



ORIGINAL ARTICLE

Larissa Castro Diógenes^{1*}
Júlio César Azevedo Nóbrega¹
Rafaela Simão Abrahão Nóbrega¹
Aderson de Sousa Andrade Júnior²
Rossanna Barbosa Pragana³
Sammy Sidney Rocha Matias¹

¹Universidade Federal do Piauí – UFPI, Campus
Universitário Professora Cinobelina Elvas – CUPCE,
Rod. Bom Jesus-Viana, Km 01, Planalto Cibrazem,
64900-000, Bom Jesus, PI, Brasil

²Embrapa Meio-Norte, Av. Duque de Caxias, 5650,
Buenos Aires, 64006-22, Teresina, PI, Brasil

³Universidade Federal Rural de Pernambuco – UFRPE,
Unidade Acadêmica de Serra Talhada – UAST,
Fazenda Saco, s/n, 56900-000,
Serra Talhada, PE, Brasil

Autor Correspondente:

*E-mail: larissa.diogenes@hotmail.com

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PALAVRAS-CHAVE

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Lâminas de irrigação
Zea mays

Microbial attributes and carbon and nitrogen stocks in Latosol under irrigated monocropping and intercropping

Atributos microbianos e estoques de carbono e nitrogênio em Latossolo sob monocultivo e consórcio irrigados

ABSTRACT: Monocropping and intercropping maize and pasture irrigated areas in promoting changes in soil biological attributes, however, little is known about these changes in environments ecotone between Cerrado and Caatinga. The aim of the study was to evaluate microbial attributes and carbon and nitrogen stocks in dystrophic yellow Latosol soil under monocropping of maize and brachiaria and intercropping of these cultures under two irrigation blades. The study was conducted in the Alvorada do Gurgéia city, Piauí State, Brazil, during the year of 2009, the treatments consisting of three production systems (monocropping of maize and brachiaria and intercropping between maize and brachiaria), under two irrigation blades ($L_1 = 647.9$ e $L_2 = 564.5$ mm) e two soil depths (0-0.10 and 0.10-0.20 m). The variables analyzed were microbial biomass, basal respiration, microbial quotient, metabolic quotient, the contents of total organic carbon, the nitrogen and carbon and nitrogen stocks. Biological attributes of the soil are influenced by monocropping and intercropping of maize and brachiaria, irrigation blades and soil depth. The blades of irrigation, by influencing the water content in the soil, have greater effect on the microbial attributes, may occur individually, as in the case of microbial carbon, or associated production systems of maize and brachiaria under intercropping or monocropping, as detected for of total organic carbon, microbial and metabolic quotient, nitrogen content and carbon and nitrogen stocks.

RESUMO: *Monocultivos e consórcio de milho e braquiária em áreas irrigadas promovem modificações nos atributos biológicos do solo; no entanto, pouco se conhece sobre essas alterações em ambientes de ecótono entre Cerrado e Caatinga. O objetivo deste trabalho foi avaliar atributos microbianos e estoques de carbono e nitrogênio em Latossolo Amarelo Distrófico sob monocultivos de milho e braquiária, e consórcio destas culturas sob duas lâminas de irrigação. O estudo foi desenvolvido no município de Alvorada do Gurgéia, Estado do Piauí, durante o ano de 2009, sendo os tratamentos constituídos por três sistemas de produção (monocultivos de milho e braquiária, e consórcio entre milho e braquiária), duas lâminas de irrigação ($L_1 = 647,9$ e $L_2 = 564,5$ mm) e duas profundidades de solo (0-0,10 e 0,10-0,20 m). As variáveis analisadas foram o carbono da biomassa microbiana, a respiração basal, o carbono orgânico total, o quociente microbiano, o quociente metabólico, o teor de nitrogênio e os estoques de carbono e nitrogênio. Os atributos biológicos do solo são influenciados pelo monocultivo e pelo consórcio de milho e de braquiária, pelas lâminas de irrigação e pela profundidade do solo. As lâminas de irrigação, por influenciarem o conteúdo de água no solo, exercem maior efeito sobre os atributos microbianos, podendo tal efeito ocorrer de forma individual, como no caso do carbono microbiano, ou associado aos sistemas de produção de milho e braquiária sob consórcio ou monocultivo, como no caso do carbono orgânico total, do quociente microbiano e metabólico, do teor de nitrogênio e dos estoques de nitrogênio e carbono.*

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1 Introduction

Population and activity increases of the edaphic microbial community determine the intensity of biochemical processes in the soil. Thus, studies on microbiological attributes have been carried out (LOURENTE et al., 2010; KASCHUK; ALBERTON; HUNGRIA, 2011; PRAGANA et al., 2012). Biomass is the living part of soil organic matter including bacteria, fungi, actinomycetes, protozoa and microfauna (FIGUEIREDO et al., 2007) that control the accumulation and decomposition of soil organic matter and transformations involving mineral nutrients. Therefore, it is an important ecological component acting as both source and reserve of nutrients (GAMA-RODRIGUES; GAMA-RODRIGUES, 2008). Besides soil microbial biomass, microbial activity is another main indicator of biological quality that varies according to soil management practices and use conditions (LOURENTE et al., 2010; SILVA et al., 2010; REIS et al., 2011). However, according to Parkin, Doran and Francop-Vizcaíno (1996), result interpretation of soil biological activity must be carefully carried out, as high respiration values not always indicate unfavorable conditions, because they may indicate, in the short term, nutrient release to plants, and in the long term, soil organic carbon loss to the atmosphere.

In the past years, the crop-livestock integration system has grown in Brazil, mainly in the Cerrado region. Because it ensures high residue inputs and organic matter accumulation in the soil (LISBOA et al., 2012), the use of crop-livestock integration system may result in sharp changes in physical, chemical and biological attributes that are useful for determining, in the short term, positive or negative effects on soil quality and sustainability of agricultural practices (CUNHA et al., 2011; PRAGANA et al., 2012).

In the state of Goiás, Silva et al. (2007), working with cover crops, obtained basal soil respiration between 1.8 and 12.4 mg kg day⁻¹ of C with brachiaria monocropping and between 0.9 and 9 mg kg day⁻¹ of C with brachiaria-corn intercropping. Regarding the metabolic quotient (qCO_2), they found values between 0.008 and 0.033 mg C-CO₂ mg⁻¹ MBC day⁻¹ for brachiaria monocropping and between 0.005 and 0.023 mg C-CO₂ mg⁻¹ MBC day⁻¹ for the intercropping system.

For the implementation of crop-livestock integration systems, the use of brachiaria intercropped with corn has become one the simplest and most practical alternatives to enable recovery of pasture and degraded soil. As intercropping is the planned cultivation of two or more species in the same area, increased phytomass yield per area is an important aspect of this system, an important fact for maintenance of soil physical, chemical and biological attributes (CECCON, 2007).

Although the effects of monocropping and intercropping with grasses on carbon and nitrogen stocks and microbiological attributes have been reported in some regions of the country (SILVA et al., 2007, 2010; SOUZA et al., 2010), there are few studies on this matter in the state of Piauí, especially in ecotone environments between cerrado and caatinga biomes. The purpose of this study was to evaluate microbial attributes and carbon and nitrogen stocks in Latosol under corn and brachiaria monocropping and intercropping at two irrigation depths.

2 Materials and Methods

This work was carried out at the 'Embrapa Meio-Norte' Experimental Unit located at 08° 25' 28" S and 43° 46' 38" W, 280 m above sea level, in the municipality of Alvorada do Gurguéia, southwest region of Piauí state, 450 km away from the state capital, Teresina, in 2009.

According to Thornthwaite & Mather classification, the region presents dry sub-humid megathermic climate with small water surplus (ANDRADE JÚNIOR et al., 2005). Average annual rainfall is defined by the Equatorial Continental Regime with annual isohyets from 700 to 1,200 mm. The rainy season occurs from November to December and from March to April and the months of January, February and March form the wettest quarter of the year, with temperatures ranging between 26 and 36 °C.

The experimental area presents plan to soft-wavy relief with soil classified as medium texture Dystrophic Yellow Latosol. The area was covered by native caatinga vegetation until 2006. It was cultivated with castor bean plants in the agricultural years of 2007 and 2008. Two months before the experiment deployment, soil samples were collected by Silva (2011b) for chemical and physical hydric characterization at 0 to 0.20 m depth (Tables 1 and 2).

OM = organic matter; P = available phosphorus; Exchangeable K⁺, Ca²⁺, Mg²⁺ and Al³⁺; H+Al = potential acidity; =sum of bases; T = cation-exchange capacity at pH 7.0; V = percent base saturation; m = aluminum saturation.

Table 1. Soil physical-hydric properties of the study area before experiment deployment in Alvorada do Gurguéia, state of Piauí.

Sand	Silt	Clay	Ds	FC	PWP	AWC
g kg ⁻¹			Mg m ⁻³	%		
864	25	110	1.52	13.54	7.72	11.64

Ds- soil density; FC – field capacity (10 kPa); PWP – permanent wilting point (1500 kPa); AWC – available water capacity. Source: Data generated in the Soil Laboratory – 'Embrapa Meio-Norte', presented by Silva (2011b).

Table 2. Soil chemical properties of the study area before experiment deployment in Alvorada do Gurguéia, state of Piauí.

pH	OM	P	K ⁺	Ca ²⁺	Mg ²⁺	Na ⁺	Al ³⁺	H+Al	SB	T	V	m
H ₂ O	g kg ⁻¹	mg dm ⁻³	cmol _c dm ⁻³						%			
6.66	4.62	5.50	0.08	1.58	0.71	0.01	0.00	1.02	2.38	3.39	70.24	0.00

OM = organic matter; P = available phosphorus; Exchangeable K⁺, Ca²⁺, Mg²⁺ and Al³⁺; H+Al = potential acidity; SB = sum of bases; T = cation-exchange capacity at pH 7.0; V = percent base saturation; m = aluminum saturation. Source: Data generated in the Soil Laboratory – 'Embrapa Meio-Norte', presented by Silva (2011b).

We adopted an experimental design in randomized blocks, with four replications, split-plot in ($3 \times 2 \times 2$) factorial: three management systems (brachiaria and corn monocropping and brachiaria-corn intercropping) randomly arranged in the blocks; two irrigation depths ($L_1 = 647.9$ mm and $L_2 = 564.5$ mm) arranged in strips in the blocks and two soil collection depths (0-0.10 and 0.10-0.20 m), in a total of 48 experimental plots. Ten simple soil samples were collected from each treatment to form the composite sample, which was repeated three times in each plot, totaling 144 samples.

Experimental plots were 12 m \times 24 m, 288 m² total plot area. The plots that received corn monocropping presented 15 rows spaced by 0.8 m. The plots that received brachiaria monocropping and those that received corn-brachiaria intercropping presented 30 rows spaced by 0.4 m. Crop area of all plots was 95 m². The spatial arrangement used in the intercropping system presented a fixed 1:1 ratio - a row of corn to a row of brachiaria. Conventional soil tillage was used with one mowing and two cross disking processes (plow and grader). Corn (BRS 1030 simple hybrid) was sowed manually, leaving five plants per linear meter after thinning, for both monocropping and intercropping. Brachiaria was sown in 0.05 m deep furrows with density equivalent to 12 kg ha⁻¹ of seeds, mixed with triple superphosphate 23 days after the corn sowing (DAS), in stage of five to six leaves. Fertilization of corn and brachiaria planting in monocropping and intercropping was performed according to soil analysis (Tables 1 and 2) and crop necessities. For the corn planting, fertilization was as follows: 40 kg ha⁻¹ of N (urea); 160 kg ha⁻¹ of P₂O₅ (superphosphate); 30 kg ha⁻¹ of K₂O (potassium chloride) and 5 kg ha⁻¹ of Zn (zinc sulfate). For the brachiaria planting fertilization, one third of the single superphosphate was applied mixed with the grass seeds (SILVA et al., 2008). Potassium chloride and urea were applied after brachiaria sowing, mixed with the two-thirds left of the single superphosphate. Topdressing of corn was performed in two stages: first, at the sprouting of the fourth leaf (24 DAS), using 40 kg ha⁻¹ of N and 15 kg ha⁻¹ of K₂O; and the second, after the sprouting of the eighth leaf (37 DAS), with the same nutrient sources and dosage. For brachiaria, topdressing occurred 15 DAS, using 60 kg ha⁻¹ of N and 30 kg ha⁻¹ of K₂O.

Weeds were controlled through hoeing and corn thinning was performed in order to leave only five plants per linear meter. For pest control (fall armyworm), three sprays were performed using a knapsack sprayer (20 liters) with *Lufenuron*-based pesticide at the ratio of 30 mL of the commercial product per 20 liters of water.

Irrigation was carried out by means of fixed conventional sprinkler system comprising two sidelines installed at 12 \times 12 m spacing operating simultaneously. The PVC sidelines were 50 mm nominal diameter and 78 m long. Each sideline held seven sprinklers with two 4.2 \times 3.2 mm nozzles, 12 m operating range, 1.80 m³ h⁻¹ flow rate and 250 KPa operating pressure. The experimental block was covered by six sprinklers, three on each sideline.

During the experiment, the mean values of the irrigation depths applied were measured with the use of nine collectors, installed in each experimental block, in a total of 27 collectors distributed along three central lines parallel to the sprinklers.

Run time was calculated with the aid of an electronic spreadsheet in the Excel[®] Microsoft software, where daily mean values for rainfall and reference evapotranspiration were recorded, with the latter estimated by the Penman–Monteith method (ALLEN et al., 2006) based on daily climatic data from the automatic weather station located in the Experimental Unit approximately 100 m away from the site where the experiment was implemented.

In November 2009, the corn was harvested and the total amount of water accumulated in each irrigation depth was determined: depth one (L_1) received 647.9 mm and depth two (L_2) 564.5 mm of water. Then soil samples were collected for microbial evaluation at the depths of 0-0.10 and 0.10-0.20 m, with an auger, which was flamed between treatments to avoid contamination. Next, the soil samples were transported to the laboratory, sifted through a 2 mm mesh sieve and stored for five days in refrigerator at 4 °C until evaluation at the Laboratory of Biosciences, ‘Bom Jesus’ Campus, Federal University of Piauí - UFPI. In order to determine basal soil respiration rates (CO₂), sample humidity was corrected to 70% of field capacity (Table 1). Subsequently, the mass of evolved CO₂ based on 20 g of soil incubated for 72 h was determined with the use of NaOH 0.05 mol L⁻¹ solution titrated with HCl 0.05 mol L⁻¹ (ALEF; NANNIPIERI, 1995). Microbial biomass carbon (MBC) was estimated by the microwave irradiation-extraction method (MENDONÇA; MATOS, 2005) and total organic carbon (TOC) was determined by colorimetry according to Quaggio et al. (1987). Soil microbial quotient ($qMBC$) was calculated by the ratio between MBC and TOC of the soil (SPARLING, 1992), and microbial metabolic quotient (qCO_2) was determined by the ratio between the soil CO₂ rate per MBC unit (ANDERSON; DOMSCH, 1993). Determination of nitrogen was performed by steam distillation with the Kjeldahl method adapted by Tedesco et al. (1995). Organic carbon and total nitrogen stocks were calculated, respectively, according to Leite et al. (2003) through the following expressions (Equation 1):

$$Cst = (TOC \times Ds \times t) \quad (1)$$

where: Cst is total organic carbon stock at a certain depth; TOC is total organic carbon content; Ds is soil density at each depth; and “t” is thickness of the layer under consideration (Equation 2).

$$Nst = (TN \times Ds \times t), \quad (2)$$

where: Nst is total nitrogen stock at a certain depth; and TN is total nitrogen content.

The results obtained were submitted to analysis of variance and multiple mean comparison by Tuckey’s test ($p < 0.05$) using the Assisat 7.6 statistical software (SILVA, 2011a).

3 Results and Discussion

Regarding MBC, only the effect of irrigation depths was verified ($p < 0.05$), with the highest mean obtained at the first irrigation depth ($L_1 = 647.9$ mm) (Figure 1). The higher water content in the soil, compared to irrigation depth number two, constituted an environment more favorable to microbial growth. Studies have shown MBC seasonal variation in function of changes in temperature, humidity,

aeration, substrate quality, pH and management system among other factors (FERREIRA et al., 2007, MARTINS et al., 2010; NASCIMENTO et al., 2010, SILVA et al., 2010, LISBOA et al., 2012); therefore, MBC is one of the most responsive indicators of tropical soil quality. High MBC contents at the time of highest incidence of available soil water were verified by Lourente et al. (2010) when analyzing crop rotation impact on microbiological attributes in Distroferric Red Latosol in the municipality of Dourados, state of Mato Grosso do Sul (MS).

CO₂ rate and TOC were influenced by the treatments with individual effect on depths for both ($p < 0.01$) (Figures 2a, b), and between irrigation depth interaction and corn and brachiaria monocropping and intercropping systems for TOC ($p < 0.01$) (Table 3).

The effect of 0-0.10 m depth on CO₂ emission results, among other factors, from the greater density of roots at this

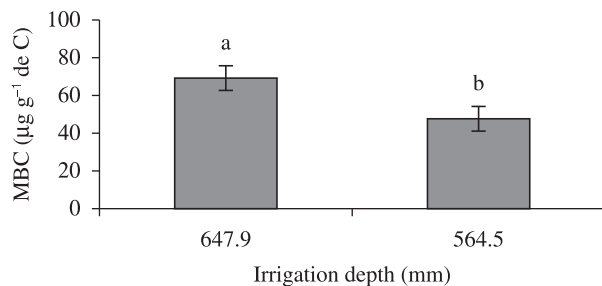


Figure 1. Microbial biomass carbon (MBC) evaluation according to irrigation depths ($L_1 = 647.9$ mm and $L_2 = 564.5$ mm). Vertical bars show standard error of the means.

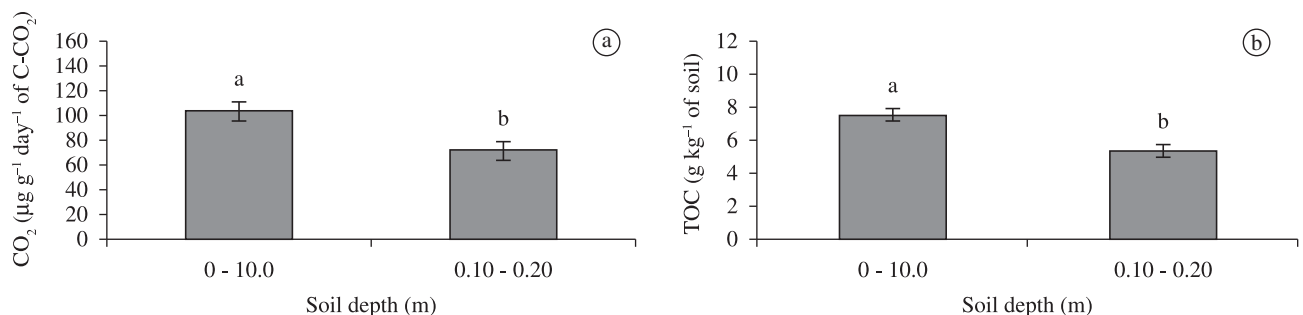


Figure 2. Basal soil respiration (CO₂) (a) and soil total organic carbon (TOC) (b) evaluation according to depth. Vertical bars show standard error of the means.

Table 3. Total organic carbon (TOC), soil microbial quotient ($qMBC$) and microbial metabolic quotient (qCO_2) according to the ratio between irrigation depths $L_1 = 647.9$ mm and $L_2 = 564.5$ mm and the corn and brachiaria monocropping and intercropping systems.

Crop system	Irrigation depths (mm)							
	$L_1 = 647.9$		$L_2 = 564.5$		$L_1 = 647.9$		$L_2 = 564.5$	
	TOC (g kg ⁻¹ of soil)		$qMBC$ (µg g ⁻¹ of C)		qCO_2 (µg CO ₂ µg MBC ⁻¹ d ⁻¹)			
Corn	4.66 Bb	6.49 Aa	11.94 Ba	9.36 Aa	0.78 Aa	0.81 Aa		
Brachiaria	3.74 Bb	6.77 Aa	23.96 Aa	7.38 Ab	0.74 Aa	0.57 Aa		
Intercropping	10.31 Aa	7.10 Ab	8.40 Ba	5.50 Aa	0.70 Aa	0.56 Aa		

Upper case refers to comparison within the same irrigation depth. Lower case refers to comparison within the same cover crop. Values followed by the same letter in the same line or column do not differ statistically by the Tukey's test ($p < 0.05$).

depth, which is also used as carbon and energy sources to microbial biomass, as well as from crop residue deposited on soil surface, corroborating Silva et al. (2010). Pragana et al. (2012), when assessing biological attributes and organic matter dynamics on Yellow Latosol in the cerrado region of Piauí state under no-tillage system, verified that respiration values decreased as soil depth increased. This effect was assigned to lower microbial activity resulting from the lower amount of organic matter that occurs in depth.

Regarding TOC, higher values were obtained at the 0-0.10 m depth (Figure 2b) as a consequence of the greater amount of residues on the soil surface. According to Leite et al. (2003), deposition of such organic residues is essential for adding organic carbon to the soil over time.

Besides depth, total organic carbon was also influenced by corn and brachiaria monocropping and intercropping systems as well as irrigation depths (Table 3). When assessing the effect of irrigation depths on corn and brachiaria monocropping and intercropping systems, a greater value was verified at irrigation depth number two ($L_2 = 564.5$ mm) for monocropping, and at irrigation depth number one ($L_1 = 647.9$ mm) for intercropping, which, in turn, also showed higher total organic carbon than monocropping. The higher TOC content presented by intercropping results from the higher concentration of roots on the system surface layers, which contributes to soil organic matter increase and accumulation (SANTOS et al., 2009).

Upper case refers to comparison within the same irrigation depth. Lower case refers to comparison within the same cover crop. Values followed by the same letter in the same line or column do not differ statistically by the Tukey's test ($p < 0.05$).

Table 4. Total nitrogen content (N), carbon (TOC stock) and nitrogen (N stock) stocks at 0-0.10 and 0.10-0.20 m depths in Dystrophic Yellow Latosol according to the ratio between irrigation depths $L_1 = 647.9$ mm and $L_2 = 564.5$ mm) and the corn and brachiaria monocropping and intercropping systems.

Crop system	Irrigation depths (mm)							
	$L_1 = 647.9$		$L_2 = 564.5$		$L_1 = 647.9$		$L_2 = 564.5$	
	N (g kg ⁻¹)		N stock (g kg ⁻¹)		TOC stock (g kg ⁻¹)			
	0-0.10 m							
Corn	0.50 Ba	0.56 Aa	0.83 Ba	0.94 Ba	9.59 Ba	11.32 Aa		
Brachiaria	0.54 Ba	0.54 Aa	0.87 Ba	0.87 Ba	7.17 Bb	11.33 Aa		
Intercropping	0.8 Aa	0.61 Ab	1.34 Aa	1.02 Ab	18.58 Aa	14.46 Ab		
	0.10-0.20 m							
Corn	0.38 Ba	0.43 Ba	0.71 Ba	0.78 Ba	6.53 Ba	9.15 Ba		
Brachiaria	0.41 Bb	0.55 Aa	0.76 Bb	1.02 Aa	3.22 Bb	13.41 Aa		
Intercropping	0.72 Aa	0.40 Bb	1.30 Aa	0.72 Bb	16.81 Aa	8.86 Bb		

Upper case refers to comparison within the same irrigation depth. Lower case refers to comparison within the same cover crop. Values followed by the same letter in the same line or column do not differ statistically by the Tukey's test ($p < 0.05$).

Soil microbial quotient ($qMBC$), the ratio that expresses how much soil carbon is immobilized in microbial biomass (CARDOSO et al., 2009), presented lower values for corn monocropping and intercropping (Table 3). Lower $qMBC$ values reflect lower use of carbon by soil microbiota and this behavior may be associated with nutrient limitation or with organic matter quality input (CUNHA et al., 2011). However, Silva et al. (2007), who studied the effect of cover crops and management systems on Dystrophic Red Latosol, verified higher $qMBC$ values at the third sampling period for brachiaria monocropping and brachiaria and corn intercropping.

N content and total organic carbon and nitrogen stocks (Table 4) were higher at the 0-0.10 m depth. Higher values occurred for the intercropping, except at the 0.10-0.20 m depth of irrigation depth number two ($L_2 = 564.5$ mm), which presented higher values for brachiaria monocropping. Besides the corn and brachiaria monocropping and intercropping systems, nitrogen fertilization may have contributed to greater N intake by the soil and, consequently, to the stock of this element, corroborating Leite et al. (2009) and Souza et al. (2010).

Higher TOC and N contents occurred in the area under intercropping probably because of the greater deposition of high C/N ratio crop residues, which contributes to slower degradation of soil organic matter favoring the accumulation of TOC and N contents in the soil.

4 Conclusions

Soil biological attributes are influenced by corn and brachiaria monocropping and intercropping systems, irrigation depths and soil depth. As irrigation depths influence soil water available content, they pose greater effect on soil microbial attributes either individually, as in the case of microbial carbon content, or associated with corn and brachiaria monocropping and intercropping systems, as in the case of total organic carbon, soil microbial quotient, microbial metabolic quotient, nitrogen content and carbon and nitrogen stocks.

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