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SEASONALITY, SOIL ATTRIBUTES AND ROOT BIOMASS IN CERRADO, CERRADÃO AND FOREST ENVIRONMENTS, WESTERN AMAZON

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Abstract

The Amazon rainforest region presents a phytophysiognomy that ranges from savannas to cerrados, all of them intimately associated to climate and soil characteristics. Evidence has been given that plant growth and development are affected by soil quality and seasonality, thus making it crucial to understand them and how they are related to each other in order to grasp the dynamics of the whole ecosystem. In this context, the goal of this research was to assess how seasonality, soil attributes, and root system biomass are related in natural cerrado, cerradão, and forest areas in southern Amazonas State, in Brazil. Soil samples were collected during dry (June/2018) and rainy (December/2018) seasons from three different layers 0.00–0.05m; 0.05–0.15m, and 0.15–0.30m deep. In each area ten sampling points were randomly chosen. Two kinds of soil samples were collected: the first using 4.0 cm height by 5.1cm internal-diameter soil sample rings; and the second were intact soil lumps. Physical and Chemical soil attributes assessed were macro-porosity (MaP), micro-porosity (MiP), total porosity (TP), soil density (SD), aggregates texture and stability (GMD and WAR), gravimetric humidity (HG), organic carbon (OC), exchangeable aluminum (Al^{3+}), potential acidity (H+Al), sum of bases (SB), cation exchange capacity (CEC), and root biomass (RB). All data were analysed via Tukey t test and student T test to compare results between seasons and areas. Increasing vegetation density (cerrado < cerradão < forest) was followed by an increment in CEC and OC, showing the importance of these attributes to maintaining biodiversity in environments. In amazon cerrado, rainy season as well a sandier soil textures provided favourable conditions to the growth and development of plants' root system. Soil attributes were little affected by seasonality, that had greater effect on MiP, TP, SD, and OC, leading to lesser values for these variables during rainy season.

Keywords: Amazonian biome. Natural vegetation. Seasonal dynamics. Soils.

1. Introduction

The Amazon rainforest region presents a phytophysiognomy that ranges from savannas to cerrados, although it is predominantly a forest in its most varied forms, all of them intimately associated to climate and soil characteristics. Diversity in phytophysiognomy has found to be related to distinctions in edaphic characteristics (Yiemer et al. 2006), then showing there is a very strict connection between type of vegetation and soil properties (Freschet et al. 2017).

Thus, in order to have an understanding of natural phenomena, modifications and any other actions that occur in a natural ecosystem, it is necessary to evaluate its adverse components, among which the soil, plant and atmosphere can be highlighted, which they joint analyzes provide important answers related to the environment under evaluation (Gomar et al. 2002).

Regarding Amazon soils, most of them can be characterized as having low nutrient availability, with its fertility essentially maintained by geochemical and biochemical processes. (Moline and Coutinho 2015). Research has shown that soil quality supports growth and development of plants as much as preservation of diversity of organisms inhabiting the soil (Costa et al. 2017).

In this sense, quantifying variations in soil chemical and physical properties is extremely important when monitoring soil quality (Zaninetti et al. 2016). For this reason, the knowledge on an area's edaphic attributes allows a more sustainable and rational productivity management, as well as predicting a forest's characteristics, considering that plant life and soil are connected (Coutinho et al. 2017).

Through researching on root distribution and biomass, valuable contribution to the understanding of root system's role and function in ecosystems can be achieved (Dias et al. 2017). Beyond their importance to water and nutrient uptake, fine roots also contribute to organic matter input to the soil due to its quick renewal, playing an important role in regulating carbon and nitrogen cycles. Fine roots growth can represent up to 50% of neat primary productivity, making it one of the main routes by which carbon is added to the soil (Luizão 2007).

In some cases, the ratio of underground to aboveground biomass in plants can be greater than one, indicating a more pronounced development of roots under the influence of soil properties (Castro and Kauffman, 1998). Additionally, it has been shown, through investigating vertical and spatial carbon distribution in plant litter, roots, and soil, that underground biomass in cerrado areas vary seasonally, presenting evidence that climate and precipitation affect root development (Morais et al. 2017).

Considering that the Amazon biome is located between the tropics, having harsh summer and winter seasons, inserting a season variable into the study of the factors determinant to environmental diversity is imperative (West et al. 2004). Therefore, the goal of this research was to assess how seasonality, soil attributes, and root system biomass are related in natural cerrado, cerradão, and forest areas in southern Amazonas State, in Brazil.

2. Material and Methods

This study took place in three natural areas: cerrado, cerradão, and forest, all located in the municipality of Humaitá, in southern Amazonas State, along the BR–319 federal highway, inside a military area belonging to Brazilian army's 54th Jungle Infantry Battalion (Figure 1).

The forest area is located at the highest and best drained portion of the landscape, working as water divide and presenting physiography of dense ombrophilous forest (Campos et al. 2012) (Figure 2). The cerrado area on the other hand appears much more uniform, composed of short trees (Campos et al. 2012) and suffering very much from wildfires during dry season. In contrast, the cerradão area is comprised of a predominantly shrubby-arboreal physiognomy (Coutinho 1978), containing a forest-like but more sparse and poor vegetation. It is marked by the presence of both typical cerrado and typical forest species, visually resembling a forest but floristically closer to a cerrado (Oliveira et al. 2019).

Soils in this region have their origin in the alluvial sediments, chronologically arising from the Holocene. They are naturally low in fertility and are located in a plain but slightly wavy terrain. They can be characterized by the presence of plinthite and/or concretions, also presenting incomplete drainage and an excess of water during part of the year, usually the rainy season (Brasil 1978).

When it comes to climate, the region is classified in group A (tropical rainy climate) and climate type Am (tropical monsoon climate) according to Köppen's classification. It has a short dry period with average annual precipitation ranging from 2200mm to 2800mm (Alvares et al. 2013). The average annual temperature ranges from 25ºC to 27ºC and the relative humidity from 85% to 90% (Brasil 1978). Its rainy season occurs between October and March while the dry season goes from June to August. The rest of the year is considered as transition period (Vidotto et al. 2007) (Figure 3).

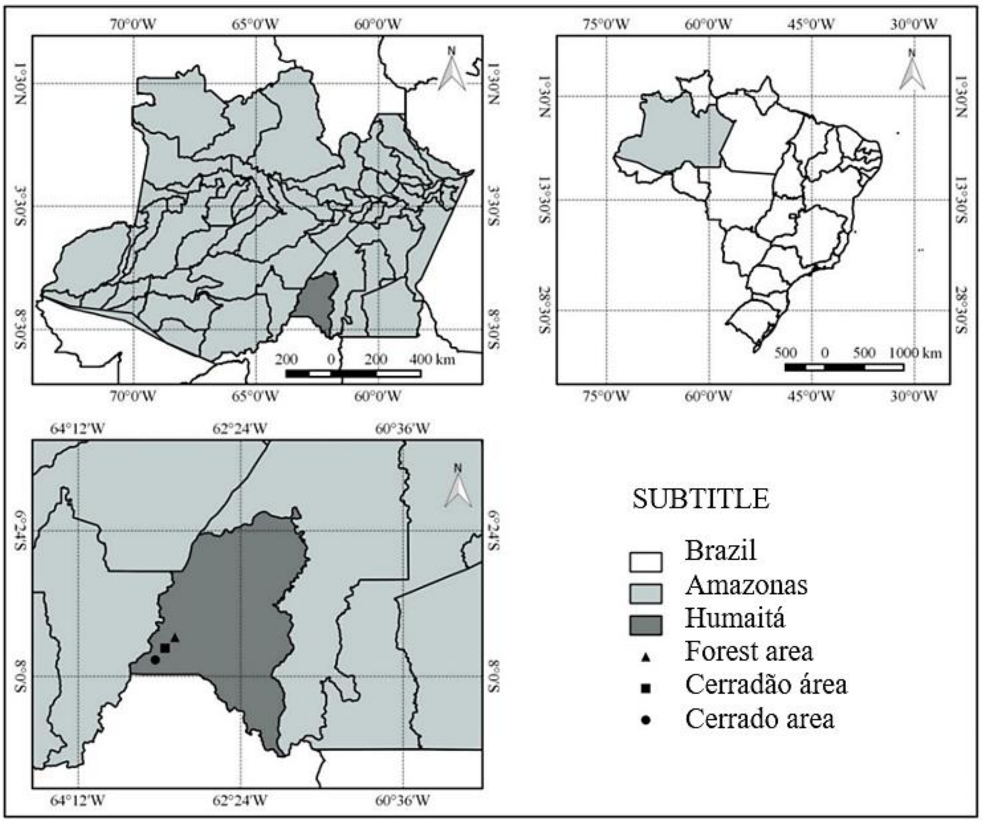

Figure 1. Study site location. Brazil map, highlighting the Amazon State, the study site, and the municipality of Humaitá, south Amazon.

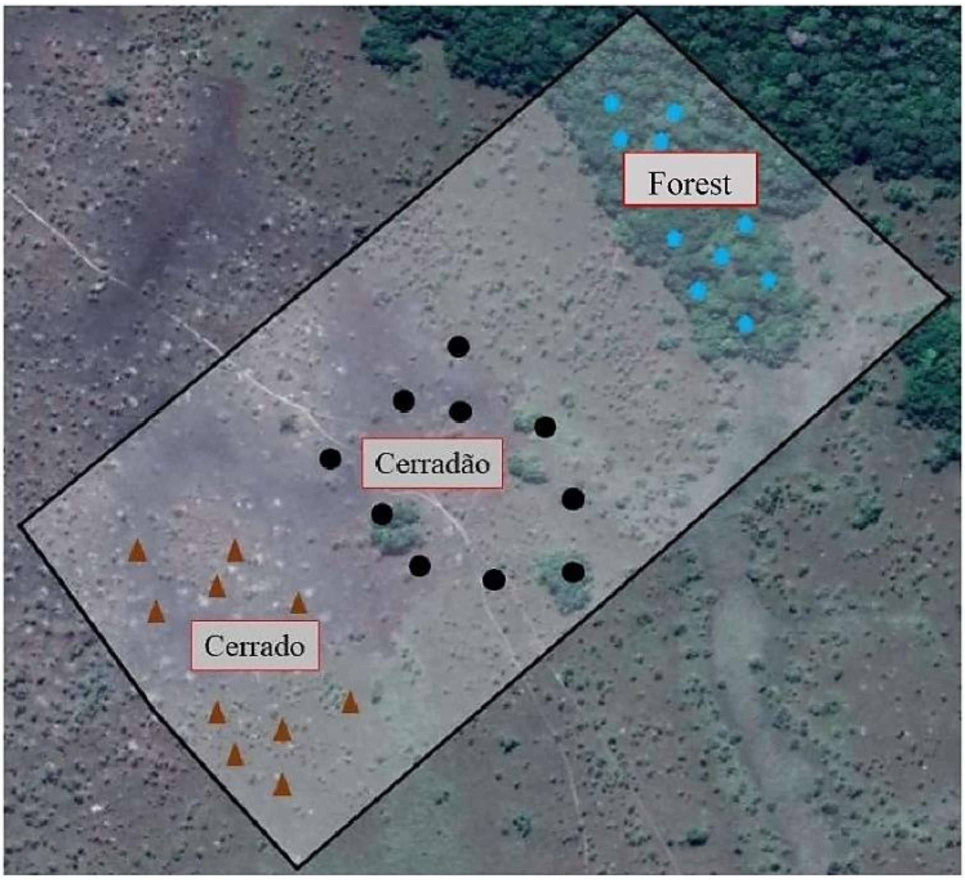

Figure 2. Sketch of the different positions for the insertion of conical sample collectors in cerrado, cerradão, and forest areas in southern Amazonas from April/2018 to March/2019.

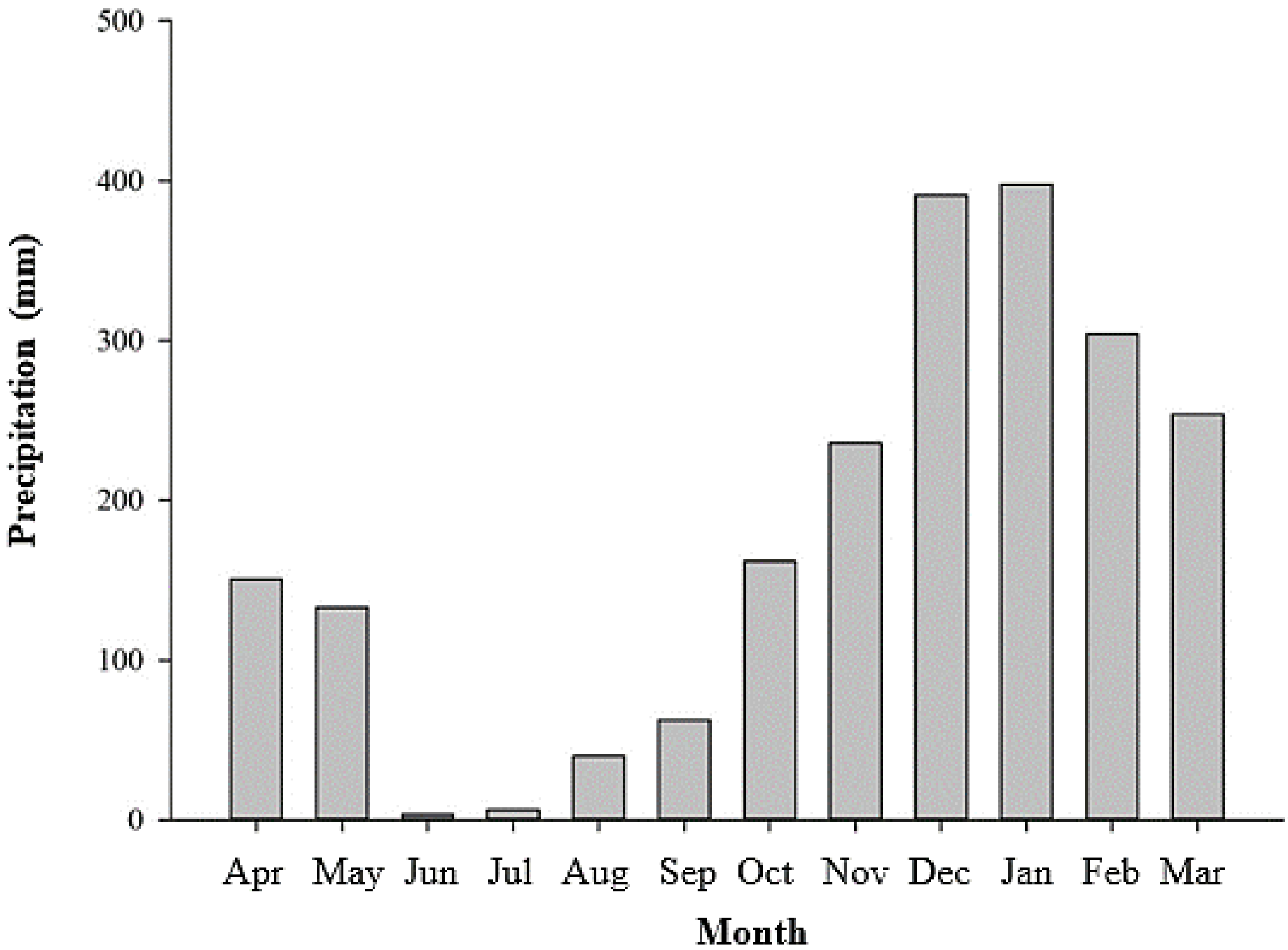

Figure 3. Total precipitation data, from April/2018 to Marçh/2019, obtained from Humaitá's weather station. Source: INMET. Instituto Nacional de Meteorologia (National Institute of Meteorology).

Physical and chemical soil analyses

Soil samples were collected in two different periods of the year: dry season (June/2018) and rainy season (December/2018), from three different layers with the following depths: 0.00–0.05m; 0.05–0.15m; and 0.15–0.30m. In each area, cerrado, cerradão, and forest, 10 sampling points were randomly chosen. Two kinds of soil samples were collected: the first using 4.0cm height by 5.1cm internal-diameter soil sample rings; and the second were intact soil lumps. All samples were shade dried and the lumps were slightly broken by hand. Then, lumps were separated using a 9.51mm diameter and a 4.76mm diameter screen sieves, and the particles retained in the 4.76mm diameter screen sieve were collected to assess aggregate stability. In addition, a part of each lump was broken by hand and separated in a 2.00mm diameter screen sieve to obtain the air-dried fine ground (ADFG) sample, which was used in physical and chemical analysis of the soil.

Chemical attributes analysed were: pH in water, determined with a potentiometer, using a 1:2.5 water to soil ratio (Teixeira et al. 2017); total potential acidity (H+Al), measured through extraction with a buffered calcium acetate solution with pH 7.0, as proposed by Teixeira (2017); exchangeable aluminum (Al^{3+}), extracted with a 1 mol L^{-1} KCl solution, then titled with a 0.025 mol L^{-1} NaOH solution, using bromothymol blue as pH indicator (Teixeira et al. 2017).

Available phosphorus (P) and potassium (K^+), and exchangeable calcium (Ca^{2+}) and magnesium (Mg^{2+}) were extracted through an ion-exchange resin. Using both exchangeable cations and potential acidity results, the parameters cation exchange capacity (CEC), sum of bases (SB), and base saturation (V%) were calculated (Teixeira et al. 2017).

Physical attributes determined were: macro-porosity (MaP), micro-porosity (MiP), total porosity (TP), gravimetric humidity (GH) and soil density (SD). Soil samples collected in soil sample rings were saturated in a plastic tray through gradually raising a layer of water up to two-thirds the height of the ring (Teixeira et al.

2017). To find Mip, samples were weighed and placed on a tension table, where a tension of -0.006 MPa was applied. After reaching equilibrium in a matrix potential of -0.006 MPa, samples were again weighed. In sequence, samples were dried in an oven at 105°C to determine Ug, Ds, and Pt via the volumetric ring method. MaP was then determined by the difference between Pt and MiP (Teixeira et al. 2017).

Granulometric analysis was performed through the pipette method, using a 0.1 mol L^{-1} NaOH solution as chemical dispersant, and mechanical agitation in a high rotation apparatus for 15 min, as proposed by Teixeira et al. (2017). Clay fraction was separated through sedimentation and sand fraction through sieving, while silt fraction was determined by the difference.

Soil aggregate stability was assessed by the wet sieving method. Separation and stability of aggregates were determined according to Kemper and Chepil (1965), with modifications in the following diameter ranges: 4.76-2.00mm; 2.00-1.00mm; 1.00-0.50mm; 0.50-0.25mm; 0.250 0.125mm; 0.125-0.063mm.

Aggregates separated in the 4.76mm sieve were, then, placed on the 2.00mm sieve in contact with water and then the 6 screen sieves were vertically agitated in Yoder apparatus (SOLOTEST model), at 32 oscillations per minute, for 15 minutes, after slow prewetting through capillarity. In sequence, the material separated in each sieve range was dried in oven at 105°C until constant weight was obtained and measured using a digital scale.

Results were expressed as percentage of aggregates separated in each of the ranges of sieves as >2mm, 2-1mm, and <1mm. The weighted average diameters (WAD) were calculated as proposed by Castro Filho et al. (1998), and the geometric weighted mean diameters (GMD) were calculated according to Schaller & Stockinger (1953) apud Alvarenga et al. (1986), using the following equations:

$$WAR=\frac{\sum_{i=1}^{N} niDi}{\sum ni}$$

$$GMD=10^{\frac{\sum_{i=1}^{N} nilogDi}{\sum ni}}$$

Where:
ni represents the percentage of aggregates separated in a certain sieve;
Di represents the average diameter of a certain sieve; and
N represents the number of sieve ranges used.

Root system biomass

To assess root biomass (less than 2mm depth) sample collecting was similarly performed in two periods of the year: dry season (June/2018) and rainy season (January/2019). Samples were collected using the monolith method in which first four 0.60m deep and 0.50m wide trenches were manually open in each studied area. Each trench was levelled and layer samples with the following depths were collected from each sampling point: 0.00-0.05m; 0.05-0.15m; 0.15-0.30m. After sampling, the soil contained in each monolith was manually washed to separate the roots, following an adaptation of the decantation/flotation methodology proposed by Schuurman and Goedewaagen (1971).

Fine roots washed and recovered in the process were dried in fan oven at 45°C, until constant weight was obtained and measured using a digital scale with 0.01g precision. Data on root biomass were obtained in terms of the weight of roots in a cubic decimeter of soil (g dm^{-3}).

Data analysis

All data obtained underwent variance analysis through F test and T test to compare the mean averages between seasons (dry and rainy) both at 5% significance. Whenever significant difference was found in F test results, Tukey test was performed to compare the mean averages of each area in each depth. Statistical analyses were performed on Statistical Package for Social Sciences (SPSS), version 12.5.

3. Results and Discussion

According to texture analysis results (Table 1), silt fraction was predominant in cerrado and cerradão areas, showing higher values in cerradão, characterized by an open clay structure. It is also possible to observe that the soil has fractions in greater amounts of sand and silt, meaning that it is in the process of weathering (Centeno et al. 2017), it is also worth mentioning that this can be attributed to the geological sand formation of the soils of the Amazon region, which results in soils with high sand contents (Mafra et al. 2002), as well as the high amount of organic matter particles that are similar in size to silt (Campos et al. 2012). Cerrado and cerradão were similar, this is justified since the cerradão has traces of the cerrado, mainly with regard to vegetation, a characteristic that is also induced by the soil (Gomes et al. 2004).

Table 1. Mean averages test results for soil texture attributes in cerrado, cerradão, and forest areas in southern Amazonas State.

Area	Layer (m)	Sand	Silt	Clay
		----------------------------	g kg^{-1}	--------------------------
Cerrado		417.00^{b}	367.50^{a}	215.50^{a}
Cerradão	0.00-0.05	332.50^{b}	505.00^{a}	162.50^{a}
Forest		483.38^{a}	344.13^{b}	172.50^{a}
Cerrado		385.38^{a}	440.50^{a}	252.50^{a}
Cerradão	0.05-0.15	337.5^{b}	605.00^{a}	162.13^{a}
Forest		380.88^{a}	384.25^{b}	235.00^{a}
Cerrado		349.13^{ab}	430.87^{a}	220.00^{a}
Cerradão	0.15-0.30	362.88^{b}	472.12^{a}	165.00^{a}
Forest		419.50^{a}	418.00^{a}	162.50^{a}

Mean averages with equal letters in a column do not differ through Tukey test at 5% significance.

Analysing the physical attributes of the soil (Table 2), it can be seen that MaP, MiP, Pt, and Ug were no statistically different among areas in dry season, this is due to the fact that despite being vegetatively distinct areas, they are close areas with flat relief and a major factor of soil modification in the amazon is water, absent in this period (Correa 1984), which can be noticed when comparing between the dry and rainy period where there is a decrease of porous spaces in the soil, this is due to the expansive clays, which in the dry period tend to contract forming cracks of varying sizes and in the rainy season they expand causing this increase and reduction of spaces in the solo (Coringa et al. 2012). On the other hand, in rainy season differences can be seen for MiP in the 0.05–0.15m layer, and for Pt and Ug in the 0.00–0.05m layer.

All areas analysed during both dry and rainy seasons presented favourable conditions to the development of plants, since all of them presented MaP values greater than $10m^{3}\ m^{-3}$, defined as limiting to root growth (Morais et al. 2020). The only exceptions, that yet could not impose a definite obstacle to plant development in the area, were during rainy season in cerrado and cerradão in the 0.15-0.30m layer. Macropores reduction to levels below 10m3.m-3 is usually considered as limiting to plant growth and productivity (Bevan 1980). What should not be strictly applied to the cerrado and cerradão vegetation, since they have a thinner and superficial root system that can adapt to these conditions (Lima et al. 2007).

Regarding seasonality, it is seen that MaP only significantly differ between dry and rainy seasons for cerradão in the 0.00-0.05m layer, reaching its highest value during dry season. This result can be explained by reductions in soil density in the layer in context. In contrast, there was significant difference between seasons for MiP in the forest, in the 0.05-0.15m layer; in cerradão, both in the 0.05-0.15m and 0.15-0.30m layers; and in cerrado, in the 0.15-0.30m layer; reaching the lowest values during rainy season.

For SD values, it can be noted that they are in accordance to average values considered ideal, ranging between 1.0 and 1.2g cm^{-3}, with greater values resulting in soil degradation (Camargo and Alleoni 1997). This result is expected since the soil is not revolved in natural environments, having a strong tendency to accumulate organic matter on the surface due to plant littering from the vegetation itself (Guareschi et al. 2012; Torres et al. 2015), what research has shown to lead to lower values in soil density (Gomes et al. 2015).

When assessing soil density (SD) during dry season, cerradão showed the least values in the 0.00-0.05m layer. Since there is no anthropic influence, this can be attributed to soil texture, considering it is the area with greater amount of fine material (Skaraboto et al. 2018). However, during rainy season, soil density in cerrado presented the least values, which can be justified by its vegetation, since it is located at the lowest part of the area, therefore promoting greater friability (Gomar et al. 2002).

Seasonality also plays a big role in cerrado, where there was significant difference between seasons in all depth layers. In contrast, forest and cerrado areas showed significant difference between seasons only in the more superficial layer (0.00-0.05m). It can also be observed the greatest values occur in dry season with significant differences via Student test, what research demonstrates to be due to natural forces (wet/dry cycles) reducing soil density (Minosso et al. 2017).

Table 2. Mean averages test results for soil physical attributes in cerrado, cerradão, and forest areas during rainy and dry season in southern Amazonas State.

Area	Map	Mip	TP	SD	WMD	GMD	GH
	-------------------%--------------------			g cm^{-3}	----------mm----------		%
Dry season							
Layer (000-0.05 m)							
Cerrado	18.26^{aA}	38.34^{aA}	56.60^{aA}	1.06^{aA}	3.25^{aA}	3.33^{aA}	28.83^{aA}
Cerradão	22.43^{aA}	41.62^{aA}	64.06^{aA}	0.81^{bA}	2.83^{aA}	3.20^{aA}	42.88^{aB}
Forest	20.70^{aA}	39.65^{aA}	60.35^{aA}	0.99^{aB}	2.08^{aA}	2.43^{aA}	32.58^{aA}
Layer (0.05-0.15 m)							
Cerrado	19.53^{aA}	38.59^{aA}	58.12^{aA}	1.12^{aA}	3.10^{aA}	3.29^{aA}	35.54^{aA}
Cerradão	14.53^{aA}	48.10^{aA}	62.63^{aA}	1.07^{aA}	2.68^{aA}	3.23^{aA}	36.81^{aA}
Forest	16.14^{aA}	41.23^{aA}	57.37^{aA}	1.10^{aA}	3.00^{aA}	3.20^{aA}	30.79^{aA}
Layer (0.15-0.30 m)							
Cerrado	17.73^{aA}	41.30^{aA}	59.03^{aA}	1.16^{aA}	3.00^{aA}	3.25^{aA}	29.21^{aA}
Cerradão	12.07^{aA}	42.28^{aA}	54.35^{aA}	1.22^{aA}	1.68^{aA}	1.78^{bA}	28.60^{aA}
Forest	17.86^{aA}	36.02^{aA}	53.88^{aA}	1.21^{aA}	2.45^{aB}	2.80^{bA}	24.17^{aA}
Rainy season							
Layer (0.00-0.05 m)							
Cerrado	26.77^{aA}	24.18^{aA}	50.95^{abA}	0.83^{abA}	2.79^{aA}	3.27^{aA}	30.16^{bA}
Cerradão	10.32^{aA}	34.05^{aA}	44.37^{aA}	1.00^{aA}	2.68^{aA}	2.75^{bA}	34.06^{abA}
Forest	22.39^{aA}	32.06^{aA}	54.44^{bA}	0.87^{bB}	3.03^{aB}	2.79^{bA}	58.08^{aA}
Layer (0.05-0.15 m)							
Cerrado	16.64^{aA}	30.84^{aA}	47.48^{aB}	0.94^{aA}	3.12^{bA}	3.22^{aA}	33.00^{aA}
Cerradão	12.42^{aA}	32.45^{aB}	44.87^{aA}	1.04^{aA}	3.12^{bA}	2.84^{aA}	31.01^{aA}
Forest	14.77^{aA}	36.66^{bB}	51.42^{aB}	0.88^{aA}	2.76^{aA}	2.95^{aA}	43.97^{aA}
Layer (0.15-0.30 m)							
Cerrado	7.70^{aB}	32.28^{aA}	39.98^{aB}	1.04^{aB}	2.88^{bB}	3.21^{aA}	30.96^{aA}
Cerradão	7.30^{aB}	32.41^{aA}	39.71^{aA}	1.21^{aA}	2.99^{bA}	2.70^{aA}	26.72^{aA}
Forest	10.53^{aB}	35.87^{aA}	46.40^{aA}	1.03^{aA}	2.65^{abA}	2.65^{aA}	34.85^{aA}

MaP: macro-porosity; MiP: micro-porosity; TP: total porosity; SD: soil density; GMD: geometric weighted mean diameter; WAR: weighted average diameter; GH: gravimetric humidity. Mean averages in the same season labelled with equal lower case letters do not differ through Tukey test at 5% significance; mean averages between seasons labelled with equal upper case letters do not differ through T student test at 5% de probability.

Mean averages for aggregation indexes GMD and WAR (Table 2) were high in both seasons, probably because of the fact that the areas in context are natural environments, with no anthropic influence. These results agree with those of Luciano et al. (2010), who observed better soil aggregation in natural areas, suggesting that the obtained result might have been due to higher biological activity.

When analyzing the same attributes exclusively during dry season, it can be seen that there was no significant difference among areas for GMD. WAR on the other hand, showed significant difference in cerrado in the 0.15-0.30m layer. It can also be seen that during dry season the mean averages for GMD decreased in all layers studied. These results agree with the ones Vasconcelos et al. (2010) and Wendling et al. (2012) found, showing soil aggregation decreased with depth when there was native vegetation above it. During rainy season, the results for the forest area were statistically different in the 0.05–0.15 m layer for GMD, while the cerrado had greater values for WAR in the 0.00-0.05 m layer.

Data shows WAR did not change significantly when seasons are compared. Oppositely, there was significant difference for GMDG in cerrado in the 0.15-0.30 m layer, with greater value in dry season; and also in cerradão, in the 0.00-0.05m layer during dry season and in the 0.15-0.30 m layer during rainy season.

Gravimetric humidity, an important factor for plant survival, was significantly different between seasons in the forest area, in the 0.00-0.05m layer, with the greatest value found in rainy season. This result can be due to a sum of effects: higher precipitation levels in rainy season; greater solar radiation in dry season, leading to more intense water evaporation from the soil; and organic matter input that supports water retention (Carneiro et al. 2014).

Analyzing the data on chemical attributes presented in Table 3 we can see there is an extreme acidity condition in all environments and layers assessed, during both seasons. These results were, however, expected, since recent studies have shown low pH values in water (below 5.0) are characteristic in southern Amazonas region soils (Campos et al. 2012; Mantovanelli et al. 2015; Aquino et al. 2016).

According to Reis and coworkers (2009), the main cause of low pH values in water for soils in southern Amazonas is due to high loss of exchangeable bases and consequent accumulation of H+ ions in the soil. Together with the intensity and consistency in precipitation levels, these areas were also originated from sediments e holocenes, therefore, being quite poor when it comes to fertility and not a good source of nutrients (Campos et al. 2015).

Results for pH in water were not significantly different between dry and rainy seasons, the only exception was in the 0.05-0.15m layer. Additionally, there was little variation along the different soil depths. These findings agree with those of Martins and coworkers (2010) that demonstrated seasonality as having no influence in this variable, thus deeply related to local geological formation (Moline and Coutinho 2015).

When it comes to the amount of organic carbon in the soil, it was predominant in the forest area, reaching higher values. Mantovanelli et al. (2015) justify this result by the greater deposition of organic matter, provided by the more biologically conducive environment to such deposition on the surface, considering the more lignified plant litter. We can also see the values decrease with depth, just as found by Costa et al. (2015) working with carbon in different environments.

Organic carbon content was higher during dry season, with significant difference in following areas and layers: in cerrado in the 0.00-0.05m and 0.05-0.15m layers; in cerradão, in the 0.00-0.05 m and 0.15-0.30m layers; and in the forest in 0.05-0.15m layer. This was not surprising because Amazon and Cerrado ecosystems usually showcase high levels of organic matter deposition on the surface during dry season, what can be explained by the more intense plant littering on the surface as much as the vegetation's phytophysiognomy (Ciancuaruso et al. 2006). Regarding Al^{3+}, only the forest in the 0.05-0.15 m layer has suffered from seasonality effects, with its highest value during dry season.

The acidities (Al^{3+} and H+Al) were extremely high during both seasons and in all areas and layers. This is very likely to be due to the effect of weathering dynamics upon the mineral material that originated the soil of the region, since it is naturally poor in fertility, accumulating these elements in it (Moline and Coutinho, 2015).

The cations exchange capacity (CEC) in the areas in question were mostly high (> 8 cmolc kg^{-1}) with the forest presenting higher values, the only exception being the 0.00-0.15m layer during dry season. One of the reasons for this might be related to the dynamics of carbon in this area, which is much more intense, see CEC values compared to CO values (Amaral et al. 2000). Amazon soils usually present low CEC levels (Alves et al. 2019), with the exception of the black lands of Indians, which are peculiarities within the region due to their high CEC (Oliveira et al. 2015), and one way to counterbalance this is by increasing the amount of organic carbon in the soil (Pedrotti et al. 2017). In addition, CEC is a very important factor, contributing to greater nutrient availability for plants (Malta et al. 2019), therefore directly related to greater diversity in the forest compared to the other areas.

In general, soils were classified as dystrophic according to its V% values, thus considered low in natural fertility (Rocha et al. 2018). The areas did not show significant differences for V% during dry season, but did during rainy season, what was similarly found by Campos et al. (2010) when studying soil attributes in Amazon natural fields.

Analyzing biomass mean averages for root system in the different environments (Table 4) we can observe cerradão had the greatest values in the first layer (0.00-0.05m). In the second layer (0.05-0.15m), cerrado had the greatest values; and in the third layer (0.15-0.30m), the forest showed the greatest values, although no statistical difference was seen. This is due to the fact that the cerrado area displayed both sclerophyll and xeromorph species (Borges et al. 2019), i.e., species usually present in the Cerrado and the Forest biomes, respectively, therefore classified as a forest exhibiting traits of a cerrado. So, it contains plants with intense superficial root development but with less spacing, in contrast to Cerrado biome, wich is a little denser (Borges et al. 2017).

Table 3. Mean averages test for soil chemical attributes in cerrado, cerradão, and forest during dry and rainy seasons in southern Amazonas.

Area	Layer (m)	pH	OC g kg^{-1}	Al^{3+} ---cmol$_c$ kg^{-1}---	H^+Al	P mg kg^{-1}	K^+ ----------cmol$_c$ kg^{-1}----------	Ca^{2+}	Mg^{2+}	SB	CEC	V %
						Dry season						
Cerrado	0.00-0.05	4.29^{aA}	26.85^{aA}	6.30^{aA}	10.93^{aA}	7.75^{aB}	0.13^{aA}	0.31^{aA}	0.07^{aA}	0.51^{aB}	11.44^{aA}	4.27^{aB}
Cerradão		4.43^{aA}	34.04^{aA}	5.28^{aA}	11.18^{aA}	10.48^{aB}	0.20^{aA}	0.31^{aA}	0.30^{aA}	0.81^{aA}	11.99^{aA}	6.76^{aB}
Forest		4.32^{aA}	30.97^{aA}	4.85^{aA}	13.38^{aA}	10.48^{aB}	0.20^{aA}	0.22^{aA}	0.22^{aA}	0.60^{aB}	13.98^{aA}	4.29^{aA}
Cerrado	0.05-0.15	4.50^{abA}	22.10^{aA}	4.50^{aA}	11.08^{aA}	5.97^{aB}	0.07^{aB}	0.25^{aA}	0.06^{aA}	0.38^{aA}	11.46^{aA}	3.31^{aB}
Cerradão		4.84^{aA}	20.35^{aA}	4.23^{aA}	11.08^{aA}	7.92^{aB}	0.11^{aB}	0.22^{aA}	0.11^{aA}	0.44^{aA}	11.52^{aA}	3.82^{aB}
Forest		4.51^{bA}	24.89^{aA}	4.83^{aA}	10.30^{aA}	10.70^{aA}	0.14^{aA}	0.25^{aA}	0.16^{aA}	0.55^{aA}	10.85^{aA}	5.06^{aA}
Cerrado	0.15-0.30	4.58^{aA}	18.79^{abA}	5.93^{aA}	8.90^{aA}	4.71^{aA}	0.05^{aA}	0.28^{aA}	0.06^{aA}	0.39^{aA}	9.29^{abA}	4.19^{aA}
Cerradão		4.86^{aA}	15.46^{bA}	5.28^{aA}	8.68^{aA}	5.90^{aA}	0.08^{aB}	0.16^{bA}	0.06^{aA}	0.30^{aA}	8.98^{aA}	3.34^{aA}
Forest		4.60^{aA}	22.07^{aA}	4.95^{aA}	9.55^{aA}	8.98^{aA}	0.12^{aA}	0.22^{abA}	0.11^{aA}	0.45^{aA}	10.00^{bA}	4.50^{aA}
						Rainy season						
Cerrado	0.00-0.05	4.32^{aA}	16.28^{aB}	6.15^{aA}	8.55^{aA}	8.44^{bA}	0.14^{aA}	0.22^{aB}	0.07^{aA}	0.43^{aA}	8.98^{aB}	4.79^{aA}
Cerradão		4.29^{aA}	16.46^{aA}	5.52^{aA}	9.43^{aA}	12.49^{aA}	0.18^{aA}	0.19^{aA}	0.18^{aA}	0.55^{aA}	9.98^{aB}	5.51^{aA}
Forest		4.43^{aA}	25.53^{aB}	4.74^{aA}	11.45^{aA}	11.78^{abA}	0.19^{aA}	0.19^{aB}	0.19^{aB}	0.57^{aA}	12.02^{aA}	4.74^{aA}
Cerrado	0.05-0.15	4.51^{bA}	14.01^{aB}	4.86^{aA}	7.45^{aA}	6.21^{bA}	0.08^{bA}	0.22^{aB}	0.06^{bA}	0.36^{abA}	7.81^{aA}	4.60^{abA}
Cerradão		4.50^{bA}	12.40^{aB}	6.35^{aA}	8.25^{aA}	7.63^{aA}	0.10^{aA}	0.12^{aB}	0.06^{bB}	0.28^{bA}	8.31^{bB}	3.36^{bA}
Forest		4.84^{aA}	16.52^{aA}	4.46^{aA}	8.40^{aA}	10.36^{aA}	0.20^{aA}	0.22^{aA}	0.11^{aB}	0.53^{aB}	8.41^{abB}	6.30^{aB}
Cerrado	0.15-0.30	4.74^{aA}	16.38^{aA}	4.29^{aA}	6.55^{aA}	4.95^{abA}	0.07^{bA}	0.22^{aB}	0.06^{bA}	0.35^{aB}	6.90^{aB}	5.07^{abB}
Cerradão		4.35^{aA}	10.13^{aA}	6.77^{aA}	7.25^{aA}	4.76^{bA}	0.08^{abA}	0.12^{aA}	0.06^{bB}	0.26^{bA}	7.51^{aB}	3.55^{bA}
Forest		4.58^{aA}	17.50^{aB}	3.13^{aA}	6.50^{aA}	8.40^{aA}	0.16^{aA}	0.22^{aB}	0.07^{aA}	0.45^{aA}	6.95^{aB}	6.47^{aA}

CO: organic carbon; Al^{3+}: exchangeable aluminum; H+Al: potential acidity. Mean averages in the same season labelled with equal lower case letters in a column do not differ through Tukey test at 5% significance; mean averages between seasons labelled with equal upper case letters do not differ through T student test at 5% de probability.

In the second layer (0.00-0.15m) the highest values in cerrado are a consequence of the biome characteristics, which is poor in nutrients when compared to the others and comprises acidic soils, forcing plants to expand their roots in search for nutrients (Braga et al. 2017). Also, Cerrado areas naturally contain forage species and short trees that have longer root systems, up to 20m deep (Siqueira et al. 2016). In the third layer (0.15-0.30m), specifically during dry season, the greater value found for the forest area can be explained based on the fact that forests have a vegetation of greater magnitude compared to the other areas, and because of that a more dense root system (Behling et al. 2014).

On the other hand, during rainy season the forest had lesser biomass values in this same layer, what can be explained by the need to deepen and enlarge roots longer than 2mm to support the plant. There was also a decrease in size along depth, what was also described in other studies such as Castro and Kauffmann (1998) and Menezes et al. (2010).

Statically, we can say that the cerradão area was very similar to the forest area due to the similarities in vegetation between these environments. The cerradão has various arboreal species although it is still essentially similar to cerrado (Kuchla et al. 2015). Also, there were significantly greater difference in the more superficial horizons, what makes sense since distinct environments bring about different characteristics to root systems, helping differentiate them (Ratuchne et al. 2016).

Table 4. Mean averages for root biomass in cerrado, cerradão, and forest areas during dry and rainy seasons in southern Amazonas.

Roots Biomas	Cerrado	Cerradão	Forest
		---------------------------------g.dm^{-3}-------------------------------	
		Dry season Layer (0.00 – 0.05 m)	
Average (n= 4)	1.40^{bB}	2.89^{aB}	2.04^{abB}
CV (%)	24.08	22.84	28.71
		Layer (0.05 – 0.15 m)	
Average (n= 4)	3.28^{aB}	2.61^{bA}	2.64^{bA}
CV (%)	35.43	36.93	40.94
		Layer (0.15 – 0.30 m)	
Average (n= 4)	1.11^{abB}	1.56^{aA}	1.78^{aA}
CV (%)	44.4	32.09	82.88
		Rainy season Layer (0.00 – 0.05 m)	
Average (n= 4)	5.00^{aA}	3.45^{bA}	3.47^{bA}
CV (%)	20.69	43.49	52.59
		Layer (0.05 – 0.15 m)	
Average (n= 4)	3.70^{aA}	1.68^{bB}	1.55^{bB}
CV (%)	18.53	53.51	78.13
		Layer (0.15 – 0.30 m)	
Average (n= 4)	2.67^{aA}	1.42^{bB}	0.75^{cB}
CV (%)	53.99	26.51	65.59

CV: coefficient of variation; N: number of samples. Mean averages in the same season labelled with equal lowercase letters in a column do not differ through Tukey test at 5% significance; mean averages between seasons labelled with equal uppercase letters do not differ through T student test at 5% de probability.

All areas showed significant difference between seasons when it comes to root system biomass, with greater values in rainy season. This can be due to the fact that water is essential in any ecosystem, taking part in plant feeding through photosynthesis (Lima et al. 2015) and in other physiological processes. Also, since dry season in Amazon is quite harsh, it contributes to reducing biomass production by the plants (Nobre et al. 2014). In this sense, during rainy season the water turns the environment into a more nutritious and physiologically adequate one, promoting the growth of the vegetation what positively affects root growth (Padilha et al. 2016), considering roots not only work uptalking nutrients but also sustaining the plant (Gubiani et al. 2014).

Regarding KMO (Kaiser-Meyer-Olkin) values, it is a measure that assesses how well the factorial analysis is adequate (Miranda et al. 2015). Its classification and ranges vary, but considerable values fall between 0.5 and 1.0, with values below 0.5 indicating that the factorial analysis is not acceptable (Reis, 2001). Since the results obtained for KMO analysis were 0.83 and 0.85 to dry and rainy seasons, respectively, all depths can be classified as good through this analysis.

Considering the variances (Table 5) as a measure of dispersion, i.e., the distance of an attribute to its expected value (Yamamoto et al. 2017), it can be seen that there is a greater distance in the following attributes: total porosity and gravimetric humidity, in dry season; sand fraction and silt fraction, in rainy season. Those were also the ones that most contributed to total variance (PC1 - PC2) (Freitas et al. 2015).

According to the graphic representation of the two principal components (Figure 4), it can be inferred which components are responsible by the differentiation as well as formation and characterization of these environments, i.e., the variables that mostly had an impact in the results, and its behaviour through seasonality and among vegetation types (Freitas et al. 2015).

Regardless of seasonality, it is possible to see that root biomass and the cerrado area are related. Also, the cerrado is related to sand fraction, with soil texture influencing root development, since there was no significant difference in fertility attributes among areas. So, it might be possible that sandier soils in cerrado promote root growth. This result agrees with the ones of Vasconcelos and Coworkers (2003), who demonstrated intense root development in maize when cultivated in a soil composed of 630 g kg^{-1} of sand. Likewise, it is possible that the results for root biomass are due to widespread small plants bearing dense root systems (Roquette et al. 2018).

Table 5. Correlations between each principal component to the analysis of the soil attributes in cerrado, cerradão, and forest areas, during dry and rainy seasons in southern Amazonas.

Attributes	Season			
	Dry		Rainy	
	[1]PC1	[2]PC2	[1]PC1	[2]PC2
Sand	0.19	-0.93*	-0.02	-0.95*
Silt	-0.06	0.96*	-0.12	0.96*
Map	-0.54	-0.74*	0.23	0.75*
TP	-0.91*	-0.29	0.94*	-0.11
SD	0.90*	0.35	-0.94*	0.17
WAR	•••••	•••••	0.13	-0.76*
GH	-0.95*	0.18	0.91*	0.33
pH	-0.71*	0.28	0.65*	0.41
OC	-0.88*	-0.22	0.91*	-0.07
Al^{3+}	0.90*	0.15	-0.91*	-0.01
P	•••••	•••••	0.20	0.77*
Mg^{2+}	-0.59	0.68*	0.46	0.77*
SB	-0.75*	0.30	0.70*	0.44
CEC	-0.83*	0.18	0.78*	0.33
RB	0.13	-0.95*	0.05	-0.95*
Explained variance (%)	52.52%	30.24%	47.68%	31.03%

MaP: macro-porosity; MiP: micro-porosity; Pt: total porosity; Ds: soil density; GMD: geometric weighted mean diameter; WAR: weighted average diameter; GH: gravimetric humidity; CO: organic carbon; Al: aluminum; SB: sum of bases; CEC: cation exchange capacity; RB: root biomass; •••••: variation did not contribute to the component.

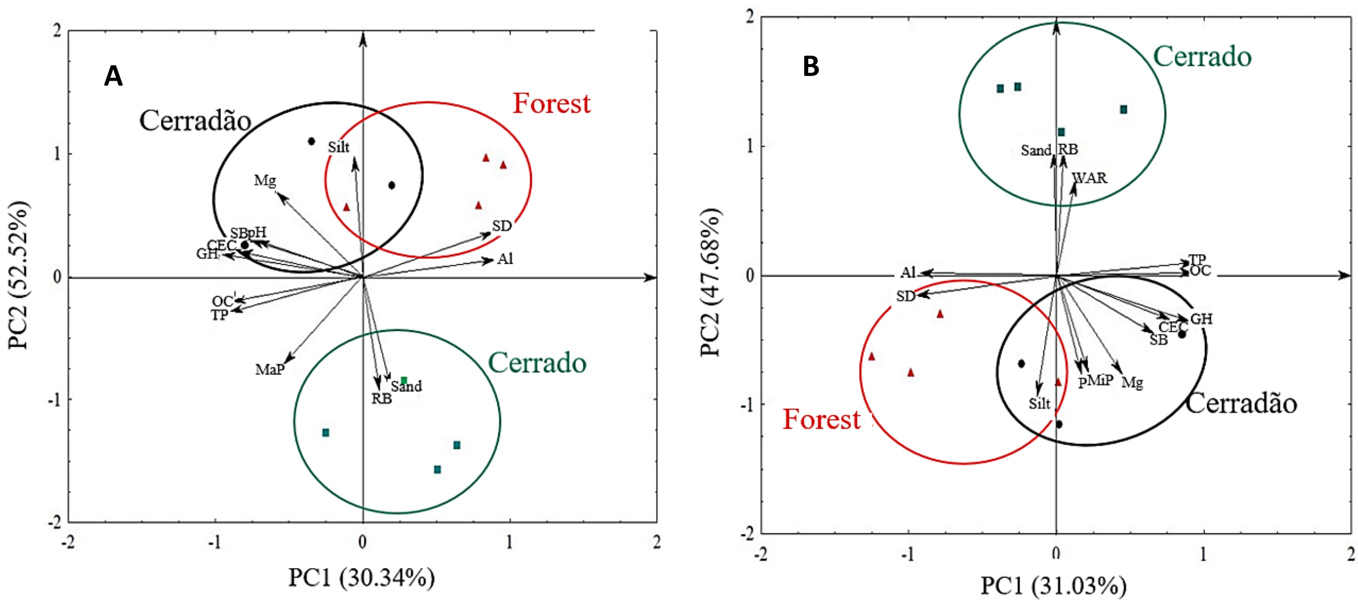

Figure 4. Principal components analysis for soil attributes and root biomass in cerrado, cerradão, and forest areas: A - Rainy season; B - Dry season. PC1: Principal component 1; PC2: Principal component 2. MaP: macro-porosity; TP: total porosity; SD: soil density; GMD: geometric weighted mean diameter; WAR: weighted average diameter; GH: gravimetric humidity; OC: organic carbon; Al: aluminum; SB: sum of bases; CEC: cation exchange capacity; RB: root biomass.

The cerrado area presents a greater correlation to chemical attributes of the soil both in dry and rainy seasons. This can be due to a more efficient nutrient cycling, making them readily available in the soil, which in turn can be explained by a marked level of diversity in cerrado areas when compared to the others (Boer et al. 2007).

Soil density was more correlated to the forest area. Since it is a more stabilized environment with considerable organic matter input through plant littering, the lowest values for soil density were found there (Aquino et al. 2014).

When comparing cerradão and forest areas, the cerradão was more correlated to the forest proving to be in fact a forest containing fragments of a cerrado, what demonstrates also that variations in dryness and humidity were present in the past but, in the end, the forest overcame the cerrado, only remaining a few of its traits (Silva et al. 2007).

4. Conclusions

Soil attributes were little influenced by seasonality, with only MiP, TP, SD e OC showing lesser values during rainy season.

Ds and aluminum content shown to be more related to the forest area, while sand fraction and root biomass shown greater correlation to the cerrado area. All other variables especially chemical attributes presented greater correlation to the cerradão.

Cerrado area was overall distinct from the other areas. Through principal component analysis, an overlapping between cerradão and forest was observed, seen through closer similarities among these environments' attributes.

Root development was favoured by the rainy season in the cerrado area, and its correlation to sand fraction was apparent in the principal components analysis, demonstrating a better performance of cerrado plants' root system.

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