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Chemical changes of soil and litter properties of riparian and non-riparian zones in a tropical dry forest

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ABSTRACT

Riparian zones of dry tropical forests are important due to their effect on nutrient cycling and carbon dynamics. It's important to evaluate the changes that occur when these areas are altered, to ascertain the magnitude of nutrient gains or losses. This study compares soil and litter chemical changes in riparian and non-riparian zones. Plots were established for soil and litter sampling in riparian and non-riparian zones. Considering chemical analysis, litter, and soil surface sampling were performed at depths of 0.0 to 0.10 m and 0.10 to 0.20 m. The descriptive and principal component analysis assessed chemical attribute sets' soil and litter characteristics. We observed higher P, K, and Ca content at both depths in soils of the non-riparian zone. The total soil organic carbon content in the non-riparian zones was 1.28 and 1.51 times greater at 0-10 and 10-20 cm depths, respectively, than in the riparian zones. Additionally, the humic acid and humin fractions had strong correlations with soil nutrients and, thus, are responsible for maintaining fertility in riparian zones. Despite the chemical and organic inputs in the non-riparian zones, no significant differences were observed regarding the chemical properties of riparian areas as opposed to the soils of non-riparian areas due to the litter of the riparian zones being richer in nutrients.

Keywords: Litter deposition, nutrient cycling, principal component analysis, semiarid regions, soil chemical properties.

Introduction

Riparian zones are areas of water saturation that are located around the banks of water courses and are characterized as dynamic environments that comprise soil, vegetation, and water bodies (Mata et al., 2021). They act as the interface between aquatic and terrestrial ecosystems, and these zones provide a range of important ecosystem services, such as habitat for flora and fauna (Naiman, Décamps & McClain, 2005), control of atmospheric carbon via sequestration (Smukler et al., 2010; Smith et al., 2012), as well as the regulation and transfer of nutrients and sediments into waterways which reduces the risk of eutrophication and biodiversity loss in aquatic environments (Likens et al., 1970).

Considering those various human activities, such as transforming riparian areas into agricultural areas, can alter soil quality, it is crucial to evaluate the physical and chemical attributes of different soil classes to identify degradation processes resulting from human occupation (Mata et al., 2021). However, the dynamics of nutrients and carbon in soils are often highly complex and strongly influenced by particular soil characteristics, such as organic matter composition and soil microbial community composition (Smukler et al., 2010; Mackay, Cunningham & Cavagnaro, 2016). In the relationship between soil processes and the overall functionality of riparian zones in tropical dry forests, it is important to consider not only soil chemical properties (e.g., soil nutrients and C) but also the chemical properties of litter, especially as a basis for riparian plant nutrition. For example, litter deposition in riparian soils plays an important role in nutrient cycling.

Since tropical dry ecosystems usually have low soil nutrient contents, the cycling of the nutrients contained in the plant biomass becomes more significant (Andrade et al., 2008; Pinto et al., 2009); plant biomass is the main transfer path in soil nutrient flow (Ferreira et al., 2007). Additionally, plant litter helps retain soil moisture, prevents erosion, and improves the physical, chemical, and biological attributes of the soil (Tilman et al., 2002; Ikpe, Owoeye & Gichuru, 2003). Several studies have highlighted the role of plant litter as a source of soil nutrients which is important to maintain soil fertility. Lima et al. (2015) verified a replacement of 93.07 kg ha^{-1} year^{-1} of N, in the caatinga area situated in the state of Piaui, Brazil. Holanda et al. (2017) verified a litter yield of 3,785.67 kg ha^{-1}, with a nutrient return of 47.09 kg ha^{-1} of N, 6.79 kg ha^{-1} of P, and 21.26 kg ha^{-1} of K, also in a caatinga area in the semiarid region of Paraiba, Brazil. However, these studies focused on non-riparian areas, while only some studies supply information concerning nutrients returned to the soil by riparian vegetation. Further, these studies need to compare the nutritional richness of litter and soil nutrients in riparian vs. non-riparian areas to clarify the authentic influence of litter on the fertility of riparian soils.

Carbon storage in riparian forests is also an environmental service of great relevance for climate balance (Zelarayán et al., 2015). Carbon storage in tropical dry forest biomass is estimated from measured organic matter in vegetation, soil, and litterfall. Becknell et al. (2012) analyzed results from 188 tropical dry forest sites across Central and South America and reported aboveground living biomass estimates in mature tropical dry forests ranging from 39 Mg ha^{-1} in Chamela, Mexico to 334 Mg ha^{-1} in Guanacaste, Costa Rica. This accounts for approximately half of the storage capacity of living aboveground biomass in humid forests which can range from 200 to 400 Mg ha^{-1} (Saatchi et al., 2011). Additionally, a study conducted by Jaramillo, Martinez-Yriznar & Sanford (2011) suggests that most of the carbon stock in tropical dry forests can be found in its soil. In terms of annual total litterfall, tropical dry forests average 4.5 - 6.0 t ha^{-1} year^{-1} with a range of 2.9 - 10.1 t ha^{-1} year^{-1}, which does not differ greatly from values found in moist and wet forests - 5.2 - 14.0 t ha^{-1} year^{-1} (Jaramillo, Martinez-Yriznar & Sanford, 2011).

Despite their valuable ecosystem services, many areas of the world’s riparian zones are highly degraded despite their tendency to remain relatively more fertile and moister while non-riparian areas become hotter, drier, and nutrient-poor (James, Reid & Capon, 2016). This is especially critical for dry forests, which are amongst the most seriously threatened forested biomes (Miles et al., 2006). This study compared soil and litter chemical changes in riparian and non-riparian zones. We hypothesized that the riparian sites would support a richer litter in nutrients and, consequently, soils with higher nutrient contents than the non-riparian sites.

Material and Methods

Study area

The study was carried out near the Municipality of Arcoverde - Pernambuco, Brazil (latitude of 08º1’3.6” South and longitude of 34º56’44.1” West), within the Agreste ecotone, which is the transitional region between sub-humid and semiarid Caatinga forests (Figure 1). The study area is located at an altitude of 663 m, with a predominance of climate type Bshs' (low latitude dry steppe climate with –autumn-winter), according to the classification of Köppen. The annual average temperature is 24°C, and the average annual rainfall is 1,058 mm, with rain concentrated in March and April. Major rivers in the area include the Moxotó, Ipanema, and Ipojuca rivers.

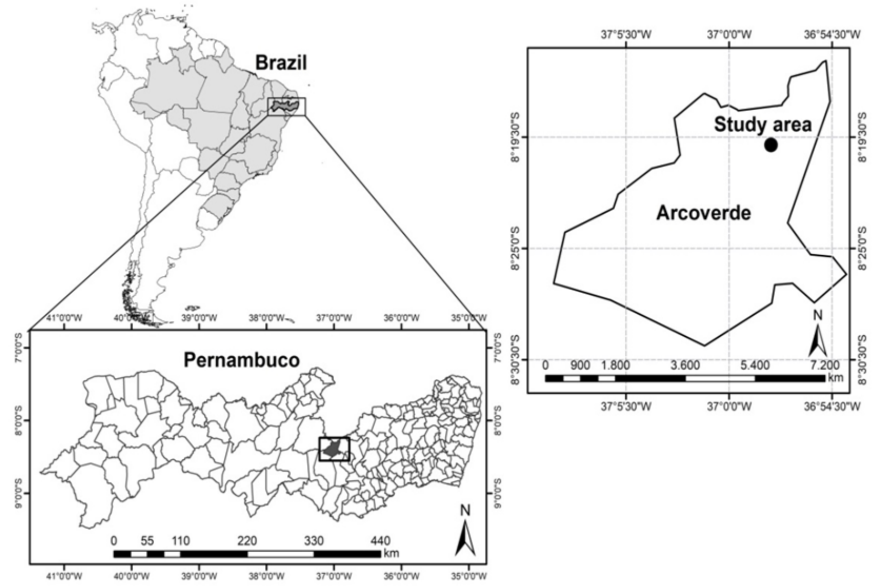

Figure 1. Location map of the study area in the state of Pernambuco, Brazil. Font: Pessoa et al. (2023).

The total area of the studied fragment has an extension of 35 hectares. The riparian zone has not been cut or burned for 56 years, while the non-riparian zone is currently utilized for cattle grazing, both in a semi-extensive regime, as well by some smallholder farmers. The soil of the fragment was classified as Argissolo Vermelho Amarelo (Albuquerque et al., 2018), corresponding to Ultisol (Soil Survey Staff, 2022).

According to Barbosa et al. (2012), the main plant species occurring in the study area are provided in Table 1. Soils in the studied fragment are typically shallow and rocky and are derived from metamorphic rocks. The examined fragment is crossed by the Beija Mão stream - an ephemeral stream whose width varies from 2 m to 24 m, and along the ephemeral stream, soils are alluvial.

Table 1. Most common species occurring in the experimental area. Font: Barbosa et al. (2012).

Family	Specie
Anacardiaceae	*Schinopsis brasiliensis* Engl.
Caesalpinoideae	*Caesalpinia pyramidalis* Tul.
Euphobiaceae	*Croton tricolor* Klotzsch ex. Baill
Euphobiaceae	*Jatropha mollissima* (Pohl) Baill.
Euphobiaceae	*Sapium lanceolatum* Huber
Lauraceae	*Ocotea* sp.
Mimosoideae	*Acacia bahiensis* Benth.
Mimosoideae	*Acacia paniculata* Wild.
Mimosoideae	*Mimosa ophthalmocentra* Mart. Ex. Benth.
Mimosoideae	*Piptadenia stipulaceae* (Benth.) Ducke
Nyctaginaceae	*Pisonha tomentosa* Casar.
Solanaceae	*Aureliana fasciculata* (Vell.) Sendtn.

Soil and litter sampling

Soil and litter sampling occurred between March to April, at the end of the rainy season. Eight 10 x 25 m plots were established in riparian and non-riparian areas (four plots each) for soil and litter sampling. Among the collected samples (soil and litter), four were sampled in riparian forest plots and four in non-riparian forest plots, with litter being collected before soil collection in each plot. The litter directly deposited on the soil surface was collected and stored in plastic bags. It consisted of leaves, fruits, flowers, twigs, and miscellaneous (undefined pieces of vegetation) of the species listed in Table 1. Soil sampling for physical and chemical analyses was performed randomly at depths of 0.0 to 0.10 m and 0.10 to 0.20 m, collecting eight sub-samples from each plot and at each depth for a composite sample.

Soil and litter analysis

The physical analysis consisted of sieving and sedimentation to determine sand, silt, and clay content, as described by Ruiz (2005). Table 2 shows the soil texture of the studied areas.

Table 2. Average and standard deviation values (s) of sand, silt, and clay in the riparian and non-riparian zones at 0-0.1 m and 0.1-0.2 m. Font: Pessoa et al. (2023).

Zone	Sand	Silt	Clay
		%	
		0-0.1 m	
Riparian	79.78 (6.70)	10.95 (4.00)	9.27 (2.99)
Non-riparian	69.24 (3.82)	18.31 (2.02)	12.46 ± 1.88
		0.1-0.2 m	
Riparian	79.16 (3.73)	10.94 (2.12)	9.90 (2.15)
Non-riparian	67.73 (2.29)	19.63 (1.36)	12.64 (1.65)

The total organic carbon (TOC) content was determined by using the Walkley–Black method with $K_2Cr_2O_7$ oxidization and $FeSO_4$ titration (Walkley & Black, 1934). The humic substances were divided into a fulvic acid fraction (FAF), a humic acid fraction (HAF), and humin (HUM) using the differential solubility technique, as proposed by the International Humic Substance Society (Swift, 1996). Quantification of organic carbon in the fractions (C-HUM, C-FAF, and C-HAF) was performed following Yeomans & Bremner (1988). As they influence nutrient availability and soil fertility, we have evaluated humic substances in both sites (riparian and non-riparian) to compare which system is more efficient in returning nutrients to the soil and more effectively contributes to nutrient cycling.

After collection, litter was packed in paper bags and placed in a forced circulation oven at 65°C until constant weight. Then, the litter was crushed, and N, P, and K contents were quantified according to methods described by Malavolta, Vitti & Oliveira (1989). N, P, and K were evaluated since they are macronutrients and contribute enormously to soil fertility.

Soil pH was measured directly from a 1:2.5 soil:water mixture using a pH meter. Exchangeable cations were extracted with ammonium acetate solution (1 mol L^{-1}) at pH 7. Ca^{2+} and Mg^{2+} were determined by atomic absorption spectrometry (USSL, 1954), and K^+ was determined by flame emission photometry (USSL, 1954). P was extracted with 0.5 mol L^{-1} $NaHCO_3$ solution at pH 8.5, and determined by colorimetry with ammonium molybdate, using a spectrophotometer at 882 nm (Olsen et al., 1954). Exchangeable acidity (H+Al) was determined by titrating 25 mL supernatant with 0.025 mol L^{-1} NaOH and using 1 g L^{-1} phenolphthalein as an indicator (Embrapa, 1997). Exchangeable aluminum (Al) was extracted with KCl 1 mol L^{-1} and titrated with NaOH 0.0606 mol L^{-1} (Embrapa, 1997).

Statistical analysis

Principal components analysis was used to evaluate soil and litter characteristics in chemical attribute sets. This method is a multivariate statistical analysis that reduces dimensionality in cases where multicollinearity occurs in the independent variables and may reveal relationships that are not previously observable in the subsets of variables (Souza, 1998). The number of principal components which represented 80% of the total variation (Cruz et al., 2004) was considered. In addition, we included components whose correlation coefficient between the main components was greater than 0.7.

Results

Soil chemical properties

Soil pH values were similar between the riparian and non-riparian zones. However, a small increase of the pH at greater depths was observed in the non-riparian zones, which was not present in the riparian zones (Figure 2). Phosphorus contents were higher in the soils at both depths of non-riparian zones, which represented 1.6 and 1.8 times more P than the soils of the riparian zones, at depths of 0-10 and 10-20 cm respectively (Figure 2).

The soils of the non-riparian zones had higher K^+ contents than those of riparian zones - 0.95 and 0.51 $cmol_c$ kg^{-1}, which were 2 and 1.4 times higher than the K^+ contents of the riparian soils, in the layers 0-10 and 10-20 cm, respectively (Figure 2). Similarly, Ca^{2+} levels were also higher in the soils of the non-riparian zones, which were respectively 6.9 and 5.15 $cmol_c$ kg^{-1} in the layers of 0-10 and 10-20 cm (Figure 2). The soils of the riparian zones had higher Mg^{2+} content than the soils of the non-riparian zones (2.78 and 4.60 $cmol_c$ kg^{-1}), both in the 0-10 and 10-20 cm layers respectively (Figure 2).

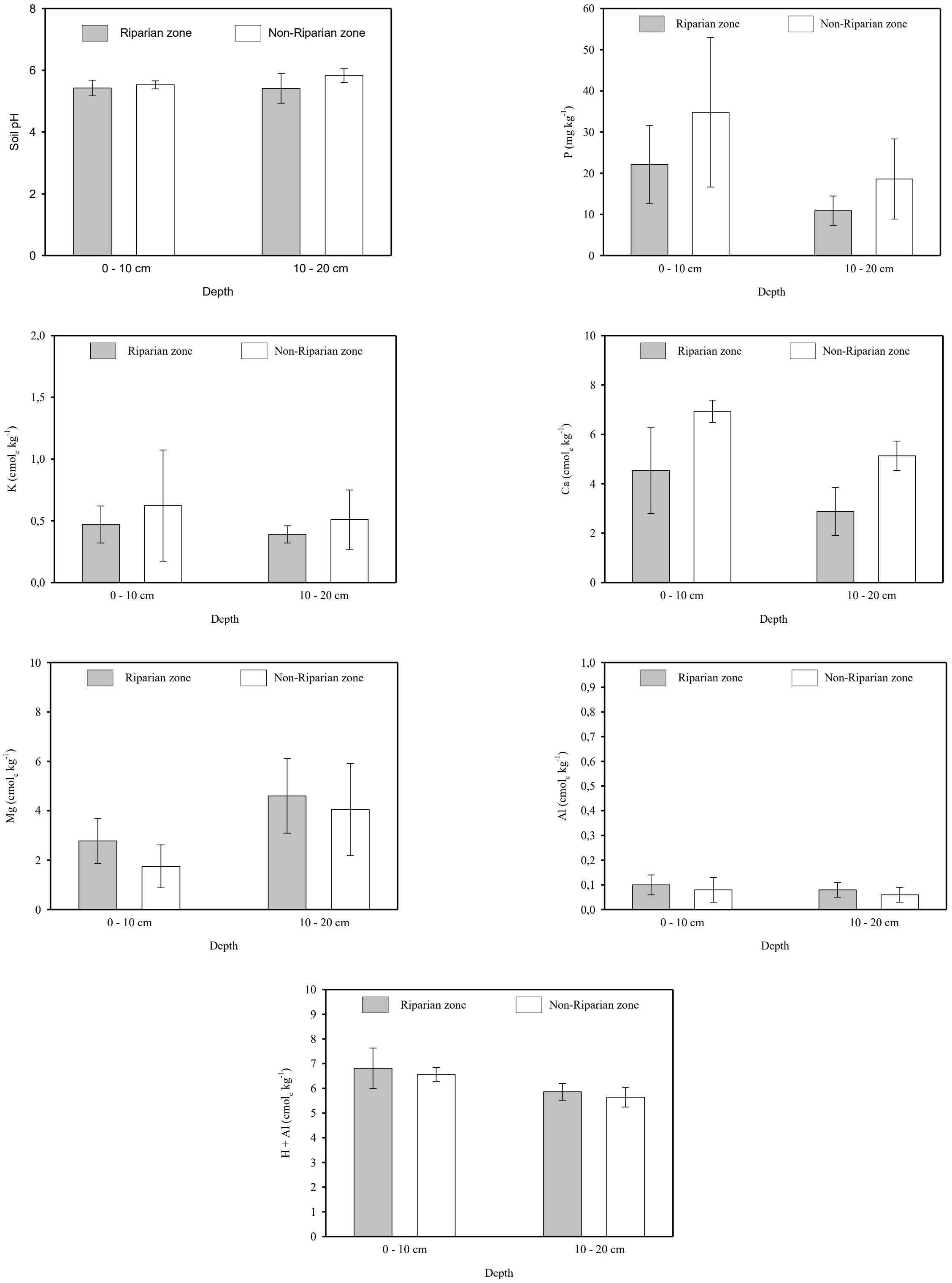

Figure 2. Average and standard deviation values of the chemical attributes in the riparian and non-riparian zone, at 0-10 cm and 10-20 cm. Font: Pessoa et al. (2023).

In general, the contents of Al^{3+} and $H^+ + Al^{3+}$ were very close between the studied areas, with only slightly lower levels in the non-riparian zones (Figure 2). These findings are corroborated by the pH values observed in the studied areas. The Al^{3+} contents were 0.08 and 0.06 cmol$_c$ kg^{-1} in the 0-10 and 10-30 cm layers, while the contents of $H^+ + Al^{3+}$ were 6.56 and 5.64 cmol$_c$ kg^{-1} in the 0-10 and 10- 30 cm, respectively.

Soil organic carbon quality

The total organic carbon contents of the soil in the non-riparian zones were 1.28 and 1.51 times higher than those observed in the riparian zones, at 0-10 and 10-20 cm depths respectively

(Figure 3). Considering the humic acid fraction, higher values of total organic carbon were observed in the non-riparian zone at the two studied depths (Figure 3) and were 0.44 and 0.28 dag kg^{-1} at 0-10 and 10-20 cm depths, respectively. In the fulvic acid fraction, the organic carbon content increased in the deeper layer of the riparian zone (0.15 – 0.32 dag kg^{-1}), while in the non-riparian zones, the values found were similar (0.16 – 0.11 dag kg^{-1}).

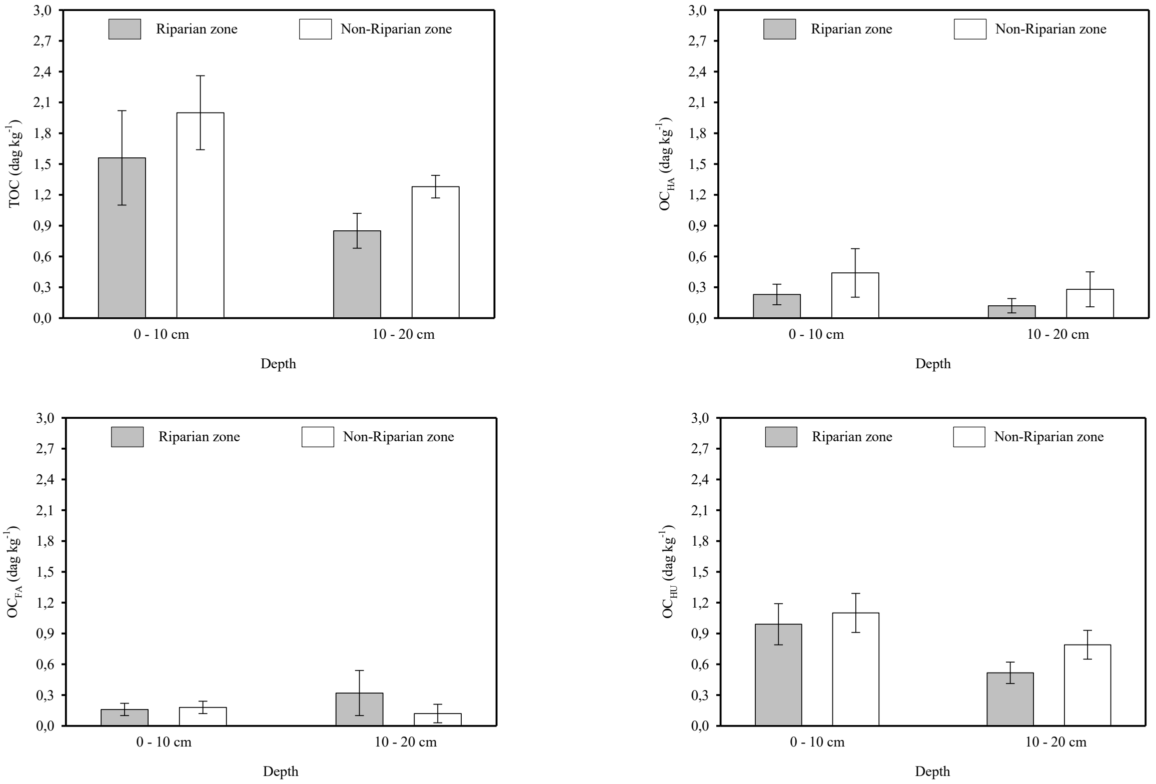

Figure 3. Average and standard deviation values of total organic carbon (TOC) levels, organic carbon of the humic acids fraction (OC_{HA}), and a fulvic fraction (OC_{FA}) and humin (OC_{HU}) in the riparian and non-riparian zones at 0-10 cm and 10-20 cm. Font: Pessoa et al. (2023).

In the two studied zones, the organic carbon content of the humin fraction was higher than the fulvic and humic acid fractions, evidencing that this is the most abundant fraction in the studied soils (Figure 3). The soils of the non-riparian zones presented higher levels of the organic carbon of the humin fraction (1.1 and 0.78 dag kg^{-1} at 0-10 and 10-20 cm depths, respectively) than did the soils of riparian zones (0.9 and 0.5 dag kg^{-1} at 0-10 and 10-20 cm depths respectively), at both studied depths. Reductions were also observed in the contents of this fraction in the 10-20 cm layer in both zones, which indicates low mobility of this fraction in the soils.

Litter nutrients

Figure 4 presents the average levels of N, P, and K in the collected litter. Analysis verified that N was the nutrient with the highest content in the litter of both areas – 11.2 and 8.6 g kg^{-1} in the riparian and non-riparian zones, respectively. Concerning P and K contents, the litter of the riparian zones also had higher values of these nutrients, than the litter of the non-riparian zone. Thus, our data indicates that the litter of the riparian zone had higher contents of the examined nutrients than the litter of the non-riparian zone and this contributed to the small differences found in the soils of these areas, despite chemical inputs in the soils of riparian zones.

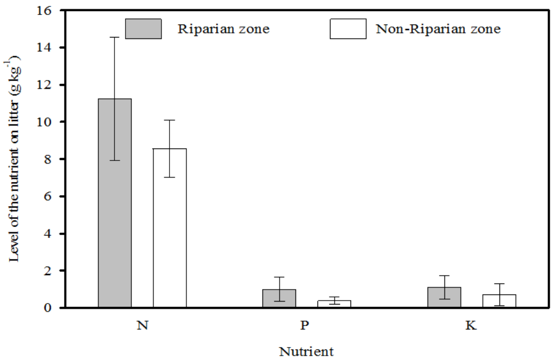

Figure 4. Average and standard deviation (s) values of N, P, and K of collected litter corresponding to riparian and non-riparian zones. Font: Pessoa et al. (2023).

Multivariate approach

Soil pH presented a negative correlation with Al^{3+} in the two studied depths (Table 3). The organic fractions of the soils (total organic carbon, humic acids, and humic acids) were positively correlated with nutrients K^{+}, $Ca^{2+,}$ and P (Table 3), at the studied depths. H^{+} + Al^{3+} had a positive correlation with the humic acids and humin fractions (Table 3). These results agree with those obtained by Ebeling et al. (2011), who also verified increasing H^{+} and Al^{3+} with the increase of the humin fraction.

Table 3. Correlation matrix of variables obtained in riparian and non-riparian zones at 0-10 cm and 10-20 cm. Font: Pessoa et al. (2023).

	pH	COT	Na	K	P	Al	H + Al	Ca	Mg	AF	AH	HU	SH
0 – 10 cm													
pH	-	0,40	0,10	0,27	-0,46	-0,80	-0,49	0,36	0,24	-0,42	0,09	0,09	0,01
COT	-	-	0,20	0,53	0,35	-0,18	0,10	0,86	0,20	0,29	0,74	0,80	0,80
Na	-	-	-	-0,38	-0,38	-0,26	0,60	0,22	0,54	0,10	0,30	0,38	0,35
K	-	-	-	-	0,43	-0,09	-0,35	0,54	-0,35	0,12	0,50	0,28	0,36
P	-	-	-	-	-	0,45	0,19	0,30	-0,26	0,09	0,52	0,30	0,38
Al	-	-	-	-	-	-	0,45	-0,31	0,13	0,19	0,11	0,15	0,16
H + Al	-	-	-	-	-	-	-	0,23	0,41	0,32	0,53	0,60	0,61
Ca	-	-	-	-	-	-	-	-	-0,08	0,29	0,84	0,75	0,80
Mg	-	-	-	-	-	-	-	-	-	-0,16	0,16	0,44	0,30
AF	-	-	-	-	-	-	-	-	-	-	0,15	0,46	0,52
AH	-	-	-	-	-	-	-	-	-	-	-	0,83	0,88
HU	-	-	-	-	-	-	-	-	-	-	-	-	0,98
SH	-	-	-	-	-	-	-	-	-	-	-	-	-
10 – 20 cm													
pH	-	0,47	-0,04	0,38	0,22	-0,81	-0,04	0,72	0,37	0,39	-0,58	-0,56	0,79
COT	-	-	-0,46	0,21	0,54	-0,57	0,38	0,82	0,27	0,05	0,60	0,82	0,62
Na	-	-	-	-0,20	-0,36	-0,26	-0,24	-0,16	0,27	0,01	-0,26	-0,40	-0,26
K	-	-	-	-	0,41	-0,29	-0,69	0,16	-0,45	-0,23	0,77	0,38	0,24
P	-	-	-	-	-	-0,46	0,15	0,16	0,13	-0,25	0,54	0,60	0,24
Al	-	-	-	-	-	-	-0,03	-0,39	-0,65	-0,29	-0,49	-0,49	-0,64
H + Al	-	-	-	-	-	-	-	0,13	-0,55	0,06	-0,14	0,37	0,17
Ca	-	-	-	-	-	-	-	-	0,00	-0,08	0,44	0,57	0,34
Mg	-	-	-	-	-	-	-	-	-	0,50	-0,16	0,12	0,43
AF	-	-	-	-	-	-	-	-	-	-	-0,25	-0,24	0,67
AH	-	-	-	-	-	-	-	-	-	-	-	0,86	0,51
HU	-	-	-	-	-	-	-	-	-	-	-	-	0,54
SH	-	-	-	-	-	-	-	-	-	-	-	-	-

The multivariate analysis of the obtained data generated the graph of the main components of the 0-10 and 10-20 cm layers (Figures 5ab), which indicated a division into groups of samples according to Euclidean distance, which is like both sampling depths. The analysis verified the formation of four groups for riparian x non-riparian areas at the two depths (Figures 5ab) and the formation of three groups for the litter (Figure 5c), characterizing the differences between the studied areas in the function of the chemical attributes of soils and litter.

The results of chemical attributes in the analysis of principal components for the 0-10 cm layer gave rise to a 3D graph with three principal components (PC1, PC2, and PC3), which obtained 45.56%, 21.12%, and 16, 09% respectively, corresponding to 82.77% of the total variation. In the 10-20 cm layer, the analysis of the principal components also obtained the three principal components - PC1, PC2, and PC3, with 42.87%, 18.48%, and 14.52% respectively, corresponding to 75.87% of the total variation. In the litter the three principal components PC1, PC2, and PC3 obtained, respectively, 56.08%, 24.2%, and 17.07%, totaling 97.35% of the total variation.

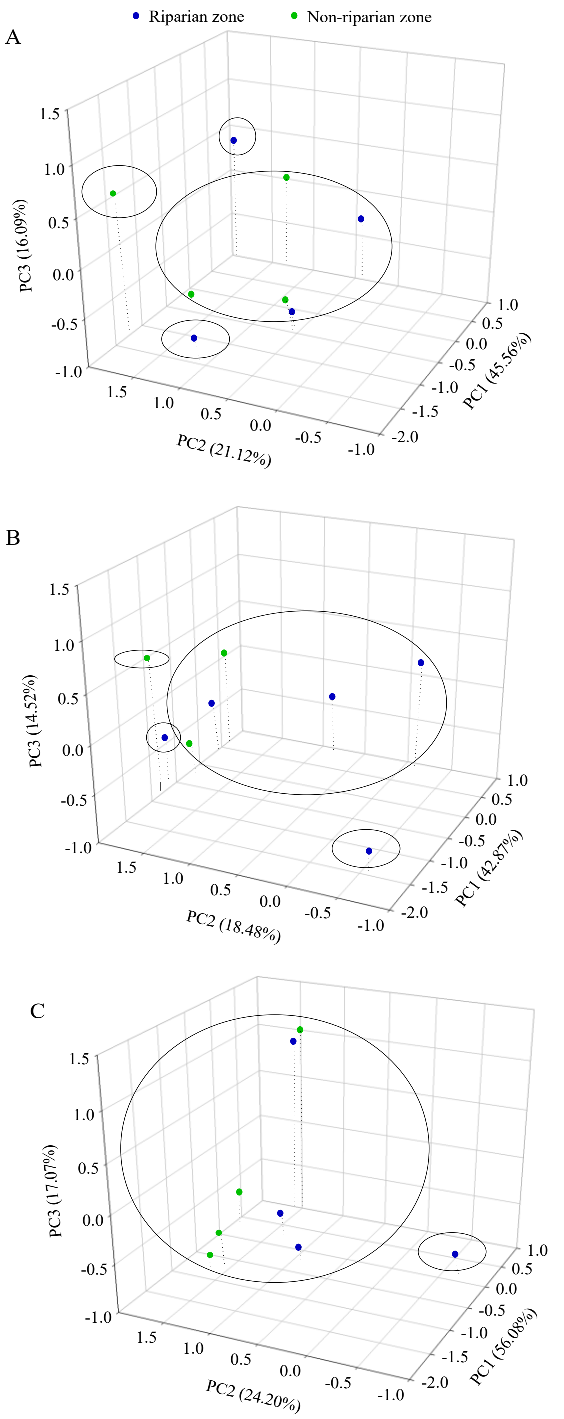

Figure 5. Dispersion of the studied variables for the principal component (PC1, PC2, and PC3) grouped for plots of Riparian and non-riparian zone, at 0-10 cm (a), 10 -20 cm (b), and litter (c).

Discussion

Although the pH values were very close between the studied areas, the constituent elements showed more significant variations, both between the areas and between the examined depths within the respective zones (Figure 2). The P findings can be attributed to the fact that the soils of the riparian zones are sandier, resulting in a lower adsorption power of P (Novais et al., 2007), as well as due to greater P losses due to leaching in the rainy season. In addition, Gu et al. (2018) state that drying and rewetting events occurring in riparian soils may accelerate the release not only of dissolved P through leaching but also of colloidal/nanoparticulate P by physical mechanisms of colloid/nanoparticle mobilization. Nevertheless, the values of P observed in the soils of riparian zones were much higher than those found by Corrêa et al. (2009), which obtained P values in a preserved caatinga area of around 7.4 and 4.62 mg dm^{-3} at depths of 0-10 and 10-30 cm, respectively.

The higher levels of K^+ found in the soils of the non-riparian zone (Figure 2) can be attributed to the use of fertilizers and manure applied in these areas. However, the K^+ contents of riparian soils were higher than those verified by several studies carried out in areas of preserved caatinga, in the Brazilian semiarid region (Corrêa et al., 2009; Dantas et al., 2012; Silva et al., 2015). Concerning the findings of Ca^{2+} levels (Figure 1), this may have occurred due to liming or the application of fertilizers (calcium phosphates) in these soils, which contributed to higher values as compared to riparian areas. Additionally, the long-term litter Ca^{2+} flux to the forest floor over years may contribute to a net Ca^{2+} loss from the forest riparian soil as more is used for biomass accretion, with subsequent forest soil Ca^{2+} depletion occurring (Likens et al., 1998; Johnson, Todd & Hanson, 2008). Other studies have indicated that Ca^{2+} is rapidly released from forest litter (Yavitt, Wright & Weider 2004; Dauer et al., 2007), which could contribute to net losses of this cation from the forested riparian soil in response to drought and increasing temperatures.

According to Franchini et al. (2001), the movement of Mg^{2+} can be explained by the organic complexation of this cation. However, this complexation also depends on plant residues on the soil surface. As in the non-riparian zone, the decomposition of plant residues is more intense due to the soil surface revolving, it gives rise to water-soluble organic compounds, which have been known to be responsible for the complexation of cations in surface layers, followed by migration in the soil profile. This explains the lower Mg^{2+} levels found in non-riparian zones.

Lower levels of Al^{3+} and $H^+ + Al^{3+}$ found in the non-riparian zones (Figure 2) may be because of liming in these areas, which increases Ca^{2+} and Mg^{2+} content and reduces H^++Al^{3+} content in the soil (Preston et al., 2017; Souza et al., 2017). However, the levels of these elements were much higher than those found in other caatinga areas in studies conducted in the Brazilian semiarid region (Pereira et al., 2009; Lira et al., 2012).

The higher carbon content in the non-riparian zones is possibly a result of the higher litter content on the soil because the riparian zone can suffer losses of litter content deposited on the surface of the soil during the rainy periods, which promotes the emergence of a temporary stream in the study area, which may then promote the removal of this material present in the soil. In addition, in the non-riparian areas, there are organic matter inputs from agricultural activities, such as manure addition, which also contribute to the higher carbon content in these areas concerning the riparian zones. Martins et al. (2015) state that clay content positively influences the stabilization of the organic matter due to the physical protection promoted by the microaggregates. As the soils of riparian zones presented a sandier texture at both depths (Table 2), this also contributed to the lower levels of organic carbon present in these soils. However, in both areas, the results found for carbon contents were like those found by other studies carried out in semiarid regions of Brazil (Melo et al., 2008; Martins et al., 2010).

Humic acid fraction results are related to the greater accumulation of litter on the soil of the riparian areas. According to Passos et al. (2007), these residues present slow decomposition, thus favoring the humification process to the detriment of the mineralization process, allowing greater chemical protection of the humic substances. The higher organic C content of the fraction of humic acids found in the 0-10 cm depth reflects the lower mobility of this fraction concerning the fulvic acid fraction.

Findings of the fulvic acid fraction verified in this study indicate greater mobility for this fraction in the soil. However, it was observed that in the riparian zones, the mobility of this fraction was superior to the non-riparian zone. Studying the quality of organic matter in areas of Caatinga in the semiarid region of Brazil, Araújo Filho (2018) verified the predominance of organic carbon in the fulvic acid fraction. As in this study, the soils were situated in riparian areas. This disagreement of results can be explained by the fact that fulvic acids are more soluble, being more susceptible to losses by leaching, and thus to shorter residence time in soils.

The organic carbon stock and the degree of soil aggregation of riparian soils can be significantly influenced by riparian plants (Kimura, Baptista & Scotti, 2017). Heikkinen et al. (2014) claim that differences in riparian plant composition influence the input of organic matter quantity and quality, and the soil carbon (C) source. The percentages of each fraction concerning total organic carbon (fulvic acid, humic acid, and humin fractions) show the predominance of humin fraction, followed by humic acids (Figure 3). Canellas et al. (2003) claim that the predominance of the humic acid fraction has been related to fertile soils with a high content of exchangeable bases. Observing the chemical characteristics of the studied profiles (Table 2), it is possible to observe that most of the soils are eutrophic, with saturation by bases exceeding 60%, which positively relates soil fertility to humic acid content. Furthermore, the organic carbon in this fraction (humin) is considered more recalcitrant and stable due to associations between C compounds and the mineral matrix of the soil (Aranda & Comino, 2014). Because of its solubility properties, humin is also considered to be the most important fraction in terms of C sequestration; the formation of strong bonds between humin and soil minerals impedes the ability of microbes to aid in decomposition (Moraes et al., 2011).

The higher levels of the examined nutrients in the litter of riparian zones (Figure 4) agree with the data obtained by several studies that evaluated the nutritional composition of the litter in tropical dry forests in Brazil, as the Brazilian caatinga (Mariano et al., 2007; Pinto et al., 2009; Souto et al., 2009). This was due to the higher degree of decomposition of the litter from the non-riparian zone, resulting in a greater release of these nutrients to the soil. In addition, the higher moisture content of riparian soils makes the elements more soluble as compared to non-riparian soils, which are drier due to less influence from the seasonal creek. Our results agree with Stutter & Richards (2012), who state that enhanced nutrient solubility from buffer soils relative to their adjacent cropland during short-term laboratory nutrient release assays using field-moist soils. The levels of N, P, and K obtained in this study were lower than those obtained by Souto et al. (2009), in research developed in the caatinga area within the semiarid region of Paraiba - Brazil, and by Mariano et al. (2007), in studies of a fragment of restinga forest in the state of Bahia - Brazil.

Soil pH and Al^{3+} are negatively correlated (Table 3) due to the release of protons during the hydrolysis process (Milne et al., 1995). This is because of the extent to which acid cations like Al^{3+} induce hydrolysis and decrease soil pH. This also contributed to the higher acidity found in riparian soils (Figure 5), in the two studied depths.

In the 10-20 cm layer, the pH indicated a positive correlation with Ca^{2+}, which is an alkaline earth metal and acts on the soil as a source of alkalinity. However, the negative correlation of pH with the humic acids and humin fractions, in the 10-20 cm layer, indicates that the acidity directly influences the formation of these two fractions (Table 3).

It was observed that in both areas the humic acids and humin fractions were predominant in the soils of the two areas. This means that the predominance of these fractions in soils may imply increases in the availability of these nutrients. These results corroborate the data in Table 2, where the highest levels of K^+, $Ca^{2+,}$ and P were in the non-riparian zones, which had higher levels of humic acids and humin fractions concerning riparian soils (Figure 3).

In the 0-10 cm layer, the principal component analysis identified four different groups between riparian and non-riparian plots. The variables that presented better discrimination of the plots, due to better correlation coefficients with the principal component (PC) in PC1 were total organic carbon, Ca^{2+}, acid humic, humin, and fulvic acid fractions; with the principal component PC2 - pH, Al^{3+} and $H^+ + Al^{3+}$; and with the principal component PC3 - Na^+, K^+, P and Mg^{2+}.

In the 10-20 cm layer, four different groups with similar characteristics were also identified concerning the studied variables, each forming a distinct group. The constituent plots of each group presented similarities among themselves, concerning the analyzed variables, which resulted in the formation of a single group. The most discriminant variables in PC1 were pH, total organic carbon, Al^{3+}, Ca^{2+}, and the acid humic, humin, and fulvic acid fractions; in PC2, Mg^{2+}, and fulvic acid fractions were the most determinant variables; and in PC3, only K^+ was the discriminant variable.

Concerning the litter of the studied areas, three distinct groups were observed. The litter of the non-riparian zone fell into a single group, indicating similar characteristics. The most discriminant variables in PC1 were N, P, and K; in PC2 the most discriminant variables were N and P; and in PC3 only the K discriminant variable was present.

Conclusion

Despite the chemical and organic inputs in the non-riparian zones, no significant differences were observed regarding the chemical properties of the soils of riparian areas as opposed to the soils of non-riparian areas, and it is attributed to the fact that the litter of the riparian zones was richer in nutrients, and this contributed to the preservation of soil fertility in these areas.

The main organic carbon fractions were the humic acid and humin fractions. As these fractions showed strong correlations with soil nutrients K, Ca, and P, it suggests that these fractions are responsible for maintaining fertility in riparian areas.

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