432.03aA	43.45bA	40.05bA	44.43aA
ICLFS	298.16cA	175.85dB	156.66cB	50.72aA	46.54aB	31.24bcC

⁽¹⁾Means followed by equal letters, uppercase in the rows and lowercase in the columns, do not differ by Tukey-Kramer's test, at 5% probability.

Comparing sampling periods, basal respiration was lower under the ICLS and ICLFS, in February 2012, with values below 10 mg kg^{-1} per day. This result may be due to the fact that the first soil sample was taken at the end of the soybean cycle, when the plants were in an advanced stage of decomposition. During this period, the accelerated death of roots reduces their activity and the availability of exudates for soil biota (Helal & Sauerbeck, 1986).

Basal respiration values in the ICLS and ICLFS differed significantly in February 2012, in the 0.00–0.10 and 0.10–0.20-m soil layers, and in September 2013 in the 0.10–0.20-m layer. The higher values in the ICLS can be attributed to the shading (Pinto Neto et al., 2014) promoted by eucalyptus in the other integrated system.

TOC varied significantly between systems only in February 2012, and native cerrado showed higher values, followed by the ICLS and ICLFS (Figure 2). After *U. brizantha* establishment, integrated systems had similar TOC values in the other three sampling periods. Perennial grasses have abundant root systems and high rhizodeposition, with uniform distribution of exudates in time, which favors the maintenance of the soil organic carbon levels (Leite et al., 2013).

Regarding total N, no significant differences were observed between the integrated systems and continuous pasture or native cerrado (Table 5). D'Andréa et al. (2004) concluded that the use of continuous pasture or conventional tillage for long periods does not change significantly soil N levels.

Microbial quotient ranged from 0.50 to 1.76 (Table 4) and it was generally higher in native cerrado and the ICLS. Values below 1% can be attributed to a limiting factor for microbial activity (Araújo Neto et al., 2014). Microbial quotient is an index of the accumulation of MBC relative to TOC, and higher values indicate better efficiency in the conversion of soil organic carbon into MBC (Xavier et al., 2006). Limiting factors to microbial activity may result in a lower use of C by microorganisms. In soils with low nutrient availability, or with poor substrate quality, or even with another limiting factor, the stressed microbial biomass is unable to fully utilize TOC (Leite et al., 2013). This variable is also related to soil carbon losses and to the stabilization of organic

Table 4. Soil basal respiration (BR) and microbial quotient (qMic) in the native cerrado, continuous pasture (CP), integrated crop-livestock (ICLS), and integrated crop-livestock-forestry (ICLFS) systems, in four sampling periods(1).

System	Soil basal respiration (mg kg^{-1} per day)			Microbial quotient (%)		
	0.00–0.10 m	0.10–0.20 m	0.20–0.30 m	0.00–0.10 m	0.10–0.20 m	0.20–0.30 m
			February 2012			
Cerrado	25.14aA	18.3aB	11.45aC		1.38a*	
Continuous pasture	-	-	-		-	
ICLS	15.29bA	4.02cB	5.38bB		1.04a	
ICLFS	10.73cA	9.47bB	4.28bC		0.78b	
			July 2012			
Cerrado	23.78^{ns}	17.86^{ns}	15.90^{ns}	1.98aA	0.90aB	0.69aB
Continuous pasture	-	-	-	-	-	-
ICLS	34.28^{ns}	18.21^{ns}	13.42^{ns}	1.09bA	0.88aB	0.53aB
ICLFS	26.06^{ns}	16.02^{ns}	13.30^{ns}	1.10bA	0.58aB	0.53aB
			September 2013			
Cerrado	43.13aA	31.00aB	23.73aC	1.76aA	0.54bC	1.00aB
Continuous pasture	33.57bA	15.92bB	11.41bB	1.07bA	0.99aA	1.04aA
ICLS	31.26bA	27.37aAB	25.57aB	1.02bA	0.61bB	0.50bB
ICLFS	26.69bA	18.69bB	21.71aB	0.90bA	0.73bAB	0.56bB
			February 2014			
Cerrado	24.10a			1.64aA	1.05bB	0.66bC
Continuous pasture	15.15b			0.89bA	0.97bA	0.91bA
ICLS	14.44b			1.14bB	1.69aA	1.65aA
ICLFS	12.62b			1.02bA	0.70bA	0.77bA

(1)Means followed by equal letters, uppercase in the rows and lowercase in the columns, do not differ by Tukey-Kramer's test, at 5% probability.

C into soil mineral fractions (Poôrto et al., 2009). Superficial layers showed higher qMic, as did the integrated systems and the native cerrado in the first three sampling periods. Soil samples collected from the ICLS in February 2014 showed increased qMic in deeper layers, which confirms the data for MBC (Table 3).

The first two principal components explained 56% of the total variance in the microbiological attributes: PC1, 33.65%; and PC2, 22.35% (Figure 3). PC1 distinguished land uses with MBC, basal respiration, and MBN gradients in depth, whereas PC2 was related to organic carbon and total nitrogen gradients. Permutation tests of site coordinates, for all extracted axes, showed significant effects of land use ($p<0.001$) on soil microbiological attributes. Axis 1 separated native cerrado – with higher basal respiration and MBC values – from the integrated systems, which were related to MBN levels. Axis 2 distinguished integrated systems with a weak tendency to show high total nitrogen levels in the ICLS, compared with the ICLFS. This may be related to a higher N absorption capacity by trees, in the ICLFS. PCA analysis also showed a significant impact of the sampling period and, therefore, of climatic conditions ($p<0.001$), on the soil microbiological attributes. Moreover, PC1 contrasted the samplings collected in the rainy season to the ones collected in dry season. Samples from the rainy season were related to higher contents of MBN (PC1) and organic carbon (PC2).

The integrated production systems are complex and dynamic, which implies that further studies to evaluate their effects on soil microbiological attributes should be carried out for greater conclusiveness. However, the present study showed that microbiological indicators, especially MBC, are sensitive to cultivation systems and that the ICLS may favor MBC in deeper soil layers.

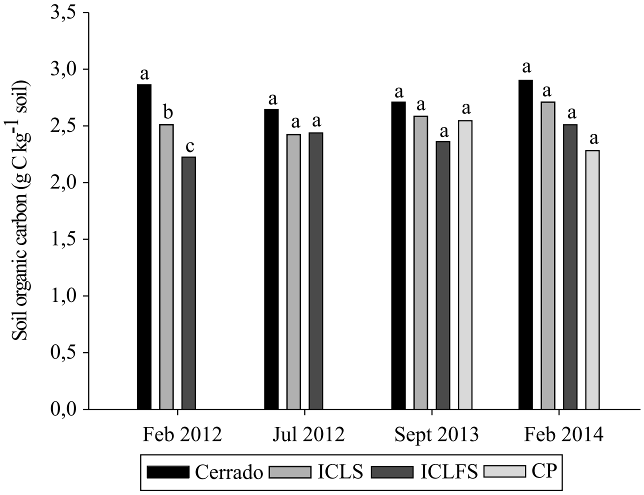

Figure 2. Soil organic carbon in the native cerrado, integrated crop-livestock (ICLS), integrated crop-livestock-forestry (ICLFS), and continuous pasture (CP) systems, along four sampling periods, considering all sampling soil depths: 0.00–0.10, 0.10–0.20, and 0.20–0.30 m. Means followed by equal letters, in each period, do not differ by Tukey-Kramer's test, at 5% probability.

Table 5. Soil total nitrogen in the native cerrado, continuous pasture (CP), integrated crop-livestock (ICLS), and integrated crop-livestock-forestry (ICLFS) systems, in four sampling periods(1).

System	Soil total N (g kg^{-1})		
	0.00–0.10 m	0.10–0.20 m	0.20–0.30 m
		February 2012	
Cerrado	1.64^{ns}	1.58^{ns}	1.61^{ns}
CP	-	-	-
ICLS	1.77^{ns}	1.56^{ns}	1.62^{ns}
ICLFS	1.44^{ns}	1.53^{ns}	1.53^{ns}
		July 2012	
Cerrado	-	1.70a*	-
CP	-	-	-
ICLS	-	1.54ab	-
ICLFS	-	1.50b	-
		September 2013	
Cerrado	1.45^{ns}	1.49^{ns}	1.61^{ns}
CP	1.47^{ns}	1.31^{ns}	1.48^{ns}
ICLS	1.47^{ns}	1.49^{ns}	1.40^{ns}
ICLFS	1.46^{ns}	1.43^{ns}	1.34^{ns}
		February 2014	
Cerrado	1.49aA	1.66aA	1.70aA
CP	1.47aA	1.15cB	1.15cB
ICLS	1.53aA	1.30bcA	1.26bcA
ICLFS	1.50aA	1.50abA	1.26bcB

(1)Means followed by equal letters, uppercase in the rows and lowercase in the columns, do not differ by Tukey-Kramer's test, at 5% probability.

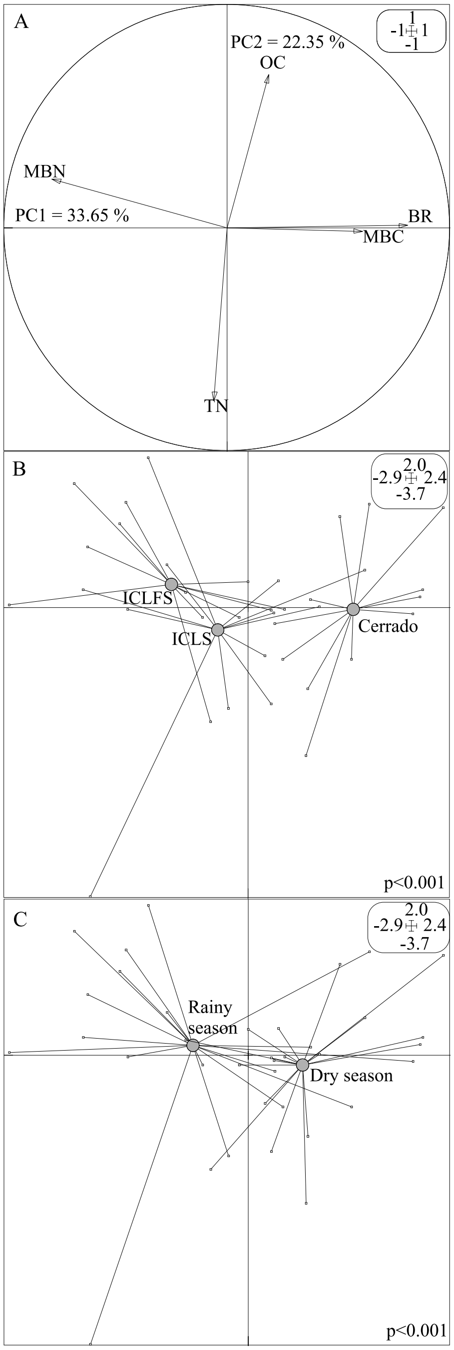

Figure 3. Principal component analysis of soil microbiological attributes in different land use systems. A, correlation circle of microbiological attributes with projections of principal components PC1 and PC2; B, ordination diagram in the PC1/PC2 plane, according to the land use systems; and C, sampling season. MBN, microbial biomass nitrogen; OC, organic carbon; BR, basal respiration; MBC, microbial biomass carbon; TN, total nitrogen; ICLFS, integrated crop-livestock-forestry system; ICLS, integrated crop-livestock system; and p, grouping probability by the permutation test.

Conclusions

1. Basal respiration and microbial biomasses of N and C are the soil microbiological attributes better able to differentiate the evaluated systems.

2. The integrated crop-livestock system favors the increase in microbial biomass carbon (MBC) and microbial quotient, in deeper soil layers, after two years of establishment.

3. In general, the native cerrado has the highest MBC levels, and the integrated crop-livestock-forestry system has the lowest ones.

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