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Soil attributes under different crop management systems in an Amazon Oxisols

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Abstract

Soil biological properties have a high potential for use in assessing the impacts of crop systems. The objective of this study is to evaluate the effects of cropping systems on the biological attributes of an oxisol in the Amazonian state of Pará. The treatments consisted of approximately 20-year-old secondary vegetation, recovered pasture, no-tillage systems (NT) maintained for 4 and 8 years after planting with corn (*Zea mays* L.) and soybean (*Glycine max* L.), and conventional tillage (CT) systems every 2 years after planting with rice (*Oryza sativa* L.) and soybean. The microbial biomass to nitrogen ratio was higher in the NT system (0.68 mg kg^{-1}), and the NT system had greater microbial NT8. Thus, the contributions of organic matter from straw improved the soil quality in these areas. The total organic carbon (TOC) content was greater in the secondary forest and CT areas (46.7 and 48.0 mg kg^{-1}, respectively), potentially due to the higher amounts of organic matter and organic matter mineralization in these areas. However, the largest TOC stocks were observed in the pasture, which corresponded with greater carbon storage (63.5 Mg ha^{-1}). By contrast, the no-till systems were not efficient for storing C, with concentrations of 5.0 and 5.3 Mg ha^{-1} in NT-4 and NT-8, respectively. These results may reflect the short period that these systems were adopted and the vast microbial activity that was observed in these areas, with microbial quotients of 8.03 and 10.41% in NT-4 and NT-8, respectively.

Key words: carbon stock, no-tillage, *Oryza sativa, Glycine max, Zea mays*, Amazon region.

1. INTRODUCTION

Intensive agriculture cultivation is a recent phenomenon in the Amazon and has only been practiced for two decades. In the state of Pará, intensive cultivation has mainly been practiced in degraded pastures (Becker, 2009). The prevailing cultivation system is the conventional tillage (CT) system, which is practiced in most areas to improve the initial soil physical properties with the addition of lime to improve the initial soil chemical properties. The CT system results in soil structural changes and the formation of compacted layers that lead to reduced water retention and infiltration and increased soil erosion (Calegari et al., 2013; Tavares et al., 2014), which are aggravated by heavy rains in the region.

The intensification of agricultural activities in systems that improve and maintain soil quality and increase productivity in open areas of the Amazon region may reduce the pace of deforestation. Therefore, farming systems must be established that promote organic matter accumulation and nutrient cycling (Denich et al., 2005) and prevent erosion and leaching.

Decreases in soil organic matter negatively affect other soil attributes and reduce soil quality (Jakelaitis et al., 2008). Thus, soil management must guarantee the maintenance or improvement of soil quality and ensure sustainable production. To monitor the soil quality, chemical, physical and biological indicators are used to measure or reflect the sustainability of ecosystem conditions.

Biological properties are sensitive bio-indicators of soil quality changes and can be used as a biomonitor for environmental changes (Doran & Parkin., 1994). Biological indicators are primarily microorganisms that perform essential functions that improve soil conditions. Thus, biological indicators monitor soil microbial processes associated with management (Powlson et al., 1987). In areas under cultivation systems, Maia et al. (2012) observed that the microbial biomass carbon (MBC) and MBC/total organic carbon (TOC) ratio were sensitive to management systems, with greater values in no-tillage systems than CT systems.

In certain regions of Brazil, soil biological attributes have been negatively impacted by conventional cropping systems (Alves et al., 2011; Calegari et al., 2013; Tavares et al., 2014; Venzke et al., 2008). In the state of Rondônia, which is in a transition area between the Cerrado and Amazon forests, Matoso et al. (2012) conducted a study comparing forest, grassland, no-tillage, minimum tillage and conventional tillage systems and found lower MBC contents in conventional tillage systems and higher MBC contents in forest and pasture areas. In the Cerrado of Minas Gerais, the MBC content was higher in native forest areas than in areas of annual maize cultivation (Jakelaitis et al., 2008), suggesting greater microbial activity and better soil quality.

In the Amazon, intense agricultural activities with high rainfall and high temperatures enhance mineralization and make it difficult to maintain organic matter. Because the accelerated decomposition of organic matter makes it difficult to accumulate straw on the soil surface, the adoption of NT by producers has been hindered. Thus, the biological attributes in NT systems may differ from those in cultivated systems with pasture and forest areas.

Understanding how use systems affect soil biological properties in the Amazon can contribute to better soil management and reduce deforestation in the region. The objective of this study is to evaluate soil quality under different cropping systems (forest, pasture, tillage with 4 and 8 years of implementation, conventional tillage and pasture systems) by determining the soil MBC, TOC, microbial biomass nitrogen (MBN), and total nitrogen and carbon contents.

2. MATERIALS AND METHODS

The study area is located in the municipality of Paragominas in northeast Para State at geographic coordinates of 02º 57' 24" S and 47º 31' 36" W. The soil in the selected area is rich in clay (EMBRAPA, 2013) with low fertility, low available phosphorous (P) and an exchange complex dominated by aluminum (Al) (Table 1).

The climate of this region is Aw according to the Köppen classification system, with an annual rainfall of 1,800 mm, a mean annual temperature of 26.5 °C, and a relative humidity of 70%-90%. This region is characterized by a rainy season from December to May, with a water surplus of 282 mm, and a drier season from June to November, with a water deficit of 512 mm (Rodrigues et al., 2003).

The management systems considered in this study included secondary 20-year-old forest (control), pasture (*Brachiaria* sp.), no-till for four years (NT-4), corn grown in succession (Oryza sativa L.) with soybean (Glycine max L.), tillage with eight years of cultivation (NT8), and conventionally cultivated corn (Zea mays L.) in succession with soybean for two years (CT-2).

In CT-2, cultivation was performed in succession with rice and soybeans. The first year of cultivation included cutting and burning, and the second year of cultivation included plowing and disking, the application and incorporation of 2 t ha^{-1} of lime and the annual application of fertilizer at 350 kg ha^{-1} (NPK formulation 02-28-20).

Table 1. Chemical properties of the soil in the conventional tillage (CT) system, no-tillage system for 4 (NT-4) and 8 years (NT-8), pasture (P) and forest (F) on dystrophic Yellow Oxisol in Paragominas

	OM[1]	pH	P	Ca	Mg	K	Al	Al+H	CTC[2]	V[3]	m[4]
	g kg^{-1}	H_2O	mg dm^{-3}	mmol$_c$ dm^{-3}							%
				0.0-0.05							
F[5]	39.9a	4.2	1.3 c	8.2c	11.7b	1.1d	15.7a	85.5a	36.8c	20.1c	42.8a
CT[6]	31.7 b	5.0	4.5bc	26.9b	17.8ab	6.0a	4.1c	51.5a	70.2a	55.9b	6.1c
P[7]	28.1b	4.9	24.5ab	22.7b	12.1b	2.0cd	8.2b	44.4bc	45.1bc	45.9b	19.0b
NT-4[8]	25.9b	6.2	31.2a	46.0a	22.5a	3.4bc	4.1c	30.3c	75.7a	70.2a	5.0c
NT-8[9]	31.4ab	5.3	31.7a	30.7b	12.8b	3.6b	5.8bc	50.6b	53.0b	48.3b	11.2bc
				0.05-0.10							
F	33.1a	4.3	1.8b	3.0d	7.4b	0.6c	14.7a	68.3a	25.9d	16.6c	59.0a
CT	25.8bc	5.3	3.8b	22.0bc	9.3b	2.7ab	7.4b	48.7b	41.2bc	40.2b	20.2bc
P	21.3c	4.5	2.7b	15.2c	10.2ab	1.5bc	13.3a	42.1bc	40.3c	38.3b	34.2b
NT-4	21.6c	6.4	36.7a	37.8a	13.6a	3.6a	3.4b	32.6c	58.4a	62.4a	6.0c
NT-8	27.4b	5.2	42.3a	28.3b	13.7a	2.8a	6.0b	50.7b	50.9a	46.8b	12.1c

[1]Organic matter. [2]Cation exchange capacity. [3]Base saturation. [4]Aluminum saturation. [5]Forest. [6]Pasture. [7]Conventional farming every 2 years. [8]No-tillage for 4 years. [9]No-tillage for 8 years.

In NT-8, tillage was conducted to a depth of 0.25 m in 2005 and 2007. In NT-4 and NT-8, *Brachiaria brizantha* was used as a cover crop. In 2007, 2.0 t ha^{-1} of lime and 350 kg ha^{-1} of fertilizer (NPK 02-28-20) were applied.

The pasture is composed of 10-year-old *Brachiaria brizantha*. During deployment, sowing was conducted after overthrowing the remaining vegetation burns of approximately 18 years. Before deployment, the area was mowed and 1.0 t ha^{-1} of lime was applied with incorporation. The subsequent management only consisted of weeding to eliminate weeds. This area was managed intensively, with a stocking rate of approximately 0.8 UA ha^{-1} during the rainy season (December to May) and 0.5 UA ha^{-1} during the dry season (June to November) with rotational grazing.

The experimental design was completely randomized with five replications. In each handling system, five plots of approximately one hectare were demarcated to establish a transect with five equidistant points. At these points, five samples were collected from each area and homogenized to form a composite sample.

Samples were collected at depths of 0-0.05 and 0.05-0.1 m. The physical and chemical soil properties were obtained as described by Embrapa (2011). Phosphorus (P) and potassium (K) were extracted by Mehlich 1 and determined by flame photometry and spectrophotometry, respectively. Calcium (Ca), magnesium (Mg) and aluminum (Al) KCl were extracted with 1 mol L^{-1} and were determined by titrimetry. The pH was determined using a soil: water ratio of 1:2.5, and the TOC content was determined using the volumetric method of oxidation with K2Cr2O7 and titration with ferrous ammonium sulfate.

Furthermore, the microbial biomass carbon content was determined using fumigation and extraction with ethanol-free $CHCl_3$ concentrate, $K_2Cr_2O_7$ (0.0667 mol L^{-1}), 10 mL H_2SO_4 and 5 mL concentrated H_3PO_4 before titrating with $Fe(NH_4)_2(SO_4)_2$, (Vance et al., 1987) and preforming calculations as described by Tate et al. (1988).

The total N content was obtained using semi-micro Kjeldahl distillation (Bremner & Mulvaney, 1982), and the MBN content was determined using Kjeldahl digestion (Bremner & Mulvaney, 1982) with a correction factor (KN) of 0.54 (Brookes et al., 1985; Joergensen & Mueller, 1996).

The MBC to soil Corg (MBC/Corg) ratio was calculated, and the total soil MBN to N (MBN/Total N) and MBC/MBN ratios were determined.

The particle size analysis was performed using the pipette method after dispersion with 1 mol L^{-1} NaOH and organic matter combustion (Table 2).

The organic carbon stock (C stock) was calculated using the formula C = Cnorm stock x Ds x E (Frazão et al., 2013), where C = the stock of organic carbon in the studied layer (ton ha^{-1}), Cnorm = the standard organic carbon (g kg^{-1}), Ds = the bulk density of the studied layer (g cm^{-3}), and e = the thickness of the sampled layer (cm).

Table 2. Soil physical attributes in the conventional tillage system (CT), no-tillage for 4 (NT-4) and 8 years (NT-8), pasture (p) and forest (F) on dystrophic Yellow Oxisol in Paragominas

	Sand	Clay	Silt	Bulk density	Bulk density
		Layer 0.0-0.2 m g kg^{-1}		Layer 0-0.05 m g kg^{-1}	Layer 0.05-0.1 m g kg^{-1}
F[1]	40	904	56	1.06	1.14
CT[2]	103	872	25	1.19	1.22
P[3]	444	506	50	1.48	1.45
NT4[4]	50	879	71	1.17	1.2
NT8[5]	51	873	76	1.20	1.21

[1]Forest. [2]Conventional tillage every 2 years. [3]Pasture. [4]No-tillage for 4 years. [5]No-tillage for 8 years.

To determine the differences in the clay contents in the treatment areas and avoid interference of the clay content when calculating the C stock, the organic carbon (Corg) data were standardized by considering the clay contents of the reference area and by using a constant soil mass for all treatments. The calculation used for the standard carbon stock considered the clay content in the 0.05 to 0.1 m layer in the reference area (forest) and was used as the standard clay content in all treatments. Thus, the soil Corg in each treatment was calculated as follows: Cnorm = CMEA x (Clayref/Claymea), where Cnorm = the standard C stock; CMEA = the average carbon content for each depth and evaluated treatment; argilaref = the clay content of the reference area (forest); and argilamea = the median clay content at each evaluated depth in each treatment.

The variables were assessed by using the Kolmogorov-Smirnov normality test, an analysis of variance and the averages compared by the Scott-Knott test at 5% by using the statistical program Sisvar (Ferreira, 2008).

3. RESULTS AND DISCUSSION

At a depth of 0 to 0.05 m, higher MBC values were obtained in the CT-2 system, lower values were obtained in the NT8 system, and no differences were observed (p>0.05) in the other treatments (Figure 1). Between 0.05-0.10 m, no difference (p>0.05) in the MBC content was observed in the CT-2, pasture and NT-4 years treatments (Figure 1). Because nitrogen and MBN contents were greater at depths of 0 to 0.05 in the NT m-8 treatment, the lowest level was observed in NT-4 (p>0.05). At a depth of 0.05-0.10 m, no difference (p>0.05) was observed between the NT8, forest and NT-4 treatments.

The highest MBC content was observed in CT-2, which potentially occurred because the soil chemical characteristics under that system are beneficial for microbial growth and are related to high cation exchange capacity (CEC; 70.2 $mmol_c$ dm^{-3}) and

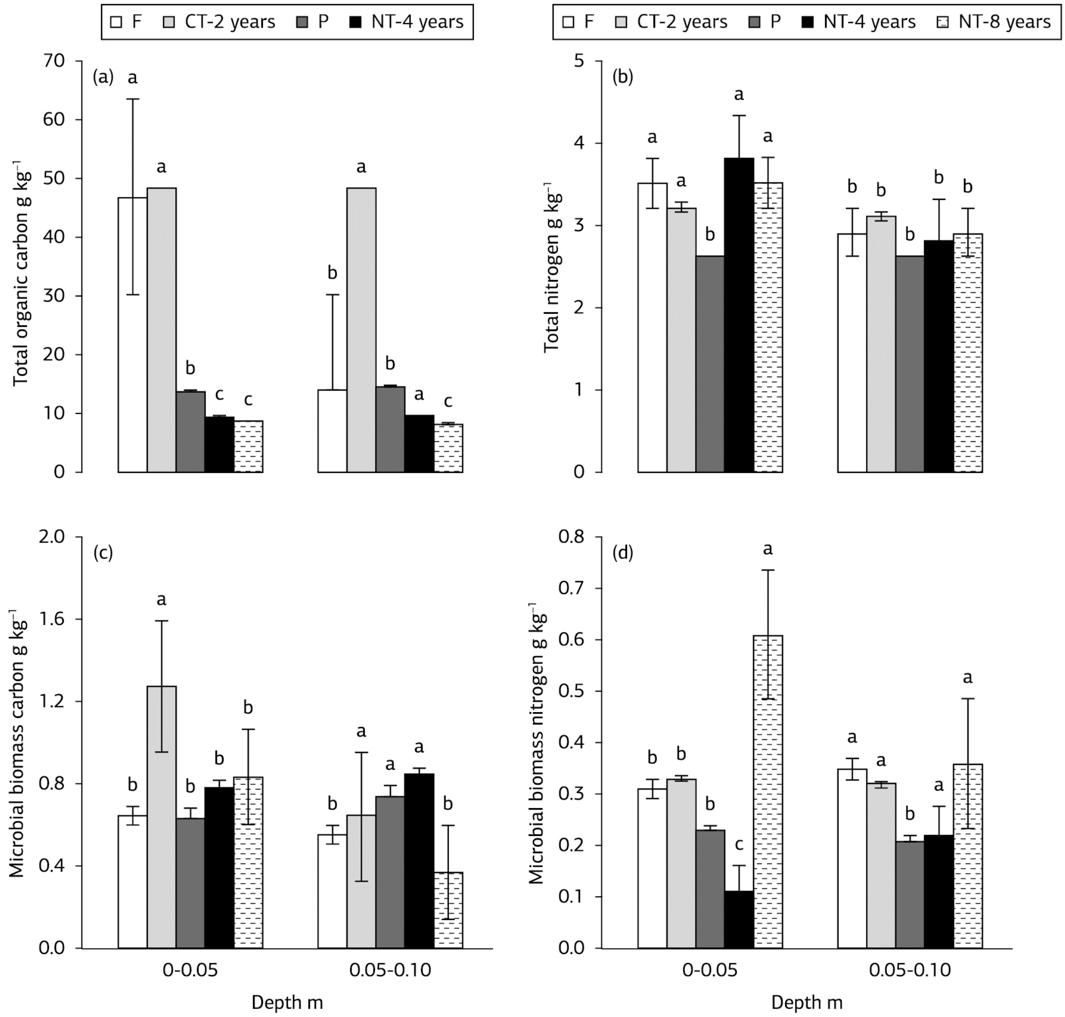

Figure 1. Lower case letters indicate a comparison among land-use systems and capital letters indicate a comparison of depths in a single management system; values are based on the Scott-Knott 5% test. F = secondary forest. P = Pasture. CT = conventional tillage every 2 years. NT-4 = no-tillage for 4 years. NT-8 = no-tillage for 8 years.

base saturation (55.9 $mmol_c\ dm^{-3}$) and low Al saturation (6.1%) (Table 1). These characteristics may be related to the deposition of ash, which has a high nutrient content. Moreover, because heat was used as a catalyst during the initial plot preparation, the organic matter was mineralized and the nutrient availability increased (Rendin et al., 2011). The most deleterious effects of fire on the MBC occurred between 3 and 12 months after burning (Wang et al., 2012). Subsequently, organic matter mineralization positively contributed to the soil microbial community.

The succession of crops and the incorporation of stubble by harrowing also contributed to the high MBN and MBC contents in CT-2. In conventional tillage systems, organic matter (OM) mineralization is higher than in no-till systems because tillage helps release nutrients (Perez et al., 2005).

Similar MBN and MBC contents in pasture and forest areas may be related to the abundant and massive root system of *Brachiaria* sp., which presents a continuous renewal of fine roots and has a large effect in the rhizosphere (Gama-Rodrigues et al., 2005).

The abundant and large root system of *Brachiaria* sp., and the continuous renewal of the roots and rhizosphere have important effects due to the excretion of large amounts of organic acids, which contribute to the aggregation of soil particles (Reid & Goss, 1980) and help maintain MBC and MBN contents. In pastures, the quantity and refresh rate of roots may behave similarly and are potentially of equal importance for the fine litter in the forest area (Matoso et al., 2012). Such root mass renewal favors the presence of microbial biomass in the rhizosphere and the liberalization of nutrients in the system (Alves et al., 2011), which improves the system balance.

Soil samples were collected during the rainy season, which is the period with the greatest grass growth and the period during which increased renewal of the root system contributes to higher MBC and MBN in these agroecosystems. In addition, appropriate stocking levels of animals in pastures promote a significant increase in MB because of the deposition of excrement (Garcia & Nahas, 2007).

The highest MBN concentration occurred in the NT-8 area and was potentially related to N immobilization in the soil (Lopes et al., 2011) because of high levels of OM. The continuous deposition of OM by no-tillage systems favors increases in OM, OM conservation, and the gradual release of nutrients based on the mineralization rate (Santiago et al., 2013).

The recent adoption of no-till systems may explain the low levels of MBC and MBN in NT-4. During the first five years of no-tillage establishment (during early stages), soils usually have low TOC and low trash accumulation between five and ten years (transition), with greater accumulation of surface trash and organic carbon (Venzke et al., 2008). These factors result in increased microbial biomass and MBN. At a depth of 0-0.05 m, the highest TOC contents were found in the forest and CT-2 areas and the lowest contents were found in the NT-4 and NT8 areas. At depths of 0.05 to 0.10 m, the CT-2 area had a higher TOC content and lower levels were observed in the NT-4 and NT-8 areas (Figure 1). Regarding total N, no significant difference was observed between the forest, PC-2, NT-4 and NT-8 areas at 0-0.05 m (Figure 1).

The highest TOC contents were observed in the secondary forest area, which may be attributed to the higher deposition and diversification of crop residues in this area relative to the other land-use areas. The lowest soil TOC concentrations in the NT system can be attributed to the presence of readily available C for microbial consumption. In the pasture system, extensive management potentially facilitated the oxidation of soil organic matter.

The contributions of plant residue due to crop fertilization in the PC-2, NT-4 and NT-8 treatments promoted positive changes in the total N content that were similar to those in the secondary forest. The cultivation of plants that fix N, such as soybean, can help increase total soil N contents due to biological nitrogen fixation and the low C: N ratio of legumes (Fonseca et al., 2007). In addition, cover grasses are favorable for the soil microbial community and promote an environment that is favorable for the development of the microbiota due to their high root density and organic exudates (Perez et al., 2005).

Studies comparing TOC contents in pastures and forests have shown conflicting results. When the production and deposition of biomass in the soil is equivalent, the TOC content varies depending on the quality of the deposited material and how the material affects microbial activity (Costa et al., 2009), which modifies biomass decomposition. In the Cerrado, conditions favor higher TOC contents in forest areas relative to pasture and NT corn cultivation systems (Jakelaitis et al., 2008). Studies of oxisols in the Brazilian Amazon have compared various land-use systems and observed higher TOC contents in native forests than in pastures (Matoso et al., 2012). Previously, authors attributed these results to the greater diversity of species in the native forest, which promoted differentiated decomposition residues that were returned to the soil. However, another study in the Brazilian Amazon indicated greater TOC contents in pastures than in native forests because of the intense renewal of pasture root systems (Loss et al., 2014).

The MBN/Total N ratio ranged from 3.2% to 19.04% (Table 3). The highest ratio occurred in the NT-8, forest, pasture and PC-2 areas and in the ratio was smaller in the NT-4 area in the 0-0.05 m layer. In the 0.05-0.10 m layer, the MBN/total N ratio was higher in the forest and NT-8 soils (Table 3).

The MBN/Total N ratio was expressed as the amount of nitrogen present in the SOM that was immobilized in microbial biomass (Matoso et al., 2012). The environmental stress conditions, such as acidity, temperature, elevated heavy metal contents, soil compaction, or low OC nutritional quality, reduce the efficiency of the microbial biomass and MBN (Lopes et al., 2011), which results in a low MBN/Total N ratio. In highly weathered soils with high acidity and low pH, such as those in the study area, CO undergoes rapid decomposition and mineralization, which results in a low soil nutrient supply.

The MBN/Total N ratio in NT-8 demonstrates that the minimum soil disturbance and the use of legumes and cover crops, such as grasses, can help retain N in the system and result in SOM with a better nutritional quality (Matoso et al., 2012).

The high MBN/Total N ratio in the 0-0.05 m layer of the pasture soil resulted from the rhizosphere effect of grasses, particularly the effect of *Brachiaria* on soil microorganisms,

Table 3. The microbial ratio (qMIC) and MBN/Total N ratio were compared with the MC/MN ratio and carbon (C stock) content under different land use and soil management systems at depths of 0-0.05 and 0.05-0.10 m

Depth m	[1]F	[2]CT	[3]P	[4]NT-4	[5]NT-8	[6]CV(%)
			qMIC (%)			
0-0.05	2.49c	3.13c	2.36c	8.03b	10.41a	25
0.05-0.10	6.97a	6.31b	5.82b	8.22a	4.32b	
			MBN/TN (%)			
0-0.05	7.00b	8.08b	7.23b	19.04a	3.22c	28
0.05-0.10	11.39a	8.75b	7.53b	11.48a	7.69b	
			MBC/MBN (%)			
0-0.05	5.02b	4.88b	3.13c	2.49c	7.42a	32
0.05-0.10	4.09a	4.70a	2.74b	2.41b	2.38b	
			C stock ($Mg\ ha^{-1}$)			
0-0.05	25.4c	29.6b	63.5a	5.0d	5.3d	92.8
0.05-0.10	6.9c	30.4a	19.4b	5.4d	5.0d	83.5

Lower case letters in the rows compare the soil management systems and capital letters in the columns compare the depths in the same management system and under the same land use; values are based on the Scott-Knott test at 5%. [1]Forest. [2]Conventional tillage every two years. [3]Pasture. [4]No-tillage for four years. [5]No-tillage for eight years. [6]Coefficient of variation.

which resulted in a large dry matter yield, density and a rapid renewal root system that contributes to increases in the soil microbial population. In forest areas, the MBN/Total N ratio is related to the diversity of the plant species with effects that are similar to those of grasses (Santos et al., 2007).

The MBC/MBN ratio was low in all of the management and land use systems, which was potentially related to the increase in the soil N content due to nitrogen fertilization, which increased the amount of dissolved nitrogen and was immobilized by soil microorganisms (Dinesh et al., 2012). The NT-4 area had the lowest average MBC/MBN ratio, which was potentially related to low Corg levels (Table 1) or the high rate of Corg decomposition.

The MBC at a depth of 0-0.05 m was higher in NT8 (10.41%), and the lowest qMIC values were observed in the grassland, forest and CT-2 areas (2.36%, 2.49% and 3.13% (Table 3), respectively, with no significant difference between them). The largest MBC contents at a depth of 0.05-0.10 m were observed in the NT-4 and forest areas (8.22% and 6.97%), with no significant differences between the other treatments.

Generally, MBC expressed as a function of qMIC is between 1% and 4% of TOC (Jenkinson et al., 1991), and the conditions under which the qMIC is less than 1% can be attributed to several factors that limit the activity of the soil microbial community (Jakelaitis et al, 2008). In all of the systems, the studied management qMIC was greater than 1%, which represents good conditions for microbial biomass growth.

The smaller soil carbon content observed in the forest area at a depth of 0-0.05 relative to the NT8 area potentially resulted from several factors, such as the soil acidity, pH (4.2), CEC (36.8 mmol dm^{-3}), and the low quality of organic matter in the forest area. The results correspond with those presented by Jakelaitis et al. (2008), who also observed higher qMBC contents in tillage areas relative to forest areas.

In both layers, the major organic carbon (C stock) surface was lower in the pasture (63.5 Mg ha^{-1} TOC) than in NT-4 and NT-8 (Table 3). At a depth of 0.05-0.10 m, the largest C stock was observed at PC-2 (30.4 Mg ha^{-1}).

The low accumulation of TOC in NT-4 and N-T8 was potentially related to the implementation of the short no-till period, the use of cover crops and the low C: N ratio. For soil coverage, two or more plant nutrients can be used together to adjust their release kinetics, ensure a continuous soil supply and increase the carbon content. In no-till fields, grass is used as the cover crop, which reduces the quality of SOM and its contributions in the soil.

The use of a braquearão (*Brachiaria brizantha*) and jack bean (Carnavália einsiformis) consortium is one alternative for increasing the supply of straw and the C content in no-till fields in the Amazon compared with the use of only one species, as shown in this study. Both species produce high amounts of dry matter. In addition, braquearão results in the accumulation of large amounts of K, Mg and C, and jack bean results in the accumulation of large amounts of N, P and Ca by (Teixeira et al., 2014).

No consensus has been reached regarding how to replace a forest or the effects of establishing pastures on carbon storage in tropical climates. The results of this study show higher carbon stocks in pasture areas relative to forest areas. Work performed at Acre in an Alfissol soil indicated greater C stock in pastures than in forests, with an increasing trend with pasture age (Araújo et al., 2011). Conversely, work conducted in Pará State indicated the presence of higher carbon stocks in native forests than in pastures that were deployed for ten years (Bernoux et al., 1999).

4. CONCLUSION

The no-tillage system in place for eight years had the highest soil quality with greater microbial activity and microbial nitrogen contents. The greater microbial activity and microbial nitrogen contents in the pasture relative to the forest are related to the incorporation of higher quality substrate and fertilizer into the pasture soils. The highest carbon stock was observed in the pasture area, with vegetation characteristics that were similar to those of grasses. Grasses are major biomass producers, including root biomass producers, with a high nitrogen ratio that contributes to lower microbial activity and a higher bulk density. By contrast, the higher microbial activity in no-till systems accelerates the decomposition of straw crops and reduces the soil carbon stock. These results indicate that implementing a tillage system in the Amazon region for eight years is insufficient for system consolidation.

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