EDGE EFFECT ON CHEMICAL ATTRIBUTES OF SOIL IN A SEASONAL FOREST

Patrícia Anjos Bittencourt Barreto-Garcia[2*], Rafael Nogueira Scoriza[3] and Alessandro de Paula[2]

[1] Received on 30.05.2018 accepted for publication on 20.05.2019.
[2] Universidade Estadual do Sudoeste da Bahia, Departmento de Engenharia Agrícola e Solos, Vitória da Conquista, Bahia, Brasil . E-mail: <patriciabarreto@uesb.edu.br> and <apaula@uesb.edu.br>.
[3] Universidade Estadual do Sudoeste da Bahia, Programa de Pós-Graduação em Ciências Florestais, Vitória da Conquista, Bahia, Brasil . E-mail: <rafaelscoriza@gmail.com>.
*Corresponding author.

ABSTRACT – The magnitude of changes in soil attributes can be used to identify the effects of natural or anthropogenic interference on forest fragments. The objective of this work was to evaluate the chemical attributes of the soil as indicators of the edge effect at a Seasonal Semi-deciduous Forest fragment in the Southwest of Bahia, Brazil. Four sampling ranges were defined in the forest fragment (Range 1: 0-10m; Range 2: 40-50 m; Range 3: 80-90 m; and Range 4: 400-410 m from the edge). A degraded native pasture area was used as the reference. Soil samples were collected at depths of 0-5, 5-10 and 10-20 cm. The samples were analyzed for pH and organic matter, P, K, Ca, Mg and Al. The superficial layer of the soil was sensitive to the changes imposed by the fragmentation, reflecting modifications in some of its chemical attributes up to a distance of 90 m from the edge towards the interior of the fragment, with more severe effects in the first 10 meters. Soil organic matter, potential acidity, CEC and pH were the most affected attributes, evidencing a gradient of variation in the edge-interior direction.

Keywords: Soil fertility; Organic matter; Atlantic forest.

EFEITO DE BORDA SOBRE ATRIBUTOS QUÍMICOS DO SOLO EM FLORESTA ESTACIONAL

RESUMO – A magnitude das alterações em atributos do solo pode ser utilizada para identificar efeitos de interferências naturais ou antrópicas em fragmentos florestais. Este trabalho objetivou avaliar atributos químicos do solo como indicadores de efeito de borda em fragmento de Floresta Estacional Semidecidual, no Sudoeste da Bahia. Foram definidas quatro faixas de amostragem no fragmento florestal (Faixa 1: 0-10m, Faixa 2: 40-50 m, Faixa 3: 80-90 m e Faixa 4: 400-410 m da borda). Uma área de pastagem nativa degradada foi utilizada como referência. Foram coletadas amostras de solo nas profundidades 0-5, 5-10 e 10-20 cm. As amostras foram submetidas a análises para determinação do pH e dos teores de matéria orgânica, P, K, Ca, Mg e Al. A camada superficial do solo mostrou-se sensível às variações impostas pela fragmentação, refletindo modificações em alguns dos seus atributos químicos até uma distância de 90 m da borda em direção ao interior do fragmento, com efeitos mais severos nos primeiros 10 metros. Matéria orgânica do solo, acidez potencial, CTC e pH foram os atributos mais afetados, evidenciando um gradiente de variação no sentido borda-interior.

Palavras-Chave: Fertilidade do solo; Matéria orgânica; Floresta Atlântica

http://dx.doi.org/10.1590/1806-90882019000100009

1. INTRODUCTION

The expansion of agricultural frontiers and urban areas is seen as one of the main causes of forest fragmentation worldwide. The area located at the fragment edges between the natural and the anthropic habitats is more exposed to the influence of the external environment, which alters the flow of energy, matter and organisms in the ecosystem. This set of ecological changes which occur between the edge and the interior is called the edge effect (Harper et al., 2005).

The edge effect generates the occurrence of abiotic and biotic gradients (Ries et al., 2004) as a result of a set of changes in the composition, structure, function and dynamics of the forest ecosystem (Liu and Slik, 2014). Such changes may lead to an increased in soil exposure, making it more vulnerable to erosion and losses in organic matter and nutrients (Lepsch, 2011).

In altered or degraded environments, the remaining tree species are mainly responsible for maintaining cycling and soil nutrient reserve (Binkley and Fisher, 2013), which guarantees its own survival. This result is due to the deposition and decomposition of deciduous materials that promote the forming of organic matter in the soil (Denardin et al., 2014) and a significant nutrient return (Binkley and Fisher, 2013), capable of maintaining or improving the physical and chemical characteristics of the soil.

Among the main factors that regulate the decomposition process are the microenvironment quality (radiation, temperature and humidity) and the nature of the deposited plant material (Gama-Rodrigues et al., 2003; Denardin et al., 2014), which are usually associated with the distribution, abundance and diversity of forest species (Moreno and Schiavini, 2001; Binkley and Fisher, 2013). Therefore, any alteration that may interfere in the vegetation cover composition can promote changes in the decomposition, and consequently in the organic matter and other soil attributes.

Although research on soil attributes has been intensively developed for production purposes in agricultural and forestry systems, soil study has been little explored from the ecological point of view (Castro, 2008). An investigation of the edge effect in the soil can represent an important tool to evaluate natural or anthropic interferences in forest fragments, as well as to help in the conservation monitoring. However, studies related to this subject are still scarce in Brazil (Santos, 2016; Santos et al., 2018).

In view of the above, the present work had the objective to evaluate soil chemical attributes as indicators of edge effect in a Semi-deciduous Seasonal Forest fragment.

2. MATERIAL AND METHODS

2.1. Characterization of the area

The study was carried out in the city of Vitória da Conquista (BA), in the Forest Reserve of the State University of the Southwest of Bahia (*UESB*), which has an area of 42 ha and is situated at 891 m of altitude at coordinates 14º 52’ 46’’ S and 40° 47’ 34’’ W. The vegetation is regionally known as “*cipó forest*”, and is classified as Montana Semi-deciduous Seasonal Forest (Barbosa et al., 2017).

The fragment presents a considerable area in the middle regeneration stage according to the criteria established by CONAMA Resolution no. 1, dated January 31, 1994 (Brasil, 1994). It is a relatively low forest (trees with height between 10 and 15 m), composed of partially deciduous mesophanerophytes, surrounded by lianas, with a predominance of Leguminosae family ecotypes, especially the *Parapiptadenia* Brenan genus (Veloso et al., 1991). The climate of the region is Cwb according to the Köppen classification, constituting a tropical climate at altitude. The average annual temperature is 21 ºC, and the precipitation varies between 700 and 1100 mm annually. The soil belongs to the Dystrophic Yellow Latosol class.

2.2. Delimitation and characterization of the ranges

Four sampling ranges were defined in the forest fragment, three corresponding to the forest transition zone (Range 1: 0-10m; Range 2: 40-50 m; and Range 3: 80-90 m from the edge), and one representing the interior of the fragment (Range 4), positioned at half the total distance between the fragment ends (400-410 m) in the sense of traversing the demarcation of the ranges. Table 1 shows the most common tree species of each of the sampling ranges, as well as their deciduous and ecological group characteristics. In addition to the ranges, a degraded native pasture area (pasture) used by cattle was also defined in order to represent the absence of forest, separated from the fragment by a road of about two meters wide.

2.3. Dendrometric Variables

Diameter-at-breast-height measurements at 1.30 m of the soil (DBH) and the total height of all trees with DBH greater than 15 cm were taken in each of the ranges using a tape measure and a rod graduated in meters. Absolute density (AD), total basal area (TBA) and mean height (H) of each range were then estimated from the obtained information (Table 2).

2.4. Soil chemical sampling and analysis

Three samples composed of soil were collected in each fragment range and in the pasture with the aid of a Dutch auger at depths 0-5, 5-10 and 10-20 cm. Each composite sample was composed of four sub-samples, collected around equidistant points, 10 meters apart. The sampling was carried out in October 2012. The soil chemical analysis followed the methods described in Embrapa (2017). The pH was determined in water (1:2.5). Available phosphorus (P) and potassium (K^+) were extracted by Mehlich^{-1} by the Braga and Defelipo (1974) method. Calcium (Ca^{2+}), magnesium (Mg^{2+}) and aluminum (Al^{3+}) exchangeable cations were extracted with 1.0 mol L^{-1} KCl, and Ca^{2+} and Mg^{2+} were measured by atomic absorption spectrophotometry and Al^{3+} by volumetry with a diluted NaOH solution. The hydrogen (H+) was extracted with 1 mol L^{-1} calcium acetate at pH 7.0 and volumetrically determined with NaOH solution. The cation exchange capacity (CEC) was calculated from the potential acidity values, exchangeable bases and exchangeable aluminum. Soil organic matter (SOM) was determined by oxidation with $Na_2Cr_2 O_7$ 4 N in acid medium.

2.5. Data analysis

The Cochran test and normality were evaluated by the Lilliefors test using the SAEG® v.9.1 statistical program. Afterwards, the data were submitted to analysis of variance according to a completely randomized design with five treatments and three replications, using the Scott-Knott test at 5 % significance and the SISVAR® v.5.3 program to compare the chemical attributes between the sampling ranges (forest fragment and pasture). Pearson correlations were established at 5% significance between the AD, TBA and H variables and the soil attributes using the ACTION® program. In addition, cluster analysis was performed using all chemical attributes with a hierarchical method and Euclidean distance, and also using the ACTION® program.

3. RESULTS

The edge effect on the forest fragment was verified by some soil chemical attributes such as pH, potential acidity (H+Al), CEC and SOM. These presented well-defined patterns, especially in the more superficial layers of the soil with a distinction between the values observed inside the fragment (Range 4) in relation to the edge (Range 1) and external environment (pasture) (Table 3).

There was a decrease in pH values in the pasture-edge-inland direction at all depths. However, contrary to pH, H+Al values demonstrated

Tabela 1 – Espécies mais comuns em quatro faixas de amostragem de um fragmento de Floresta Estacional Semidecidual.

Table 1 *– Most common species in four sampling ranges of a semi-deciduous seasonal forest fragment.*

Family	Species	Dec[(1)]	EG	Ref	Range			
					1	2	3	4
Anacardiaceae	*Astronium graveolens* Jacq.	D	P	A				X
Boraginaceae	*Patagonula bahiensis* Moric.	D	S	B	X			
Euphorbiaceae	*Sapium glandulatum* (Vell.) Pax	D	P	A	X	X	X	X
Fabaceae	*Machaerium acutifolium* Vogel	SD	P	A		X		
Fabaceae	*Machaerium brasiliense* Vogel	SD	S	B	X	X		
Anacardiaceae	*Astronium graveolens* Jacq.	D	P	A				X
Fabaceae	*Machaerium fulvovenosum* Lima	SD	S	B		X	X	
Fabaceae	*Machaerium nyctitans* (Vell.) Benth.	SD	P	A	X	X		
Fabaceae	*Platypodium elegans* Vogel	SD	P	A	X			
Fabaceae	*Pseudopiptadenia contorta* (DC.) G. P. Lewis & M.P. Lima	PN	P	C	X	X	X	
Rutaceae	*Metrodorea mollis* Caub.	PN	L				X	X

[(1)]Dec = deciduousness, SD = semi-deciduous, D = deciduous, PN = perennial, EG = ecological group, P = pioneer, S = secondary, L = late, Ref = bibliographic reference, A = Lorenzi (1992); B = Lorenzi (1998); C = Lorenzi (2009), Ranges 1, 2, 3 and 4 = 0-10 m, 40-50 m, 80-90 m and 400-410 m from the edge, respectively.

Tabela 2 – Parâmetros da estrutura da vegetação em quatro faixas de amostragem de um fragmento de Floresta Estacional Semidecidual.
Table 2 – *Vegetation structure parameters in four sampling ranges of a semi-deciduous seasonal forest fragment.*

Range(1)	AD (nind/ha)	TBA (m^2/ha)	H(m)
1	1650	1,168	7,4
2	1550	1,367	7,7
3	1370	1,369	8,2
4	1060	1,379	8,4

(1)Ranges 1, 2, 3 and 4 = 0-10, 40-50, 80-90 and 400-410 m from the edge, respectively. AD = absolute density, TBA = total basal area and H = mean height of the trees.

an increasing gradient of the pasture towards the interior of the fragment (Table 3). In addition, significant positive correlations were found between potential acidity and SOM in the superficial layer, and negative correlations between pH and SOM at all depths (Table 4).

SOM also showed significant associations with Ca^{2+}, sum of bases (SB) and CEC (Table 4), especially in the superficial layers. In general, CEC and SOM presented higher values within the studied fragment, although differences were more evident in the 0-5 cm layer, which was distinguished from the pasture and edge (Table 3).

For phosphorus and K^+, Ca^{2+} and Mg^{2+}, cations, it was not possible to observe a clear gradient indicating the occurrence of edge effect, although there were significant differences between the ranges (Table 3). The K contents at the 0-5 cm depth resembled the outer environment, edge and interior of the fragment. In the other depths, pasture and edge presented higher values than the other ranges. There was generally little variation between the ranges for Ca^{2+} and Mg^{2+} (Table 3).

In the case of P, the pasture presented a superior value to the fragment ranges in the most superficial layer (0-5 cm), while the pasture resembled at least one of the ranges in the other depths (Table 3).

Significant correlations were verified between tree vegetation variables (AD, TBA and H) and soil chemical attributes (Table 4). Absolute density presented a positive relation with pH and negative with H+Al, CEC and SOM. The opposite was observed for TBA and H, which presented negative coefficients with pH and positive with SB, CEC and SOM (Table 4).

Figure 1 shows the similarity dendrogram obtained for each of the soil depths. Two distinct groups were formed in the 0-5 cm layer, with the first composed by grass and edge (range 1), and the second by the other ranges of the fragment, with differentiation

Tabela 3 – Atributos químicos do solo no gradiente pasto-borda-interior de fragmento de floresta estacional semidecidual.
Table 3 – *Chemical soil attributes in the pasture-edge-interior gradient of the semi-deciduous seasonal forest fragment.*

	pH	P	K^+	Ca^{2+}	Mg^{2+}	H^++Al^{3+}	SB	CEC	SOM
		mg dm^{-3}	cmolc dm^{-3} of soil						g dm-3
					0 - 5 cm				
Pasture	6.3 a	5.0 a	0.15 a	2.6 b	1.40 a	1.9 d	4.2 a	5.8 d	29.0 c
Range 1 (1)	5.6 b	2.7 b	0.16 a	2.2 b	1.07 a	3.3 c	3.4 a	6.7 c	36.7 b
Range 2	5.1 c	1.0 b	0.13 b	3.0 a	1.20 a	4.1 b	4.3 a	8.5 b	54.3 a
Range 3	5.0 c	1.0 b	0.11 c	3.1 a	1.07 a	4.0 b	4.3 a	8.4 b	51.3 a
Range 4	4.6 d	2.3 b	0.15 a	2.5 b	1.23 a	6.2 a	3.9 a	10.1 a	54.7 a
					5 - 10 cm				
Pasture	6.0 a	2.0 a	0.13 a	1.9 a	0.77 a	2.1 c	2.8 a	4.9 c	21.0 b
Range 1	5.0 b	1.3 b	0.14 a	1.0 c	0.73 a	3.9 b	1.9 b	5.7 b	23.0 b
Range 2	4.8 b	1.0 b	0.08 b	0.8 c	0.50 b	4.3 b	1.4 c	5.8 b	25.7 b
Range 3	4.9 b	1.0 b	0.07 b	1.2 b	0.63 b	4.0 b	1.9 b	6.0 b	25.7 b
Range 4	4.4 c	2.0 a	0.08 b	0.9 c	0.53 b	5.8 a	1.5 c	7.3 a	31.3 a
					10 - 20 cm				
Pasture	5.7 a	2.0 a	0.10 b	1.6 a	0.63 a	2.3 c	2.3 a	4.6 c	15.5 b
Range 1	4.8 b	1.0 a	0.13 a	0.7 b	0.50 a	3.9 b	1.3 b	5.2 b	18.3 a
Range 2	4.5 c	1.0 a	0.07 c	0.5 b	0.47 a	4.2 b	1.1 b	5.3 b	19.0 a
Range 3	4.6 c	1.0 a	0.05 c	0.6 b	0.37 a	4.0 b	1.0 b	4.9 c	18.3 a
Range 4	4.2 d	2.0 a	0.05 c	0.4 b	0.37 a	5.0 a	0.8 b	5.9 a	19.3 a

(1)Ranges 1, 2, 3 and 4 = 0-10 m, 40-50 m, 80-90 m and 400-410 m from the edge, respectively. SB = Sum of bases, CEC = Cation Exchange Capacity, SOM = Soil Organic Matter. Equal letters in the column do not differ by the Scott-Knott test at 5% significance.

Tabela 4 – Coeficientes de correlação entre variáveis da vegetação e atributos químicos do solo.
***Table 4** – Coefficients of correlation between variables of vegetation and soil chemical attributes.*

	pH	P	K^+	Ca^{2+}	Mg^{2+}	H^++Al^{3+}	SB	CEC	SOM
					0-5 cm				
AD [(1)]	0.89*	-0.06	0.06	-0.07	-0.52	-0.91*	-0.20	-0.88*	-0.61
TBA	-0.84*	-0.64*	-0.61*	0.71*	0.55	0.59	0.83*	0.82*	0.92*
H	-0.89*	-0.21	-0.35	0.32	0.36	0.77*	0.44	0.84*	0.70*
SOM	-0.71*	-0.3	-0.43	0.64*	0.52	0.63*	0.72*	0.84*	-
					5-10 cm				
AD	0.86*	0.58	0.56	-0.01	0.46	-0.84*	0.29	-0.92*	-0.91*
TBA	-0.57	-0.63*	-0.95*	-0.10	-0.81*	0.46	-0.54	0.45	0.61*
H	-0.70*	-0.73*	-0.74*	0.20	-0.45	0.65*	-0.17	0.76*	0.80*
SOM	-0.77*	0.62*	-0.51	-0.1	-0.32	0.48	-0.27	0.70*	-
					10-20 cm				
AD	0.85*	-0.85*	0.72*	0.75*	0.83*	-0.84*	0.63*	-0.63*	-0.60
TBA	-0.72*	0.34	-0.93*	-0.77*	-0.70*	0.50	-0.79*	0.24	0.59
H	-0.75*	0.55	-0.86*	-0.66*	-0.94*	0.57	-0.92*	0.40	0.46
SOM	-0.53*	0.33	-0.19	0.11	0.31	0.42	0.17	0.59*	-

[(1)] AD = absolute density, SB = Sum of bases, CEC = Cation Exchange Capacity, TBA = total basal area, H = mean height of the trees, SOM = Soil Organic Matter. Numbers highlighted with an asterisk (*) are significant ≤ 5%.

in range 4. The sparation was only observed between the ranges of the fragment and the pasture at depths of 5-10 and 10-20 cm (Figure 1), with no indication of edge effect at any of the distances considered.

4. DISCUSSION

The reduction in the pH values from the border to the interior of the fragment (Table 3) can be attributed to a greater mineralization of the organic matter and the release of acid exudates by the tree roots which confer greater acidity to the soil of more preserved forest environments (Barreto et al., 2006; Iarema et al., 2011). These two processes exert an important influence on soil acidification, since the first process results in producing organic acids, while the second is the result of the release of protons by the roots in order to balance the high cation absorption by the trees (Koutika et al., 2014; Kasongo et al., 2009; Mafra et al., 2008). A similar pH variation pattern was verified by Cunha et al. (2005) in areas of Semi-deciduous Seasonal Forest in the Londrina (PR) region, with lower results in the center of the fragment in relation to the edge.

In turn, the highest SOM levels observed in the fragment interior (Table 3) may be related to the more stable condition of the environment, which causes larger accumulations of litter, as verified by Santos et al. (2018), who studied the same sampling ranges and forest fragment of this study. For Cardoso et al. (2011) and Feitosa et al. (2016), the vegetation interferes with the amount and quality of the organic material input according to their diversity, shoot and root biomass, where higher values of these three parameters provide materials with different degrees of susceptibility to decomposition and consequently higher SOM levels. According to Binkley et al. (1992), increases in the amount of organic matter in the soil provide an increase in the exchangeable complex, reducing the pH in soils with low cation availability, which explains the acidity gradient observed in the present study.

Significant associations of SOM with negative (pH) and potential (positive) acidity (Table 4) corroborate the previously discussed results, demonstrating that increases in SOM content contribute to a soil acidity increase. The inverse relationship between pH and H+Al was also observed by Cunha Neto et al. (2018), in soils under forests and pasture.

The high correlation coefficients between SOM and CEC (0.6 to 0.8) are indicative of the strong influence of this first attribute in the supply of negative electrical surface charges, increasing the cation exchange capacity of the soil (Kasongo et al., 2009). In addition, SOM plays an important role in the forest succession as a source of nutrients to plants in tropical and subtropical soils (Barreto et al., 2006; Fontana et al., 2011; Feitosa et al., 2016). For this reason, the removal or disturbance of a forest is usually associated with a reduction of soil CEC, as verified by Iarema et al. (2011).

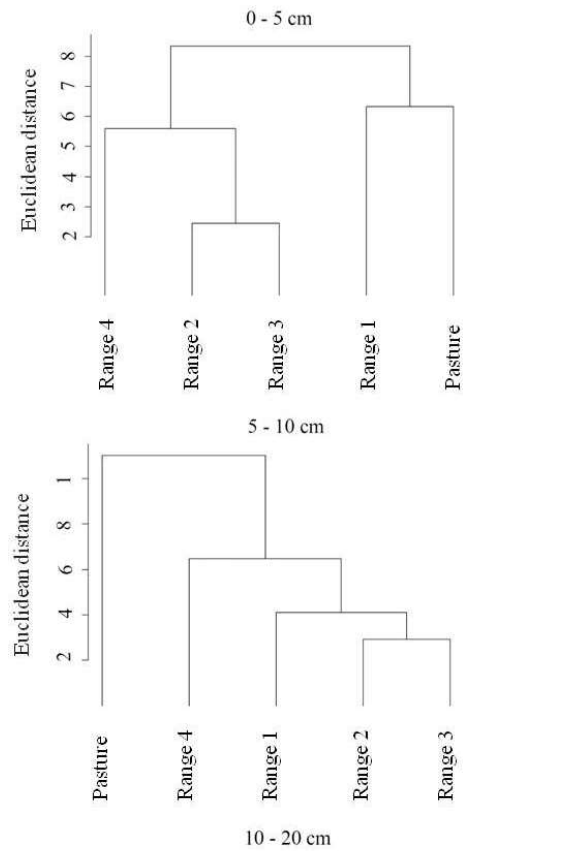

Figure 1 – Dendrogram of similarity between pasture and forest fragment ranges based on soil chemical attributes at three depths (0-5, 5-10 and 10-20 cm). Range 1, 2, 3 and 4 = 0-10 m, 40-50 m, 80-90 m and 400-410 m from the edge, respectively.

Figura 1 – Dendrograma de similaridade entre o pasto e as faixas do fragmento florestal, com base nos atributos químicos do solo em três profundidades (0-5, 5-10 e 10-20 cm). Faixas 1, 2, 3 e 4 = 0-10 m, 40-50 m, 80-90 m e 400-410 m da borda, respectivamente.

The higher CEC values observed in the interior of the fragment in relation to the other sampling ranges in all studied depths suggests that the edge effect influenced the fertility of the soil up to 90 meters from the edge towards the interior of the fragment. The mean CEC of the interior of the fragment (7.8 cmolc dm^{-3}) is compatible with the condition of a well-conserved area within an anthropic matrix, which denotes greater soil capacity to retain cations in the form of outer-sphere complexes and provide nutrients to plants for an extended period (Meurer et al., 2012).

The highest P levels in the topsoil layer (0-5 cm) of the pasture (Table 3) may be an indication that manure addition to the soil from grazing cattle increased the availability of the soil surface element. According to Braz et al. (2002), grazing cattle feces releases P in organic form, which is gradually available due to the mineralization process, which represents a reduced P loss of the system by leaching or adsorption to soil colloids.

The absence of a clear gradient of variation in the levels of P, K, Ca^{2+} and Mg^{2+} suggests that the edge effect would not be directly affecting these attributes, possibly due to the continuous deposition of plant residues which act as a substrate for nutrient cycling. The forest contents decreased in relation to the pasture only in the case of Ca^{2+} in the 5-10 and 10-20 cm layers, which may be related to the higher nutritional demand of the forest. The Ca^{2+} contents were between 0.4 and 3.1 cmolc dm^{-3} (Table 3), and are lower than the average observed by Skorupa et al., (2012) in different Deciduous Seasonal Forest phytophysiognomies (3.4 $cmol_c$ dm^{-3}).

Considering that the vegetation is a determinant factor in the dynamics of absorption, nutrient cycling and organic matter accumulation in the soil (Selle, 2007), changes in the plant community may explain variations in soil properties. In agreement with this hypothesis, the significant correlations of soil chemical attributes with absolute density, total basal area and mean height of trees (Table 4) show the close relationship between vegetation structure and soil properties, as observed by others authors (Moreno and Schiavini, 2001; Godinho et al., 2013).

The set of chemical soil attributes variation evaluated by the cluster analysis showed dissimilarity between sampling ranges at 0-10 cm depth (Figure 1). Differentiation of range 1 and pasture, which constituted group 1, was observed in relation to ranges 2, 3 and 4, which comprised group 2 (Figure 1). This shows that the edge effect exerted greater influence on soil fertility in the first ten meters of the edge towards the fragment interior. In addition, the separation of group 2 into two subgroups (I: range 4, II: ranges 2 and 3) denotes that the fragment transition zone, located between 40 and 90 m from the edge, is also influenced by the edge effect, but less intense than range 1. This less prominent effect must be related to the fact that ranges 2 and 3 provide a more favorable micro-environment to biogeochemical cycling and consequently to the maintenance of soil chemical attributes.

On the other hand, the indication of similarity between the fragment ranges at depths of 5-10 and 10-20 cm (Figure 1) shows that the most superficial layer of the soil (0-5 cm) was more responsive to the variations of the medium, probably due to the greater influence of changes in the deposition of residues, decomposition and accumulation of organic matter (Vogel et al., 2013). However, this result may also be indicative of the fact that the effects of fragmentation and edge formation in the studied fragment are still recent, and as such they may also be expressed in deeper layers of the soil over the years.

5. CONCLUSION

The superficial layer of the soil is sensitive to the variations imposed by the fragmentation, reflecting modifications in some of its chemical attributes up to a distance of 90 m from the edge towards the interior of the fragment, with more severe effects in the first 10 meters. Soil organic matter (SOM), potential acidity (H+Al), CEC and pH were the most affected attributes, evidencing a gradient of variation in the inner-edge direction, being positive for SOM, H+Al and CEC, and negative for pH.

The integrated analysis of soil chemical attributes is a suitable method to detect changes caused by the edge effect and can be used as an indicator of the impact caused by forest fragmentation.

6. REFERENCES

Barbosa V, Barreto-Garcia PAB, Gama-Rodrigues E, Paula A. Biomassa, carbono e nitrogênio na serapilheira acumulada de florestas plantadas e nativa. Floresta e Ambiente. 2017;24:e20150243.

Barreto AC, Lima FHS, Freire MBGS, Araújo QR, Freire FJ. Características químicas e físicas de um solo sob floresta, sistema agroflorestal e pastagem no sul da Bahia. Caatinga. 2006;19(4):415-25.

Binkley D, Richter D, David MB, Caldwell B . Soil Chemistry in a Loblolly/Longleaf Pine Forest with Interval Burning. Ecological Applications. 1992; 2 (2): 157-164.

Binkley D, Fisher RF. Ecology and management of forest soils. 4th.ed. Oxford: Wiley-Blackwell; 2013.

Braga JM, Defelipo BV. Determinação espectofotométrica de fósforo em extratos de solos e planta. Revista Ceres, 1974;21(113):73-85.

Brasil. Resolução CONAMA nº. 1, "Define vegetação primária e secundária nos estágios pioneiro, inicial, médio e avançado de regeneração da Mata Atlântica, a fim de orientar os procedimentos de licenciamento de exploração da vegetação nativa em São Paulo" 31 de Janeiro de 1994. Diário Oficial da União, Brasília, DF (1994 fev. 3); Sec. 1:1684-85. http://www2.mma.gov.br/port/conama/legiabre.cfm?codlegi=142. 15 abr. 2019.

Braz SP, Nascimento Júnior D, Cantarutti RB, Regazzi AJ, Martins CE, Fonseca DM. Disponibilização dos nutrientes das fezes de bovinos em pastejo para a forragem. Revista Brasileira de Zootecnia, 2002;31(4):1614-23.

Cardoso EL, Silva MLN, Curi N, Ferreira MM, Freitas DAF. Qualidade química e física do solo sob vegetação arbórea nativa e pastagens no Pantanal Sul-Mato-Grossense. Revista Brasileira de Ciência do Solo, 2011;35(2):613-22.

Castro DM. Efeitos de borda em ecossistemas tropicais: síntese bibliográfica e estudo de caso em fragmentos de Cerrado, na região nordeste do estado de São Paulo [dissertação] São Paulo: Universidade de São Paulo; 2008.

Cunha MET, Rodrigues E, Costa Júnior C, Ribeiro MCS. Identificação do efeito de borda em fragmentos florestais nativos da região de Londrina, utilizando como ferramenta a fertilidade do solo, Botucatu, SP. In: Anais 2º Encontro Internacional de Agroecologia e Desenvolvimento Rural. Botucatu: 2005.

Cunha Neto FV, Pereira MG, Leles PSS, Abel ELS. Atributos químicos e físicos do solo em áreas sob diferentes coberturas florestais e pastagem em Além Paraíba – MG. Ciência Florestal. 2018;28(1):13-24.

Denardin RBN, Mattias JL, Wildner LP, Nesi CN, Sordi A, Kolling DF, et al. Estoque de carbono no solo sob diferentes formações florestais, Chapecó-SC. Ciência Florestal. 2014;24(1):59-69.

Empresa Brasileira de Pesquisa Agropecuária -

Embrapa. Manual de métodos de análise de solo. 3ª ed. Brasília: Centro Nacional de Pesquisa de Solos; 2017.

Feitosa KKA, Vale Júnior JF, Schaefer CEGR, Sousa MIL, Nascimento PPRR. Relações solo–vegetação em "ilhas" florestais e savanas adjacentes no nordeste de Roraima. Ciência Florestal. 2016;26(1):135-46.

Fontana A, Silva CF, Pereira MG, Loss A, Brito RJ, Benites VM. Avaliação dos compartimentos da matéria orgânica em área de Mata Atlântica. Acta Scientiarum. 2011;33(3):545-50.

Gama-Rodrigues AC, Barros NF, Santos ML. Decomposição e liberação de nutrientes do folhedo de espécies florestais nativas em plantios puros e mistos no sudeste da Bahia. Revista Brasileira de Ciência do Solo. 2003;27(6):1021-31.

Godinho TO, Caldeira MVW, Rocha JHT, Caliman JP, Viera M. Fertilidade do solo e nutrientes na serapilheira em fragmento de Floresta Estacional Semidecidual. Ecologia e Nutrição Florestal. 2013; 1(3): 97-109.

Harper KA, Macdonald E, Burton PJ, Chen J, Brosofske KD, Saunders SC et al. Edge influence on forest structure and composition in fragmented landscapes. Conservation Biology. 2005; 19(3):768-782.

Iarema AA, Fonte LEF, Fernandes RBA, Schaefer CEGR, Pereira LC. Qualidade física e química do solo em áreas de exploração florestal no Mato Grosso. Revista Árvore. 2011;35(3):737-44.

Kasongo RK, Ranst EV, Verdoodt A, Kanyankagote P, Baert G. Impact of Acacia auriculiformis on the chemical fertility of sandy soils on the Batéké plateau, D.R. Congo. Soil Use and Management. 2009;25(1): 21 - 27.

Koutika LS, Epron D, Bouillet JP, Mareschal L. Changes in N and C concentrations, soil acidity and P availability in tropical mixed acacia and eucalypt plantations on a nutrient-poor sandy soil.Plant and Soil 2014; 379(1–2): 205–216.

Lepsch IF. 19 lições de pedologia. São Paulo: Oficina de Textos; 2011.

Liu J, Slik JWF. Forest fragment spatial distribution matters for tropical tree conservation. Biological Conservation, 2014;171:99-106.

Lorenzi H. Árvores brasileiras: manual de identificação e cultivo de plantas arbóreas nativas do Brasil. Nova Odessa: Plantarum; 1992. v.1. 385p.

Lorenzi H. Árvores brasileiras: manual de identificação e cultivo de plantas arbóreas nativas do Brasil. Nova Odessa: Plantarum; 1998. v. 2. 384p.

Lorenzi H. Árvores brasileiras: manual de identificação e cultivo de plantas arbóreas nativas do Brasil. Nova Odessa: Plantarum; 2009. v.3. 385p.

Mafra AL, Guedes SFF, Klauberg Filho O, Santos JCP, Almeida JA, Rosa JD. Carbono orgânico e atributos químicos do solo em áreas florestais. Rev. Árvore [online]. 2008;32(2): 217-224.

Meurer EJ, Rheinheimer RD, Bissani CA. Fenômenos de sorção em solos. In: Meurer EJ, editor. Fundamentos de química do solo. 5ª.ed. Porto Alegre: Evangraf; 2012.

Moreno MIC, Schiavini I. Relação entre vegetação e solo em um gradiente florestal na Estação Ecológica do Panga, Uberlândia (MG). Revista Brasileira de Botânica. 2001;24(4):537-44.

Ries L, Fletcher RJ, Battin J, Sisk TD. Ecological responses to habitat edges: mechanisms, models, and variability explained. Annual Review of Ecology. 2004;35(1): 491-522.

Santos MOD. Inter-relação entre atributos microbiológicos do solo como indicadora de efeito de borda em fragmentos de floresta estacional semidecidual [dissertação] Vitória da Conquista: Universidade Estadual do Sudoeste da Bahia; 2016.

Santos RS, Barreto-Garcia PAB, Scoriza RN. Fungos micorrízicos arbusculares e serapilheira como indicadores do efeito de borda em fragmento de Floresta Estacional. Ciência Florestal. 2018;28(1):324-35.

Selle GL. Ciclagem de nutrientes em ecossistemas florestais. Bioscience Journal. 2007;23(4):29-39.

Skorupa ALA, Guilherme LRG, Curi N, Silva CPC, Scolforo JRS, Marques JJGSM. Propriedades de solos sob vegetação nativa em Minas Gerais: Distribuição por fitofisionomia, hidrografia e variabilidade espacial. Revista Brasileira de Ciência do Solo. 2012;36(1):11-22.

Veloso HP, Rangel Filho ALR, Lima JCA. Classificação da vegetação brasileira adaptada a um sistema universal. Rio de Janeiro: IBGE, Departamento de Recursos Naturais e Estudos Ambientais; 1991.

Vogel HLM, Lorentz LH, Azevedo JVS, Rott LAG, Motta MSM. Efeito de borda no estoque de serapilheira e nutrientes em um fragmento de floresta nativa no Bioma Pampa-RS. Ecologia e Nutrição Florestal. 2013;1(1):46-54.