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Numerical quality rating of a Yellow Latosol under an integrated crop-livestock system

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Ações antrópicas afetam a atmosfera da terra, despertando para uma consciência global sobre a necessidade de sistemas agrícolas sustentáveis. O objetivo deste estudo foi determinar índices de sustentabilidade do solo para um sistema de integração lavoura-pecuária em um Latossolo Amarelo do cerrado brasileiro no Piauí, utilizando uma classificação numérica. Foram estudados três sistemas de manejo do solo: preparo convencional (PC) com disco de arado e grade pesada em cultivo de soja; plantio direto com rotação de milho soja e milheto como cobertura viva (NT + M); e dois sistemas de integração lavoura-pecuária, um com cinco meses, em pastagens e cultivo de soja (ICL + S) e outro com pastejo contínuo (ICL + P). Uma área sob mata nativa (NF) foi avaliado, como um solo sob condições naturais. Propriedades físicas, químicas e biológicas foram avaliadas no 0,00-0,05 m camada. Na análise de componentes principais, os ambientes ICL + S e ICL + P foram classificados como um único grupo, e pode ser caracterizados pelas propriedades de carbono orgânico no solo, reservatórios de carbono e nitrogênio no solo, o nitrogênio da biomassa microbiana, e total de nitrogênio. A propriedade do solo que melhor caracterizou o ambiente CT foi a atividade da enzima FDA (hidrolisa acetato). As propriedades que melhor caracterizam o ambiente NF são a capacidade de troca catiônica, carbono da biomassa microbiana, microporosidade, índice de estabilidade de agregados, diâmetro médio geométrico e percentagem de agregados estáveis> 2,00 milímetros.

Palavras-chave: Análise multivariada, física do solo, matéria orgânica.

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Anthropic action is affecting the Earth's atmosphere, awakening a global awareness about the need for sustainable farming systems. The objective of this study was to determine indices of soil sustainability for an integrated crop-livestock system in a Yellow Latosol of the Brazilian Cerrado in Piauí by using a numerical rating. Three systems of soil management were studied: an area under conventional tillage (CT) with plow disk and heavy harrow and soybean cultivation; an area under no-tillage with soybean-maize rotation and millet as a cover crop (NT+M); and two areas under an Integrated Crop-Livestock System, one with five-month pasture grazing and soybean cultivation and the other with continuous pasture grazing (ICL + S and ICL + P, respectively). An area under Native Forest (NF) was evaluated as well as a soil under natural conditions. The physical, chemical, and biological properties were evaluated in the 0.00-0.05 m layer. The environments ICL + S and ICL + P were classified as a single group, and can be characterized by the properties soil organic carbon, soil carbon and nitrogen pools, microbial biomass nitrogen, and total soil N. The property that best characterizes the CT environment is enzyme activity FDA (Fluorescein diacetate hydrolysis). The properties that best characterize the NF environment are cation exchange capacity, microbial biomass carbon, microporosity, aggregate stability index, geometric mean diameter, and percentage of stable >2.00 mm aggregates.

Key words: Multivariate analysis, soil physics, organic matter.

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INTRODUCTION

The conversion of native forests into intensive land use and management systems can change the soil physical, chemical, and biological properties, modifying the soil quality and reducing the sustainability. Therefore, a sustainable management of agricultural activity should be based on quantitative measurements of soil, plant, and climate properties. Nowadays, the planning of a sustainable management is rather complex because sustainable production requires maximum performance at low cost.

The compaction caused by excessive machinery traffic, agricultural implements, and animal trampling is one of the main causes of the degradation of the productive capacity of agricultural soils (Araújo et al., 2010; Cruz et al., 2003). The evaluation of the effect of these changes is based on the measurement of certain soil physical properties such as soil bulk density and porosity (Collares et al., 2011; Marchão et al., 2007) as well as aggregate stability (Araújo et al., 2010; Souza et al., 2010a; Calonego & Rosolem, 2008).

Soil chemical and physical properties are important to determine the soil quality, but the period of evaluation and cultivation until these variables respond to a system is long. Measures of biological processes, in contrast, are sensitive and early indicators of environmental changes (Nicoloso et al., 2008). In view of the importance of these biological indicators for soil processes, studies that relate the amount of biomass and soil microbial activity can provide information for a proper planning of soil management systems and for monitoring edaphic processes (Silva et al., 2009; Sampaio et al., 2008).

The quantification of microbial biomass carbon (Cmic), basal respiration (C-CO2), and their relationships, e.g., the metabolic quotient (qCO_2), have been used to study processes of nutrient cycling and transformation (Matias et al., 2009; Sampaio et al., 2008) and to assess the dynamics of soil organic matter (Souza et al., 2010b ; Carneiro et al., 2008; Costa et al., 2008).

Agricultural development in the tropics requires soil analyses before appropriate management recommendations can be generated (Souza et al., 2010a; Carneiro et al., 2009; Cruz et al., 2003). Since the conventional statistical analyses are often insufficient to describe the interactions in such a system, one of the proposed solutions is the use of a numerical rating obtained by multivariate statistics (Ferreira, 2008). This analysis tool has a greater capacity to describe the inter- and intra-dependence relationships in agricultural systems. Numerical rating is one of the solutions for the characterization of soil properties and studies of cause and effect in the implementation of appropriate management plans (Gomes et al., 2004; Carvalho Junior et al., 2008). Methods of multivariate statistics are used to simplify or facilitate the interpretation of a phenomenon by the simultaneous analysis of all measured variables.

Principal component analysis (PCA) is one of the methods most commonly used by soil scientists. The goal of PCA is to find a property in a set of data that is able to explain a significant part of the variance of the entire population sampled by means of linear correlations. This type of analysis is interesting for soil scientists because the most significant variables in the pedogenetic processes can be selected (Siqueira et al., 2010). Gomes et al. (2004) used PCA to study the relationship between the physical, chemical, and mineralogical properties of soils of the Cerrado biome. Siqueira et al. (2010) also investigated the relationships between the physical, chemical, and mineralogical properties and magnetic susceptibility based on PCA.

The objective of this study was to determine indices of soil sustainability for an integrated crop-livestock system on a Yellow Latosol of the Brazilian Cerrado in Piauí, based on numerical rating.

MATERIAL AND METHODS

Study area

The study was carried out in an experimental unit of the Brazilian Agricultural Research Corporation (Embrapa) and conducted by the Centro de Pesquisa Agropecuária do Meio-Norte (CPAMN) in an area of the Fazenda Nova Zelândia in Uruçuí (3º 37'S and 43º 22'W), in the southwest of the State of Piauí. The soil of the area was classified as a dystrophic Yellow Latosol with a sandy loam texture (chemical properties see Table 1). According to the Köppen system, the climate type is Aw, the average temperature 26.5°C, annual rainfall 1.200 mm, and the rainy season lasts from October to April, with most rain between January and March.

Three systems of soil management were studied: an area under conventional tillage (CT) with plow disk and heavy harrow and soybean cultivation; an area under no-tillage with soybean-maize rotation and millet as cover crop (NT+M); and two areas under an Integrated Crop-Livestock System, one with five months of pasture grazing and soybean cultivation and the other with continuous pasture grazing (ICL + S and ICL + P, respectively). In the areas of the Integrated Crop-Livestock System, after soybean cultivation, a rotation of maize and brachiaria as cover crop was performed, and the animal pasture was managed at a rate of 2.4 A.U (450 Kg per animal unit) per hectare. The animals began grazing in the area 45 days after maize harvest. Under ICL + S, the effective permanence of the animals was 42 days, while under ICL + P, the effective permanence of the animals reached 168 days. The brachiaria production was 42 t ha^{-1} fresh matter. An area under Native Forest (NF) was evaluated as well as a soil under natural conditions (Table 2).

Soil sampling and analysis

The soil physical properties bulk density and porosity as well as aggregate stability were analyzed. To evaluate soil bulk density and porosity, undisturbed samples were collected in volumetric rings (average height 0.04 mm height, diameter 0.05 mm). Soil porosity (macroporosity and microporosity) was determined with a tension table. After saturation, the samples were subjected to a tension of 0.006 MPa (EMBRAPA, 2011). Total porosity and bulk density were determined according to EMBRAPA (2011), and macroporosity as the difference between total porosity and microporosity.

The soil samples used to determine the aggregate stability were collected and stored to prevent aggregate deformation. The material that passed through a 4.76

mm sieve and the material retained on a 2.00 mm sieve was used to study the aggregate stability. This variable was determined by careful wet sieving, after the sample was slowly wetted by capillarity (Castro Filho et al., 1998). A set of sieves with meshes of 2.00 mm, 1.00 mm, 0.50 mm, 0.25 mm, and 0.105 mm were used. Using a vertical oscillation device, the soil samples were graded to a depth of 0.04 m with a frequency of 32 oscillations per minute and subjected sieving for 10 minutes (EMBRAPA, 2011).
The soil retained in each sieve was quantified and classified in five aggregate diameter groups (4.76-2.00 mm, 2.00-1.00 mm, 1.00-0.50 mm, 0.50-0.25 mm, and 0.105 mm). From these mass values and the known water content of the wet-sieved soil samples , the mean weight diameter (MWD) and geometric mean diameter (GMD) were calculated by equations 1 and 2; and stable aggregate percentage >2.00 mm (AGRI) and aggregate stability index (ASI) were calculated by equations 3 and 4, as proposed by Castro Filho et. (1998).

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

Where: xi = mean diameter of each size fraction (classes) and wi = proportion of the total sample weight occurring in the size fraction i.

$$\text{GMD}=\exp\left[\frac{\sum_{i=1}^{n} w_i \log x_i}{\sum_{i=1}^{n} x_i}\right] \quad (2)$$

Where: wi = aggregate weight (g) within an aggregate class with average diameter xi and xi = mean diameter of each size fraction (classes) (mm).

$$\text{ASI}=\left[\frac{\text{dry sample weight -}w_p\text{25-sand}}{\text{dry sample weight-sand}}\right]100 \quad (3)$$

Where: W_p25 = aggregate weight (g) <0.25 mm (g) and sand = weight of particles with diameters between 2.0 and 0.053 mm (g).

$$\text{AGRI}=(w_i>2.00\text{ mm})100 \quad (4)$$

In each plot, soil was sampled in the 0-5 cm layer, at 9 points along. The soil samples were sieved (< 2.0 mm) and 300 g of soil per sample was separated in plastic bags and stored in a refrigerator at 4 to 8 °C for further evaluation of microbial biomass and activity. The remaining samples were air-dried. The material was ground and sieved (< 0.21 mm) to determine soil organic carbon (Corg) by the wet combustion method using a mixture of potassium dichromate and sulfuric acid under heating (EMBRAPA, 2011).
The soil chemical analyses were conducted at the Soil Quality Laboratory of the Federal University of Piauí. The soil pH was determined in a 1:2.5 soil/water extract. Exchangeable Al, Ca and Mg were determined by extraction with 1 M KCl. The available P and exchangeable K were extracted by Mehlich^{-1} and determined by colorimetry and photometry, respectively (EMBRAPA, 2011).
The soil microbial biomass carbon (Cmic) was determined according to Anderson & Domsch (1990) by extraction of organic carbon (Corg) from fumigated and unfumigated soils with K_2SO_4. Organic carbon was measured with dichromate digestion, and an extraction efficiency coefficient of 0.38 was used to convert the difference in soluble C between the fumigated and non-fumigated soils in microbial Cmic.
Fluorescein diacetate hydrolysis (FDA) was analyzed, and a measure of soil microbial activity was determined as indicator by the method of Schnurer & Rosswall (1982). The microbial quotient (qmic) was calculated as the ratio of Cmic:Corg and expressed as µg Cmic µg Corg^{-1} (Anderson & Domsch, 1990).
The carbon stock was calculated for the studied layer by the expression:

$$\text{Cstock} = (\text{Corg} \times \text{Bd} \times \text{e})/10 \quad (5)$$

where Cstock is the stock of organic carbon at a given depth (Mg ha^{-1}); Corg is the total organic carbon content (g kg^{-1}); Ds is the average depth of the bulk density (Mg m^{-3}); and e is the thickness of the studied layer (cm).

The stock of total soil nitrogen was calculated similarly to the carbon stock by the expression:

$$\text{Nstock} = (\text{N x Bd x}) \quad (6)$$

where Nstock is the stock of total soil nitrogen at a given depth (Mg ha^{-1}); N is the total nitrogen content (dag kg^{-1}); and e is the thickness of the studied layer (cm).

Statistical analysis
The results were subjected to analysis of variance, and the means compared by the Tukey test (P<0.05) when necessary, using SAEG software, v 9.0. Principal component analysis was performed for the properties studied in the different treatments. The goal of PCA is to find a property in a set of data that can explain a significant part of the variance by means of linear correlations (Ferreira, 2008). The PCA was performed using software Statistica 7.0.

RESULTS AND DISCUSSION

Soil bulk density and porosity
Soil bulk density was highest in the management system ICL + P (p <0.05) (Table 3). The systems studied induced a significant reduction (p <0.05) in total porosity compared to NF, except for CT, which was equal to NF though without differing from the other systems. For microporosity, the management systems ICL + S, NT + M, and CT were equal (p <0.05) and had intermediate behavior in relation to NF and ICL+P, which differed from each other. For macroporosity, no significant difference (p <0.05) was detected between the management systems and NF.
The highest values of soil bulk density detected in the integrated crop-livestock system with continuous grazing (ICL + P) reflects the effect of surface compaction, which can occur in integrated crop-

livestock systems under no-tillage despite the absence of tillage, due to the animal pressure on the soil surface (Collares et al., 2011; Araújo et al., 2010). These results corroborate those reported by Marchão et al. (2007) and Flores et al. (2007), who observed an increase in soil bulk density in the profile under pasture and no-tillage in the surface layer of an integrated crop-livestock system. This observation confirms the reduction in total porosity observed in the management systems in relation to NF, except for CT, which was equal to NF, even though it did not differ from the other systems. This fact was likely due to the immediate result of soil tillage operations in this layer, reducing the adhesion of soil particles and enabling a greater number of pores (Cruz et al., 2003).

Soil aggregate stability

The indicators of soil structural quality MWD, GMD, ASI, and AGRI differed significantly ($p < 0.05$) between the management systems, compared to NF (Table 4). The values of MWD and GMD were similar for NF, CT and ICL + P and higher than for NT + M and ICL + S. The ASI was lowest in NT + M. For AGRI, the values were lowest in the management systems NT + M and ICL + S. The ICL + P and CT and NF had higher values for AGRI (Table 4), because these management systems were comparable to the other systems studied. In a Latosol under integrated crop-livestock systems, Souza et al. (2010a) found similar results to those of this study, with higher levels of aggregate stability in integrated crop-livestock systems.

*Table 1. Chemical characterization of a Yellow Latosol in the 0.00-0.20 m layer under different management systems. *NF = native forest; CT = conventional tillage; ICL+P = integrated crop-livestock with continuous pasture grazing; ICL+S = integrated crop-livestock with soybean; NT+M = no-tillage with millet.*

Systems	pH	Resin P	K	Ca^{+2}	Mg^{+2}	H + Al^{+3}
	$CaCl_2$	mg dm^{-3}		$mmol_c$ dm^{-3}		
ICL+S	5.0	26.5	2.88	17.25	14.75	25.75
ICL+P	4.8	23.5	2.98	16.25	10.5	33.5
NT+M	5.2	17	1.23	21.5	17.5	25.25
CT	5.1	4.5	1.25	12.25	10.5	20.75
NF	3.9	4.0	0.7	6.25	7.0	100.25

The highest values ($p<0.05$) obtained for the MWD in NF reflect the state of equilibrium in this system, thus favoring the maintenance and stability of the aggregates. In the conventional tillage (CT) system, the MWD values ($p>0.05$) were equal to the area of native forest in the 0.00 - 0.05 m layer.

*Table 2. History of different management systems. *NF = native forest; CT = conventional tillage; ICL+P = integrated crop-livestock with continuous pasture grazing; ICL+S = integrated crop-livestock with soybean; NT+M = no-tillage with millet.*

Systems	History of agricultural years				
	2001/2002	2002/2003	2003/2004	2004/2005/200	2006/2007
ICL+S	Rice	Soybean	Maize+Cattle	Soybean/Millet	Soybean/Millet
ICL+P	Rice	Soybean	Maize+Cattle	Brachiaria/Catt	Brachiaria/Cattle
NT+M	Native forest	Native forest	Soybean/Millet	Soybean/Millet	Soybean/Millet
CT	Native forest	Native forest	Native forest	Native forest	Soybean
NF	Native forest	Native forest	Native forest	Native forest	Native forest

Table 3. Soil density, porosity, macroporosity, and microporosity of a Yellow Latosol in the 0.00-0.05 m layer under different management systems(1). (1) ICL+S = integrated crop-livestock with soybean; ICL+P = integrated crop-livestock with continuous pasture grazing; NT+M = no-tillage with millet; CT = conventional tillage; NF = savanna-like native forest. (2) means followed by the same letter in columns do not differ from each other by the Tukey test at 5% probability; ns = not significant.

Management System	Bulk density(2) Mg m^{-3}	Porosity m^3 m^{-3}	Microporosity m^3 m^{-3}	Macroporosity m^3 m^{-3}
ICL + S	1.32b	0.514b	0.447ab	0.067 ns
ICL + P	1.48a	0.490b	0.442b	0.049 ns
NT + M	1.26b	0.518b	0.453ab	0.065 ns
CT	1.33b	0.528ab	0.453ab	0.075 ns
NF	1.27b	0.571a	0.489a	0.082 ns
CV (%)	5.11	4.33	4.45	28.44

Table 4. Mean weight diameter (MWD), geometric mean diameter (GMD), stable aggregate percentage >2.00 mm (AGRI) and aggregate stability index (ASI) of a Yellow Latosol in the 0.00-0.05 m layer under different management systems[(1)]. [(1)] ICL+S = integrated crop-livestock with soybean; ICL+P = integrated crop-livestock with continuous pasture grazing; NT+M = no-tillage with millet; CT = conventional tillage; NF = savanna-like native forest. [(2)] Means followed by the same letter in columns in each soil depth, do not differ from each other by the Tukey test at 5% probability; ns = not significant.

Management System	% of Aggregate class					MWD	GMD	ASI	AGRI
	Mean in millimeters per class								
	4.76-2.0	2.0-1.0	1.0-0.50	0.5-0.25	0.105	mm			
ICL + S	66.96	4.72	5.84	13.60	5.28	2.41b	1.31b	95.05ab	66.96b
ICL + P	76.58	3.06	1.83	8.27	5.32	2.70ab	1.42ab	94.82ab	76.58ab
NT + M	71.84	5.08	3.24	8.66	6.78	2.60b	1.37b	93.43b	71.84b
CT	81.29	1.94	2.37	6.83	3.49	2.83ab	1.48ab	96.51ab	81.29ab
NF	89.34	1.50	1.27	2.49	1.82	3.09a	1.59a	98.06a	89.34a
CV (%)						7.8	6.19	2.09	17.13

The MWD in CT was most likely due to the short time of adoption of this system in the area (Table 2). In a study of aggregate stability, Castro Filho et al. (1998) stated that conventional tillage systems promote aggregate breakdown caused by the intense soil tilling; this system can compromise aggregate stability and reduce MWD in the crops over time. The small variation in MWD among the tillage systems studied may be ascribed to the method used, which, according to Wendling et al. (2005), does not distinguish newly formed aggregates from those stabilized after formation. Therefore, in conventional systems, aggregation may have been caused by compression of soil particles without the mechanisms that usually contribute to aggregate stabilization (Cruz et al., 2003).

The pattern of GMD of the soil structural stability (Table 4) was similar to that observed for MWD. This showed the effect more clearly of the dense root system of grasses, which are the constituents of the native vegetation, on the stability of the soil aggregates subjected to cattle trampling and agricultural machinery traffic in the management systems, corroborating results reported by Souza et al. (2010a).

In relation to the ASI, the management systems studied were equal to NF except for NT + M (Table 4). The low efficiency of ASI in the response to the conversion of savanna-like native forest to agricultural production systems may be related to how this index is calculated.

The index is based on the <0.105 mm aggregate class only, which encompasses not only aggregates or sand (single grains) but also the clay scattered during the process of stirring the sample for sieving, which is not characterized as part of the aggregates (Wendling et al., 2005).

Unlike ASI, the AGRI, which is characterized by the percentage of aggregates larger than 2.0 mm (Table 4), was more sensitive in responding to the changes resulting from the different soil management systems adopted and from the NF, which corroborates the behavior observed by Wendling et al. (2005).

Soil organic matter

The data for Corg, Nstock, Cstock, qMIC and FDA ratio of the study sites are shown in Table 5. The soil Corg and Cstock contents were higher in ICL + S, ICL + P and NT + M than in CT and NF. However, N and Nstock were higher in ICL + S and NT + M than at the other sites. The values for the qMIC ratio were higher in NF than in ICL + S, ICL + P and NT + M. The FDA hydrolysis showed differences between the sites. The values for FDA hydrolysis decreased in the order of CT > ICL + S > ICL + P > NF and NT + M.

The higher Corg contents found in the systems ICL + S, ICL + P, and NT + M were due to the accumulation of plant residues on the soil surface (Table 5). This accumulation is caused by the absence of incorporation of these residues by tillage, as done in CT, which may decrease the mineralization rate. The absence of soil tillage also results in a greater presence of roots, which increases the input of carbon substrates into the system via root exudates, thus contributing to the occurrence of higher Corg concentrations in the management systems without soil tillage; a similar behavior was observed by Souza et al. (2010b).

The values of total nitrogen (N) were highest in ICL + S, followed by NT + M, which did not differ from ICL + S, but were comparable to ICL + P, CT, and NF (Table 5). The behavior of the soil carbon and nitrogen stocks (Cstock and Nstock) was similar to that observed for Corg and N levels. In different soil management systems in the Cerrado in Piauí, Matias et al. (2009) also observed a comparable behavior between the Corg and N contents and their soil stocks.

In the ICL + P and ICL + S systems, which differed significantly ($p < 0.05$) from the other systems, the Cstock values were also higher, followed by NT + M, NF and CT, respectively (Table 5). For Nstock, three groups were distinguished: ICL + S, tending to higher Nstock values; ICL + P and NT + M, with an intermediate performance, and NC and CT with smaller pools. Results similar to those obtained in this study were reported by Nicoloso et al. (2008), who studied the balance of organic carbon in an integrated crop-livestock system.

The properties organic carbon and nitrogen contents as well as their stocks were the clearest discriminators in the evaluation of the total variation between NF and the different management systems studied. This result contradicts reports that the microbial biomass is a more sensitive indicator of changes in the MOS levels than the soil organic C content (Gama-Rodrigues & Gama-Rodrigues, 2008; Carneiro et al., 2008).

However, Sampaio et al. (2008) reported that microbial C values are not always related to soil Corg, corroborating the behavior observed in this study, because the pattern of the microbial quotient (qMIC) differed from that of Corg (Table 5). According to Gama-Rodrigues & Gama-Rodrigues (2008), qMIC reflects the efficiency of the conversion of Corg into Cmic, as well as nutrient release capacity of soil organic matter.

The highest microbial quotient value, shown by CT in relation to ICL + S, ICL +P, and NT + M, may be due to the lower content of Corg observed in the soil under this system (Table 5). In the case of NF, having the highest microbial quotient suggests that Corg is available for the soil microbiota because the relation Cmic $Corg^{-1}$ is an indicator of organic matter availability for microorganisms and a high microbial quotient indicates that a very active organic matter subject to changes (Anderson & Domsch, 1990).

The highest FDA hydrolysis in CT could be related to increased biological activity caused by soil tillage, by liming and by fertilization, making the environment more favorable to the action of microorganisms by creating an environment with higher water content I the soil profile, better aeration, and increased nutrient availability (Souza et al., 2006). Also associated with the shorter period of implementation of this system than of the other systems studied (Table 2), this increased biological activity results in the rapid release of nutrients to the soil solution and loss of organic carbon in the soil in the long term (Matias et al., 2009). The FDA hydrolysis is an indicator of the total activity of heterotrophic microorganisms in the soil. In addition to the hydrolases, which are linked to the cycles of key elements in the soil such as C, N, P, and S, the microorganisms release lipases, proteases, and esterases to the soil. These enzymes are not specific and are involved in the degradation of many types of organic waste, which may have influenced the higher value of FDA hydrolysis in CT.

The management systems studied influenced ($p < 0.05$) Cmic significantly, resulting in a Cmic reduction in comparison with NF (Figure 1). The behavior of Nmic was similar to that of Cmic, and the CT management system had the lowest Nmic values. In the integrated crop-livestock system, Cmic had an intermediate behavior, without differing from the other systems with lower nor from those with higher value (NF). The Cmic content was highest in NF and statistically different from the treatments with lower contents (NT+M and CT). This trend of Cmic recovery in the integrated crop-livestock systems in relation to NF is probably associated with the fasciculated roots of the grasses, which are found mainly in the surface layer and that result in higher input of carbon into the soil via the rhizosphere and necromass, thus acting in the activation of the microbiota in the soil (Carneiro et al., 2008). Working with different sheep stocking rates, Garcia & Nahas (2007) found higher amounts of nitrogen immobilized by the microbial biomass in areas with grazing animals than in ungrazed areas. These different effects of N availability, possibly resulting from the excretion and urine of animals, were not observed in our study.

Microbial growth is often limited by the lack of nutrients in the soil, but the addition of carbon or nitrogen sources to the soil can increase the biomass and thus immobilize them in the cell construction (Graham et al., 2002). Corroborating the results found for Nmic in this study, Coser et al. (2007) observed no increase in Nmic by N addition to the soil in agricultural and forestry systems.

Multivariate analysis

The first three components explained 76% of the variance of the variables analyzed in different environments (Table 6). According to Carvalho Junior et al. (2008), determining a number of principal components that accumulate a percentage of explained variation of at least 70% is sufficient. The results of Splechtna & Klink (2001) for soil properties were similar, where PC1 and PC2 explained 60% of the total variation of the properties studied. Siqueira et al. (2010)

Table 5. Organic carbon (Corg), total nitrogen (N), carbon and nitrogen stocks (Cstock and Nstock), microbial quotient (qMIC) and enzyme activity (FDA) of a Yellow Latosol in the 0.0-0.05 m layer under different management systems. (1) ICL + S = integrated crop-livestock with soybean; ICL+P = integrated crop-livestock with continuous pasture grazing; NT+M = no-tillage with millet; CT = conventional tillage; NF = savanna-like native forest. (2) means followed by the same letter in columns do not differ from each other by the Tukey test at 5% probability.

Systems[1]	Corg	N	Cstock	Nstock	qMIC	FDA
	g kg^{-1}		Mg ha^{-1}		%	µg FDA g of $soil^{-1}$ h^{-1}
ICL + S	9.19a	0.89a	6.05ab	0.59a	1.23b	0.103b
ICL + P	8.69a	0.49b	6.44a	0.36ab	1.31b	0.097c
NT + M	8.31ab	0.63ab	5.23bc	0.40ab	1.03b	0.056e
CT	4.71c	0.29b	3.14d	0.19b	1.75ab	0.140a
NF	7.05b	0.40b	4.46c	0.24b	2.52a	0.094d
CV(%)	8.29	32.31	8.99	30.76	34.09	39.9

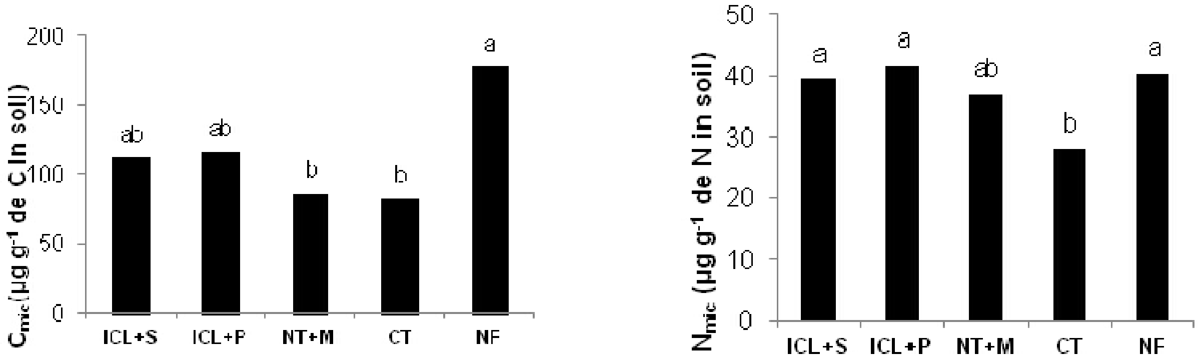

Figure 1. The microbial biomass carbon (Cmic) and microbial biomass nitrogen (Nmic) activity of a Yellow Latosol, under different management systems(1). (1) ICL+S = integrated crop-livestock with soybean; ICL+P = integrated crop-livestock with continuous pasture grazing; NT+M = no-tillage with millet; CT = conventional tillage; NF = savanna-like native forest.

reported that it is ideal to work with PCs with a weight of > 1. Among the evaluated properties, the physical characteristics (ASI, AGRI and GMD) were the best discriminators, positively correlated with PC1 (Table 6).
Thus, the higher the values on the PC1 axis, the higher were the values of these properties, confirming Araújo et al. (2010) about the importance of structural quality indicators to monitor soil quality under these managements. Thus, in studies addressing the impact of the studied systems on this type of environment, the properties AGRI, ASI, and GMD are the most suitable as response indicators (Figure 2), which shows the relationship between the different management systems and the properties of soil quality indicators for the principal components 1 and 2. For PC2, the chemical properties (CEC, Cmic and Corg) were the best discriminators, with positive correlations, also indicating the influence of the different systems on the chemical properties, mainly on soil carbon content. Silva et al. (2009) evaluated the physical, chemical and biological properties of an Oxisol in forest stands in the Cerrado region and found that the sensitivity of the biological properties and Corg to differentiate the systems was far higher than that of the physical and chemical properties, reinforcing the importance of including these properties in studies on environmental impacts and evaluation of soil quality.
In the environments 1, 2 and 3 (integrated crop-livestock with soybean, integrated crop-livestock with continuous pasture grazing and no-tillage with millet), the properties Corg, N, Nmic, Cstock and Nstock were most influential in distinguishing these environments and were clustered in a single group (Figure 1). In this group, the Nstock, Cstock, Corg, Nmic, N, density and pH properties were higher, while CT increased the FDA properties. Carneiro et al. (2009) studied the physical, chemical and biological properties of a Cerrado soil under different use and management systems and observed that conservation systems were not grouped together with the reference area, but had a higher increase of Corg and Cstock in the surface layer.
In environment 5 (savanna-like native forest), the values of AGRI, ASI, and GMD were higher, confirming previous results. Therefore, these properties can be used as indicators of changes in these environments. These results are important for future studies addressing the identification and mapping of areas with potential as integrated crop-livestock system and to determine the impact on the environment resulting from this management system.

CONCLUSIONS

The environments ICL + S and ICL + P were classified as a single group and can be characterized by the properties Corg, Cstock, Nmic, Nstock and N. The property that best characterizes the CT environment is FDA. The properties that best characterize NF are CEC, Cmic, Micro, ASI, GMD, and AGRI. Thus, these properties can be used as indices of sustainable production in integrated crop-livestock systems at similar locations.
The numerical classification using principal component analysis was useful to identify the properties that can be used as soil quality indicators for the management systems studied.

Table 6. Correlation of soil properties with the principal components (PC) and classification of scores of properties according to their contribution. Bd = bulk density (Mg m^{-3}); Micr = microporosity (m^3 m^{-3}); Macr = macroporosity (m^3 m^{-3}); AGRI = stable aggregate percentage >2.00 mm (mm); ASI = aggregate stability index (mm); GMD = geometric mean diameter; Corg = organic carbon (g kg^{-1}); N = total nitrogen (g kg^{-1}); Cstock = carbon stocks (Mg ha^{-1}); Nstock = nitrogen stocks (Mg ha^{-1}); Cmic = microbial biomass carbon; Nmic = microbial biomass nitrogen FDA = enzyme activity (µg FDA g of $soil^{-1}$ h^{-1}); pH = active acidity (pH in CaCl2); CEC = cation exchange capacity ($mmol_c$ dm^{-3}).

Properties	PC 1		PC 2		PC 3	
	Correlation	Order of Importance	Correlation	Order of Importance	Correlation	Order of Importance
Bd	-0.294	15	-0.283	11	0.827	1
Micr	0.741	4	0.324	10	0.084	14
Macr	0.312	14	0.007	15	-0.708	2
AGRI	0.902	2	0.113	14	0.235	7
ASI	0.829	3	0.195	12	0.101	12
GMD	0.919	1	0.151	13	0.187	10
Corg	-0.616	8	0.698	3	0.203	9
N	-0.600	9	0.519	8	-0.383	4
Cstock	-0.646	7	0.558	6	0.449	3
Nstock	-0.663	5	0.489	9	-0.267	5
Cmic	0.503	11	0.700	2	-0.100	13
Nmic	-0.321	13	0.647	4	0.250	6
FDA	0.342	12	-0.592	5	0.027	15
pH	-0.660	6	-0.534	7	-0.220	8
CEC	0.532	10	0.761	1	-0.156	11
Cumulative variance (%)	39.126	-	63.717	-	76.380	

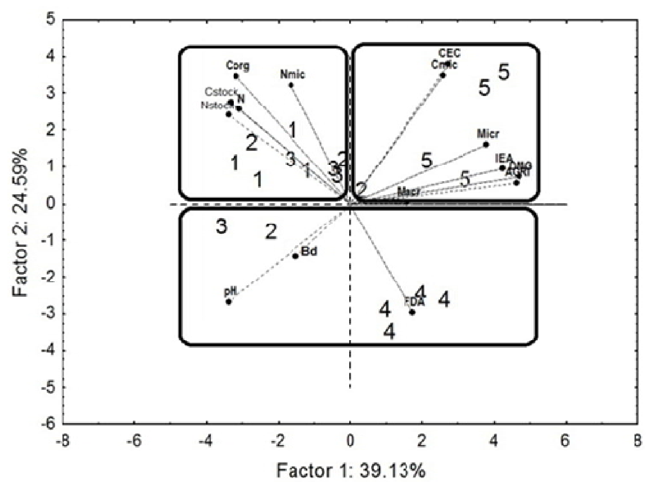

Figure 2 - Diagram of management systems and soil properties in the 0.00 - 0.05 m layer for the principal components 1 and 2. (1) ICL+S = integrated crop-livestock with soybean; (2) ICL+P = integrated crop-livestock with continuous pasture grazing; (3) NT+M = no-tillage with millet; (4) CT = conventional tillage; (5) NF = savanna-like native forest. Means followed by the same letter do not differ from each other by the Tukey test at 5% probability.

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