Impact of land use in areas of buffer zone around Cicuta's Forest, Volta Redonda, Rio de Janeiro, Brazil

Impacto do uso do solo em áreas de Zona de Amortecimento da Floresta da Cicuta, Volta Redonda, Rio de Janeiro, Brasil

Impacto del uso del suelo en áreas de Zona de Amortiguamiento de la Floresta da Cicuta, Volta Redonda, Rio de Janeiro, Brasil

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Abstract

Anthropic actions have caused the degradation of Brazilian soils, especially due to reduced forest cover. The objective of this work was to evaluate soil attributes in areas under different forms of land use, located in the buffer zone of the Relevant Ecological Interest Area (ARIE) Cicuta Forest, middle Paraiba do Sul Valley, Rio de Janeiro, Brazil. Eight plots (10m × 12.5m) were installed in three different forms of land use (degraded pasture area; reforestation area with native species; and a fragment of a forest area) for evaluation of chemical and

biological parameters. Although the fragment of a forest area presents a greater homogeneity regarding the nitrogen, polyphenols, humidity, and pH parameters, which shows greater environmental stability in this area, the microbiological parameters showed that there is a low activity, which might be indicative of a degraded environment, probably due to the small size of the forest fragment present in the buffer zone of the Relevant Ecological Interest Area (ARIE) Cicuta Forest.

Keywords: Degraded areas; Landscape ecology; Forest fragmentation; Soil quality; Litter forest settlements.

Resumo

Ações antrópicas tem causado a degradação dos solos brasileiros, especialmente devido a redução da cobertura florestal. O objetivo do trabalho foi avaliar os atributos edáficos em áreas sob diferentes formas de uso de solo, destinadas à implantação de Zona de Amortecimento da Área de Relevante Interesse Ecológico (ARIE) Floresta da Cicuta, localizada na região do Médio Vale do Paraíba, Rio de Janeiro, Brasil. Para isto, foram instaladas 8 parcelas (10m x 12,5m) em três diferentes formas de uso do solo (Área de pastagem degradada; Área de reflorestamento com espécies nativas; Área de fragmento florestal), para avaliação de parâmetros químicos e biológicos. Apesar da área de fragmento florestal apresentar uma maior homogeneidade quanto aos parâmetros nitrogênio, polifenóis umidade e pH, o que evidencia uma maior estabilidade do ambiente nessas áreas, os parâmetros microbiológicos mostraram que existe uma baixa atividade nessas áreas, o que pode ser um indicativo de ambiente degradado, provavelmente devido ao tamanho reduzido dos fragmentos florestais presentes na Zona de Amortecimento da Área de Relevante Interesse Ecológico (ARIE) Floresta da Cicuta.

Palavras-chave: Áreas degradadas; Ecologia da paisagem; Fragmentação florestal; Qualidade do solo; Serrapilheira.

Resumen

Las acciones humanas han provocado la degradación de los suelos brasileños, especialmente debido a la reducción de la cubierta forestal. El objetivo del trabajo fue evaluar las características del suelo en áreas bajo diferentes formas de uso de la tierra, destinadas a la implementación de la zona de amortiguamiento del Área de Relevante Interés Ecológico (ARIE) Floresta da Cicuta, ubicada en la región del Valle Medio del Paraíba, Rio de Janeiro, Brasil. Se instalaron 8 parcelas (10m x 12,5m) en tres formas diferentes de uso del suelo (área

de pastos degradados; área de reforestación con especies nativas; área de fragmentos de bosque), para la evaluación de parámetros químicos y biológicos. El área de fragmentos de bosque presentó mayor homogeneidad en los parâmetros nitrógeno, polifenoles, humedad y pH, lo que muestra una mayor estabilidad del ambiente en estas áreas, pero los parámetros microbiológicos mostraron que existe una baja actividad en estas áreas, lo que puede ser un indicio de ambiente degradado, probablemente debido al pequeño tamaño de los fragmentos de bosque presentes en la zona de amortiguamiento del Área de Relevante Interés Ecológico (ARIE) Floresta da Cicuta.

Palabras clave: Zonas degradadas; Ecología del paisaje; Fragmentación forestal; Calidad del suelo; Arpillera.

1. Introduction

Forests play an important role in the functioning of ecosystems as they perform multiple environmental functions and services. The Atlantic Forest was one of the largest tropical forests in the Americas, originally covering about 150 million hectares. However, it has suffered a huge forest loss, and currently, most of the fragments cover less than 50 hectares (Ribeiro, et al., 2009) and are insufficient to support the long-term survival of this rich endangered rainforest without reestablishment key connectivity links, especially between the larger remnants. In the current critical conservation scenario of the Atlantic Forest, all remnants are important for the conservation of this ecosystem.

The Area of Relevant Ecological Interest (ARIE), Cicuta Forest, is a Conservation Unit located between Serra do Mar and Mantiqueira (Rio de Janeiro State, Brazil), between the municipalities of Volta Redonda and Barra Mansa, is one of the last fragments of Atlantic forest belonging to the Semi deciduous Seasonal ecosystem in the Paraíba do Sul (Alves & Zaú, 2005), with activities in its surroundings with significant negative environmental impacts (e.g., industrial processes, urbanization and infrastructure services).

In this sense, the buffer zones of Conservation Units are considered strategic areas for the protection of their surroundings, being established to, among other functions, act as a transition environment and mitigate the effects of forest fragmentation, thereby seeking to control the edge effects. ARIE Cicuta Forest Buffer Zone has about 1,500 hectares, of which 622.52 ha is forested area and 887.48 of other uses (pasture, urban occupation, and industrial activities); less than 50% of the zone of damping presents forested areas. Also, this forested area is completely fragmented, consisting of 31 forest fragments with an average size of 20

ha, ranging from 0.43 to 144 ha, which tends to increase the influence of the external environment on these fragments, leading to their degradation (Vasconcellos, 2019). In buffer zones, human activities are subject to specific norms and restrictions, and the selection of quality indicators in these areas becomes of great importance for the monitoring and conservation of these ecosystems.

The use of indicators that are representative of the soil's physical, chemical, and biological attributes is extremely important for soil quality assessment, aiming at monitoring changes in the environmental quality of an area and proposing mechanisms that lead to alternatives that minimize impacts on the environment. Davari, et al. (2020) in a large-scale study was conducted to investigate the impacts of deforestation on soil quality indicators observed that deforestation and, therefore, dry farming significantly increases soil pH, electrical conductivity, bulk density and soil erodibility factor and tend to reduce soil organic carbon, total porosity, saturated hydraulic conductivity, showed that forest clearance and subsequent cultivation practice, due to land degradation, has a significant negative impact on soil quality index.

The present study aimed to evaluate soil chemical and microbiological attributes in areas under different forms of land use, intended for the implementation of buffer zones in a Conservation Unit located in urban areas.

2. Methodology

2.1   Study area

The experiment was carried out in the buffer zone of ARIE Cicuta Forest, in the Paraíba do Sul River Basin, at 21º56'53,52"S and 42º53'40,42"W. The average altitude is between 400 and 450 m.a.s.l. The climate of the region is mesothermal (Cwa), with dry winters and hot and rainy summers, with high humidity (Alves & Zaú, 2005). The average annual precipitation of the region is 1,390 mm yr-1, with a dry period from June to September. The average annual temperature is 22.3ºC, with a maximum annual average temperature of 24ºC and minimum annual average of 17ºC (Chico Mendes Institute for Biodiversity Conservation - ICMBio, 2018). The topography of the region is rugged with strong wavy to mountainous relief.

The study comprised three sample areas: FF, remnant forest fragment of the Atlantic Forest, in an initial stage of succession, with an area of about 2.0 ha, with characteristics

similar to the other fragments present in the ARIE Cicuta Forest Buffer Zone; RN, reforestation area with native species, with 2m × 2m spacing, and soil cover with *Brachiaria* spp., receiving in each pit, a base fertilization of 200g of dolomitic limestone, before planting, and fertilization of 150g of NPK formulation (20-20-20), carried out at the time of planting, with 6 months of planting; DP, degraded pasture, with predominance of *Brachiaria* spp. The soil is predominantly Acrisol with sandy texture.

2.2   Sampling and analysis

In each of the study units (FF, forest fragment; RN, reforestation with native species; DP, degraded pasture) two plots with dimensions of 20×25m (500 m²) were delimited, divided into a total of eight subplots of 10m × 12.5m (125m²) for each study unit, a total of 24 subplots. Ten simple soil samples were collected from each subplot, at a depth of 0–10 cm, which was homogenized, resulting in a composite soil sample from each subplot. The samples were collected randomly in each sampling unit, and in the plots under RN, the collection occurred between the planting lines. All soil samples were collected in July (dry season) and presented sandy texture.

For the chemical analysis of the soil, the samples were dried, broken, and passed through a 2-mm mesh sieve. For microbiological analysis, samples were stored in the refrigerator in paper bags for processing. To determine the current soil moisture content (SMC), the collected samples were oven-dried at 105ºC for 24 h, according to EMBRAPA (2011).

The soil pH values in water, exchangeable Ca^{2+}, Mg^{2+}, K^+, Na^+, Al^{3+}, and $H^+ + Al^{3+}$, soil organic carbon (SOC), soil total nitrogen (STN), and available K and P were determined according to EMBRAPA (2011). For the determination of the pseudo total heavy metals Cd, Pb, Zn, Fe, Cu, Mn, and Ni, the soil samples were sieved (450-µm), and their contents were determined using the United States Environmental Protection Agency (USEPA) methodology 3051A (USEPA, 2007); the extracts being analyzed by air/acetylene flame atomic absorption spectrophotometry. The soluble polyphenols in the litter were extracted with 50% methanol and determined by colorimetry, using the Folin-Denis reagent, according to Anderson & Ingram (1996).

The soil basal respiration (SBR) was assessed according to Silva, et al. (2007a). Fluorescein diacetate (FDA) hydrolysis was determined by the method of Schruner & Rosswall (1982). The determination of carbon (MBC) and nitrogen (MBN) from soil

microbial biomass were done by the fumigation extraction method and according to EMBRAPA (Silva, et al., 2007a; 2007b), respectively.

2.3   Statistical analysis

For data analysis, we used the cluster analysis with the correlation index (Gotelli & Ellison, 2011). Subsequently, the data regarding the chemical and microbiological attributes of the soil were submitted to the nonparametric Kruskal-Wallis test (p-value <0.05) to assess whether samples were taken from groups with equal median environmental values. The post-hoc test was performed using Mann-Whitney pair comparisons (p-value <0.05) (Brower & Zar, 1984). The analyses were performed using the software "R" version 3.4.3 (R Development Core Team, 2017).

3. Results and Discussion

The cluster analysis (Figure 1) showed the formation of five distinct groups (A, B, C, D, and E), with a correlation above 0.950 in relation to the similar characteristics they have for the studied variables. The dendrogram shows that the groups had a good fit with a cofenetic correlation coefficient of 0.91, corroborating the similarity value found.

Figure 1. Dendrogram with Euclidean distance of the different forms of land use in the ARIE Cicuta Forest Buffer Zone. FF, forest fragment; RN, reforestation area with native species; DP, degraded pasture.
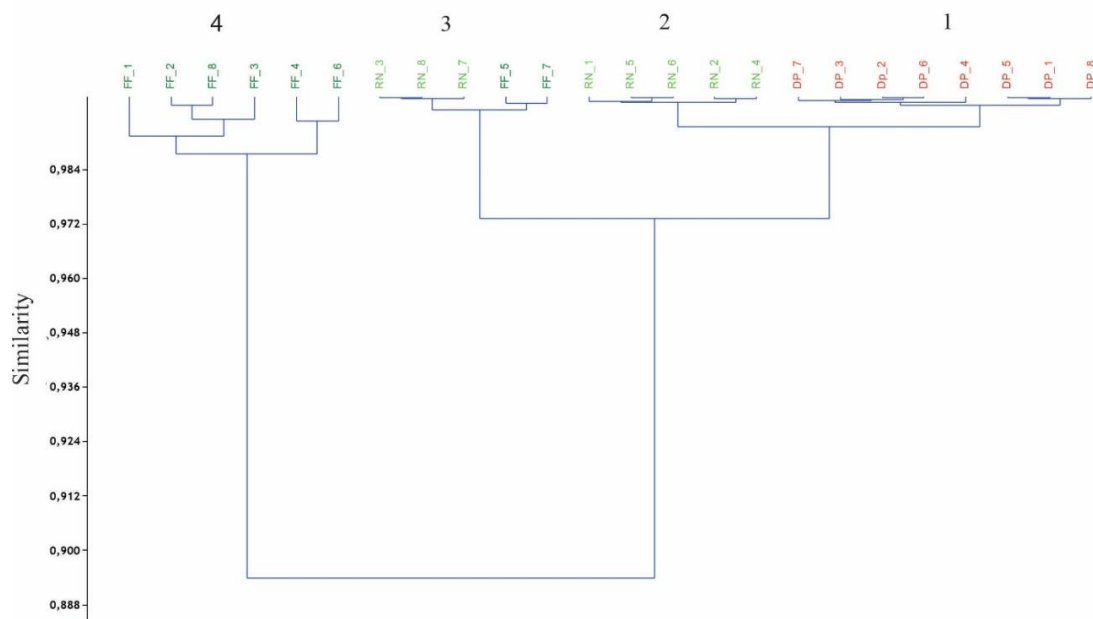
Source: Authors.

Group A (Figure 1) consisted only of the RN 2 and 3 points, totally removed from the other groups, probably due to the high N values found in these areas that can be attributed to the cultural treatments, performed through fertilization with NPK commercial fertilizer.

The FF was the system that presented greater homogeneity among the collected samples, forming group D, except for soil sample FF 3, which is in group B (Figure 1). These results highlight the importance of forest ecosystems in environmental stability, resulting in greater uniformity in the chemical and biological characteristics of the soil.

Soil moisture content (SMC), soil pH, STN, polyphenols and tannin contents in the litter are important variables responsible for forest fragment grouping (Table 1). Guareschi, et al. (2014) evaluated the chemical and physical attributes of the soil in a pasture area and three other areas of the Submontane Seasonal Forest fragment in different succession stages in Paraíba Valley and concluded that, independent of the successional stage, the secondary forest has higher values of STN and SOC compared to pastures, and that this is due to the larger input of vegetable residues on the soil surface. Davari, et al. (2020) in a study to investigate the impacts of deforestation on soil quality indicators observed that deforestation and, therefore, dry farming significantly increased, among other factors, soil pH and reduced soil

organic carbon, having a significant negative impact on soil quality index.

Table 1. Mean values and p-value (Kruskal–Wallis test, 5%) for the chemical and biological parameters under different forms of land use in the ARIE Cicuta Forest Buffer Zone. DP, degraded pasture area; RN, reforestation area with native species; FF, forest fragment area.

Variables	DP	RN	FF	Kruskal - Wallis (p ≤ 0,05)
pH	6,1 ± 0,07	5,14 ± 0,03	4,6 ± 0,13	8,961 E-05
SOC (%)	1,42 ± 0,1	1,37 ± 0,1	1,60 ± 0,1	0,3102
SMC (%)	21,4 ± 3,2	26,6 ± 1,3	41,9 ± 2,9	0,0006
STN (%)	0,18 ± 0,01	0,32 ± 0,12	0,21 ± 0,01	0,0531
P $(mg.L^{-1})$	1,42 ± 0,10	1,37 ± 0,07	1,58 ± 0,10	0,3102
K $(mg.L^{-1})$	200,38 ± 29,6	102,5 ± 10,4	76,6 ± 13,7	0,0008
Mg $(cmol_c.dm^{-3})$	3,9 ± 0,66	0,06 ± 0,03	0,13 ± 0,36	0,0004
Ca $(cmol_c.dm^{-3})$	3,2 ± 0,3	1,9 ± 0,2	2,1 ± 0,4	0,0197
Mn $(mg.kg^{-1})$	358,7 ± 74,5	46,3 ± 5,0	63,7 ± 13,1	0,0004
Cu $(mg.kg^{-1})$	3,62 ± 1,1	1,94 ± 0,6	1,79 ± 0,4	0,5955
Ni $(mg.kg^{-1})$	20,12 ± 6,4	4,93 ± 4,9	50,67 ± 6,3	0,0063
Pb $(mg.kg^{-1})$	5,51 ± 0,7	7,78 ± 0,6	9,12 ± 0,5	0,0050
Polyphenols (%)	4,4 ± 0,5	4,6 ± 0,3	8,2 ± 0,9	0,0004
Tannin (%)	0,18 ± 0,02	0,19 ± 0,01	0,32 ± 0,04	0,0004
FDA(µgFluoresc./gSS/h)	103,3 ± 4,9	139,9 ± 7,4	117,6 ± 2,6	0,0027
MBC $(mg.kg^{-1})$	124,4 ± 3,1	93,5 ± 4,3	86,4 ± 2,4	0,0004
MBN $(mg.kg^{-1})$	16,10 ± 1,8	11,17 ± 1,37	17,52 ± 1,8	0,0461
SBR$(mgCO_2.g^{-1}SS.d^{-1})$	10,9 ± 0,1	10,5 ± 0,7	8,9 ± 0,6	0,0266

Each value corresponds to an average of 8 repetitions ± standard deviation. p≤0.05 in the Kruskal-Wallis test indicates a significant difference at 5% level for each variable between the different forms of land use. SOC - soil organic carbon, SMC - soil moisture content, STN - soil total nitrogen, FDA - fluorescein diacetate hydrolysis, MBC – carbon from soil microbial biomass, MBN - nitrogen from soil microbial biomass SBR - soil basal respiration. Source: Authors.

In the area of degraded pasture (DP) higher values of pH and nutrients were observed (Table 1), possibly associated with the recurrent effects of fire. According to Ribeiro, et al. (2017) higher pH values are observed due to the effect of ash from fires, which are rich in elements such as Ca, K and P and accumulate in the soil. Although dolomitic limestone and fertilizer were used in the reforestation area (RN), this occurred in the planting pit and sampling was performed between the lines, which may have influenced the lower values in the RN area when compared to DP.

Figure 2a presents the boxplot plot of STN percentages for the three forms of land use (FF, RN, and DP), where it was possible to observe differences between the studied environments.

Figure 2. Boxplot of polyphenol data from different land-use forms in the Cicuta Forest ARIE Buffer Zone. FF, forest fragment; RN, reforestation area with native species; DP, degraded pasture.
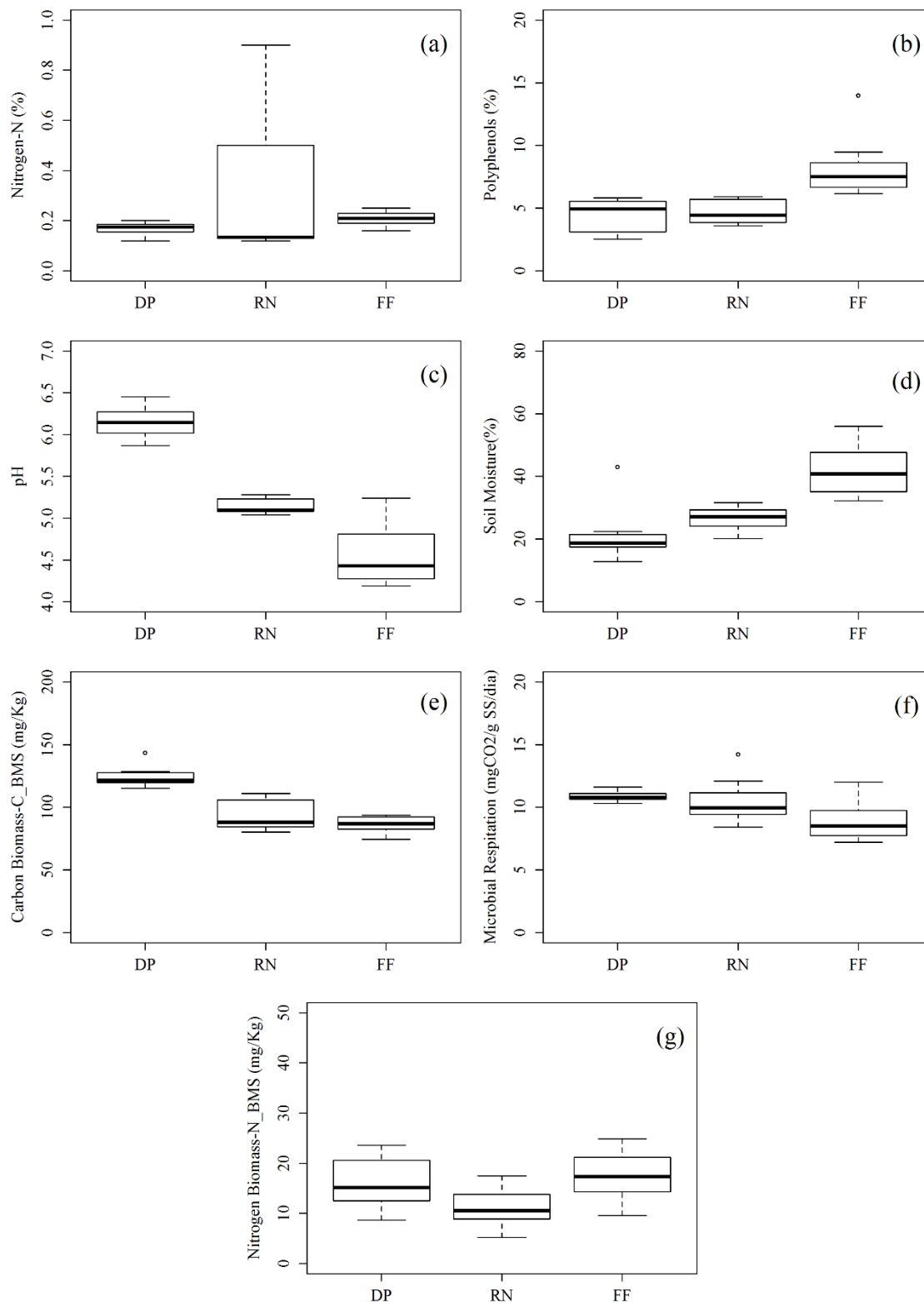
Source: Authors.

The area of reforestation with native species (RN) showed high amplitude in STN values, which might mean values above normal in relation to the total area, characteristic of a greater dispersion. Such occurrence can be explained by PCA (Figure 1), where it is possible to observe high dispersion of RN 2 and 3 soil samples due to the higher soil N accumulation, possibly caused by the cultural treatments in the collected sites, mainly linked to fertilization.

In the DP, it was possible to verify the lowest average values and the smallest variability between the STN values (Figure 2a). We detected significant differences in STN when compared (Mann Whitney test) the FF to the DP area (Table 2).

Table 2. Comparing the nitrogen (N) levels (%) in soils under different forms of land use in the ARIE Cicuta Forest Buffer Zone. The Kruskal-Wallis test and Bonferroni test for multiple comparisons at 5% significance were used. DP, degraded pasture area; RN, reforestation area with native species; FF, forest fragment area.

STN (%)	DP	RN	FF
PD		0,3696	0,01511*
RF			0,113
FF	0,04532*	0,3391	
P valor = 0,05314	X2=5,829		
Polyphenols (%)	**DP**	**RN**	**FF**
PD		0,636	0,0009391*
RF	1		0,0009391*
FF	0,002817*	0,002817*	
P valor = 0,0004311	X2=15,48		
pH	**DP**	**RN**	**FF**
PD		0,0009229*	0,000931*
RF	0,002769*		0,008554*
FF	0,002793*	0,02566*	
P valor = 8,981E-05	X2=18,61		
SMC (%)	**DP**	**RN**	**FF**
PD		0,02395*	0,005385*
RF	0,07185		0,0009391*
FF	0,01615*	0,002817*	
P valor = 0,005657	X2= 14,96		
MBC (mg.kg-1)	**DP**	**RN**	**FF**
PD		0,0009391*	0,0009391*
RF	0,002817*		0,4309
FF	0,002817*	1	
P valor = 0,0003937	X2= 15,68		
SBR(mgCO$_2$.g^{-1}SS.d^{-1})	**DP**	**RN**	**FF**
PD		0,1031	0,03058*
RF	0,3092		0,06588
FF	0,09174	0,1976	
P valor = 0,0266	X2= 7,235		
MBN (mg.kg-1)	**DP**	**RN**	**FF**
PD		0,1036	0,5665
RF	0,3107		0,01813*
FF	1	0,05439	
P valor = 0,04607	X2= 6,155		

STN - soil total nitrogen, SMC - soil moisture content, MBC – carbon from soil microbial biomass, SBR - soil basal respiration, MBN - nitrogen from soil microbial biomass. Source: Authors.

For Bustamante, et al. (2012), the maintenance of terrestrial ecosystems, such as forests, is essential because changes in land use are factors that cause changes in biogeochemical flows in ecosystems, and STN is particularly dependent on microbial

processes. Forests provide, in addition to climate stability, N retention in both biomass and soil.

Figure 2b shows the boxplot of polyphenols in relation to the three forms of land use (DP, RN, and FF areas). Polyphenols are molecules that can control N dynamics through the bonds of these molecules, forming protein-polyphenol complexes (Majuakim & Kitayama, 2013). However, in addition to the higher values of polyphenol found in the FF area (Table 1 and Figure 2b), higher N availability was also observed in this area, when comparing the DP and RN areas, not observing relationship between the presence of polyphenol and STN reduction, what can be explained by differences in species composition and forest structure.

The lower soil pH values in the FF area (Figure 2c and Table 1), with significant differences between the studied land-use forms (Table 2), corroborate the results of Iarema et al. (2011), who state that the most acidic pH evidences the presence of organic acids from the decomposition of organic residues (coming from litter).

Significant differences in SMC were also observed in the three study areas (Figure 2d, Table 2), and the highest moisture percentages were found in the FF (Table 1).

Despite the higher grouping and higher concentrations of STN and polyphenols in the litter of fragment forest (FF) areas, these values did not reflect a greater microbial biomass development evidenced by MBC, MBN and SBR values.

The highest concentrations of MBC were found in DP area (Figure 2e), with a significant difference for the other study areas (Table 2). The microbial activity in pasture might be greater than that of an area with native vegetation because the grasses are C4 plants and contribute with greater organic C input to the soil (Silva et al., 2012). According to Souza, et al. (2010), in soil management systems that include grass for grazing, there is a greater presence of roots, promoting an increase in the proportion of rhizosphere. The greater the amount of these roots (allied to the cut of the shoot, which causes high exudation of organic compounds), the greater is the favoring of soil microbial biomass (SMB), which makes use of these compounds as a source of organic C.

Dividing the soil basal respiration (SBR) and the MBC can be obtained the metabolic quotient (qCO2), which is used to estimate the efficiency of substrate use by soil microorganisms.

The lowest average values of qCO2 were observed in DP (0.0876) when compared with the FF area (0.1030) and RN (0.123), showing greater microbial activity in the DP area.

The highest mean concentrations of MBN were found in the FF area, followed by the DP (Figure 2f). These values were significantly higher than the RN area (Table 2). However,

despite the higher MBN values in the FF area, these are low when compared to literature data, considering the dry season. Silva, et al. (2012) analyzed several types of fragments in different successional stages, and the average obtained was 40mgkg-1 in the dry season. Mazzetto, et al. (2016) found MBN averages of 37.89 mg.kg-1 in native areas.

These results suggest that even the forest fragment might be degraded in this study area, probably due to the small size of the remaining area (2 ha), evidencing an edge effect due to the totally degraded conditions present. These results highlight the importance of restoration of these areas, forming biological corridors with the objective of interconnecting the forest fragments present (Pereira & Cestaro, 2016).

In studies by Chirol, et al. (2018) in the Rio de Janeiro of Tijuca Massif, observed that in border areas, the substitution of climax species for pioneer species causes mismatches in soil nutrients and such effects can be propagated to adjacent forests.

According to Machado, et al. (2008), small forest fragments scattered throughout the landscape in many regions of Brazil represent perhaps the only form of conservation available at the present time; however, these small units are most sensitive to the effects of forest fragmentation and are more susceptible to degradation. These small mosaics of a larger, now unrecoverable unit epitomizes a remarkable environmental heterogeneity reflected here in a pale and imperfect manner. Knowledge of the mechanisms of generation and maintenance of diversity, as well as the ecological processes to which they are subjected, is essential for the establishment of pertinent actions and policies for the conservation and restoration of these remaining areas.

4. Conclusions

The different forms of land use studied in the ARIE Cicuta Forest buffer zone (degraded pasture; reforestation with native species; forest fragment) influenced the chemical and biological characteristics of the soil, showing lower pH values and higher soil moisture, as well as higher concentrations of polyphenols in the litter in the forest fragment areas.

The forest fragment area, although presenting a greater homogeneity in the chemical and biological characteristics of soils relative to degraded pasture area and reforestation area with native species, presented low values of variables related to microbial biomass development (MBC, MBN, SBR), which might suggest that these areas are not sufficient for biome stability in this region, probably due to their small size.

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