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INFLUENCE OF SPATIAL VARIABILITY OF SOIL CHEMICAL ATTRIBUTES ON THE NUTRITIONAL STATUS AND GROWTH OF THE RUBBER TREE

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Abstract
The productive potential of the rubber tree (*Hevea brasiliensis*) is dependent on its genetic composition, in addition to edaphoclimatic factors and management practices. However, as soil properties are not homogenous, knowing the spatial variability of soil attributes would be important to increase productivity and reduce production costs. In this context, the objective of this study was to determine the spatial variability of chemical attributes of the soil and its influence on the nutritional status and growth of rubber tree clones. Clones FX 3864, FDR 5788, CDC 312, and RRIM 600 were planted at Jaturnaíba Farm, in the municipality of Silva Jardim, Rio de Janeiro State, Brazil. The sampling sites were distributed at a spacing of 20 × 20 m on the northern and southern sides of the relief. The chemical attributes of the soil (pH, Ca^{2+}, Mg^{2+}, K^{+}, P, Al^{3+}, H+Al, sum of bases, cation exchange capacity, and base saturation) were evaluated at a depth of 0–20 cm in the different clone plantations. Additionally, the N, P, K, Ca, and Mg content as well as trunk circumference and total plant height, were also evaluated. Geostatistics was used to determine the spatial variability of the soil and clone attributes, while Ordinary Kriging was used to draw variability maps of the variables. A difference in the distribution of the variables, which was dependent on the slope of the relief, was detected through the maps. The southern side presented better conditions as some degradation was observed on the northern side. Certain soil characteristics influenced the distribution of the attributes of the planted clones; for example, the low concentration of Ca^{2+} in the soil caused Ca deficiency in the FX clone on the southern slope, indicating that liming did not supply enough nutrients for this clone. Our results showed that the variability in soil attributes influenced the nutritional status and growth of the rubber tree clones, indicating that variability maps can guide the planting and management of the rubber tree, providing more efficient management.

Keywords: Geostatistics. *Hevea brasiliensis*. Soil fertility.

1. Introduction

The rubber tree (*Hevea brasiliensis*), which is indigenous to Brazil, is one of the most important species of the Euphorbiaceae family, presenting great economic potential as the main source of non-synthetic rubber. Once the largest global producer of non-synthetic rubber, Brazil is currently a major importer from Asian countries such as Indonesia and Malaysia (Barreto et al. 2016), with imports accounting for 60 % of national consumption (Homma 2017). Demand for non-synthetic rubber in Brazil continues to increase, and current production cannot meet market needs; therefore, latex rubber production in Brazil must expand (Barreto et al. 2016), using clones that present good productivity and latex quality.

There were some initiatives in mid-2010 to expand Hevea culture in the states of São Paulo, Bahia, Mato Grosso, Espírito Santo, and Minas Gerais (Homma 2015). A total of 18.68 % of the area of the state of Rio de Janeiro is deemed to have adequate soil, temperature, and water conditions for the development of the rubber tree (Naime et al. 2009). Oliveira et al. (2014) analyzed studies conducted on rubber trees on family properties in Rio de Janeiro and reported that rubber trees developed well in both agrosilvipastoril and agroforestry systems (AFS), although better results were observed for AFS.

Rubber tree production is determined by genetic potential combined with intrinsic factors related to soil, climate, and management practices (Virgens Filho 2007). Soil fertility is essential to increase crop cultivation and yield. However, soil attributes may vary spatially due to soil formation factors, management techniques, fertilization, and crop rotation (Bernardi et al. 2015). Recent studies have used geostatistics to determine and understand the variability and spatial dependence of variables (Pelissari et al. 2014; Silva et al. 2016). Geostatistics has important spatial modeling tools that are useful for the analysis of spatial or temporal attributes, in addition to being a tool that can save on time and labor.

Geostatistics has previously been used in studies evaluating soil attribute variability, as well as productivity and circumference of rubber plants. Roque et al. (2005) evaluated the spatial variability of the chemical attributes of an *Argissolo Vermelho-Amarelo* (Ultisol) after 16 years of rubber tree clone cultivation in São Paulo and reported that the variables P, K, Ca, and Mg presented higher variability compared to other nutrients, and that the attributes have greater spatial continuity in areas with a greater slope. The same area was studied by Roque et al. (2006), who evaluated the correlation of spatial variability and rubber productivity with trunk circumference and reported that the spatial variability of dry rubber productivity was related to trunk circumference, which significantly influenced dry rubber yield from rubber tree clones.

Consequently, the aim of this study is to test the hypothesis that the spatial distribution of the chemical attributes of the soil affects the nutritional status and development of the rubber tree. Therefore, the objective of the study was to observe the spatial variability of chemical attributes of the soil and analyze its influence on the nutritional status and growth of rubber tree clones.

2. Material and Methods

Location and characterization of the study area

The study was carried out in 2015 at Jaturnaíba Farm (municipality of Silva Jardim, Rio de Janeiro, Brazil; 42°23'30" W and 22°39'03" S). The soil of the area has been classified as a typical *Argissolo Amarelo* (Ultisol). The terrain of the region is wavy, with slopes ranging from 18 to 23 %, and with an average height of 45 m. The climate of the region is tropical humid, type Cwa according to Köppen (1948), with an average annual temperature of 23 °C and average annual precipitation of 1500 mm.

The area had been used for pasture and presented signs of degradation before the rubber trees were planted in 2009. Planting was performed with a spacing of 3 × 6 m, on raised beds with dimensions of 40 × 40 × 50 cm. Each planting bed was fertilized with 300 g of limestone, 300 g of formulated fertilizer NPK (2–16–6), and 10 L of bovine manure for basic fertilization. Liming was performed in the area two years after planting by applying 2 mg limestone per ha. NPK fertilization was carried out annually, with an equivalent dose of 60 kg of N, 30 kg of P_2O, and 60 kg of K_2O per ha.

Jaturnaíba farm currently has approximately fifty thousand rubber trees. For this study, an area of 10 ha, exhibiting a convex microrelief, an average lower altitude of 11 m and higher altitude of 45 m was selected. The property had different clones propagated through grafting, and we evaluated clone varieties FX 3864, FDR 5788, CDC 312, and RRIM 600. The plots of each evaluated clone were located on different sides of the terrain (northern and southern), with clones FX (0.9 ha), FDR (0.8 ha), and RRIM (0.7 ha) located on the northern side, while clones FX (0.9 ha), FDR (0.6 ha), RRIM (0.6 ha), and CDC (0.93 ha) on the southern side.

Clone growth

Clone growth was assessed by measuring total height and trunk circumference. The total height was measured using a scaled stick and the circumference using a measuring tape. Trunk circumference was measured 1.20 m from the ground, the height at which latex was collected.

Evaluation of the nutritional status of the clones

Adult and mature leaves were collected at four points of the canopy and in the middle third of the crown. Shaded leaves were also collected. Nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), and magnesium (Mg) contents were subsequently analyzed (Tedesco et al. 1995). The nutritional status and interpretation of the results were evaluated using tables of critical levels or sufficiency ranges, following Malavolta et al. (1997).

Analysis of chemical attributes of the soil

Soil samples were collected from different rubber tree clone plantations at a depth of 0–20 cm. The following variables were determined from the samples, following Donagemma et al. (2011): water pH, calcium (Ca^{2+}), magnesium (Mg^{2+}), potassium (K^{+}), phosphorus (P), potential acidity (H+Al), and aluminum (Al^{3+}). Sum of bases concentrations, cation exchange capacity (CEC), and base saturation (V %) were calculated from the concentrations evaluated.

Environmental covariates

Environmental covariates were generated to help in the discussion of the spatialization of soil and rubber tree clone attributes. They were derived from a digital elevation model (DEM), at a scale of 1:25000 from Project RJ-25, which exhibits a 20 m resolution. The DEM was converted from a raster to a vector format and then interpolated using the Topogrid (Topo to Raster) algorithm of the ArcGis 10.2 software, for a 5 m DEM.

The DEM was adjusted to eliminate spurious depressions (Fill). Level curves were generated, and a contour smoothing routine (Smooth) was also performed, making the DEM more compatible with the 1:25000 scale that produced the DEM. The DEM was generated from vector files of 5 m equidistant levels, adapted from Mendes Júnior et al. (2012).

The following soil attribute maps were generated: DEM, slope, Topographic Wetness Index (TWI) that characterizes areas of surface water saturation and soil water content by combining the slope and catchment area (Beven and Kirkby 1979; Moore et al. 1991), and Total Potential Thermal Insulation (TPI). The maps were generated using the SAGA GIS 2.0.8 software, and all the input models had a 5 m pixel spatial resolution.

Geostatistical analysis

Geostatistical analysis was used to determine the spatial variability of the soil and plant attributes. A sampling grid with a spacing of 20 × 20 m was used to distribute the sampling sites. Twenty samples were collected on the southern side of each of the FX, FDR, RRIM, and CDC clone plantations, while 20, 21, and 23 RRIM, FDR, and FX clone samples, respectively, were collected on the northern side, making a total of 144 samples.

Soil samples were collected between planting lines. The measurements and leaves of the four trees closest to the grid point were collected to evaluate circumference, total height, and nutritional status. The average of the four values obtained for each evaluation was the variable. After the collections, each sampling site was georeferenced using a geodetic GPS Promark 2.

Semivariograms were generated to obtain the spatial structures of chemical attributes of the soil and of growth and nutritional status variables, in which spherical, exponential, and Gaussian mathematical models were tested. Semivariograms were generated using the variogram function. After choosing the appropriate model and adjusting manually (trial and error), the models were adjusted automatically using the fit.variogram function in R software 3.4.0. The spatial dependence was considered strongly spatial if the ratio was ≤ 25 %, moderately spatial between 25 and 75 %, and weakly spatial if it was > 75 % (Cambardella et al. 1994). For the spatialization of the soil and plant variables, the Ordinary Kriging method was used based on the *krige* in the gstat package of the R software 3.4.0.

Validation of predictions

The same points used for calibration were used to evaluate the performance of the predictions. The mean error of prediction (MEP) was calculated using the predicted and observed values and the square root of the mean error (SRME). MEP measures the trend or bias of prediction, while SRME measures the accuracy.

3. Results

Environmental covariates

The DEM covariates and slope exhibited a similar distribution on both sides, with small variations (Figures 1 and 2). However, the TWI (Figura 2A) and TPI (Figura 2B) covariates presented differences between the northern and southern slopes. On the northern side, the TWI indicated a higher flow of water on the landscape surface compared to the southern side. The northern side also showed a higher TPI with an average of 9500 kJ m^{-2}, while the southern side presented an average of 7000 kJ m^{-2}.

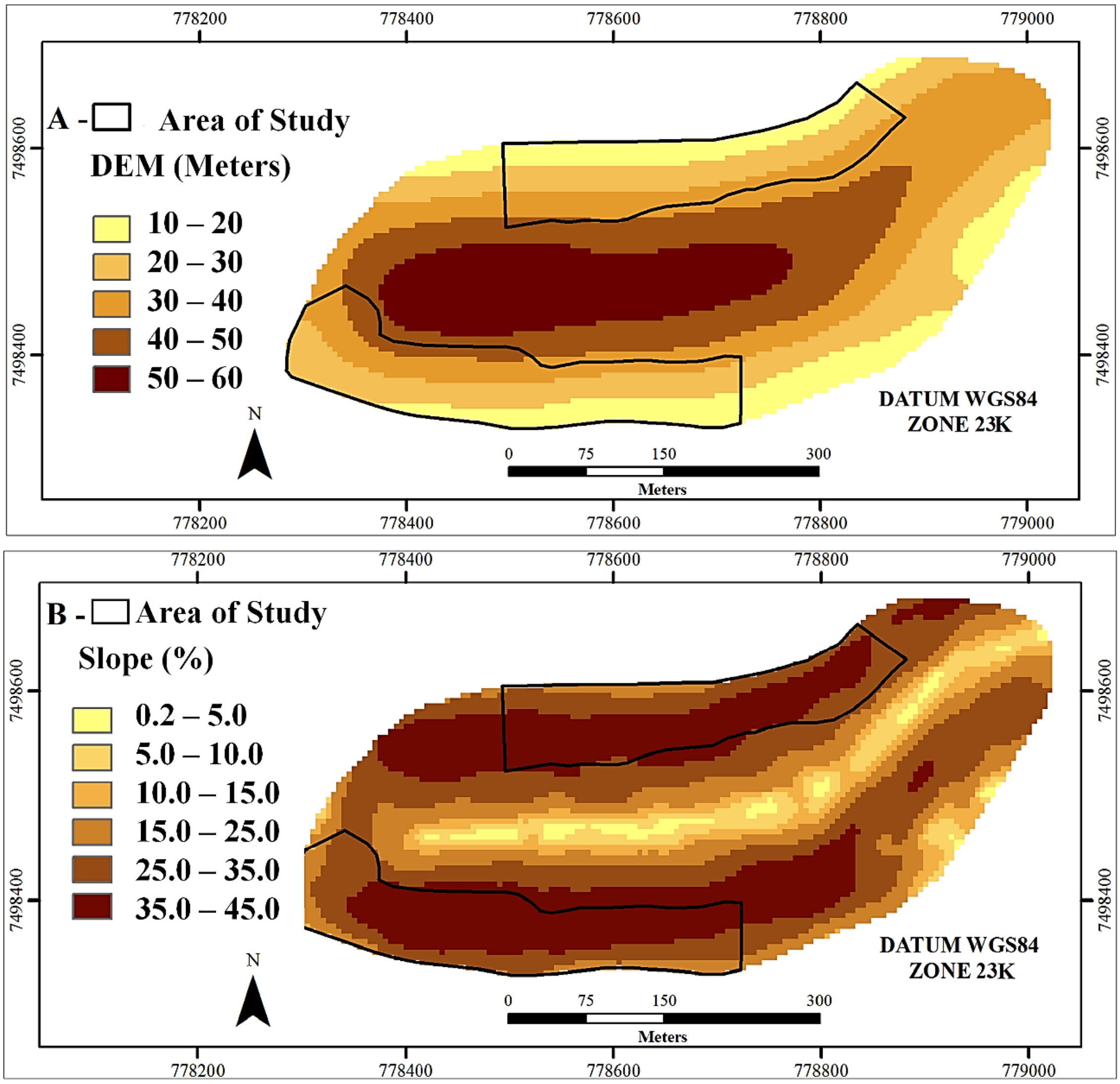

Figure 1. A - Digital Elevation Model and B - slope of Jaturnaíba Farm, Silva Jardim, Rio de Janeiro, Brazil.

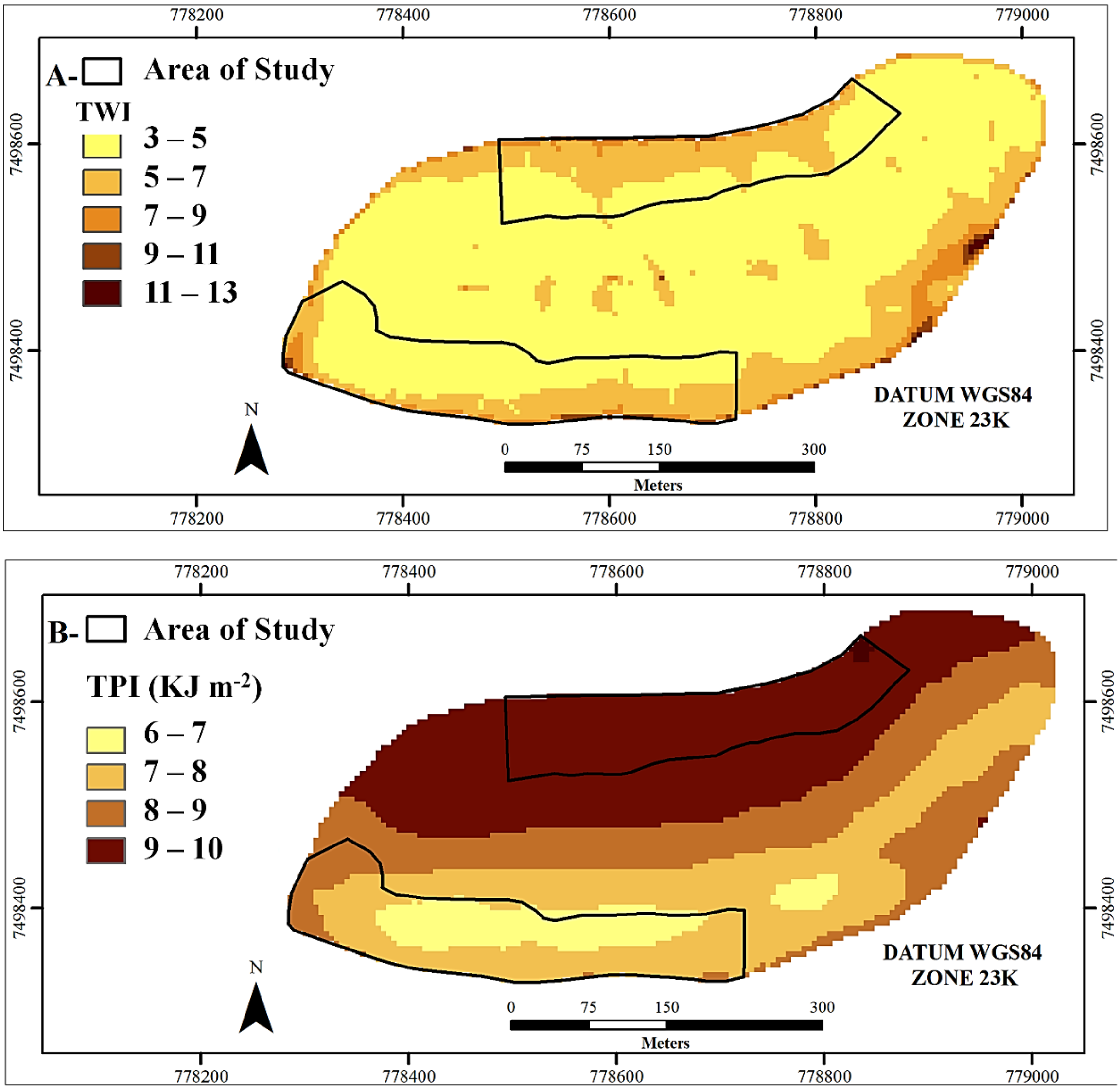

Figure 2. A - Topographic Wetness Index and B - Total Potential Thermal Insulation of Jaturnaíba Farm, Silva Jardim, Rio de Janeiro, Brazil.

Semivariogram

A spatial difference was observed in the soil and plant attributes between the north and south slopes when the parameters of the semivariograms were compared (Table 1). Spatial dependence was not found for the variables soil K^+ and plant N as they showed a pure nugget effect, *i.e.*, no spatial dependence. The spherical and Gaussian models exhibited the best adjustments for the variables.

The range values (a) were high for the evaluated attributes, indicating the effectiveness of the sampling grid in detecting the spatial variation of these variables. Most of the range values were larger than the sampling spacing (20 m). The nugget effect of the chemical attributes of the soil and plants indicated a difference between the northern and southern sides. Only the pH and CEC of the south side were higher or equal to the north side. The other attributes of the south side all presented lower values than the north side.

Spatialization of the chemical attributes of the soil

Once the spatial dependence structure of the variables had been established, the maps with the spatial distribution of the attributes on the two slopes (Figure 3) were constructed, except for K^+ which showed a pure nugget effect.

The FX clone plantation soil presented lower variability and higher levels of Al^{3+} on the south side. The highest levels of Al^{3+} in the soil coincided with the areas of the same clone that had the lowest pH, Ca^{2+}, and Mg^{2+} values. The RRIM and FDR clone plantation soils on the south side showed practically the same Al^{3+} contents and spatial variability. Although the RRIM clone soil had low variability on the north side, it also presented a significant increase in Al^{3+} levels. High variability was observed in the FDR clone soil on the north side, presenting both high and low levels of Al^{3+}. The variability of soil Al^{3+} content for the CDC clone plantation soil was similar to pH, Ca^{2+} and Mg^{2+}, showing a distribution with a banded pattern ranging from low to high values.

The sum of bases (Figure 4B) showed homogeneous variability among the clone plantations on the south side. The FX clone soil showed a lower sum of bases on the south compared to the north side. The soils of the RRIM and FDR clones also showed higher sum of bases values on the south side.

Homogeneity was observed in the spatial variability of the CEC (Figure 4C) for both slopes. The smallest and the highest CECs of the soil were observed on the south side. The FX clone plantation soil exhibited the lowest values on the south side compared to the other clones. The variability in soil V % (Figure 4D) confirmed the difference seen among the chemical attributes between the two slopes. In general, the north side showed a base saturation of up to 20 %, while the south side had V % greater than 30 %. The V % variability in both areas was below 50 % for most of the plantations, except for the CDC clone plantations on the south side and FDR on the north side, which exhibited V % values between 50 and 60 %.

On the south side, the V % variability was similar to Al^{3+}, pH, and sum of bases, strengthening the performance of these attributes in the soil V %. The soils of the RRIM and FDR clones showed a reduction in V % on the north side. Although the V % distribution of the FX clone soils was uniform on both slopes, the south side exhibited the lowest V % values. The CDC clone presented a soil V % distribution similar to pH, Ca^{2+}, Mg^{2+}, and sum of bases, presenting a banded pattern distribution ranging from low to high values.

Table 1. Semivariogram parameters and adjusted models of the soil attributes and rubber trees on the northern and southern slopes at Jaturnaíba Farm, Silva Jardim, Rio de Janeiro, Brazil.

	Attribute	Model	C_0	C	a	GDE	Class
				Northern side			
Soil	pH	Sph	0.01	0.05	47.40	0.20	Strong
	Ca^{2+}	Sph	0.00	0.13	48.30	0.00	Strong
	Mg^{2+}	Sph	0.02	0.20	48.30	0.10	Strong
	P	Gauss	0.39	0.18	78.00	0.68	Moderate
	H+Al	Sph	0.12	1.85	37.90	0.06	Strong
	Al^{3+}	Sph	0.00	0.23	44.50	0.00	Strong
	Sum of bases	Sph	0.27	0.35	48.30	0.44	Moderate
	CEC	Sph	1.00	0.34	36.90	0.75	Weak
	V %	Exp	0.00	270.30	20.60	0.00	Strong
Plant	P	Sph	0.00	1.55	63.00	0.28	Strong
	K	Sph	0.80	0.75	90.00	0.52	Moderate
	Ca	Gauss	2.43	11.50	43.00	0.17	Strong
	Mg	Sph	0.09	4.76	27.50	0.02	Strong
	Circumference	Sph	8.30	17.30	73.00	0.32	Moderate
	Height	Sph	0.16	0.43	99.80	0.27	Moderate
				Southern side			
Soil	pH	Gauss	0.05	0.12	140.00	0.30	Moderate
	Ca^{2+}	Gauss	0.18	0.52	170.00	0.26	Moderate
	Mg^{2+}	Gauss	0.13	0.10	90.00	0.57	Moderate
	P	Sph	0.20	0.10	50.00	0.66	Moderate
	H+Al	Sph	1.00	0.55	70.00	0.65	Moderate
	Al^{3+}	Gauss	0.10	0.31	128.00	0.24	Strong
	Sum of bases	Gauss	0.50	0.89	128.00	0.36	Moderate
	CEC	Sph	1.00	0.28	35.80	0.78	Weak
	V %	Sph	98.00	170.00	166.00	0.36	Moderate
Plant	P	Gauss	0.60	0.26	120.00	0.70	Moderate
	K	Sph	0.33	0.94	17.00	0.26	Strong
	Ca	Gauss	20.00	15.00	60.00	0.57	Moderate
	Mg	Gauss	3.80	3.80	50.00	0.50	Moderate
	Circumference	Sph	0.50	37.60	66.80	0.01	Strong
	Height	Sph	0.01	0.79	66.40	0.01	Strong

C_0 = nugget effect; C = contribution; a = range (m); GDE = degree of spatial dependence; Sph = spherical; Gauss = Gaussian; Exp = exponential.

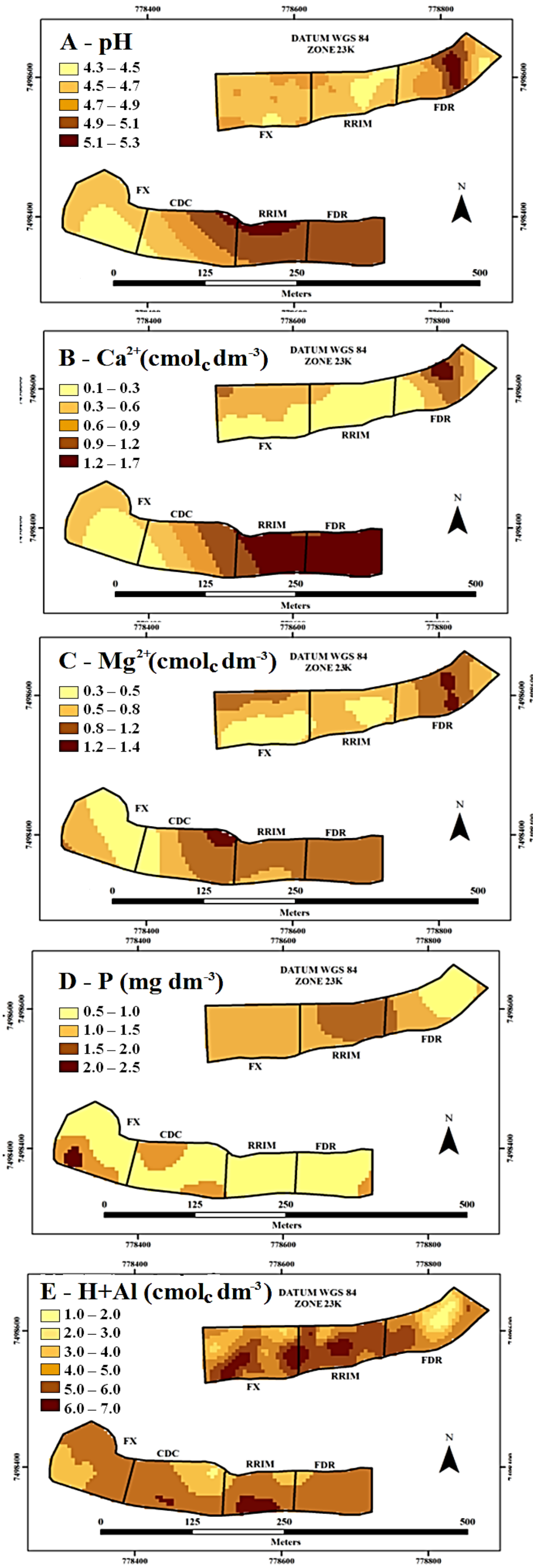

Figure 3. A - Spatial variability of pH, B - calcium, C - magnesium, D - phosphorus, and E - H+Al of the rubber tree clone soils on the northern and southern slopes at Jaturnaíba Farm, Silva Jardim, Rio de Janeiro, Brazil.

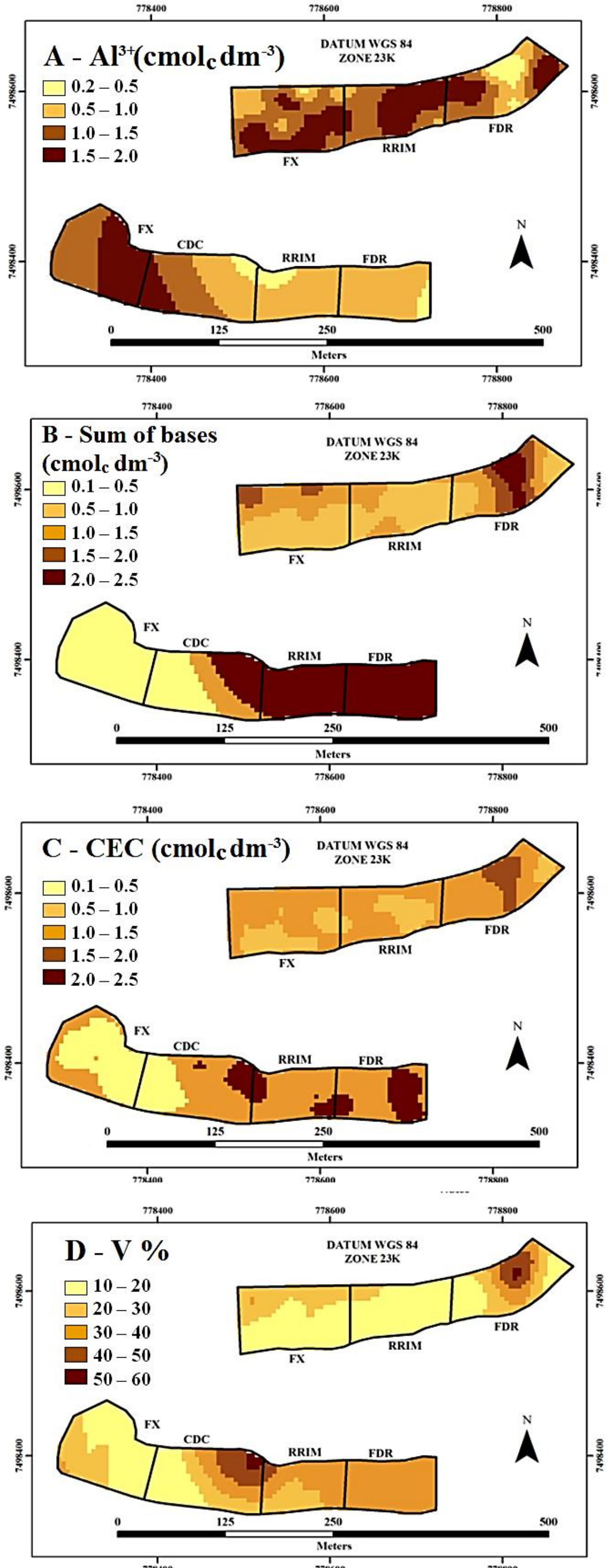

Figure 4. A - Spatial variability of Al^{3+}, B - sum of bases, C - cation exchange capacity - CEC, and D - base saturation - V % of the rubber tree clone soils on the northern and southern slopes at Jaturnaíba Farm, Silva Jardim, Rio de Janeiro, Brazil.

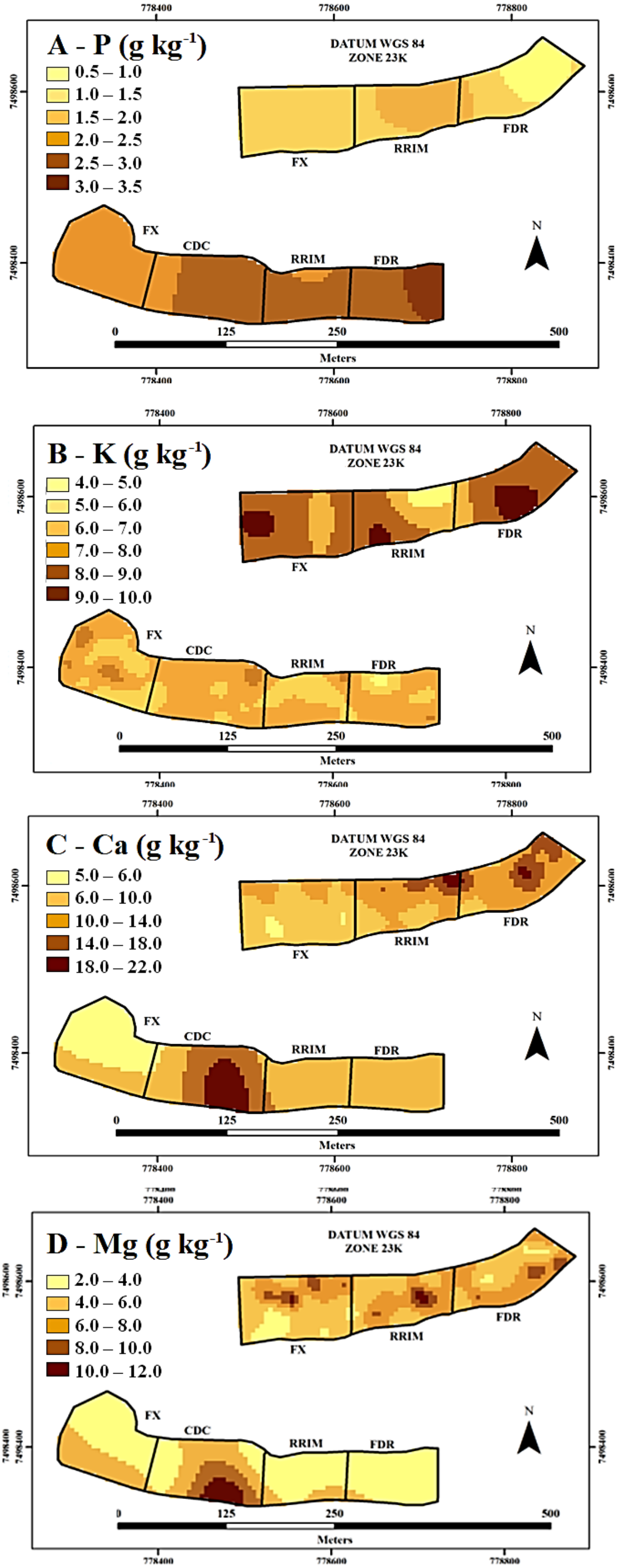

Figure 5. A - Spatial variability of P, B - K, C - Ca, and D - Mg in the rubber trees on the northern and southern slopes at local of study, Silva Jardim, Rio de Janeiro, Brazil.

Spatialization of the rubber tree clone attributes

The maps were constructed with the spatial distribution of nutrient contents in leaves and plant growth, circumference, and height on both slopes (Figures 5 and 6), except for N, which showed no spatial dependence. The P levels (Figure 5A) in the leaves of the rubber tree clones presented a homogeneous spatial distribution on both sides. Although the FX clone on both slopes showed no variability in leaf P content, leaf P levels were higher on the south side. The RRIM and FDR clones presented greater variability on both slopes compared to the FX clone. Higher P levels were also recorded for the southern side.

The levels of K (Figure 5B) also presented variability in the study area. The levels were higher in the FX, RRIM, and FDR clones on the north compared to the south side. The clones located on the north side of the planting area presented leaf Ca content (Figure 5C) greater than the south slope. The FX clone plants showed Ca deficiency only on the south slope, likely resulting from a low Ca^{2+} concentration in the FX clone soil (Figure 3B).

The Mg contents (Figure 5D) in the leaves of the rubber trees showed greater variability on the north side compared to the distribution of the other nutrients. On the south side, a higher homogeneity and a similar distribution in Mg contents were observed compared to the soil Mg^{2+} (Figure 3C).

The spatial variability of the plant circumference (Figure 6A) differed between the slopes in the study area. The north side had a more uniform distribution, while the clones on south side presented a more discontinuous variability in circumference. The FX clone exhibited the widest and most homogenous circumference among the clones planted in the area, presenting values between 40 and 50 cm. A percentage of the CDC clone area also had plants with circumferences above 40 cm. The RRIM clone on the north side showed a significant increase in plant circumference compared to the south side. The FDR clone plants on both slopes showed a heterogeneous distribution, with both low and high circumference values.

Plants with heights between 6 and 8 meters predominated on the north slope (Figure 6B), except for the FX clone, which exhibited heights ranging from 8 to 9 m in a small area. The southern side showed greater variability in plant height, with clones FX and CDC exhibiting the greatest heights. The RRIM and FDR clones showed reduced plant height and circumference on the southern slope, with the FX and CDC clones showing the greatest values.

4. Discussion

Environmental covariates

The higher flow of water (TWI) on the landscape surface on northern side contributed to soil particle runoff and nutrient loss. The higher TPI rates in the northern side indicating that there is greater insolation on the north side throughout the year. A greater degradation had been observed on the north side before the rubber trees were planted in the area, with moderate to strong *in loco* furrow erosion, supporting the observed results.

The study area has a convex microrelief and some of the water is transported to the flatter regions, which may cause variations in soil attributes. The flow of water is related to the slope and curvature of the area, which causes erosion and deposition (Nizeyimana and Bicki 1992). The higher insolation on northern side may have also contributed to the difference between the two slopes, increasing temperatures in this region throughout the year and favoring a high rate of organic matter decomposition, which is a source of nutrients in the soil.

Semivariogram

The spherical and Gaussian models also presented the best adjustment in the studies of Vieira et al. (2012) and Pelissari, Caldeira and Santos (2014), describing that they are the most well-adjusted for soil and plant variables. Silva et al. (2016) evaluated the spatialization of chemical and physical attributes of the soil at Seropédica, Rio de Janeiro, Brazil in an AFS and adjusted the exponential model for the pH, H+Al, Ca^{2+}, Al^{3+} and P soil variables, the Gaussian model for the CEC; the Mg^{2+} and V % attributes were spatially independent.

According to the same authors, the pH, H+Al, Ca^{2+}, Al^{3+}, and P soil attributes exhibited moderate spatial dependence, whereas in this study soil pH, H+Al, Ca^{2+}, Al^{3+}, and P showed a high degree of spatial dependence, with the exception of the T value which exhibited a weak spatial dependence.

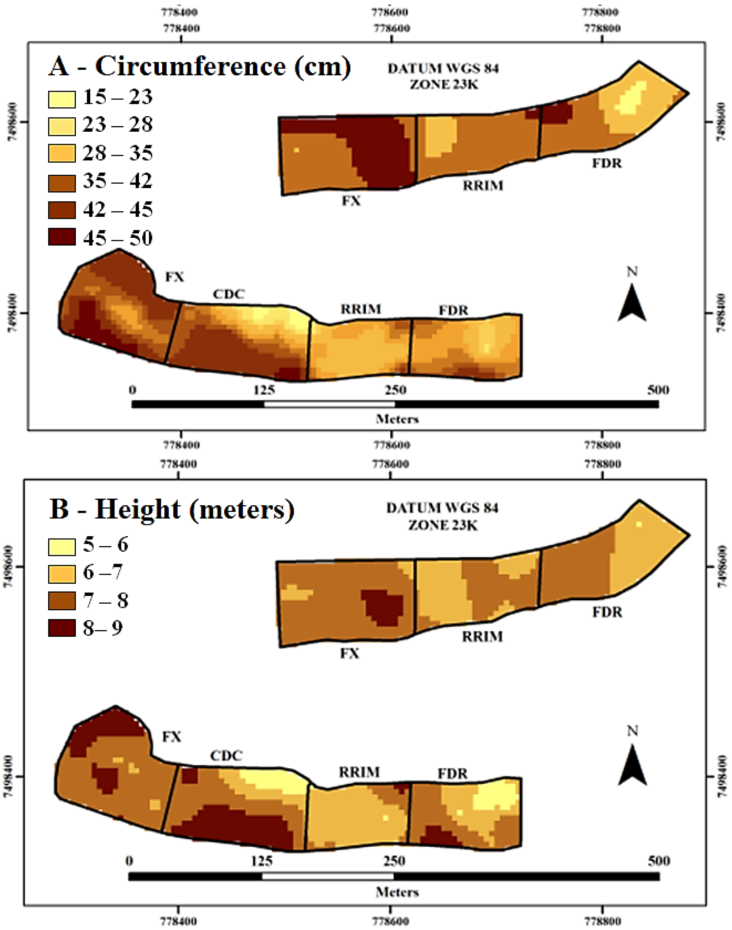

Figure 6. A - Spatial variability of circumference B - and height in the rubber trees on the northern and southern slopes at local of study, Silva Jardim, Rio de Janeiro, Brazil.

The range values larger than the sampling spacing indicate that there is a soil and plant attributes were correlated, enabling interpolations (Oliveira et al. 2013). Based on these values, spatial variation could also be observed between the chemical attributes in each slope. The north side may have reduced the range, characterizing a less continuous distribution of the variables due to the higher percentage of degradation resulting from the erosive processes.

Cavalcante et al. (2007) evaluated the variability of the chemical attributes of the soil under different soil uses and management practices and found that management systems that minimize soil mixing and native vegetation areas (Cerrado) presented a lower nugget effect and greater range in comparison to the conventional tillage system. These results reinforce the better soil conservation on the southern side, which is due to a lower state of degradation.

Spatialization of the chemical attributes of the soil

Motomiya et al. (2011) evaluated the spatial dependence of the chemical attributes of the soil in a cotton crop area in the Cerrado biome and did not observe a spatial dependence for K^{+}, similar results with found in the present study. Silva et al. (2016) evaluated the spatial variability of the chemical and physical attributes of the soil in an agroforestry system and found that Mg^{2+} and V % exhibited a pure nugget effect. The authors reported that the sample spacing may have influenced the results since the distance may have been overestimated, contributing to the lack of spatial dependence. These results show that the level of spatial dependence of the soil attributes may vary according to location and management practices.

The higher soil acidity in the FX clone area is due to the greater extraction of nutrients by this clone, especially Ca^{2+} and Mg^{2+}, that reduced the soil concentration of basic cations. The greater state of degradation may have contributed to the high pH values on the north side. The reduced pH in a section of the FX clone soil on the south side may also indicate that this clone requires better soil conditions (e.g., organic matter content, aeration, and porosity) for improved nutrient extraction from the soil and subsequent plant growth. Vieira et al. (2010) evaluated the spatial distribution of rubber tree development and recorded a strong correlation between soil density and plant circumference, such that, in general, less dense areas exhibited rubber tree trunks with a larger circumference.

The observed reduction of the pH in the north side can be indicating the greater state of degradation of this side. In the soil of the CDC clone on the south slope the low to high pH range may be associated with the heterogeneous application of liming in the area. The higher water flow in the RRIM clone plantation on the north side may contribute to the reduction in soil Ca^{2+} content, being influenced by the higher degradation observed on this slope.

The larger water flow and the higher levels of Ca^{2+} e Mg^{2+} in the lower third indicate that water flow in the terrain may be transporting these nutrients to lower regions. Artur et al. (2014) evaluated the influence of the terrain on the variability of the chemical attributes of the soil and reported a reduction in Ca^{2+} and Mg^{2+} contents in the convex microrelief, and an increase in concave and flat areas. The authors attributed this variation to the water flow in the pedoform, which resulted in spatial variability in Ca^{2+} and Mg^{2+} contents. The reduction of Ca^{2+} and Mg^{2+} levels in the study area may also be due to the uptake of these nutrients by plants during growth. Pelissari et al. (2014) evaluated the spatial variability of the chemical attributes of the soil in 2- and 9-year-old *Tectona grandis* plantations and recorded a reduction in soil Ca^{2+} and Mg^{2+} throughout crop development.

The relationship between pH and the reduction in soil P indicates that soil pH must be adjusted to allow greater P availability for the rubber tress. Santos et al. (2015) studied the influence of the chemical attributes of the soil on rubber tree growth in Espírito Santo and found a positive correlation between soil P levels and an increase in plant circumference and height.

The variability observed to the Al^{3+} distribution can be indicating from irregular liming in the study area. The lower sum of bases of the FX clone on the south side may be associated with a higher uptake of nutrients on this side. However, RRIM and FDR clones on the south side have had greater availability of nutrients, likely due to the better conservation status of the soil on that slope. The RRIM and FDR clones both showed a reduced nutrient-extraction capacity than the FX clone.

The CDC clone on the south side and FDR on the north side exhibited V % values between 50 and 60 %, and according to Roque et al. (2005), rubber tree plantations with soil V % around 50 to 60 % exhibited a greater annual increase in trunk circumference. In the FX clone area exhibited lowest V % values on the south side indicating that this clone has a greater soil nutrient extraction capacity. The heterogeneity in the V % distribution under the CDC clone indicates irregular liming in the region.

The spatialization maps of the chemical attributes of the soil showed a good adjustment in predicting the variables on both the northern and southern sides. There was a relationship between attribute distribution, such that areas with high pH also presented the highest sum of bases, V %, Ca^{2+}, and Mg^{2+} contents along with reduced Al^{3+} contents. According to Sousa et al. (2007), a reduction in pH occurs with increasing Al^{3+} present in soil solutions through the release of the source material, nutrient uptake by the crops, and/or the leaching of basic cations. According to the same authors, the application of correctives such as liming can reduce Al^{3+} and provide Ca^{2+} and Mg^{2+}, increasing the sum of bases and V % and thus improving the availability of some nutrients for plants and the activity of microorganisms.

The northern side was in a state of higher degradation compared to the southern slope, with a greater presence and evolution of laminar erosion and furrows, leading to greater runoff and degradation of the superficial soil horizons. Removing the superficial layer reduces soil fertility, which may explain the differences in the concentrations and distribution of the attributes between the two slopes. The south slope was less degraded and therefore presented a higher nutrient content and more homogeneous variability, providing better soil quality.

Spatialization of the rubber tree clone attributes

The absence of spatial dependence of variable N, according to Cambardella et al. (1994) and Silva et al. (2016), may be due to sampling error that can be influenced by the spacing adopted in the sample collection. The clones planted on the south side had P levels above the levels considered adequate, based on the reference levels of nutrient contents in the leaves, for the diagnosis of the nutritional status of the rubber tree elaborated by Malavolta et al. (1997) (reference values ranging from 1.6 to 2.3 g kg^{-1}). The clones on the north side presented reduced leaf P levels, with a band below the reference levels for the culture. These P levels above the levels considered adequate that were observed for the south side indicate that phosphate fertilization is not necessary in this area; moreover, these high values may cause a nutritional imbalance, impairing plant metabolism and affecting plant growth and production.

The reference values of K established by Malavolta et al. (1997) for the culture of rubber trees are between 10 and 14 g kg^{-1} and all the plants on the south side, as well as most on the north side, recorded K content below the ideal for the culture, likely affecting latex production and making K fertilization necessary in these areas. Bataglia et al. (1988) evaluated the nutritional status of 40 rubber trees in several regions of the state of São Paulo and observed that the rubber tree plantations (*seringais*) with higher yields also exhibited higher levels of K in the leaves.

The clones located on the north side of the planting area presented values higher Ca content than those established by Malavolta et al. (1997) (7.6 to 8.2 g kg^{-1}). The low concentration of Ca in the plant reveals that the soil application of Ca^{2+} is not enough to nourish the clone to suitable levels. No Mg deficiency was observed in the area, with all the clones showing levels close to, or above, the ideal 1.7 to 2.4 g kg^{-1} range (Malavolta et al. 1997). The FX, RRIM, and FDR clones on the south side presented Mg contents closer to the ideal value for culture, indicating a better nutritional balance. The Mg contents on the north side were higher than the reference values, which may result in a nutritional imbalance and impair plant growth and productivity.

Overall, the FX clone had greater circumference growth on both slopes, followed by the CDC clone on the southern side. The wider circumferences of these two clones indicate greater fitness for latex exploration in a shorter period after the implantation of the settlement. In addition, the presence of areas with a more homogeneous distribution of the circumference indicates that a larger number of trees are suitable for simultaneous exploitation, reducing the time spent in collecting the latex, as the producer would not have to travel long distances to find the trees that are already producing.

According to Vieira et al. (2012), this scenario is important because a larger number of plants with larger diameters have greater prospects for latex exploration. Roque et al. (2006) mapped the productivity and trunk circumferences of rubber tree clones in a Red-Yellow Argisol and concluded that circumference influenced the productivity; in addition, the spatial variability of productivity was also related to the trunk circumference. In contrast, Virgens Filho (2007) reported that a wider circumference does not result in higher latex production, which would instead be related to clone interactions and edaphoclimatic conditions.

The greatest heights in clones FX and CDC may be due to these clones showing a higher nutrient uptake in the study area, corroborating the lower sum of base contents, CEC, and even lower V %. Therefore, this greater interaction with edaphic aspects may have resulted in increased development of these clones.

Comparison of the plant growth maps on both sides (Figure 3) with the chemical attributes of the soil (Figure 2), although study area is small, indicated that growth maps are more homogeneous in variability than the chemical attributes. Vieira et al. (2012) evaluated the spatial variability of growth characteristics and soil attributes of the rubber tree and reported that plant-related attributes presented greater homogeneity than soil attributes, corroborating the results found in this study; the authors suggested that this occurred because the spatial variability of growth characteristics resulted from the interaction of several factors (edaphic, plant and atmosphere), while soil attributes (physical, chemical, and biological) are more susceptible to the type of management practiced.

5. Conclusions

The chemical attributes of the soil presented spatial variability in the study area and this variability, probably, influenced the nutritional status, distribution, and growth of the rubber tree clones. Therefore, geostatistics may be suitable as a guide for the planting and management of the rubber tree, providing subsidies for more efficient management. The FX and CDC clones presented increased growth in circumference and height in the study area, with broader interactions with the soil conditions of the area. Therefore, using these clones in the study area and in sites with similar soil and edaphoclimatic characteristics is recommended.

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