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Biological Soil Properties in Integrated Crop-Livestock-Forest Systems

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ABSTRACT: Currently, agricultural productivity and sustainable development are the desired bases for the creation of production systems. Farming for greater production and the efficient use of soil resources are at the core of modern systems. However, the way in which agricultural management and practices can change soil quality has become increasingly important. The aim of this study was to detect changes in soil biological properties caused by implementation of the integrated crop-livestock-forest system (iCLF) and to identify the properties suitable for detecting changes in soil biological quality. Soil samples were collected from the 0.00-0.10 m layer in Nova Canaã do Norte, MT, Brazil, and Cachoeira Dourada, GO, Brazil, in areas of the iCLF with 1 (iCLF1) or 3 (iCLF3) eucalyptus rows and in areas of recovered and degraded pasture. In Cachoeira Dourada, in the iCLF1, samples were taken in the tree row and at 2.5, 5.0, and 10.0 m from this row. In Nova Canaã in the iCLF3, samples were taken in the center row and at 3.0, 6.0, 9.0, and 12.0 m from this row. In Cachoeira Dourada, samples were taken in the center row and at 1.5, 3.0, 4.5, 6.0, and 9.0 m from this row. All samples had five replicates. In Nova Canaã, the iCLF1 caused less disturbance in the microbial population than the degraded pasture, which was evidenced by the lower metabolic quotient and basal respiration. The sampling position in relation to the tree row had little effect on comparison of the iCLF with the degraded pasture in regard to soil biological properties. Carbon and N of the microbial biomass and the microbial quotient were the best properties for differentiating the iCLF from the degraded pasture. ICLFs have not yet led to improvements in soil biological quality in relation to the degraded pasture.

Keywords: soil biological quality, soil management, degraded pasture.

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INTRODUCTION

In the current Brazilian livestock-raising scenario, degradation of pasture areas, presently comprising about 70 million hectares in the midwestern and northern regions of Brazil, is one of the greatest problems (Embrapa, 2015). In general, pastures have some degree of degradation and the main causes are related to low soil fertility, grazing pressure, and, in some cases, physical impediments (Kluthcouski and Aidar, 2003). Agricultural soil degradation in pastures leads to an increase in the proportion of weeds, gradually decreasing pasture support capacity; however, degradation can also be biological, which considerably reduces the capacity of soils to sustain crop production. In this case, pasture will be replaced by plants with lower nutritional requirement, and even areas devoid of vegetation may arise (Dias-Filho, 2014).

Therefore, agricultural systems that maximize production of food, fiber, energy, and water and that are environmentally less aggressive and more sustainable have become important, even in social aspects. The integrated crop, livestock, and forest system (iCLF) has been an important means for achieving synergism between optimized production and land use and maximized environmental quality in agricultural systems. This system consists of spatial-temporal combination of agriculture, livestock, and forestry, through succession, rotation, or intercropping. Its many possibilities (Balbino et al., 2012) bring several benefits to the farmer and the environment, and it improves physical, chemical, and biological soil conditions. This system is built upon technical foundations that maximize yield and consider environmental and economic sustainability (Alvarenga et al., 2010).

Management of these systems has different and little-known dynamics - time of adoption, adequate animal stocking, and grazing intensity, for example, can change soil biological properties (Souza et al., 2008; 2010). The pasture age component may influence soil biological properties; properties such as total organic carbon, microbial carbon, and microbial quotient may gradually increase, which is important for a sustainable system, while the metabolic quotient property may decrease with pasture age (Muniz et al., 2011). In reforested areas, biological properties have proven to be more sensitive in detecting the impact of different forest plantations on chemical and physical properties (Silva et al., 2009). Increased C and organic matter contents are beneficial and a consequence of plant residue accumulation on the soil surface, and this may contribute to soil aggregation (Salton et al., 2005).

These iCLFs are designed to have a different microbial structure from that of degraded pastures due to the greater diversity of their microbial community. However, the structure of this community is rarely investigated in integrated systems such as the iCLF, especially in the tropics (Lisboa et al., 2014). Thus, little information is available on the effects of increased species diversity on soil biological quality.

The change in soil quality can be detected in the short and long term with the use of soil biological quality indexes, obtained from indicators that describe ongoing changes. The aim of this study was to detect changes in soil biological properties due to conversion of degraded pastures into iCLFs and to identify properties suitable for detecting changes in soil biological quality.

MATERIALS AND METHODS

Changes in soil biological properties after implementation of integrated production systems were evaluated in two areas: Gamada Farm in Nova Canaã do Norte, MT (10° 38′ 13″ S, 55° 42′ 32″ W), and Boa Vereda Farm in Cachoeira Dourada, GO (18° 27′ 43″ S, 49° 35′ 58″ W). In Nova Canaã do Norte, an iCLF with single-row strips of eucalyptus (iCLF1) and another with triple-row strips of eucalyptus (iCLF3) were evaluated. In both systems, the strips were spaced at 20 m, and plant spacing in the row was 2 m; for the iCLF3, the spacing between tree rows was 3 m. A degraded remnant of the conventional pasture on which the iCLFs were implemented was used as a reference. In Cachoeira Dourada, an iCLF3 with the same spacing between plants in the row (2 m) and between the tree rows (3 m) (though the strips were spaced at 14 m) and a conventional recovered pasture were evaluated. A degraded conventional pasture was also used as a reference (Figure 1). In both areas, pasture degradation was caused by grazing pressure and low grass yield (*Urochloa brizantha* in Nova Canaã do Norte and *Pennisetum clandestinum* and *U. decumbens* in Cachoeira Dourada), which contributed to soil physical degradation, according to Assis et al. (2015).

In Nova Canaã do Norte, the iCLFs were implemented in 2009 in a clayey *Latossolo Vermelho-Amarelo Distroférrico*, according to the Brazilian System of Soil Classification (Embrapa, 2006), and in Cachoeira Dourada, the iCLF3 was implemented in 2008 in a clayey *Latossolo Vermelho Ácrico* (Embrapa, 2006). Both soils are Oxisols, according to the Soil Taxonomy System (Soil Survey Staff, 2014). Both areas were planted to the species *Eucalyptus urograndis*, which is a hybrid between *E. grandis* W. Hill ex Maiden and *E. urophylla* S. T. Blake. In Nova Canaã, the land has been used for agriculture for more than 10 years; first for cultivation of rice, then soybean, and subsequently pasture with *Urochloa brizantha* (Hochst. Ex A. Rich.) Webster cv. Xaraés. Upon implementation of the iCLFs, in the first year of eucalyptus planting, rice (*Oryza sativa* L.) was grown in no-tillage; in the second and third years, early maturity soybean (*Glycine max* L.) and early maturity rice were grown; and in the third year, corn (*Zea mays* L.) was intercropped with forage (*Urochloa* spp or *Panicum* spp), which was also the case in the fourth year, when beef cattle were introduced with F1 derived from industrial cross-breeding of the Spanish Rúbia Gallega with Nellore.

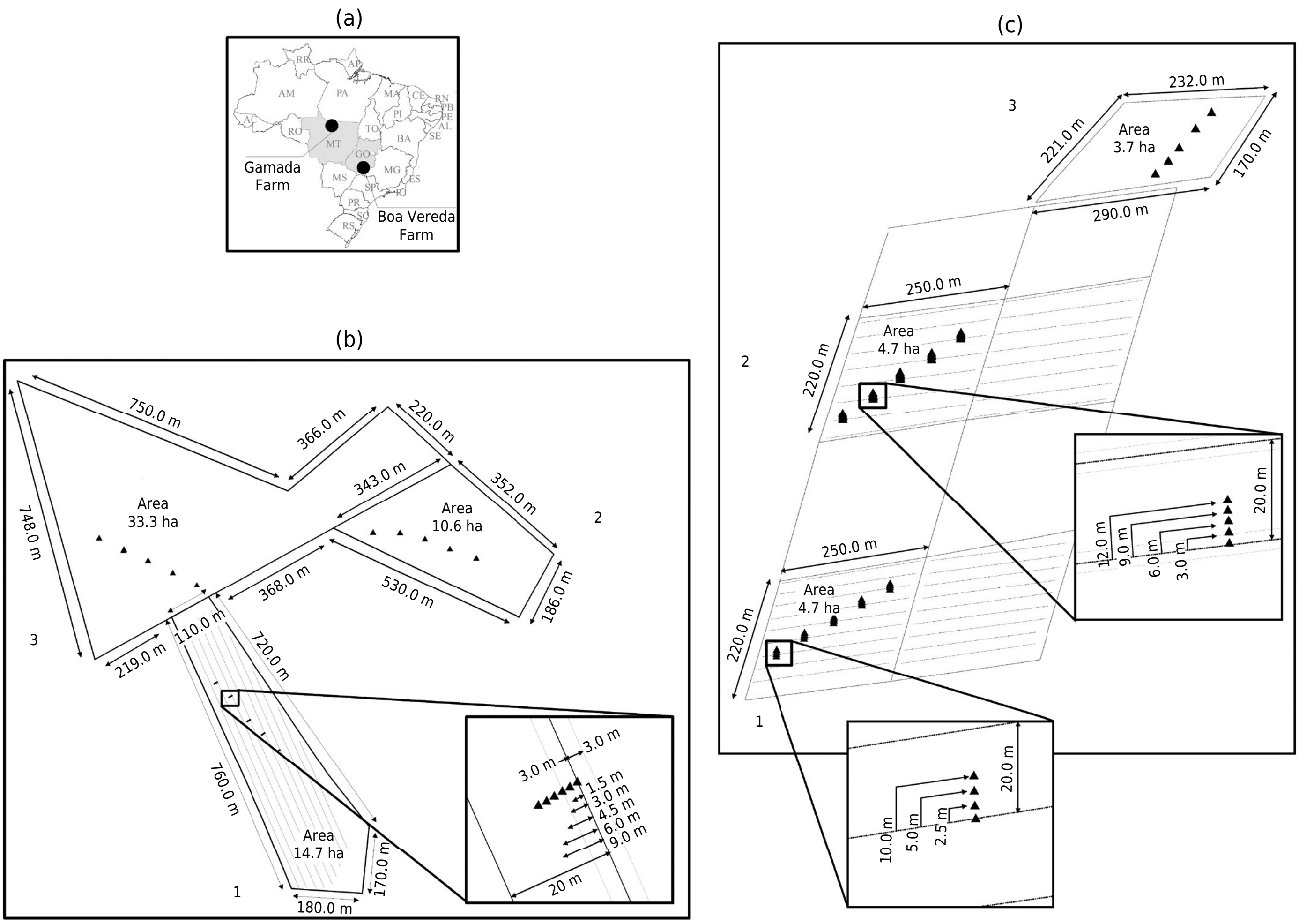

Figure 1. (a) Location of the studied areas; (b) Boa Vereda Farm: 1. area under iCLF with three eucalyptus rows, 2. area under degraded pasture, 3. area under recovered pasture; (c) Gamada Farm: 1. area under ICLF with single eucalyptus row, 2. area under ICLF with triple eucalyptus rows, 3. area under degraded pasture. Source: Assis et al. (2015).

In Cachoeira Dourada, the iCLF3 was implemented in an area that had been in pasture for about 30 years. The soil was harrowed, leveled, limed, and planted to eucalyptus and soybean. In the second year, corn was intercropped with the *U. brizantha* cultivars BRS Piatã and Marandú, and beef cattle (Nellore crosses) were introduced. The recovered pasture consisted of Kikuyu grass (*Pennisetum clandestinum*) and *U. brizantha*. This area was also limed in 2008 and the soil was prepared in the same way as in the iCLF3 for planting *U. brizantha*. The degraded pasture, without liming, consisted of Kikuyu grass (*P. clandestinum*) and *U. decumbens*.

Disturbed soil samples were collected in the 0.00-0.10 m layer in March 2012 to analyze the soil biological properties. In the iCLF1, the samples were taken from the tree row and at 2.5, 5.0, and 10.0 m from this row. In the iCLF3 of Nova Canaã do Norte, the samples were taken from the center row and at 3.0 (outermost row), 6.0, 9.0, and 12.0 m from the row. In Cachoeira Dourada, the samples were taken from the center row and at 1.5, 3.0 (outermost row), 4.5, 6.0, and 9.0 m from this row (Figure 1). Five replicates were taken for each sample. The samples were stored at 4 °C until the biological analyses were performed.

Soil organic carbon (SOC) was determined by the modified Walkley-Black method (Claessen, 1997). Microbial biomass carbon (MBC) and nitrogen (MBN) were determined by the fumigation-extraction method (Vance et al., 1987) and by the Kjeldahl method (Tedesco et al., 1995), respectively. The samples for soil basal respiration (BR) were incubated in an air-conditioned room at 28 °C for 10 days to stabilize the microorganisms; then, hermetically sealed vials with the samples were once more incubated at 28 °C for 7 days for further reading of released CO_2 (Anderson, 1982). The metabolic quotient (qCO$_2$) was calculated by the ratio between the basal respiration rate (BR) and the MBC (Anderson and Domsch, 1993). The microbial quotient (*q*MIC) was calculated by the ratio between MBC and SOC (Anderson and Domsch, 1993).

Correlation analyses were performed between each major component and the biological properties studied for the two areas, using principal component analysis (PCA). In addition, PCA biplots were generated for the first and second principal components. All statistical analyses were performed with R 3.0.2 software. The Microsoft Excel 2013 data analysis tool was used to perform the *t* test (α 5 %) to compare the means of the biological properties at each sampling position in the iCLFs and in the recovered pasture with those of the degraded pasture used as reference, and the data analysis tool was also used for the Pearson correlation analysis among the properties.

RESULTS

Nova Canaã do Norte

The graphical representation and correlation indices of the biological properties in the principal components allowed characterization of the properties that most influenced discrimination of the sampling positions in the iCLFs and pasture systems (Figure 2, Table 1). The cumulative variability explained by the first two principal components was 88 %, with the first component explaining 48 % of the total variance and the second 40 %. Microbial biomass C (-0.70), MBN (-0.97), BR (-0.81), and SOC (-0.54) were more correlated with the first principal component, whereas qCO$_2$ (-0.82) and *q*MIC (0.84) were more correlated with the second principal component.

Three groups were formed: the first by the degraded pasture, the second by all sampling positions in the iCLF1, and the third by the sampling positions in the iCLF3. MBC, MBN, and qMIC discriminated pasture from the iCLFs at all their sampling positions, while BR, SOC, and qCO$_2$ discriminated iCL3 from the iCLF1.

The iCLFs provided lower MBC, MBN, and *q*MIC in the soil than the degraded pasture did (Table 2). Soil under pasture had an MBC from 59 to 80 % higher than the iCLF1 and from 87 to 114 % higher than the iCLF3, according to the sampling position. The MBN values were from 233 to 700 % and 111 to 233 % higher, and *q*MIC were from 35 to 70 % and 69 to 118 % higher for the iCLF1 and iCLF3, respectively. These three properties had positive mutual correlation (Table 3).

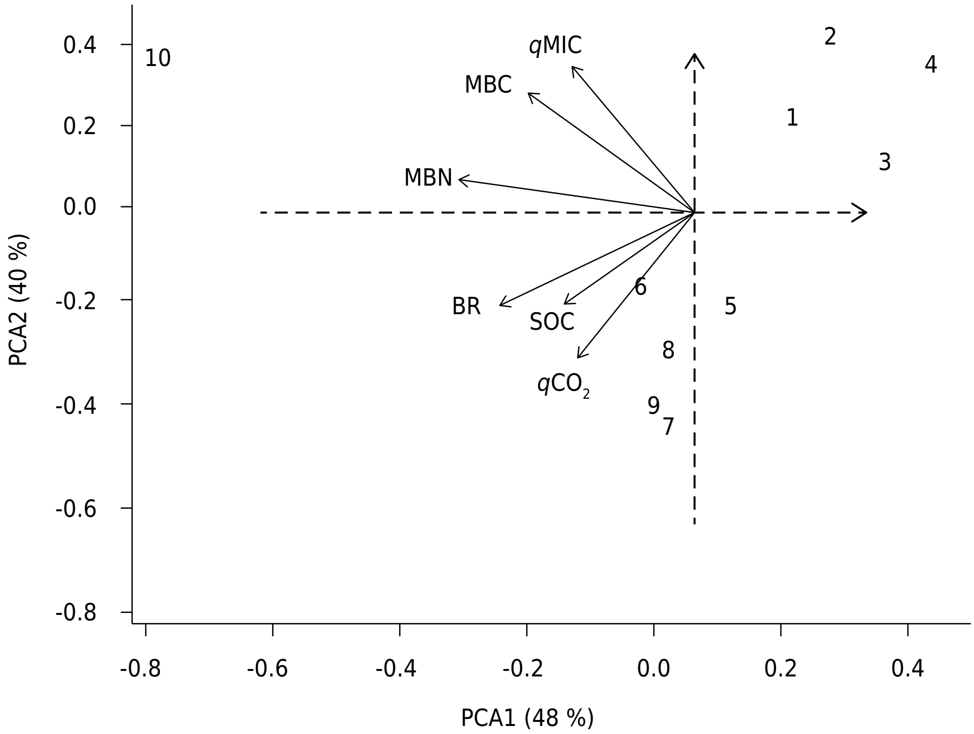

Figure 2. Biplot generated by principal component analysis (PCA) of the biological properties in the 0.00-0.10 m soil layer of the *Latossolo Vermelho Amarelo distroférrico* (Oxisol) subjected to different uses in Nova Canaã do Norte. MT. 1, 2, 3, and 4: iCLF1 and sampling on the tree row and at 2.5, 5.0, and 10.0 m from this row, respectively; 5, 6, 7, 8, and 9: iCLF3 and sampling on the central row and at 3.0, 6.0, 9.0, and 12.0 m from this row, respectively; 10: degraded pasture. MBC: microbial biomass carbon; MBN: microbial biomass nitrogen; BR: soil basal respiration; qCO_2: metabolic quotient; SOC: soil organic carbon; and *q*MIC: microbial quotient.

Table 1. Correlation between each principal component and biological properties of the 0.00-0.10 m soil layer in Nova Canaã do Norte, MT, and Cachoeira Dourada, GO

Property[1]	**PCA1**[2]	**PCA2**	**PCA1**[2]	**PCA2**
	Nova Canaã do Norte		Cachoeira Dourada	
MBC (mg kg^{-1})	-0.70	0.69	0.99	0.12
MBN (mg kg^{-1})	-0.97	0.18	0.98	0.03
BR (mg kg^{-1} h^{-1} CO_2)	-0.81	-0.52	0.75	-0.62
qCO_2 (mg CO_2 kg^{-1} Cmic h^{-1})	-0.49	-0.82	-0.24	-0.94
SOC (g kg^{-1})	-0.54	-0.51	0.92	-0.34
*q*MIC (%)	-0.52	0.84	0.49	0.79

[1] MBC: microbial biomass carbon; MBN: microbial biomass nitrogen; BR: soil basal respiration; qCO_2: metabolic quotient; SOC: soil organic carbon; *q*MIC: microbial quotient. [2] PCA1: first principal component, PCA2: second principal component.

The soil under the iCLF1 had lower BR and qCO_2 at all sampling positions and lower SOC at 2.5 and 10.0 m from the tree row than the soil under degraded pasture (Table 2), while the iCLF3 showed no difference from the pasture for these variables. In the iCLF1, depending on the sampling position, BR showed a reduction of 89 to 92 % and qCO_2 a reduction of 83 to 87 % compared to the values under pasture. Positive correlations were found between BR and qCO_2 and between BR and MBN (Table 3).

Cachoeira Dourada

Principal component analysis showed that the cumulative variability explained by the first two components was 95 %, with the first component explaining 61 % of the total

Table 2. Microbial biomass carbon (MBC), microbial biomass nitrogen (MBN), soil basal respiration (BR), metabolic quotient ($q\mathrm{CO_2}$), soil organic carbon (SOC) and microbial quotient (*q*MIC), according to the systems and sampling positions studied in Nova Canaã do Norte, MT, and Cachoeira Dourada, GO, 2012

System	Position[(1)]	MBC	MBN	BR	$q\mathrm{CO_2}$	SOC	*q*MIC
	m	mg kg^{-1}		mg kg^{-1} h^{-1} $\mathrm{CO_2}$	mg $\mathrm{CO_2}$ kg^{-1} MBC h^{-1}	g kg^{-1}	%
				Nova Canaã do Norte			
iCLF1	0	439*	12*	0.55*	1.25*	17.34	2.54*
	2.5	442*	12*	0.40*	0.94*	15.57*	2.85*
	5	390*	5*	0.48*	1.20*	17.27	2.27*
	10	389*	6*	0.39*	1.02*	14.87*	2.67*
iCLF3	0	328*	13*	3.63	10.61	15.75	2.20*
	3	376*	19*	3.60	9.30	16.81	2.29*
	6	329*	12*	3.64	11.08	18.83	1.77*
	9	350*	15*	3.66	9.88	17.50	2.01*
	12	335*	14*	3.67	10.73	18.68	1.84*
Rec pasture[(2)]		702	40	5.07	7.29	18.19	3.86
				Cachoeira Dourada			
iCLF3	0	658*	8*	1.33	2.01	20.39*	3.24
	1.5	618*	10*	1.27	2.07	21.01*	2.98
	3	651*	10*	1.31	2.03	19.91*	3.30
	4.5	600*	9*	1.40	2.32	19.95*	3.04
	6	567*	7*	1.29	2.25	19.77*	2.89
	9	576*	5*	1.17	2.08	19.89*	2.90
Rec pasture[(2)]		764*	22	1.90*	2.49*	27.19	2.87
Deg pasture[(3)]		877	32	1.51	1.74	25.78	3.46

[(1)] In relation to the tree row for the iCLF1 system and in relation to the central tree row for the iCLF3 system. [(2)] Recovered pasture. [(3)] Degraded pasture. Means in the columns followed by an asterisk are significantly different from the pasture by the *t* test at 5 %, considering the pasture area as reference.

Table 3. Coefficient of correlation (r) between soil properties in the 0.0-0.10 m soil layer, in Nova Canaã do Norte, MT, and Cachoeira Dourada, GO

	MBC	MBN	BR	$q\mathrm{CO_2}$	SOC	*q*MIC
			Nova Canaã do Norte			
MBC	1					
MBN	0.798**	1				
BR	0.182	0. 715*	1			
$q\mathrm{CO_2}$	-0.260	0.352	0.899**	1		
SOC	0.117	0.378	0.562	0.521	1	
*q*MIC	0.947**	0.667*	0.005	-0.415	-0.205	1
			Cachoeira Dourada			
MBC	1					
MBN	0.972**	1				
BR	0.667	0.689	1			
$q\mathrm{CO_2}$	-0.369	-0.288	0.441	1		
SOC	0.875**	0.900**	0.884**	0.055	1	
*q*MIC	0.593	0.482	-0.052	-0.795*	0.135	1

MBC: microbial biomass carbon; MBN: microbial biomass nitrogen; BR: basal soil respiration; $q\mathrm{CO_2}$: metabolic quotient; SOC: soil organic carbon; and *q*MIC: microbial quotient. Value of r followed by * and ** is significant at 5 and 1 % probability, respectively.

variance and the second component 34 %. The correlation indices for the biological properties in the principal components are shown in table 1.

Four groups were formed: the first by the degraded pasture, the second by the recovered pasture, the third by the iCLF3 at the sampling positions in the center row of trees and at 3.0 m from that row, and the fourth by the iCLF3 at the sampling positions of 1.5, 4.5, 6.0, and 9.0 m from the center row of trees (Figure 3).

The positive correlations in PCA1, i.e., to the right in the plot, indicate that MBC (0.99), MBN (0.98), and *q*MIC (0.49) served to discriminate the degraded pasture from the iCLF3 at all their sampling positions, while BR (0.75) and SOC (0.92) discriminated the recovered pasture from the iCLF3. In PCA2, the sampling positions of iCLF3 in the center row of trees and at 3.0 from that row were discriminated from the positions at 1.5, 4.5, 6.0, and 9.0 m from the center row of trees by qCO_2 (-0.94) and *q*MIC (0.79).

The soil under degraded pasture had higher MBC and MBN than the soil under the iCLF3 (Table 2). In addition, MBC was 15 % higher in Cachoeira Dourada than in the soil under recovered pasture. The soil under degraded pasture had MBC and MBN from 33 to 55 % and from 220 to 540 % higher than in the iCLF3, respectively, depending on the sampling position. These two properties had high positive correlations (Table 3). Although *q*MIC had a higher absolute value in the soil under degraded pasture, it showed no statistical difference from the other systems.

BR and SOC were higher in the soil under recovered pasture than under the iCLF3 (Table 2). The SOC in the soil under degraded pasture was also 23 to 30 % higher than under the iCLF3, depending on the sampling position. The recovered pasture showed no difference from the degraded pasture for SOC, but BR and qCO_2 were 26 and 43 % higher, respectively. SOC had high positive correlations with MBC, MBN, and BR (Table 3).

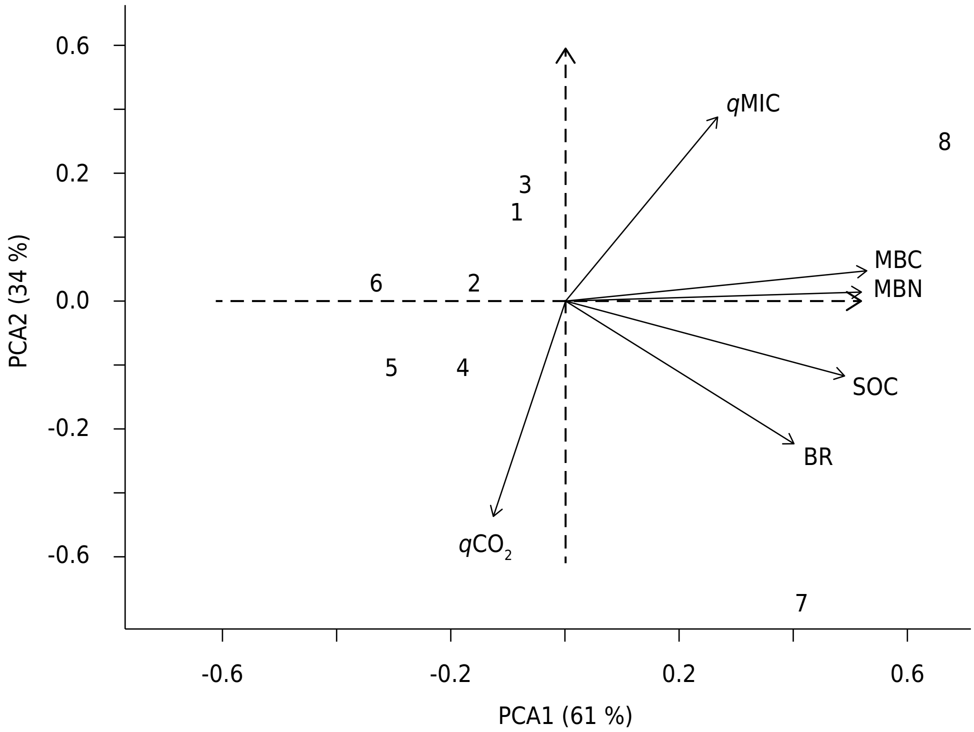

Figure 3. Biplot generated by principal component analysis (PCA) of the biological properties in the 0.00-0.10 m soil layer of the *Latossolo Vermelho Ácrico* (Oxisol) under different uses in Cachoeira Dourada, MT, Brazil. 1, 2, 3, 4, 5, and 6: sampling in the center row and at 1.5, 3.0, 4.5, 6.0, and 9.0 m from this row, respectively; 7: recovered pasture; and 8: degraded pasture. MBC: microbial biomass carbon, MBN: microbial biomass nitrogen, BR: soil basal respiration, qCO_2: metabolic quotient, SOC: soil organic carbon, and *q*MIC: microbial quotient.

In absolute values, qCO_2 was lower and *q*MIC was higher in the soil under the iCLF3 at the sampling positions in the center row of trees and at 3.0 m from that row compared to the soil at the positions of 1.5, 4.5, 6.0, and 9.0 m from the center row of trees (Table 2); this may have contributed to the separation into different groups. These properties had a negative correlation (Table 3).

DISCUSSION

The higher values of MBC and MBN in the soil under degraded pasture compared with the integrated systems, both in Nova Canaã do Norte and in Cachoeira Dourada, are probably due to no tillage of the pasture for conversion into farm land, which can preserve the fungal hyphae and large number of fine roots, increasing the input of organic substrates into the system via root exudates (Reis Júnior and Mendes, 2007). The fasciculate grass root system, which is very concentrated in the first 0.10 m depth, results in increased C input into the soil through the rhizosphere and necromass, both of which activate the microbiota in the soil (Carneiro et al., 2009). Soils under pasture can have high levels of organic matter due to the efficiency of grasses in incorporating organic material into the soil (Netto et al., 2009). In order to form the iCLF1 and iCLF3, pastures underwent intense transformation, and favorable microbiota conditions were probably lost. Likewise, management practices for pasture recovery resulted in a reduction in MBC content in the soil compared with the degraded pasture in Cachoeira Dourada. Properties considered sensitive to management, MBC and MBN, expressed this change well, and their high positive correlation corroborates the results obtained by other authors (Chaer and Tótola, 2007) for areas with different eucalyptus management practices. According to these authors, this implies a relatively invariant C:N ratio in the microbial biomass of the areas studied.

The higher MBC values in the areas of degraded pasture show that even in situations where pastures are not well managed, they are capable of carrying large microbial biomass, probably due to the high organic matter content and dense root mass protecting the rhizospheric environment (Alvarenga et al., 1999). Another factor that may explain higher MBC rates in pastures than in areas of the iCLF with eucalyptus is the presence of substances with antimicrobial activity found in the necromass of this species. Lower MBC values are reported in areas with eucalyptus compared with other crops (Costa et al., 1995). The high MBN found in pastures indicate that these systems behave as important N storage compartments in the soil, and this N becomes available to plants after the death of microorganisms (Souza et al., 2010).

The *q*MIC value can be used to reflect the efficiency of conversion of organic C into microbial C (Sparling, 1992). Losses and stability of *q*MIC in the soil mineral fraction may vary according to soil class, management practices, utilization, plant cover, and sampling time (Anderson and Domsch, 1993). This ratio also expresses the amount of organic C in the soil immobilized in the microbial biomass, demonstrating microorganism behavior in C immobilization, which may be inversely proportional to the intensity of management practices in a soil (Cardoso et al., 2009; Silva et al., 2010). The soil was intensively managed during the conversion of pasture into the iCLFs, resulting in lower *q*MIC in integrated systems than in the degraded pasture in Nova Canaã do Norte. This suggests that lower management intensity leads to a higher MBC/SOC ratio and, as the integrated systems had similar potential for reserving SOC in the soil, there is high correlation of *q*MIC with MBC and MBN.

The *q*MIC values found in Nova Canaã do Norte and Cachoeira Dourada are corroborated by the literature, which considers that the microbial component normally composes 1 to 4 % of the organic C content (Jenkinson and Ladd, 1981). However, the absolute values of *q*MIC under the iCLF3 were higher in Cachoeira Dourada than in Nova Canaã do Norte. Perhaps for this reason, the iCLF3 in Cachoeira Dourada showed no difference from the degraded pasture in relation to *q*MIC. The *q*MIC had the lowest discriminating power among the properties that indicated the separation of these systems, and its low efficiency in the discrimination of agricultural systems here corroborates the results of other studies (Islam and Weil, 2000; D'Andréa et al., 2002; Jakelaites et al., 2008; Pôrto et al., 2009).

The higher BR and qCO_2 values in the soil under degraded pasture and under the iCLF3 in Nova Canaã do Norte and the positive correlation among these properties suggest that an imbalance may have occurred in these environments. Systems that promote lower qCO_2 are considered better from the biological point of view, because they prevent CO_2 losses by microbiota respiration. An increase in CO_2 would result in lower C incorporation into microbial biomass (Gama-Rodrigues, 1999; Silva et al., 2010), which can occur due to the low efficiency of the microbial community or some type of stress (Anderson and Domsch, 1993). This differentiation between systems caused by CO_2 rates may indicate equilibrium for lower values and stress or disturbance conditions for higher values (Tótola and Chaer, 2002). Thus, the soil under the iCLF1 shows greater equilibrium in its metabolic activities, placing less stress on the microbiota, which is desirable in farming systems. This result indicates that differences are found in the soil properties when the soil is under pasture and it is converted into an iCLF, but the number of rows adopted in an integrated system can also influence the microorganism dynamics in the soil and the quality of these properties. In Cachoeira Dourada, the recovered pasture emerged as a more disturbed environment than the degraded pasture, because of the higher BR and qCO_2 values, which indicate stress conditions for soil microbiota, which was likely caused by the management practices applied for its recovery. Although the difference was not statistically significant, the degraded pasture showed higher *q*MIC, which was negatively correlated with qCO_2. High *q*MIC rates presuppose good quality of organic matter (Wardle, 1994), and directly reflects microbial activity and explains the negative correlation between this property and qCO_2. Improvement in soil biological quality can be achieved by adopting agricultural systems that reduce qCO_2. In this regard, the iCLF3, over three years, was not able to improve soil quality in relation to the degraded pasture.

The high amount of C immobilized in the microbial biomass and the high BR and qCO_2 values appear not to have initially hampered the accumulation of SOC in the soil under degraded pasture in Nova Canaã do Norte, since it was higher or similar to that observed under the iCLFs. Similarly, in Cachoeira Dourada, SOC was higher in the soil under pasture than in the iCLF3 at all sampling positions, which is in line with the positive correlations between MBC, MBN, and SOC. The effectiveness of grass in maintaining SOC in the soil, as reported in other studies (D'Andréa et al., 2004; Pôrto et al., 2009), accounts for the high SOC values found in soils under pasture.

The accumulation of SOC under pasture associated with high BR values, and even positive correlation between these properties in Cachoeira Dourada, indicates [unlike the results of Carneiro et al. (2009)] that the soil microbial population may not be consuming high amounts of C for its maintenance to the point of promoting loss of this element. Pastures can have high respiratory rates due to the presence of animals and the addition of manure to the soil, promoting a significant increase in microorganism biomass. This is noteworthy because additional substrate plays an important role in microbial metabolism and growth, which modifies the availability of nutrients in the soil (Assis Júnior et al., 2003).

High respiration rates may reflect stress conditions for microbiota, but may also reflect a high level of ecosystem productivity, and this should be analyzed considering each situation (Islam and Weil, 2000); thus, BR results should be carefully interpreted (Silva et al., 2007).

High respiration rates are desirable when rapid decomposition of organic residues and nutrient availability to plants are intended, but this high activity may also reflect faster decomposition of organic matter, which can compromise chemical and physical processes important for the soil, such as aggregation, water retention capacity, cation exchange capacity, and nutrient losses (Reis Júnior and Mendes, 2007).

Our findings show that because of the soil disturbance caused by implementation of the integrated systems and the short time to evaluation of the biological properties, the iCLFs were not yet consolidated to the point of improving the biological quality of the soil compared with the degraded pasture.

CONCLUSIONS

The integration system with one eucalyptus row disturbed the microbial population less than the degraded pasture, which is shown by the lower metabolic quotient and lower basal respiration.

The sampling position in relation to the tree row had little effect on comparison of soil biological properties of the integrated systems and the degraded pasture.

Microbial biomass carbon and nitrogen and microbial quotient were the properties that mainly discriminated the integrated systems from the degraded pasture.

The crop-livestock-forestry integration systems at three years after implementation have not yet improved the biological quality of the soil in relation to degraded pasture.

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