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INDICATOR ATTRIBUTES OF SOIL QUALITY IN AREAS UNDER DIFFERENT LAND USE SYSTEMS, IN THE WESTERN AMAZON

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Resumo

Atributos indicadores da qualidade do solo em áreas sob diferentes sistemas de uso da terra, na Amazônia Ocidental. A antropização de ambientes naturais, quando realizada de forma inadequada, promove a ruptura do equilíbrio ecológico, podendo influenciar na fauna, flora e na biodiversidade em geral, incluindo o ambiente edáfico e seus componentes. O objetivo foi avaliar os atributos do solo em áreas com diferentes tipos de cobertura vegetal e formas de manejo do solo. O estudo foi realizado em área de floresta nativa (Floresta Equatorial Subperenifólia) e área de cultivo (espécies anuais), em Porto Velho-RO, Brasil. Foram coletadas amostras em duas camadas (0-10 e 10-20cm), em Latossolo Vermelho-Amarelo, para avaliação da biomassa microbiana pelo método de fumigação-extração (FE), bem como, atributos químicos e físicos do solo. Foi possível verificar um aumento significativo da densidade do solo e redução da umidade e melhoria dos atributos químicos decorrentes do uso da área. O teor de matéria orgânica diminuiu acentuadamente na área manejada (25%), comparada com a floresta, na camada superficial (0-10cm). O C-biomassa microbiana, sob a floresta nativa, apresentou valor médio 54% maior (883 μgC g^{-1}), na comparação com a área submetida a manejo (410 μgC g^{-1}) na camada superficial. O N-biomassa microbiana oscilou entre 21,3 a 19,5 μgN g^{-1} na área de floresta nativa, e entre 9,3 e 11,5 μgN g^{-1} na área manejada, respectivamente nas camadas de 0-10 e 10-20cm. Na área de floresta nativa, a adição da matéria orgânica no solo feita pelo aporte de serapilheira da vegetação mostrou-se um importante fator condicionante para a comunidade microbiana, demostrando o emprego desse atributo como indicador de qualidade do solo.
Palavras-chave: Solos amazônicos, uso e manejo, Atributos do solo.

Abstract

The anthropization of natural environments, when performed inadequately, promotes the disruption of the ecological balance and can influence the fauna, flora and biodiversity in general, including the edaphic environment and its components. The objective was to evaluate the soil attributes in areas with different types of vegetation cover and different forms of soil management. The study was carried out in native forest area (Subperennial Equatorial Forest) and cultivated area (annual species), in Porto Velho, Rondônia, Brazil. Samples were collected in two layers (0-10 and 10-20cm), on a *Latossolo Vermelho-Amarelo*, to evaluate microbial biomass by the fumigation-extraction (FE) method, as well as the chemical and physical soil attributes. It was possible to verify a significant increase in soil density and reduction of moisture and improvement of chemical attributes resulting from the use of the area. The organic matter content decreased sharply in the managed area (25%), compared to the forest, in the superficial layer (0-10cm). Microbial C-biomass under the native forest showed 54% higher mean value (883 μgC g^{-1}) compared to the managed area (410 μgC g-1) in the superficial layer. The microbial N-biomass ranged from 21.3 to 19.5 μgN.g^{-1} in the native forest area, and from 9.3 to 11.5 μgN g^{-1} in the managed area, respectively in the 0-10 and 10-20cm layers. In the native forest area, the addition of organic matter to the soil by the vegetation litter was an important conditioning factor for the microbial community, demonstrating the use of this attribute as an indicator of soil quality.
Keywords: Amazonian soils, use and management, soil attributes.

INTRODUCTION

The Amazon Forest is the largest remaining tropical forest in the world, accounting for about 40% of the planet's tropical forests (GOMES, 2018). In Brazil, it covers an area of 3.7 million km^2, which represents approximately 70% of the Continental Amazon and 50% of the national territory. This biome has the largest percentage of its extension in Conservation Units (10%), although 15% of the total area has already been removed due to the construction of highways, mining activities, colonization, advancement of the agricultural frontier and logging (MELLO; ARTAXO., 2017). The Amazon biome remained virtually intact until the 1960s, when productive activities in the region maintained basically extractive characteristics, with little effect on native vegetation. minerals, fauna, flora and soil, accessible to be explored (GOMES, 2018).

As for the soil resource, its use in the state of Rondônia follows, in many aspects, the pattern observed in other places in the Amazon, with the removal of the original vegetation cover always alongside areas that have already been altered. This intervention takes place mainly from highways, rivers and roads, and is almost always more intense in the vicinity of cities (RICARTE, 2016).

As a consequence of vegetation removal, soils become exposed to mechanical processes that can modify their physical, chemical and biological characteristics, since the soil of the Amazon biome depends on its vegetation cover to maintain its biotic and abiotic characteristics (MAZZETTO *et al*. al., 2016). This problem is especially aggravated in regions with a hot climate, due to progressive demographic pressure, incorrect use and management of the soil, cultivation in areas without agricultural suitability and reduction of natural soil fertility due to unsustainable agricultural practices.

Soil, among natural resources, represents an important indicator of agricultural sustainability because it is directly affected by the inappropriate use or management of areas destined for agricultural activities, in addition to being integrated with other natural resources, such as water and biodiversity (SANTOS *et al*. al., 2018). Changes in the physical, chemical and biological attributes of the soil may indicate alterations in areas formerly covered by native forest ecosystems that were subjected to anthropization processes. These changes are related to the degradation factors that allow identifying the resilience of the soil and its recovery capacity through appropriate management or even a change in the type of use, according to the agricultural suitability of the soil (FREITAS *et al*., 2017).

Paes *et al*. (2016) observed that soil biological attributes are potentially sensitive indicators of stress or changes in its productivity, where microbial biomass in experimental condition is a useful tool for interpreting the diagnosis for soil use and management concomitant with nutrient cycling. Its quantification in the form of microbial carbon makes it possible to monitor much more quickly the disturbances to which the ecological balance has been subjected and the variations in the total organic matter resulting from soil management and use, as it reacts more quickly than the physical and chemical attributes (SANTOS *et al*. 2018).

Conceptually, soil microbial biomass corresponds to the living part of soil organic matter, excluding roots and animals larger than approximately 5000 μm^3. It is composed of microorganisms such as bacteria, fungi, actinomycetes, algae and protozoa, which form a diverse community in its components and functions, and complex in its interrelationships. The soil microbial population acts as a catalyst for important chemical transformations in the soil and, consequently, plays an essential role in the functioning of ecosystems (BATISTA *et al*., 2018).

The high anthropic pressure in Rondônia raised the interest in evaluating how and in what way this factor has affected the microbiological composition of the soil, using the microbial biomass as a bioindicator, in order to predict alterations in other areas under climatic conditions and of similar management and land use. The hypothesis of the study consists in the fact that edaphic attributes can function as indicators of soil quality in anthropized areas in the Amazon Biome. Therefore, the objective was to study the alterations caused by the modification of native forest area in management area using physical, chemical and biological attributes (microbial biomass) of the soil.

MATERIAL AND METHODS

Study area

The study was carried out in the area surrounding the municipality of Porto Velho, at the experimental station of Embrapa-Rondônia, where two areas were selected: 1) area with natural forest and 2) anthropic area with annual crop rotation (corn-soybean) and planting conventional, currently with soybean cultivation. In both studied areas, the soil was classified as *Latossolo Vermelho-Amarelo Álico* with a very clayey texture (clay content greater than 60%), which varies from 700 g kg^{-1} in the 0–11 cm superficial layer to 760 g kg^{-1} in the 11–29 cm layer, located in flat relief. The predominant climate in the region is tropical, humid and hot, throughout the year. The average temperature is 24 – 25 Cº and the average annual precipitation is 2200 – 2300 mm. The average annual relative humidity varies from 80% to 90% in summer, and around 75% in autumn-winter (ALVARES *et al*., 2013).

For each type of land use, four quadrants 50 m apart were defined. In each of them, five simple soil samples were randomly collected in layers of 0-10 and 10-20cm, which were homogenized, individually for each layer, to form composite samples, being deformed samples (clod) and volumetric ring. After collection, soil moisture was determined by the gravimetric method (SM) (TEIXEIRA *et al*., 2017) with the water content raised to 60% of field capacity (FC), so that the activity of microorganisms was not compromised. Subsequently, the samples were placed in plastic bags with ventilation, at a controlled temperature, part of this soil was taken to be dried in the shade and crushed, and subsequently passed through a 2 mm sieve to obtain fine air-dried soil (FADS), material which was used to carry out the chemical analyses.

The determination of soil density was performed with the aid of the volumetric ring (TEIXEIRA *et al.*, 2017) and obtained by the following equation:

$$Bd = \frac{Ds}{Sv}$$

Where: Bd = bulk density (g cm^{-3}); Ds = dry soil (g) e Sv = soil volume (cm^{3}).

The chemical analyzes from the TFSA included the determination of hydrogenion potential (pH) in water; exchangeable potassium, calcium, magnesium and aluminum; assimilable phosphorus; potential acidity (H+Al), and calculation of base saturation (V%), cation exchange capacity (T value) and aluminum saturation (m %) (TEIXEIRA *et al.*, 2017). Total soil organic carbon was determined by the wet oxidation method (TEIXEIRA *et al.*, 2017) and organic matter determined by multiplying the value by 1.724.

To determine soil microbial biomass (SMB), the fumigation-extraction (FE) method proposed by Vance *et al.* (1987), in which C and N become extractable by K_2SO_4 0.5 mol L^{-1} after fumigation for 24 hours with chloroform.

The extraction of C from the soil is carried out in a 250 ml Erlenmeyer flask with 100 ml of potassium sulfate (K_2SO_4) 0.5 mol L^{-1}. The determination of the extracted C is carried out by means of a digestion of 8 ml of the filtered extract in the presence of 2 ml of potassium dichromate ($K_2Cr_2O_7$) 0.2 mol L^{-1}, 10 ml of concentrated sulfuric acid (H_2SO_4) and 5 ml of concentrated phosphoric acid (H_3PO_4). Dichromate excess was determined by titration with ammonium ferrous sulfate $(NH_4)Fe(SO_4).6H_2O$, using barium diphenylamine sulfonate as an indicator.

N extraction was also performed using potassium sulfate (K_2SO_4), the same extract being used for C from microbial biomass. 30 ml of this extract was used and inserted into a digestion tube, adding 1 ml of concentrated H_2SO_4. It was concentrated in an oven at 60°C for 12 hours. Next, 7 ml of digesting mixture was added and taken to the digester block, at an initial temperature of 100 ºC, which was slowly increased to a temperature of 360 ºC. After digestion and cooling, the extract was distilled using 10 ml of 2% boric acid, and a volume of 50 ml was collected for titration with H_2SO_4 0.05 mol L^{-1}. The N of the microbial biomass was obtained by the difference between the N content of the fumigated subsample and the N content of the control subsample, with the subsequent division by the value 0.54, which refers to the correction factor (KEC factor) used in this methodology, as proposed by Brookes *et al*. (nineteen ninety).

Statistical analyses

Data were compared by means of means using Student's t test, individually observing how the attributes behaved between the observed experiments and whether there was a significant change at 5% probability. In order to proceed with the global evaluation of the results, which allows verifying the intra and interspecific relationships of the attributes with the areas tested, the data (layer of 0-10 and 10-20 cm) were associated in a single soil layer, 0-20 cm, and the scores obtained through multivariate analysis of variance (MANOVA) were used to generate the principal component analysis (PCA) using the statistic 7 program. With this procedure, we sought to identify the attributes associated with each area, in order to individualize them.

RESULTS

Physical and chemical soil attributes

Bulk density (BD) values were significantly higher in the Anthropized area, compared to the Forest area, in both soil layers (Table 1). Higher values of soil moisture (SM) were also observed in the superficial layer (0-10 cm) in the anthropized area.

Table 1. Soil physical attributes (0-10 and 10-20 cm) in native forest (forest) area and cultivated area with annual agricultural species (Anthropized) in Porto Velho, Rondônia, Brazil.
Tabela 1. Atributos físicos do solo (0-10 e 10-20 cm) em área de floresta nativa (Floresta) e área de cultivo com espécies agrícolas anuais (Antropizada) em Porto Velho, Rondônia, Brasil.

Area	Layer	BD	SM	FC
	cm	(g cm^{-3})	----------%---------	KPa
Forest	0-10	0.88 b	b 23.32 b	10.00a
	10-20	1.00 b	25.40 a	12.00a
Anthropized	0-10	1.13 a	32.98 a	11.00a
	10-20	1.17 a	26.09 a	10.00a

Bd: bulk density; SM: soil moisture; FC: field capacity. Mean value, obtained by four composite sample, followed for different letters in same column and layer of soil, present significative differences (5% of probability) by student T test.

There were three patterns for the chemical attributes, regardless of the soil layer. The first one refers to mean pH, Ca, Mg, S and V values that were significantly higher in the anthropized area; the second, mean values of H+Al, Al, T significantly higher in the native forest area; and the third, absence of significant differences for P and K, in the comparison between the two areas (Table 2).

Table 2. Soil chemical attributes (0-10 and 10-20 cm) in native forest area (Forest) and cropping area with annual agricultural species (Anthropized) in Porto Velho, Rondônia, Brazil.
Tabela 2. Atributos químicos do solo (0-10 e 10-20 cm) em área de floresta nativa (Floresta) e área de cultivo com espécies agrícolas anuais (Antropizada) em Porto Velho, Rondônia, Brasil.

Area	Layer (cm)	pH	P	K	Ca	Mg	Al+H	Al	S[1]	V[2]	T[3]	m[4]
			mg dm^{-3}	----------------------mmol dm^{-3}------------------						%	mmol dm^{-3}	%
FO	0-10	3.60b	2.00a	1.20a	0.70b	1.70b	158.40a	24.90a	3.58b	2.00b	162.00 a	87.00a
	10-20	3.80b	1.00a	1.00a	0.40b	1.10b	128.70a	22.00a	2.50b	2.00b	131.20 a	90.00a
AN	0-10	5.10a	3.00a	1.60a	25.60a	12.70a	71.00b	2.30b	39.94a	36.00a	110.90 b	5.00b
	10-20	5.00a	2.00a	1.50a	17.10a	11.30a	64.40b	3.10b	29.89a	32.00a	94.30 b	9.00b

1 – Bases sum; **2-** bases saturation; **3-** cation exchange capacity **4** – aluminum saturation
FO: forest; AN: anthropized.

Figure 1 shows the organic matter content in the systems evaluated in the respective layers. A reduction in organic matter content was observed in the anthropized area compared to the forest area, which was more pronounced (25%) in the superficial layer (0-10 cm).

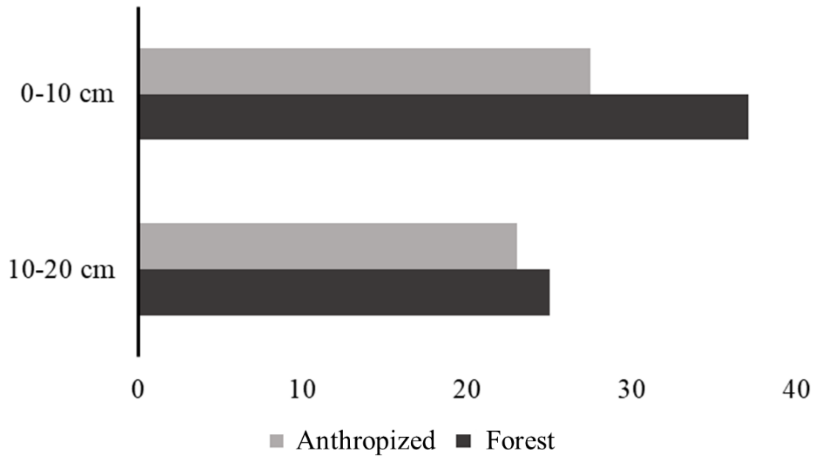

Figure 1. Organic matter content (g.kg-1) (0-10 and 10-20 cm) in native forest area (Forest) and area cultivated with annual agricultural species (Anthropized) in Porto Velho, Rondônia, Brazil.
Figura 1. Teor de matéria orgânica (g.kg^{-1}) (0-10 e 10-20 cm) em área de floresta nativa (Floresta) e área de cultivo com espécies agrícolas anuais (Antropizada) em Porto Velho, Rondônia, Brasil.

C of microbial biomass

It was verified that in the natural conditions, that in the forest area, the highest values of microbial C-biomass occurred in the surface layer of the soil, associated with the highest levels of organic matter. The value observed in this layer was 23% higher than that quantified in the 10-20 cm layer (Figure 2). The effect of organic matter in the studied layers was not verified in the anthropized area in which in the layer of 10-20 cm higher values of microbial C-biomass were quantified, in approximately 8%, in comparison to the superficial layer. The highest values in this each can probably be due to the mobilization of surface layers incorporating carbon in the subsurface.

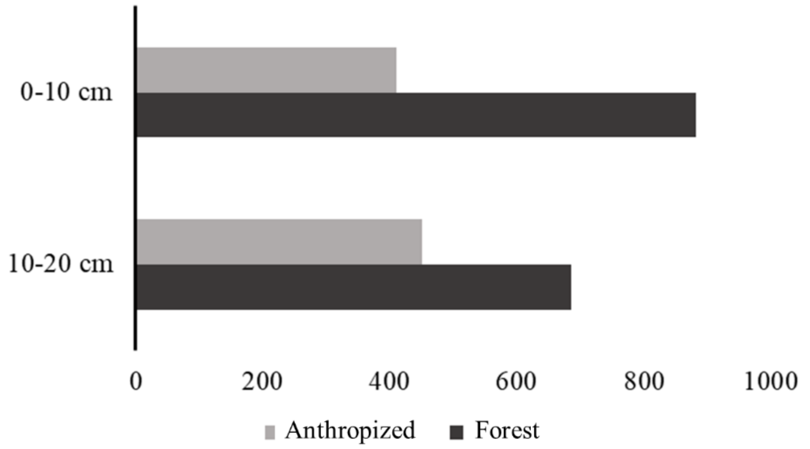

Figure 2. Soil microbial C-biomass (0-10 and 10-20 cm) in native forest area (Forest) and cultivation area with annual agricultural species (Anthropized) in Porto Velho, Rondônia, Brazil.
Figura 2. Biomassa-C microbiana do solo (0-10 e 10-20 cm) em área de floresta nativa (Floresta) e área de cultivo com espécies agrícolas anuais (Antropizada) em Porto Velho, Rondônia, Brasil.

It was verified that in the soil under forest there is a continuous deposition of litter that favors the addition of carbon and consequently the biological activity in the superficial layer.

N of microbial biomass

Through the analysis of figure 3, it was verified that the N of the microbial biomass was higher in the forest area, in both layers. However, no difference was observed in depth in the forest area, a pattern different from what was verified for the carbon content. While in the anthropized area in the surface layer, a slightly higher value was observed compared to the subsurface layer (10-20cm) in which the highest carbon content was quantified.

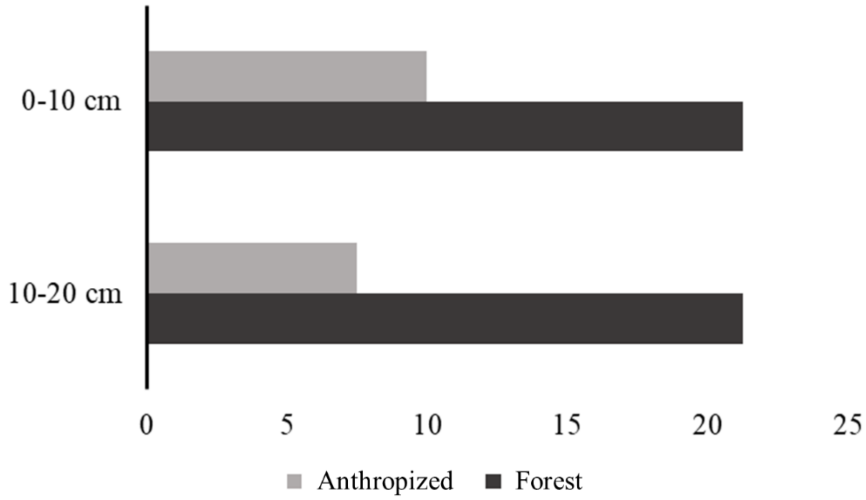

Figure 3. N in soil microbial biomass (0-10 and 10-20 cm) in native forest area (Forest) and cropping area with annual agricultural species (Anthropized) in Porto Velho, Rondônia, Brazil.
Figura 3. N na biomassa microbiana do solo (0-10 e 10-20 cm) em área de floresta nativa (Floresta) e área de cultivo com espécies agrícolas anuais (Antropizada) em Porto Velho, Rondônia, Brasil.

Multivariate analysis of principal components

Using the PCA, it was possible to observe that the relationship between main components 1 and 2 explained 95.03% of the data variance, and that there was an individualization of the areas due to their specific association with certain attributes (Figure 4). In this sense, the soil in the anthropized area was associated with higher average values of US, soil density, pH, Ca, Mg, K, S, V and P. The Forest area, which was positioned in the opposite region to the anthropized area, was associated with higher values of H+Al, Al, T, m, OM, C and N in the microbial biomass.

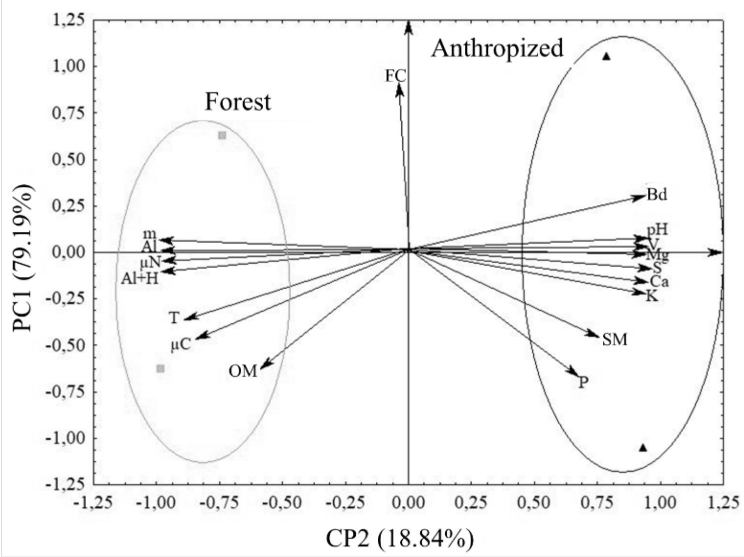

Figure 4. Principal component analysis (PCA) of soil attributes (0-20 cm) in native forest area (forest) and cultivated area with annual agricultural species (Anthropized) in Porto Velho, Rondônia, Brazil. Bd: bulk density; S: bases sum; SM: soil moisture, OM; soil organic matter: FC; field capacity: µC: microbial biomass carbon; µN: microbial biomass nitrogen.

Figura 4. Análise de componentes principais (ACP) dos atributos do solo (0-20 cm) em área de floresta nativa (Floresta) e área de cultivo com espécies agrícolas anuais (Antropizada) em Porto Velho, Rondônia, Brasil. DS: densidade do solo; S: soma de bases; US: umidade do solo, MO; matéria orgânica do solo: CC; capacidade de campo: µC: carbono da biomassa microbiana; µN: nitrogênio da biomassa microbiana.

DISCUSSION

Soil preparation operations, as well as cultivation, significantly altered the physical and chemical attributes of the soil. The highest values of Bd, a physical attribute that can be used as an index of the structural condition of a given soil, were modified as a function of machine traffic in the anthropized area. Soil preparation operations for cultivation, when carried out outside the soil friability range, can promote soil compaction, reducing porosity by the effect of pressure, or by the destruction and individualization of aggregates, transport of finer material and filling of soils. pores. Similar patterns were verified by Lima *et al*. (2018) who also observed an increase in Bd in a cultivated area, when compared to an area of native forest. For Milagres *et al*. (2018), the increase in Bd is related to the decrease in soil organic matter content. This inverse correlation between Ds and organic matter content was also observed in this study, since the highest Bd values were quantified in the anthropized area, in which the lowest levels of organic matter were quantified.

The increase in SM in the surface layer (0-10 cm) in the anthropized area, compared to the forest area, may also be associated with the increase in Bd. With the increase of Bd, there is a reduction of spaces for water movement, a fact that decreases the infiltration and percolation capacity of water in depth (PANACHUKI *et al*., 2006).

There was an improvement in the chemical attributes of the soil in the anthropized area, since liming and fertilization were carried out, practices commonly used for the conventional cultivation of grains (LACERDA *et al*., 2015). However, the negative impact of soil preparation and use in the anthropized area was also observed, due to the decrease in the cation exchange capacity, a fact that can be attributed to the decrease in the organic matter content due to soil turning (PEREIRA and THOMAZ, 2015).

The values observed indicate that in the anthropized area, the application of limestone was efficient, providing an increase in the values of pH, exchangeable calcium and magnesium, sum of bases and saturation by bases, parallel to the reduction of exchangeable aluminum and aluminum saturation, in terms of levels of P and K these were higher in the anthropized area, however when the comparison between the environments was carried out, no significant differences were verified between the studied areas. A possible explanation for the lack of difference can be attributed to the extraction of these nutrients by the crop (grains) (LACERDA *et al*., 2015).

Higher organic matter contents in the forest area may be associated with greater litter deposition, compared to the anthropized area. In this area, the soil organic matter originating from the vegetation is used by the microbial biomass in the first 20 cm (REIS *et al*., 2019). However, there was little effect of the use system on the content of organic matter in the 10-20 cm layer in the anthropized area, in which the incorporation of plant residues with mechanization can contribute to the replacement of the organic matter that was decomposed. Several authors have registered a decrease in organic matter content, both in depth and also in different land use systems such as pasture, burned forest areas and other use systems (VALADÃO JÚNIOR *et al*., 2017). It is estimated that the carbon stock in the soils of the Legal Amazon is 47 Pg C in the 0-100 cm layer, with 45% (21 Pg C) concentrated in the top 20 cm (REIS *et al*., 2019).

The higher levels of organic matter in the surface layer of the native forest area, compared to the subsurface layer (10-20 cm), are due to litter input. In the comparison between the soil layers of the anthropized area, the decrease in organic matter indicated that the incorporation of crop residues in the soil preparation system favored the increase of organic matter in the subsurface layer, which practically differed little from the forest area, in this same layer (CARVALHO *et al*., 2019).

Microbial C-biomass proved to be very sensitive to the type of land use. The magnitude of changes caused in this attribute, by type of use, is probably closely related to the influence of the quantity and quality of litter supplied (DUARTE *et al*., 2014). Changes in soil characteristics, such as increasing temperature, decreasing field capacity and increasing DS, negatively interfere with microbial biomass. Areas subject to vegetation cover protection or in which there is a greater supply of litter, contribute to the increase in microbial biomass by providing more favorable conditions for the development of microorganisms.

Negative effects on microbial biomass were more noticeable in the surface layer (0-10cm). In the anthropized area, the 60% decrease in microbial biomass C in the most superficial layer compared to the forest area can be attributed to the lower contribution and diversity of organic material in the anthropized area compared to the forest area, consequently affecting negatively affect the environment of the soil microbiota (MARTINKOSKI *et al*., 2017).The simultaneous reduction of carbon and nitrogen compared to the natural area and the anthropized area was also observed by Sousa *et al*. (2019).

Although the organic matter content was higher in the surface layer both in the forest area and in the anthropized area, the fact that the microbial biomass is lower in the 0-10 cm layer in the soil of the anthropized area, probably indicates that in the 10-20 cm a more favorable microhabitat for microbial activity occurs, indicating that extremes of humidity can be harmful to microbial activity (MATSUNAGA *et al*., 2018). The soil moisture that is configured as an optimal condition for soil microorganisms would be around 20 to 25% moisture (MATSUNAGA *et al*., 2018). Another factor that would negatively influence microbial activity would be soil mechanization, which would be reduced mainly in the most superficial layer due to soil disturbance (MARTINKOSKI *et al*., 2017).

SANTANA *et al*. (2017) found that, under natural conditions of primary forest, soil microbial biomass is concentrated in the surface layer. Studying fluctuations in soil biomass, activity and microbial population as a response to environmental variations, he found that among the cultivated systems, those that produced the highest amount of plant biomass and promoted good soil cover were those that presented the highest values of microbial biomass, in comparison to bare soil systems (SANTANA *et al*., 2017).

Changes in microbial population and activity maybe a direct consequence of the availability of nutrients to microorganisms, or indirect, such as the increase in pH due to liming (SOUSA *et al*., 2019). Soil preparation results in a decrease in microbial biomass and the ratio with organic matter due to the sensitivity of changes due to changes in soil management or use (REIS *et al*., 2019).

The association of soil chemical attributes with the anthropized area, which was identified by the multivariate analysis of principal components, is a function of conventional tillage in which fertilizer and limestone were used (LACERDA *et al*., 2015). As for the native forest area, with higher levels of aluminum and organic matter, it can be explained by the greater input of litter, contributing to the increase in the organic matter content. The higher levels of Al may be due to the rapid cycling of nutrients, causing their content to be low in the soil, as they are stored in the vegetation.

Microbial biomass is highly sensitive to changes in the environment and is directly related to the attributes observed in the forest area (HOFFMAN *et al*., 2018), with a reduction in its values compared to the anthropized area. This pattern may be due to the changes imposed in this environment, it appears that areas when managed can contribute to the reduction of the activity of organisms and consequently of the biomass (SANTANA *et al*., 2017). Another related factor is the organic material that is deposited by the forest area and that provides a favorable environment for the development of soil microbiota (SANTANA *et al*., 2017).

CONCLUSÕES

- Chemical attributes were higher in the managed environment due to fertilization and soil acidity correction.
- Depending on the management applied, there is an increase in soil density and higher values of moisture in the surface layer.
- The microbial biomass in the studied areas was influenced by vegetation cover and management methods.
- Due to its sensitivity to the management adopted, microbial biomass becomes an important indicator of soil quality.

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