

Soil microbiological properties and available nitrogen for corn in monoculture and intercropped with forage

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Abstract – The objective of this work was to evaluate the effects of corn (*Zea mays*) in monoculture and intercropped with forage on soil microbiological properties and nitrogen availability under no-tillage in the Cerrado (Brazilian savanna). The experiment was carried out from the 2007/2008 to the 2010/2011 crop season, in a Latossolo Vermelho-Amarelo distrófico (Typic Haplustox). A randomized complete block design with three replicates was used, with the following treatments: corn in monoculture; corn intercropped with *Panicum maximum*; corn intercropped with *Urochloa humidicola*; *P. maximum* in monoculture; and *U. humidicola* in monoculture. Soil samples were taken at 0.00–0.05, 0.05–0.10, 0.10–0.20, and 0.20–0.30-m soil depths, in the beginning and in the end of the last crop season. The intercropping systems of corn increased soil nitrogen availability, but did not alter total nitrogen and organic carbon contents in the soil, when compared to corn in monoculture. Corn intercropped with *P. maximum* increased soil microbial biomass nitrogen and microbial nitrogen quotient, in comparison to corn in monoculture, as well soil as microbial biomass carbon in the surface soil layer, when compared to corn intercropped with *U. humidicola*.

Index terms: *Panicum maximum*, *Urochloa humidicola*, *Zea mays*, nitrogen microbial quotient, soil microbial biomass, soil quality.

Propriedades microbiológicas do solo e disponibilidade de nitrogênio para milho em monocultura e em consórcio com forrageiras

Resumo – O objetivo deste trabalho foi avaliar o efeito de cultivos de milho (*Zea mays*) em monocultura e consorciado com forrageiras nas propriedades microbiológicas de solo e na disponibilidade de nitrogênio, em plantio direto, no Cerrado. O experimento foi realizado nas safras de 2007/2008 até 2010/2011, em Latossolo Vermelho-Amarelo distrófico. Utilizou-se o delineamento de blocos ao acaso, com três repetições e os seguintes tratamentos: milho em monocultura; milho em consórcio com *Panicum maximum*; milho em consórcio com *Urochloa humidicola*; *P. maximum* em monocultura; e *U. humidicola* em monocultura. Amostras de solos foram retiradas nas profundidades de 0,00–0,05, 0,05–0,10, 0,10–0,20 e 0,20–0,30 m, no início e no final da última safra. Os cultivos consorciados de milho aumentaram o nitrogênio disponível no solo, mas não alteraram os conteúdos totais de nitrogênio e carbono orgânico, quando comparado ao cultivo do milho em monocultura. O consórcio de milho com *P. maximum* aumentou o nitrogênio da biomassa microbiana e o quociente microbiano de nitrogênio no solo, em comparação ao milho em monocultura, bem como o carbono da biomassa microbiana, na camada superficial do solo, quando comparado ao consórcio com *U. humidicola*.

Termos para indexação: *Panicum maximum*, *Urochloa humidicola*, *Zea mays*, quociente microbiano de nitrogênio, biomassa microbiana do solo, qualidade do solo.

Introduction

The adoption of no-tillage (NT) practices when intercropping forages with cash crops has great potential to improve soil quality through carbon sequestration, water and nutrient cycling, and improvement of soil biological diversity (Lemaire et al., 2014). The Cerrado (Brazilian savanna) biome is occupied with

approximately 26% of pasture lands, with several degrees of degradation (Sano et al., 2010), and accounts for 45% of corn production in the Midwest region of Brazil (Acompanhamento..., 2015). Therefore, the use of diversified systems in the Cerrado, such as cash crop-forage intercropping, should be encouraged and better understood.

Soil organic matter (SOM) is considered a key indicator of soil quality because it is the most important component of soil fertility in highly weathered soils (Lopes et al., 2013). Studies have reported increases in SOM under NT practices with intercropping of forages and cash crops, mainly due to higher inputs of plant residues, which can increase soil nutrient availability and soil C sequestration (Boeni et al., 2014). Increments in soil organic C are commonly related to improvements in chemical and biological properties (Araújo et al., 2007; Lopes et al., 2013).

Increases in soil microbial biomass (SMB), under NT, are well documented (Figueiredo et al., 2007; Ferreira et al., 2011). However, differences in plant residue quality and chemical composition may affect SMB growth (Ferreira et al., 2011; Cong et al., 2015), which, in turn, may be positively related to N (NO_3^- and NH_4^+) mineralization potential in the soil and, consequently, to its uptake by SMB (Burger & Jackson, 2003). Dourado-Neto et al. (2010) highlighted that, in tropical agroecosystems, soil N pool can provide up to 79% of the total N uptake by plants, showing the importance of SOM preservation and of plant residue inputs for N availability to crops.

To reduce environmental impacts on the Cerrado, one of the most threatened biomes in the world (Hunke et al., 2015), intercropping systems have been increasingly adopted. However, there is still a lack of information on the effects of different combinations of plant species on soil microbiota and on N availability in these systems for the Cerrado. Plant species differ in the way they allocate biomass and, therefore, in the quantity and quality of their residues (Carvalho et al., 2012), which may affect C input and the levels of N and microbial biomass in the soil.

The objective of this work was to evaluate the effects of corn (*Zea mays* L.) in monoculture and intercropped with forage on soil microbiological properties and N availability under no-tillage in the Cerrado (Brazilian savanna).

Materials and Methods

The experiment was conducted at the experimental farm of Universidade de Brasília, DF, Brazil (15°55'S, 47°51'W, at 1,080-m altitude). The climate, according to Köppen, is Aw, a seasonal tropical savanna, and the soil of the studied area is classified as a Latossolo

Vermelho-Amarelo distrófico, i.e., a Typic Haplustox. Prior to the experiment, in 2007, the following results were obtained from soil chemical and particle analyses, in the 0.0–0.20-m layer: 5.6 pH in water; 0.5 mg dm⁻³ P (Mehlich-1); 19.6 mg dm⁻³ K⁺; 0.9 cmol_c dm⁻³ Ca²⁺; 0.6 cmol_c dm⁻³ Mg²⁺; 4.6 cmol_c dm⁻³ H+Al; 0.2 cmol_c dm⁻³ Al³⁺; 32.5 g dm⁻³ organic matter; 525 g kg⁻¹ clay; 275 g kg⁻¹ silt; and 200 g kg⁻¹ sand.

Fifteen experimental plots were established in October 2007, in an area where *Andropogon gayanus* Kunth 'Planaltina' had been grown for a period of six years. Each plot had 80 m² (10x8 m), of which 48 m² were evaluated. The experiment consisted of the following treatments under NT: corn in monoculture; corn intercropped with *Panicum maximum* Jacq. 'Aruana'; corn intercropped with *Urochloa humidicola* (Rendle) Morrone & Zuloaga; *P. maximum* in monoculture; and *U. humidicola* in monoculture. A randomized complete block design, with three replicates, was used. The experimental plots were kept as previously described, and agricultural practices were repeated in the following cash crop seasons: 2007/2008, 2008/2009, 2009/2010, and 2010/2011.

In November 2010, prior to corn sowing, a herbicide mixture of glyphosate [N-(phosphonomethyl) glycine], with 1.08 kg ha⁻¹ a.i. (3 L ha⁻¹), and of 2,4-dichlorophenoxyacetic acid (2,4-D), with 1.1 kg ha⁻¹ a.i. (1.5 L ha⁻¹), was applied for forage and weed desiccation.

The early-maturing triple-cross corn hybrid 'BG7055' was sown in December 2010, in eight rows spaced 0.9 m apart, with six plants per meter, totaling 65,000 plants per hectare. For fertilization, 30 kg ha⁻¹ N, 100 kg ha⁻¹ P₂O₅, 70 kg ha⁻¹ K₂O, and 66 kg ha⁻¹ fritted trace elements (FTE) BR-12 were applied. Forty-four days after corn emergence, when plants had around eight leaves, 70 kg ha⁻¹ N were also applied in the form of ammonium sulfate.

The species *P. maximum* and *U. humidicola* were sown in the 2007/2008 and 2009/2010 seasons with 30 kg ha⁻¹ seed, considering the pure live seed percentage. The same procedure was adopted in the intercropping and monoculture plots. The seeds were sown in between corn rows, after corn seeding. The average amount of plant biomass (dry matter) produced by the *P. maximum* and *U. humidicola* forages in consortium, at the end of the 2009/2010 season, was 2.17 and 2.12 Mg ha⁻¹, respectively. In the

plots with monoculture forages, the obtained values were 1.74 Mg ha⁻¹ for *P. maximum* and 2.10 Mg ha⁻¹ for *U. humidicola*. The plots with monoculture forage received 60 kg ha⁻¹ P₂O₅ and 60 kg ha⁻¹ K₂O, and N was divided into two side-dressing doses of 30 kg ha⁻¹, totaling 60 kg ha⁻¹ N.

Soil samples were collected at the beginning (before corn planting) and at the end (after harvest) of the 2010/2011 crop season, in December 2010 and April 2011, respectively, at the depths of: 0.00–0.05, 0.05–0.10, 0.10–0.20, and 0.20–0.30 m. For each plot, 15 subsamples were collected at three locations within the plot. At each location, one sample was collected in the planting row and another four samples were collected in between corn rows (equidistant lines).

Total organic carbon (TOC) was determined by oxidation with potassium dichromate in the presence of acid without external heat source (Walkley & Black, 1934). Total soil nitrogen (TN) was estimated by the Kjeldahl method, according to Bremner & Mulvaney (1982).

To measure available N, the extraction method Na₃PO₄/borax buffer pH 11.2 + NO₃⁻ was used (Serra, 2006). Calculations were performed from the calibration curve obtained with the distillation of standard solutions containing 0, 15, 30, 45, and 60 µg mL⁻¹ N. The extracted N was determined by colorimetric spectrophotometry at 440 nm.

Microbial biomass nitrogen (MBN) was obtained with the method of chloroform fumigation-extraction, described by Brookes et al. (1985) and Vance et al. (1987), using a correction factor of 0.54 (Wardle, 1994), and the microbial nitrogen quotient (qMIN) was determined by the ratio between MBN and TN. In addition, microbial biomass carbon (MBC) was calculated according to Vance et al. (1987), using a correction factor of 0.38 (Wardle, 1994), whereas the microbial carbon quotient (qMIC) was obtained by the ratio between MBC and TOC.

Data were subjected to the analysis of variance, and the means were compared by Tukey's studentized range test, at 5% probability. Data from all treatments, depths, and sampling periods were further analyzed with Pearson's linear correlation analysis. Analyses were performed using the Sisvar software, version 5.3 (Universidade Federal de Lavras, Lavras, MG, Brazil).

Results and Discussions

The corn/*U. humidicola* intercropping provided the highest contents of TOC and TN in the 0.00–0.05-m soil layer, whereas *U. humidicola* in monoculture, the lowest ones (Figure 1). These results indicate the benefits of integrating this forage with corn, with increases of 13% in TOC and 9% in TN in the uppermost soil layer, when compared to sole *U. humidicola*. Corn fertilization may have increased forage root development – which, in some species, can reach up to 4 Mg ha⁻¹ in the 0.00–0.40-m layer (Saraiva et al., 2014) – and affected soil TOC and TN. Moreover, under NT systems, corn roots, which are more concentrated in surface soil layers (Silva et al., 2000), together with the deposition of plant residues, may have also contributed to increases in TOC and TN. It should be noted, that although the enhanced levels of TN may also be attributed to N fertilization in corn, the simultaneous increase in TOC suggests the possibility of synergy between C and N, whereby C sequestration enhances N sequestration, and vice versa (Cong et al., 2015). Diógenes et al. (2013) found higher TOC values for corn intercropped with *U. ruziziensis*, when compared to this forage in monoculture.

Four years after the establishment of the experiment, no differences were found in TOC content between *U. humidicola* and *P. maximum*, nor between the intercropping systems and corn in monoculture. The largest compartment of organic C, approximately 67%, in Oxisols in the Cerrado region is allocated in organomineral complexes, an interaction that minimizes microbial attack and decomposition, reducing the turnover rate of organic matter (Boemi et al., 2014). This may explain the lack of significant differences between some of the management systems. Changes in C concentration from particulate organic matter, which accounts for 33% of TOC and plays a very important role in biological activity, are more evident following shifts in soil management and cropping systems (Coser et al., 2012; Boeni et al., 2014).

The corn/*P. maximum* intercropping system showed the highest soil N availability (AN) in the 0.00–0.05-m layer and prior to corn planting, followed by corn/*U. humidicola*, *P. maximum*, corn, and *U. humidicola* (Table 1). Corn/*P. maximum* also increases C content of the particulate organic matter fraction, indicating that this may be the reason for higher AN under this system (Burger & Jackson, 2003; Coser et al., 2012).

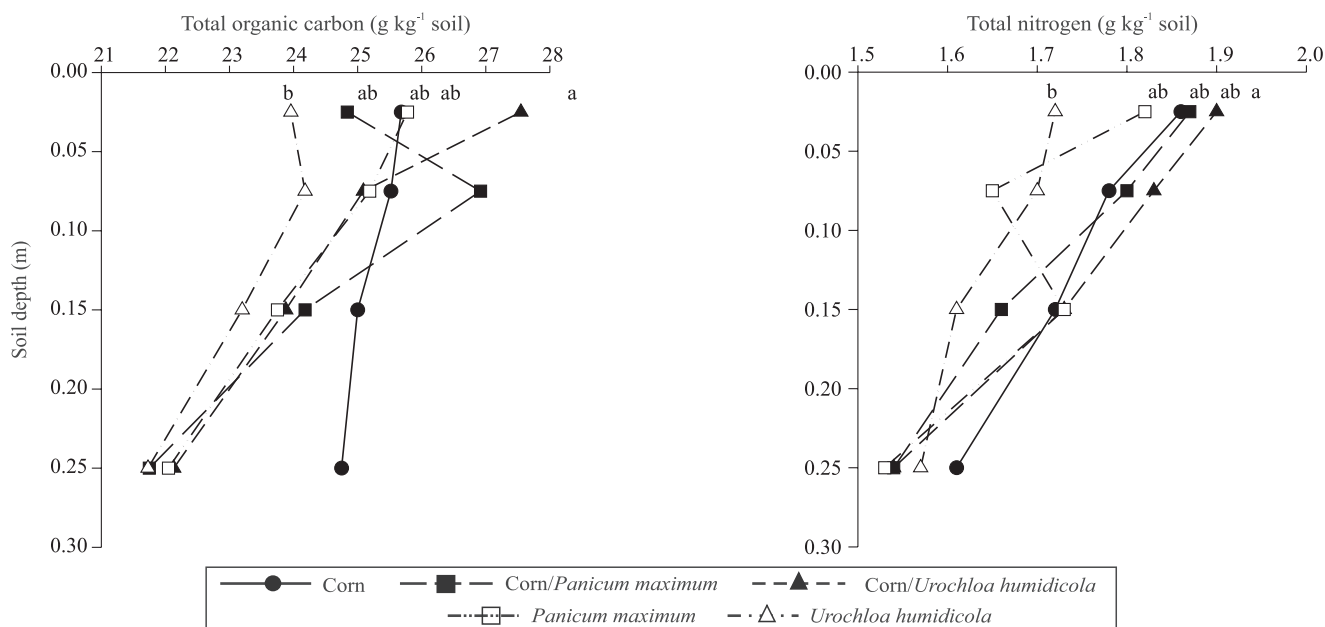


Figure 1. Total organic carbon and nitrogen in soil under monoculture of corn (*Zea mays*), *Panicum maximum*, and *Urochloa humidicola*, as well as under integrated systems with these species, at different soil depths. Means followed by equal letters do not differ by Tukey's test, at 5% probability.

Table 1. Available nitrogen and its relation to total nitrogen in soil under monoculture of corn (*Zea mays*), *Panicum maximum*, and *Urochloa humidicola*, as well as under integrated systems with these species, at different soil depths, in two sampling periods: before planting of corn and after corn harvest⁽¹⁾.

Cropping system	Available nitrogen (mg kg ⁻¹)		Available nitrogen/ Total nitrogen (%)	
	Before planting corn	After corn harvest	Before planting corn	After corn harvest
0.0–0.05 m				
Corn	50.42bA	54.10aA	2.87aA	2.80aA
Corn/ <i>Panicum maximum</i>	71.12aA	53.33aB	3.78aA	2.89aB
Corn/ <i>Urochloa humidicola</i>	68.93aA	53.42aB	3.84aA	2.69aB
<i>Panicum maximum</i>	67.54aA	59.21aA	3.72aA	3.24aA
<i>Urochloa humidicola</i>	48.76bA	59.42aA	2.82aA	3.50aA
0.05–0.10 m				
Corn		58.81a		3.30a
Corn/ <i>Panicum maximum</i>		54.00a		3.00a
Corn/ <i>Urochloa humidicola</i>		54.37a		3.00a
<i>Panicum maximum</i>		55.88a		3.39a
<i>Urochloa humidicola</i>		56.78a		3.36a
Sampling periods	59.24A	52.70B	3.37A	3.05A
0.10–0.20 m				
Corn		58.05a		3.39a
Corn/ <i>Panicum maximum</i>		57.53a		3.46a
Corn/ <i>Urochloa humidicola</i>		53.60a		3.12a
<i>Panicum maximum</i>		52.94a		3.08a
<i>Urochloa humidicola</i>		51.05a		3.17a
Sampling periods	55.06A	54.21A	3.25A	3.23A
0.20–0.30 m				
Corn		52.92a		3.94a
Corn/ <i>Panicum maximum</i>		45.43a		2.96a
Corn/ <i>Urochloa humidicola</i>		41.64a		2.75a
<i>Panicum maximum</i>		48.15a		3.17a
<i>Urochloa humidicola</i>		52.50a		3.36a
Sampling periods	49.43A	46.83A	3.30A	2.91B

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

Furthermore, 78% of the mineralizable N in the soil depends on the size and fraction proportions of SOM (Ros et al., 2011).

The content of available N under the intercropping systems decreased from the beginning to the end of the season, possibly indicating net N mineralization of N-organic forms during the rainy season or uptake of N (NO_3^- -N and NH_4^+ -N) by the plants during this period.

Considering all the cropping systems, depths, and sampling periods, the percentage of AN compared to TN (AN/TN) ranged from 2.75 to 3.94%, with no significant differences (Table 1). These ranges indicate that only a small fraction of TN is easily decomposable by soil microorganisms.

MBN ranged from 10.47 to 48.31 mg kg⁻¹, which represented between 0.67 and 2.79% of TN (Table 2). Corn/*P. maximum* showed the highest soil MBN in the 0.00–0.05-m layer, prior to corn sowing, which was significantly higher than that of the sole cropping

systems (Table 2). The species *U. humidicola* and *P. maximum* in monocultures did not differ from each other regarding MBN and qMIN, in the 0.00–0.05 m layer. The introduction of *P. maximum* as an intercrop in corn production systems favors SMB growth in this soil layer. Higher qMIN and MBN in the corn/*P. maximum* intercropping system may represent higher N cycling efficiency and availability in short-term periods (Xavier et al., 2006).

After corn harvest, corn/*U. humidicola* showed higher MBN and qMIN in the 0.00–0.05-m layer than corn in monoculture. This may be explained by root exudates released by *U. humidicola*, which inhibit soil nitrification (Subbarao et al., 2006) and may reduce N losses in the form of NO_3^- -N, increasing soil microbial biomass N. The soil nitrification process under *P. maximum* was between 47–73% lower than under *U. humidicola* (Ipinmoroti et al., 2008).

Table 2. Microbial biomass nitrogen and microbial nitrogen quotient (qMIN) in soil under monoculture of corn (*Zea mays*), *Panicum maximum*, and *Urochloa humidicola*, as well as under integrated systems with these species, at different soil depths, in two sampling periods: before planting of corn and after corn harvest⁽¹⁾.

Cropping system	Microbial biomass nitrogen (mg kg ⁻¹)		qMIN (%)	
	Before planting corn	After corn harvest	Before planting corn	After corn harvest
0.00–0.05 m				
Corn		27.71b		1.51b
Corn/ <i>Panicum maximum</i>		48.31a		2.59a
Corn/ <i>Urochloa humidicola</i>		34.99ab		1.88ab
<i>Panicum maximum</i>		27.96b		1.54b
<i>Urochloa humidicola</i>		33.97b		1.98ab
Sampling period	36.31A	32.87B	2.02A	1.77B
0.05–0.10 m				
Corn	28.90abA	25.63bA	1.56abA	1.49bA
Corn/ <i>Panicum maximum</i>	20.69bB	33.26abA	1.16bB	1.85bA
Corn/ <i>Urochloa humidicola</i>	38.79aA	41.30aA	2.22aA	2.15abA
<i>Panicum maximum</i>	25.08abB	36.39abA	1.49abB	2.27aA
<i>Urochloa humidicola</i>	24.54bB	45.19aA	1.42bB	2.71aA
0.10–0.20 m				
Corn	14.57bB	30.77aA	0.82bB	1.87aA
Corn/ <i>Panicum maximum</i>	29.46abB	45.17aA	1.73abB	2.79aA
Corn/ <i>Urochloa humidicola</i>	20.47bB	45.97aA	1.23abB	2.57aA
<i>Panicum maximum</i>	42.29aA	31.54aA	2.50aA	1.85aA
<i>Urochloa humidicola</i>	12.50bB	33.46aA	0.79bB	2.06aA
0.20–0.30 m				
Corn	21.47aB	30.70bA	1.40aB	1.84bA
Corn/ <i>Panicum maximum</i>	20.93aB	27.31bA	1.39aA	1.74bA
Corn/ <i>Urochloa humidicola</i>	26.05aA	24.81bA	1.85aA	1.50bA
<i>Panicum maximum</i>	21.18aB	27.84bA	1.44aA	1.75bA
<i>Urochloa humidicola</i>	10.47bB	40.56aA	0.67bB	2.58aA

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

Comparing the tropical forages, MBN and qMIN were higher under *P. maximum* in the 0.10–0.20 and 0.20–0.30-m soil layers, prior to corn planting. However, after corn harvest, *U. humidicola* showed greater MBN and qMIN than *P. maximum*, possibly due to the nitrification inhibitors released by this forage.

MBC ranged from 74.73 to 248.9 mg kg⁻¹ (Table 3). Considering the interpretative classes for microbial indicators in a clayey Oxisol in the Cerrado region (Lopes et al., 2013), the MBC values in the 0.00–0.05 and 0.05–0.10-m layers varied from low to moderate.

The amount of MBC obtained under corn/*P. maximum* (248.9 mg kg⁻¹ soil) was almost twice as

high as with corn/*U. humidicola* (127.2 mg kg⁻¹ soil). Since both forages produced similar amounts of shoot dry matter in the 2009/2010 season (2.12 and 2.17 Mg ha⁻¹, respectively), the higher MBC under corn/*P. maximum* may be related to the quality of its residues, including lower C:N ratios and lignin contents. Plant litter quality can explain decomposition rates and the release of nutrients to the soil, affecting the levels of MBC (Carvalho et al., 2012).

When both forages were compared as a monoculture, *P. maximum* had higher MBC in the 0.10–0.20-m layer. Lopes et al. (2010) reported that MBC is greater under *P. maximum* pastures than in those with *Urochloa* spp., in the 0.00–0.10-m layer. These authors associated the higher content of MBC in *P. maximum* pastures with greater amounts of shoot dry matter and released exudates, when compared to *Urochloa* spp. However, in the present study, the amounts of shoot dry matter produced by both forages were similar and, therefore, the greatest MBC values should be related to root exudates and to the chemical composition of *P. maximum* litter.

Comparing sampling periods, MBC ranged from 119.6 to 172 mg kg⁻¹, prior to corn planting, and from 137.8 to 199.7 mg kg⁻¹ after corn harvest. However, differences between sampling periods were only significant between the layers at 0.05–0.20-m soil depths, in which MBC was greater after corn harvest (Table 3). As also observed for TOC, higher MBC after corn harvest may be associated with the decomposition of plant residues and to nutrient mineralization, which would provide nutrients to SMB during the corn growing season.

The ratio of biomass C to soil organic C (qMIC) reflects the contribution of microbial biomass to soil organic C and, therefore, indicates the quality of SOM (Wardle, 1994). Differences in qMIC among cropping systems were found up to 0.20-m depth (Table 3), with values ranging from 1.03 to 0.33%. As also verified for MBC, corn/*P. maximum* showed greater qMIC than corn/*U. humidicola* in the 0.00–0.05 and 0.10–0.20-m layers. Therefore, corn/*P. maximum* seems to be more efficient in converting TOC in MBC than corn/*U. humidicola* (Wardle, 1994).

Despite the similarity in the values of qMIN and AN/TN, the lack of correlation between AN and MBN may be an indication that the AN pool is a distinct fraction of MBN (Table 4). However, it is important

Table 3. Microbial biomass carbon (MBC) and microbial carbon quotient (qMIC) in soil under monoculture of corn (*Zea mays*), *Panicum maximum*, and *Urochloa humidicola*, as well as under integrated systems with these species, at different soil depths, in two sampling periods: before planting of corn (BPC) and after corn harvest (ACH)⁽¹⁾.

Cropping system	MBC (mg kg ⁻¹)		qMIC (%)	
	BPC	ACH	BPC	ACH
0.00–0.05 m				
Corn	193.2ab		0.75ab	
Corn/ <i>Panicum maximum</i>	248.9a		1.03a	
Corn/ <i>Urochloa humidicola</i>	127.2b		0.45b	
<i>Panicum maximum</i>	210.7ab		0.84ab	
<i>Urochloa humidicola</i>	149.3b		0.64ab	
Sampling period	172.0A	199.7A	0.73A	0.76A
0.05–0.10 m				
Corn	167.4ab		0.65ab	
Corn/ <i>Panicum maximum</i>	173.7ab		0.66ab	
Corn/ <i>Urochloa humidicola</i>	202.2a		0.82a	
<i>Panicum maximum</i>	126.8b		0.51b	
<i>Urochloa humidicola</i>	141.1ab		0.60ab	
Sampling period	138.3B	186.1A	0.57A	0.72A
0.10–0.20 m				
Corn	151.3ab		0.61ab	
Corn/ <i>Panicum maximum</i>	187.0a		0.78a	
Corn/ <i>Urochloa humidicola</i>	122.1bc		0.53bc	
<i>Panicum maximum</i>	159.0ab		0.69ab	
<i>Urochloa humidicola</i>	85.34c		0.37c	
Sampling period	127.3B	154.6A	0.58A	0.62A
0.20–0.30 m				
Corn	180.0a		0.72a	
Corn/ <i>Panicum maximum</i>	74.73b		0.33a	
Corn/ <i>Urochloa humidicola</i>	107.9ab		0.55a	
<i>Panicum maximum</i>	130.7ab		0.61a	
<i>Urochloa humidicola</i>	150.3a		0.72a	
Sampling period	119.6A	137.8A	0.60A	0.58A

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

Table 4. Pearson's correlation coefficient between microbial biomass nitrogen (MBN), total nitrogen (TN), MBN/TN (qMIN), available N (AN), microbial biomass carbon (MBC), total organic carbon (TOC), and MBC/TOC (qMIC) in soil under monoculture of corn (*Zea mays*), *Panicum maximum*, and *Urochloa humidicola*, as well as under integrated systems with these species, at different soil depths.

Variable	TN	qMIN	AN	MBC	TOC	qMIC
MBN	0.23**	0.96***	0.08 ^{ns}	0.39***	0.09 ^{ns}	0.33***
TN	-	-0.02 ^{ns}	0.27*	0.40***	0.45***	0.20*
qMIN		-	0.01 ^{ns}	0.29**	-0.02 ^{ns}	0.29**
AN			-	0.20*	0.04 ^{ns}	0.19*
MBC				-	0.20*	0.90***
TOC					-	-0.21*
qMIC						-

^{ns}Nonsignificant. ** and ***Significant at 1 and 0.1% probability, respectively.

to outline that SMB may have mineralized AN during the corn growing season, as it decreased between sampling periods. Therefore, SMB was shown to be a source of N, rather than a sink. Significant correlations were observed between AN and TN. Yagi et al. (2009) reported that TN was the best indicator of soil N mineralization potential.

The results obtained in the present study, in a four year experiment, show that the effects of tropical forages intercropped with corn, under NT system, on soil N, C, and soil microbiological properties are mostly seen on the surface soil layer, where, in general, the presence of *P. maximum* represented an interesting alternative for intercropping, since it increases N and MBN availability in the soil. Increases in soil C, N, and microbial biomass may further benefit soil fertility and productivity of intercropping systems in the Brazilian Cerrado.

Conclusions

1. Intercropping systems of corn (*Zea mays*) with the evaluated tropical forages increase soil available nitrogen to the cash crop, microbial biomass carbon and nitrogen, and microbial nitrogen quotient, when compared to monocultures, especially in the 0.00–0.05-m soil layer.

2. *Panicum maximum* provides greater stimulation of soil microbial biomass than *Urochloa humidicola*, which results in increased soil nitrogen availability.

3. The intercropping system with corn increases the capacity of *U. humidicola* to accumulate carbon and nitrogen in the 0.00–0.05-m soil layer.

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