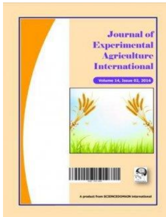

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Spatial Distribution of Rubber Tree Dendrometrics Variables and Soil Chemical Attributes

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Authors' contributions

This work was carried out in collaboration between all authors. Authors JSSL and MSA did the data acquisition, data analysis, writing and editing. Authors AAS and SAS managed the analyses of the study. All authors read and approved the final manuscript.

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ABSTRACT

To know the relations between the developments of the crops and the chemical attributes of the auxiliary soil in their management. This work aimed to examine the spatial and temporal variability of rubber tree dendrometric parameters (Fx 3864 clone) and soil chemical attributes P (phosphorus) and K (potassium) levels. Diameter at breast height (DBH), height (HGT) and volume (VOL) of 200 trees were measured at three different periods. A total of 60.0 soil samples was also randomly collected from soil layers 0.0 – 0.20 m and 0.20 – 0.40 m depth. Data were submitted to descriptive statistics, correlation analysis and geostatistics. The rubber tree height measured at the first and second periods correlated significantly with the P and K levels from the 0 – 0.20 m layer and with the P level from the 0.20 – 0.40 m layer. For the third measuring period, the rubber tree parameters correlated significantly with the K level from the 0 – 0.20 m layer. Dendrometric variables of rubber trees exhibit strong spatial dependence at the early tree growth stage.

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Keywords: Spatial variability; semivariograms; precision forestry.

1. INTRODUCTION

Rubber tree (*Hevea brasiliensis* L.) is a plant native to the Amazonia region when cultivation in tropical zones has attracted much interest due to the high rubber productivity obtained from improved clones and efficient crop management [1]. The use of clones for developing a rubber tree plantation has shown to be advantageous, specifically due to the physiological uniformity among trees. According to [2], a clone is a group of plants obtained by vegetative propagation from a same matrix plant. Consequently, all rubber trees obtained from the same clone exhibit identical genetic structure, which is responsible for their homogeneity and low variability under similar environmental conditions.

Numerous works have evaluated the performance of rubber tree clones, for instance, [3,4,2,5,6]. Other authors have also examined the spatial variability of rubber tree dendrometric parameters and latex productivity, as well as the chemical and physical properties of soils [1,7] and [8]. [9] state that the growth of forest species is correlated with slope faces of cultivated areas and there is variability of soil fertility among genotypes.

Researches on spatial distribution of rubber tree dendrometric parameters and their dependence on soil properties have been essential for understanding the relationships among these variables [8]. [10] stated that spatial distribution maps of soil properties reveal the large environmental variability found by plants during their growth. [11] reported that soil fertility is determining on the productivity of agricultural crops, and that its spatial distribution influences significantly the average crop yield in a cultivation area.

The spatial and temporal analysis of the dendrometric parameters of the rubber tree in the initial phase of growth allows to estimate the parameters for trees in non-sampled sites and determine their correlations with the soil chemical attributes. The results are presented in crop growth maps in different stages of measurements, aiding in the rational management of fertilization, less impact on the environment and aiming for a higher production of latex in the extraction phase

This study aimed of this work was to analyze the spatial and temporal variability of the dendrometric parameters of the rubber tree (clone Fx 3864) (height, diameter and volume) at the initial plant growth stage and its relation with the chemical attributes phosphorus (P) and potassium (K) of a Oxisol.

2. MATERIALS AND METHODS

2.1 Location and Management Area

This work was carried out in Nova Venécia – ES. According to Köppen, the region climate is classified as Am hot tropical, with elevated temperatures from November to March. The average annual rainfall is between 1400 – 2200 mm while the average temperature is 24 – 26°C.

The area under investigation comprised a Oxisol with clay texture. The size fractions at the layers 0 – 0.20 m and 0.20 – 0.40 m depth were: clay 47.6 and 49.6 dag kg^{-1}, silt 12.5 and 11.9 dag kg^{-1}, fine sand 28.9 and 27.9 dag kg^{-1}, and rough sand 10.7 and 10.6 dag kg^{-1}, respectively.

The area at 65 meters altitude level had been cultivated with *Brachiaria brizantha*, and was mowed mechanically 40 days before tillage with a three rod-equipped subsoiler, which was coupled to the three-point hydraulic system of a utility tractor. The depth of work was 0.50 m with distanced passes in 7.0 meters. Soil furrowing was performed after subsoiling to define the lines for transplanting the Fx 3864 clone seedlings. The seedlings were transplanted in manually dug cavities 0.30 depth and 0.15 width, at spacing 7x3 m, in January 2013.

The transplanted seedlings were fertilized using the formulation 20-00-20 (0.05 kg) with addition of 5 L water per pit at intervals of 30 days until completing one year. In addition ammonium sulfate (0.01 kg) was applied to the soil around the cavities at 10, 30 and 60 days after transplant. During the first two months, water was added (5 L) to each plant twice per week. Once completed one year of seedling transplant, 0.10 kg of formulation 20-00-20 were added to the soil at every 60 days.

2.2 Analyzed Parameters

A systematic sampling grid (200 sampling spots at spacing of 7x6 m) was built in the area comprising a flat topography for measuring the dendrometric parameters of rubber trees at age 14 months. Each sampling spot corresponded to one rubber tree. Soil samples were collected from the layers 0 – 0.20 m and 0.20 – 0.40 m depth at a distance of 0.50 m from each tree on line, totaling 60 spots over the area with a simple random distribution after 18 months of transplant. The macronutrient phosphorus (P) and potassium (K) were used to characterize the soil fertility.

The dendrometric parameters diameter at breast height (DBH) and height (HGT) were collected in March/2014, August/2014 and January/2015 for each of the 200 rubber trees. DBH was determined with a measuring tape in mm at 1.30 m from the ground. The tree crown height was determined with a graduated scale in cm, which was positioned next to the tree trunk.

Rubber tree volume (VOL - m^3) was determined by equation 1, according to [5]:

$$\mathrm{VOL} = \frac{\pi * \mathrm{DBH}^2}{4} * \mathrm{HGT} * f \quad (1)$$

Where DBH is the diameter at breast high; HGT is the tree canopy height; and *f* is the form factor assumed to be 0.7 for rubber trees.

2.3 Exploratory Data Analysis

Before the geostatistical analysis the dendrometric and soil chemical data (P and K) were tested to see the influence of outliers on position and dispersion measuremen. Data normality was evaluated using the Kolmogorov-Smirnov test ($p \leq 0.05$). Correlations between rubber tree dendrometric parameters and soil chemical attributes (P and K) were determined by Pearson correlation ($p \leq 0.05$) and t-test ($p \leq 0.05$) was used to compare the mean values of the soil chemical attributes (P and K) from both layers.

The dendrometric parameters were transformed into [z(t)] using equation 2, varying from 0 to 1 for standardizing the maps into an equivalent scale. This mathematical procedure aimed to facilitate the visualization of region comprising the highest and lowest values in the different measuring periods.

$$\mathrm{z(t)} = \frac{\mathrm{xi} - \mathrm{Min}}{\mathrm{Max} - \mathrm{Min}} \quad (2)$$

where x_i is the experimental value; Min and Max are the minimum and maximum values respectively.

2.4 Geostatistical Analysis

Geostatistical analysis was used to identify and quantify the spatial dependence degree of the parameters under study. This analysis was conducted by fitting theoretical functions to the experimental semivariogram models, based on the assumption of stationarity of the intrinsic hypothesis, according to equation 3.

$$\gamma(h) = \frac{1}{2\mathrm{N}} * \sum_{\mathrm{i=1}}^{\mathrm{N(h)}} [\mathrm{Z(xi)} - \mathrm{Z(xi + h)}]^2 \quad (3)$$

where N(h) is the pairs number of the experimental values Z(xi) and Z(xi+h) separated by a distance vector h (m). Initially, the parameters under study were submitted to trend analysis using the X- and Y-axes by means of regression equation to the quadratic level and involving all interactions between these axes, as described by [12].

Theoretical models (Spherical, Gaussian and Exponential) were tested for adjusting the semivariogram scaled by the data variance. The following parameters were defined: nugget effect (C_0), still (C_0 + C), structural variance (C), spatial dependence range (*a*), and spatial dependence degree (SDD). The SDD, equation 4, was classified into low (SDD > 75%), medium (25% < SDD < 75%) and high (SDD < 25%) according to [13].

$$SDD = \left(\frac{C_0}{C_0 + C}\right) * 100 \quad (4)$$

where C_0 is the nugget effect and C_0+C is the sill in which the semivariogram is stabilized.

The most appropriate semivariogram theoretical model was selected through cross-validation analysis with significant correlation (CR) between the experimental and predicted data, as reported by [12]. Once proved their spatial dependence, the transformed dendrometric parameters and the soil chemical properties (P and K) were estimated for non-samples regions. Thematic maps were then constructed using the ordinary kriging interpolation technique.

3. RESULTS AND DISCUSSION

3.1 Statistical Analysis

Descriptive analyses of the rubber tree (Fx 3864 clone) dendrometrics parameters measured at three different periods and the soil chemical variables (P and K) from the layers 0 – 0.20 m (layer 1) and 0.20 – 0.40 m (layer 2) depth are presented in Table 1.

Although presenting similar mean and median values, the variables DBH1, DBH2, DBH3 and VOL3 were not normally distributed according to the Kolmogorov-Smirnov test ($p \leq 0.05$). An asymmetric distribution is observed for all variables with accumulation of data below the mean value, except for HGT1, HGT2, K1 and K2. In relation to kurtosis, VOL1, VOL2 and P2 displayed positive kurtosis coefficients (Kc), while the other variable presented negative Kc, suggesting dispersion with respect to the mean value.

The most frequent HGT were 3.82 m, 4.18 m and 5.00 m for the measurements 1, 2 and 3, respectively. Considering mean values, the DBH2 to DBH1 ratio was 1.32:1, while the DBH3 to DBH2 ratio was 1.26:1. According to [1], the larger the DBH, the higher the rubber yield in the production stage. The mean VOL3 of the rubber tree Fx 3864 clones with age 22 months was 2.8×10^{-3} m^3. [5] reported a mean volume of $4,5 \times 10^{-3}$ m^3 for 23-month aged rubber trees (RRIM 600 clone) cultivated in doubled lines at spacing 6x2.5 m and intercalated with cedar and mahogany in an agroforest system in the Northwest region of Sao Paulo.

This difference in rubber tree volume may be explained by the genetic structure of the clones, crop management techniques and edaphoclimatic conditions of each experimental area. [14] studied models for predicting the biomass volume of rubber trees all ages and concluded the models are more appropriate for the estimation of biomass at the regional level than for individual trees, due to the variability presente.

The mean VOL values increased from the first to the third measuring period, and consequently, CV was observed to decrease gradually. This behavior was also found by [7] for the PB 235 rubber tree cultivar whose trunk girth was monitored over 7 years. This indicates that the VOL variability in rubber tree clones reduces over time.

The mean P12 values (P from the layers 1 and 2) were below 20 mg dm^{-3}, which is the minimum P level recommended for rubber trees by [15]. These values suggest technical failure in implementing the rubber tree crop, once P was not added to the soil before he third measuring period, i.e., at the initial growth stage of the rubber trees. The mean K12 values (K from the layers 1 and 2) are in accordance with specifications.

According to t-test, the mean P value of the layers 1 and 2 were statistically different, being higher at the layer 1 (0 – 0.20 m depth). However, there was no statistical difference in K values with respect to the soil layer. It is worth mentioning that high nutrient concentrations were expected in the soil located at the transplanting lines of the clonal rubber trees seedlings due to the mechanical process used to prepare the soil and the addition of fertilizers during the first year of cultivation. This result shows that the soil layer is an important factor for spatial dependence studies.

The coefficient of variation (CV) was used to evaluate the variability of the data. According to the criterion proposed by [16], the CVs were classified as follows: medium (10% <CV≤ 20%) for DBH1, DBH2, HGT3, DBH3, K1 and K2; high (20% <CV≤ 30%) for HGT1 and HGT2 and very high (CV> 30%) for VOL1, VOL2, VOL3, P1 and P2. The very high CV for P may be ascribed to the inefficient fertilization procedure and the low P mobility in soil. Concerning VOL, this parameter is influenced by the variability of DBH and HGT. [8] reported CV values for rubber tree dendrometric parameters (DBH and HGT) ranging from 10% to 20%.

The parameters P12 and K12 (layers 1 and 2) presented very high variability and mean values, respectively. The variability in K is dependent on the fertilization procedure, which tends to homogenize the distribution of K in soil, thereby influencing the CV and also the high K mobility. [1] found the largest CV for P from layer 1 CVs (46.3% and 65.0%) and K (36.5% and 27.4%), whereas the lowest CV was observed for pH (4.4% and 6.7%), respectively, for cultivation of the rubber tree clones PB 235 and RRIM 600.

Table 1. Descriptive analysis of rubber tree dendrometric parameters measured at three periods and soil chemical attributes (P and K)

	M	Md	Min	Max	Q1	Q3	S	Ks	Kc	CV(%)
Dendrometrics variables (1, 2 e 3 = measurements)										
HGT1(m)*	2.59	2.63	1.37	3.82	2.33	2.96	0.53	-0.33	-0.21	20.3
DBH1(cm)	2.11	2.23	1.27	3.18	1.91	2.23	0.37	0.32	-0.26	17.6
VOL1 (m^3)*	6.7E-4	6.13E-4	1.74E-4	1.74E-3	4.3E-4	8.4E-4	3.1E-4	0.90	0.56	46.3
HGT 2 (m)*	2.82	2.85	1.31	4.18	2.50	3.18	0.57	-0.12	-0.13	20.3
DBH 2 (cm)	2.78	2.86	1.91	3.82	2.55	3.18	0.39	0.02	-0.23	14.1
VOL2 (m^3)*	1.26E-3	1.15E-3	2.6E-4	3.37E-3	8.9E-4	1.62E-3	5.5E-4	0.77	0.48	43.4
HGT 3(m)*	3.94	3.90	2.60	5.00	3.50	4.34	0.63	0.14	-0.79	16.0
DBH3 (cm)	3.50	3.50	2.23	4.77	3.18	3.82	0.53	0.11	-0.61	15.0
VOL3(m3)	2.80E-3	2.57E-3	8.9E-4	6.2E-3	1.84E-3	3.49E-3	1.19E-3	0.71	-0.24	42.5
Chemical attributes (1 e 2 = soil layer)										
P1 ($mgdm^{-3}$)*	9.4a	8.5	4.0	18.1	5.6	12.0	4.12	0.63	-0.80	43.8
P2 ($mgdm^{-3}$)*	6.1b	5.1	1.7	14.8	3.1	8.2	3.67	0.99	0.04	59.7
K1 (mg dm^{-3})*	88.2a	92.0	57.0	117.0	81.0	97.0	15.34	-0.55	-0.12	17.4
K2 (mg dm^{-3})*	85.0a	85.7	59.0	104.0	79.0	91.5	11.36	-0.18	-0.22	13.4

*1: measured in March/2014; 2: measured in August/2014 and 3: measured in January/2015; M: mean value; Md: median; Min: minimum value; Max: maximum value; Q1: first quartile; Q3: third quartile; S: standard deviation; Ks: asymmetry coefficient; Kc: kurtosis coefficient; CV: coefficient of variation and * normal distribution by the Kolmogorov-Smirnov test ($p \leq 0.05$)*

The variability of any soil chemical attribute is related to the intrinsic (texture and mineralogy, for example) and extrinsic (cultivation and fertilization) properties of the soil, and thus is dependent on the soil management. In the present case, the fertilizer was added to the cavities during the seedlings transplant step and around the trees every 30 days. [17] and [18] reported that the development of the plant root system is accelerated when the soil quality attributes required for each crop are attained by the soil preparation method.

Histograms of breast height diameter (DBH) for the Fx 3864 rubber tree clones cultivated for 14, 19 and 22 months are shown in Fig. 1. [5] reported that the latex extraction can be initiated when 75% of the rubber trees after 23-month cultivation have their DBH falling into the largest diameter class. This percentage is a favorable indicative for obtaining the highest rubber yields due to direct relationship between rubber tree diameter and latex yield. As shown in Fig. 1, this behavior was not observed here, once the trees whose DBH is within the range 3.32 – 4.77 cm encompass only 60% of the total number of rubber trees.

The Pearson correlations ($p \leq 0,05$) between the rubber tree dendrometrics variables and the soil chemical attributes (P and K) were low, between 20% and 40%, but statistically significant: HGT1-HGT2xP1 (r = 31%), HGT1-HGT2xK1 (r = 33%), HGT2xP2 (r = 28%), HGT3xK1 (r = 37%), HGT3xP2 (r = 27%), DBH2-VOL2xP1 (r = 34%) and DBH3-VOL3xK1 (38%). It can be verified the same correlation value between HGT1 and HGT2 with P1 (31%) and with K1 (33%), between DBH2 and VOL2 and P1 (34%), and between DBH3 and VOL3 and K1 (38%). On the other hand, there was no significant correlation between the dendrometric variables and the P and K nutrients from the soil layer 2. The positive linear correlation between the rubber tree variables and the chemical attributes suggests that these attributes reach their highest values in areas comprising the largest P and K concentrations and vice versa. This result is in good agreement with those reported by [3], which found that the rubber tree growth is mainly influenced by the N and P levels. The percentage of rubber trees prepared for bleeding was strongly correlated with the N and K macronutrients, denoting the effect of K on the rubber tree growth uniformity.

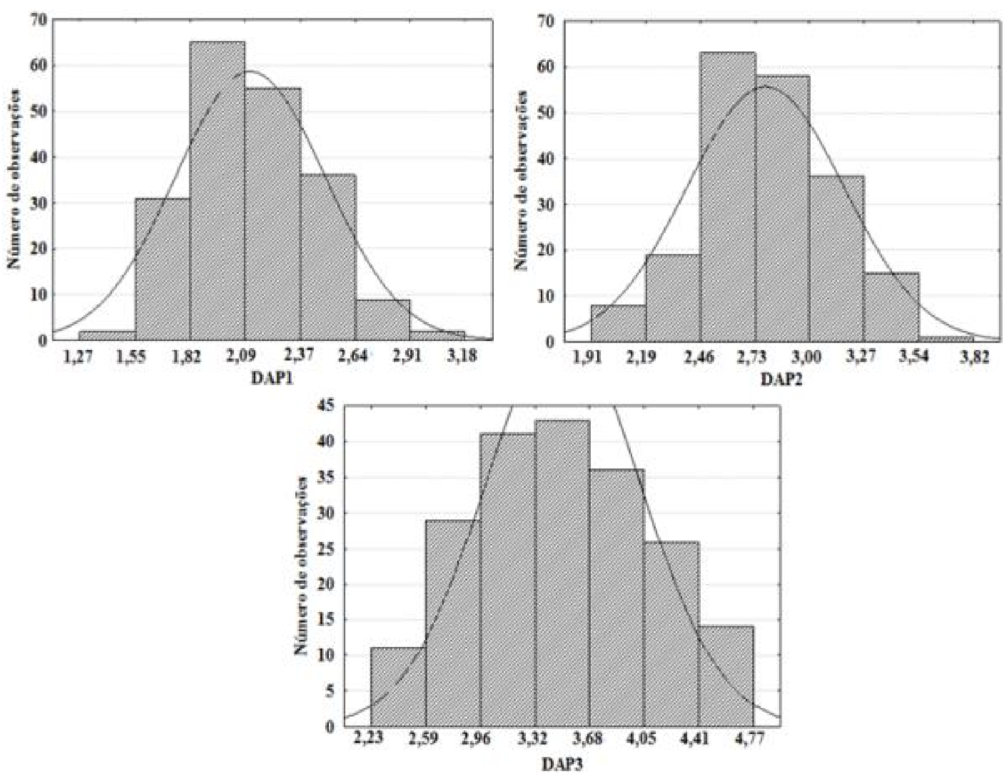


Fig. 1. Histograms of rubber tree DBH distributions (Fx3864 clone) for three measuring periods

3.2 Geostatistical Analysis

The rubber tree dendrometrics parameters and the soil chemical attributes (P and K) were found to be spatially dependent (Table 2) with semivariogram theoretical models well fitted to the exponential and spherical mathematical functions. The parameters C_0 and C_0+C of each variable were scaled by the data variance.

The transformed dendrometrics parameters (t) DBH1t, DBH2t, DBH3t, VOL1t, VOL2t and VOL3t presented spatial dependence with best fitting to the exponential model, whereas the parameters HGT1t, HGT2t and HGT3t were best adjusted to the spherical model. [7] adjusted the exponential semivariogram to the rubber tree stem perimeter at breast high, leading to a moderate spatial dependence. [8] adjusted the spherical semivariogram to the height and DBH of rubber trees.

It is observed a similarity among the values found for the parameters in the semivariograms scaled by the data variance for DBH1t and DBH2t, HGT1t and HGT2t and HGT3t and VOL1t and VOL2t, thus revealing the same pattern of spatial distribution in the area. The data obtained in the first (1) and second (2) measuring periods with rubber tree growth nearly constant over time, i.e., the lowest and highest parameter values in a particular region became smaller and/or larger throughout the whole experimental period.

The DBH3t from the third measuring period (3), and VOL1t from the first measuring period (1) presented the highest spatial dependence ranges, 20.0 m and 17.0 m, respectively. These parameters exhibit the highest spatial continuity in the area, which favors the interpolation process due to the greater number of neighboring points. Accordingly, VOL presents the spatial distribution pattern of DBHt and HGTt, once it is calculated from these two parameters. [8] did not find similarity among the spatial patterns of the rubber tree dendrometrics parameters. [19] found adjustments to the spherical model with a range of 57.0 and 92.0 m, respectively, for diameter at breast height and height for other rubber tree clones in the latex production phase.

The semivariograms adjusted to the P and K macronutrients were spherical to P12 and exponential to K12 (layers 1 and 2). The R^2 of the selected models exceeded 84%, meaning that most of the variability involving the estimated semivariance values is explained in the fitting. Therefore, both parameters were used to select the best models, as well as the significant correlation (CR) between the experimental data and the data predicted by cross-validation. [20] examined the spatial dependence of fertility

Table 2. Models and parameters of scaled semivariograms including dendrometric parameters and chemical attributes (P and K)

	Model	C_0	C_0+C	a (m)	SDD (%)	R^2 (%)	CR
			Chemical attributes **(standardized)**				
P1	ESF	0.32	1.05	25.0	30.0	96.0	*
P2	ESF	0.37	1.04	23.0	33.0	86.0	*
K1	EXP	0.33	1.04	36.0	32.0	84.0	*
K2	EXP	0.50	1.08	26.0	46.0	89.0	*
			Dendrometric variables **(standardized)**				
HGT 1t	ESF	0.04	0.96	12.5	4.0	95.0	*
HGT 2t	ESF	0.05	0.97	12.5	5.5	95.0	*
HGT 3t	ESF	0.02	0.95	10.0	3.0	80.0	*
DBH 1t	EXP	0.10	1.03	14.0	9.0	90.0	*
DBH 2t	EXP	0.07	1.00	11.0	7.5	80.0	*
DBH 3t	EXP	0.11	1.00	20.0	12.0	50.0	*
VOL1t	EXP	0.09	1.03	17.0	8.5	92.0	*
VOL2t	EXP	0.03	0.98	13.0	4.0	92.0	*
VOL3t	EXP	0.02	1.00	9.0	3.0	81.0	*

*t: transformed data; ESF: spherical model; EXP: exponential model; C_0: nugget effect; C_0+C: sill; a: range; R^2: multiple determination coefficient; SDD: spatial dependence degree and * significant correlation between the experimental and predicted data by cross-validation.*

attributes of a dystrophic latosol and obtained fitting of the semivariogram to the spherical model for 70% of the attributes. [21] adjusted the spherical model to 67% of the chemical attributes of a clay soil.

The longest range values observed in this work were longer than the shortest sampling distance, 6 m, meaning that both soil and rubber tree samples are spatially correlated to one another. This allows estimating the values from non-sampled regions by interpolation.

It can be verified that the range values were higher in the 0-0.20 m layer for P and K, with values of 26.0 and 36.0 m, respectively. This shows higher spatial continuity in the area. [22] found range values of 11.8 m and 29.6 m for K and P, respectively, in a Ultisol occupied by a consortium between conilon coffee and rubber tree. The P spatial continuity was longer than that of K.

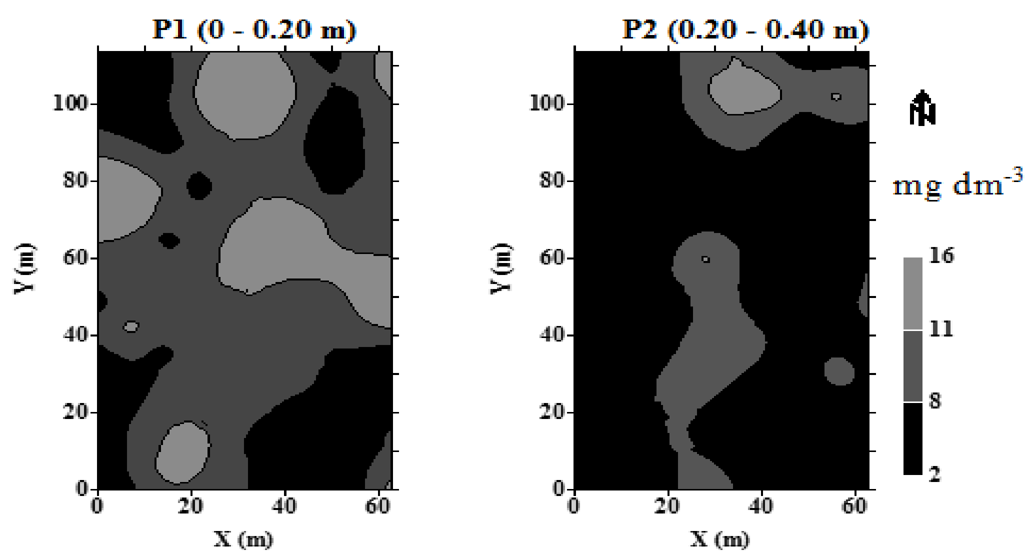
According to [8], it must be taken into account that the nugget effect values (C_0) represent distinct quantities, since the rubber tree dendrometrics variables are expected to display sample populations more stable than those of the soil chemical properties. This is explained by the fact that the spatial variability of dendrometrics variables is represented by integration of a series of factors related to the plant-soil-atmosphere system, while the soil properties are more susceptible to the management techniques used on the area. The rubber tree dendrometric variables are thus more stable in time, and consequently, display nugget effect values (C_0) lower than those of the soil chemical properties (P and K).

According to the classification proposed by [13], all rubber tree dendrometrics variables exhibited high SDD values (SDD ≤ 25.0%), which result in lower variance in estimations and higher assurance for estimating values of non-sampled regions. The SDD values of the soil chemical attributes (P and K) were found to be moderate (25% < SDD ≤ 5%), meaning that the spatial variance contributes to the total variance at a low extent.

Once proven the spatial dependence of the transformed dendrometrics variables and the P and K from both soil layers, spatial distribution maps were built for each variable using the ordinary kriging technique in pixels of 7x3m and 1x1m for dendrometrics variables and chemical attributes, respectively. Figs 2-5 shows the spatial distribution maps for P, K, DBHt, HGTt and VOLt.

3.3 Soil Chemical Attributes

The maps of P from both layers (Fig. 2) denote the spatial distribution pattern, same fitting model and similar range (*a*) values. The region characterized by the highest P contents (11 to 16 mg dm^{-3}) in the 0-0.20 m layer overlaps at the top part of the area in the 0.20-0.40 m layer. The P and K maps display higher spatial continuity along the crop trenches (longer length), revealing the effect of the mechanical and fertilization procedures used to transplant the rubber trees.



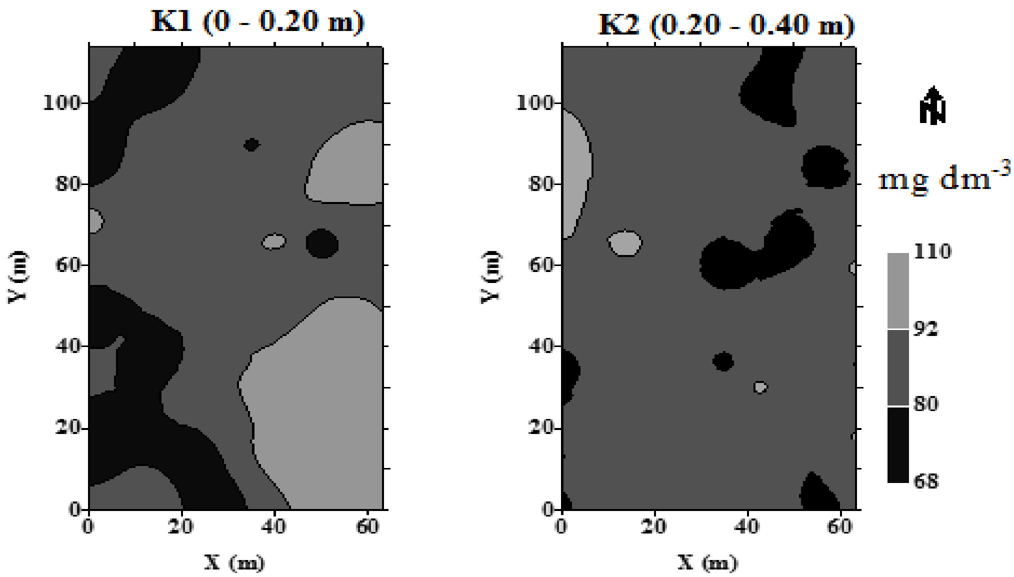


Fig. 2. Spatial distribution maps of P and K (layers 1 and 2)

The P1 (0 - 0.20 m layer) and P2 (0.20 - 0.40 m layer) presented values between 8.0 and 11.0 mg dm^{-3} and 2.0 and 8.0 mg dm^{-3}, respectively, in most parts of their area. Altogether, this shows that both soil layers contained P levels lower than 20 mg dm^{-3}, which is the minimum P level recommended by [15] for proper growth of rubber trees. This occurred due to inefficient technical guidance, once P was added to the crop only after the three measuring periods, thereby influencing the early growth of the rubber trees.

The mean K values did not present significant differences regarding the soil layer according to the t-test ($p \leq 0.05$). Spatial analysis allows visualizing this behavior, once most parts of the area comprise K levels between 80 – 92 mg dm^{-3}. K levels from 92 to 110 mg dm^{-3} are observed at the upper lateral right and the lower regions in the 0 – 0.20 m layer. However, this fact was not sufficient for revealing statistical differences in K levels with respect to the soil layer depth, which is a good indication.

[23] applied the fuzzy logic and geostatistical in the definition of spatial variability of soil fertility cultivated with rubber tree. The inference rules indicated that the total area shown in the fuzzy maps of soil fertility requires the application of correctives and fertilizers, as it has degrees of relevance less than 0.50 and greater than 50% of the area. This methodology reduced the number of maps to interpret the soil fertility in the area, allowing the visualization of the spatial and gradual variability of the needs of each region.

3.4 Dendrometric Parameters

The maps reveal that the rubber tree dendrometrics variables display both spatial and temporal variability. Regarding DBH (Fig. 3), it is verified the presence of various color islands, which indicates lower spatial continuity due to shorter ranges of spatial dependence. The largest DBH values are dispersed throughout the area considering the three measuring periods. With respect to shape, it may be suggested that the largest DBH values are virtually ascribed to the same rubber trees that presented the best responses at their early growth stage. Most of rubber trees exhibited DBH within the class from 0.33 to 0.66 at the three measuring periods. According to [24], the knowledge about the spatial distribution magnitude and the correlation among parameters may facilitate soil fertilization management in specific locations.

The central and lower regions of the area show islands characterized by clear colors for the highest DBH1t and DBH2t values (Fig. 3), HGT1t, HGT2t and HGT3t (Fig.4) and P and K levels in the 0 – 0.20 m soil layer (Fig. 2). This confirms the linear Pearson correlation between the dendrometrics variables and these soil nutrients.

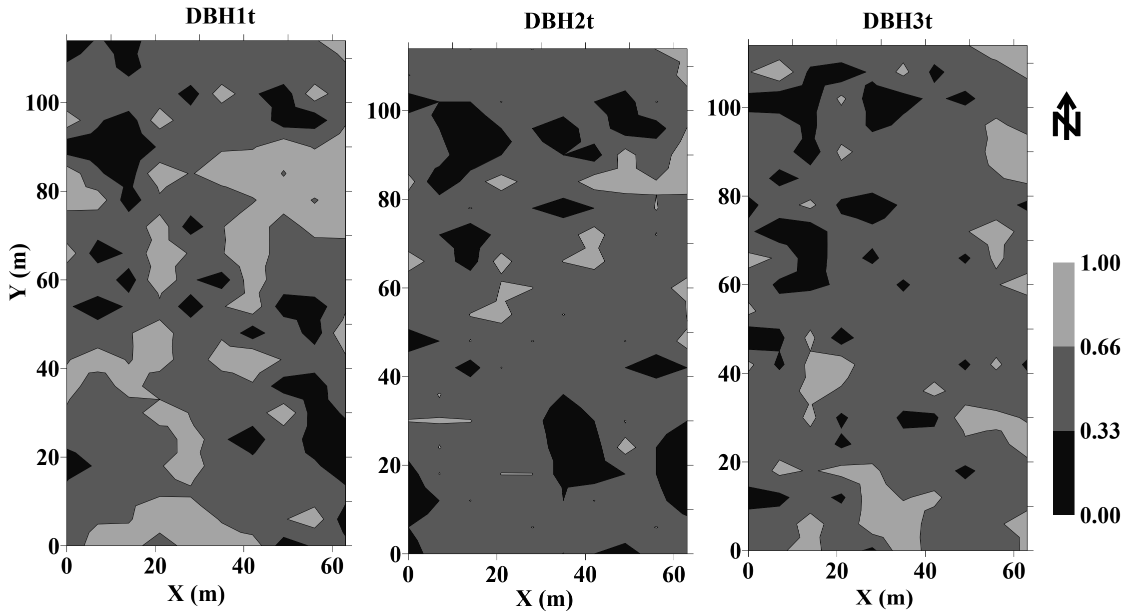


Fig. 3. Spatial distribution maps of transformed (t) rubber tree DBH for three measuring periods

The HGT of the rubber trees (Fig. 4) was observed to be spatially dependent towards the measuring periods, likewise to the DBH behavior. This indicates a correlation between HTG and DBH, with larger frequency in the class from 0.33 to 0.67. The third measurement shows regions earlier characterized by trees with little height development, which then grown and reached greater heights over time, especially in the lower region of the area. This was most likely due to high K levels contained in this region.

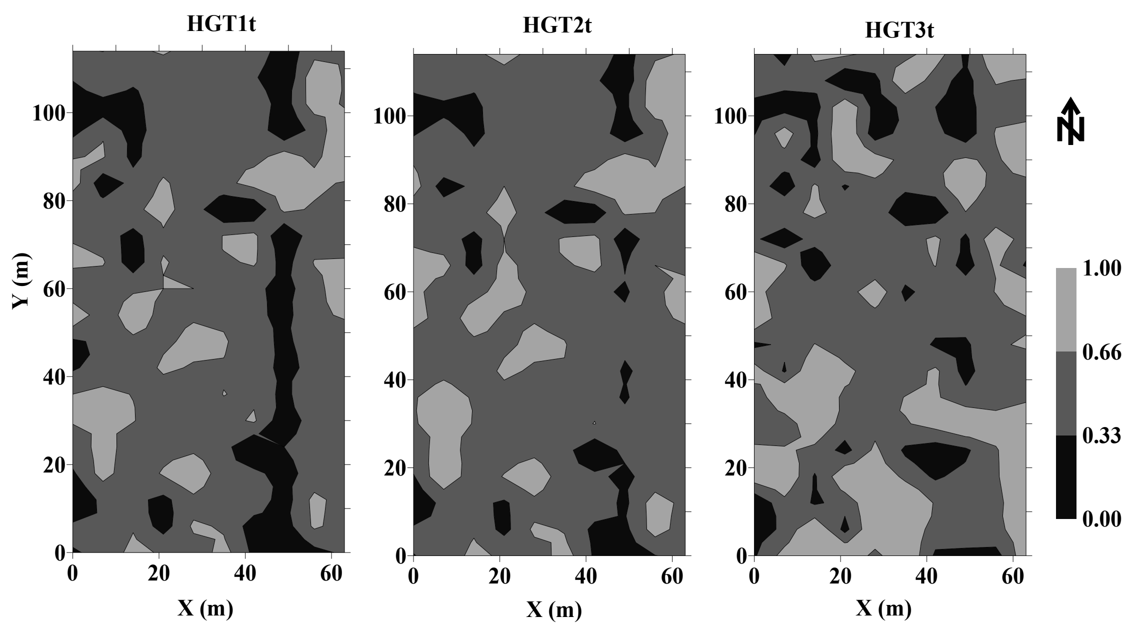


Fig. 4. Spatial distribution map of transformed (t) rubber tree height (HGTt) for three measuring periods

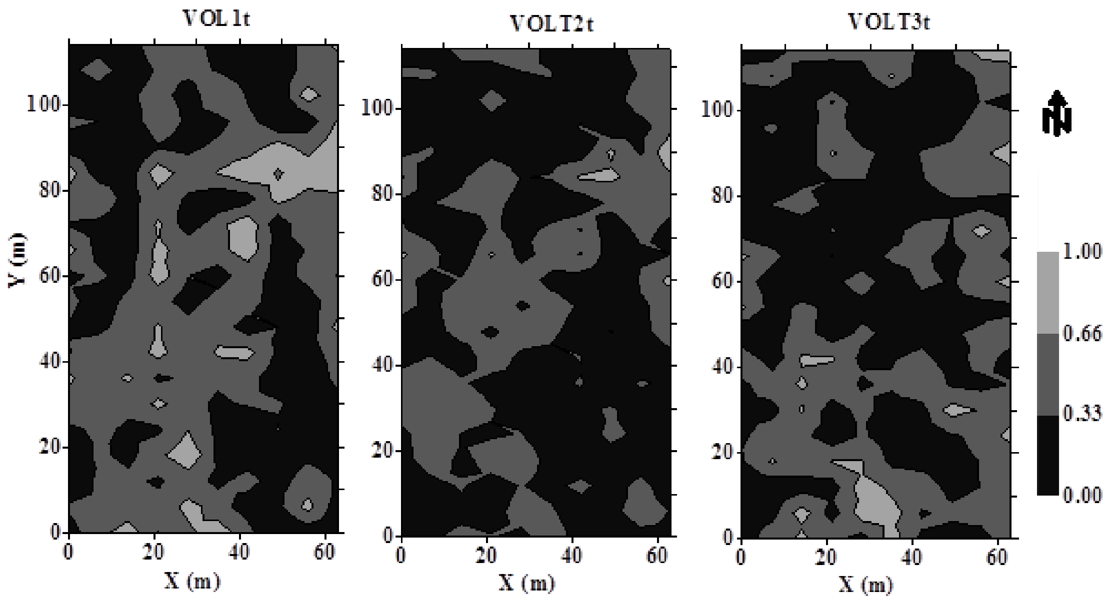


Fig. 5. Spatial distribution map of transformed (t) rubber tree volume (VOLt) for three measuring periods

Fig. 5 shows the VOL spatial distribution maps, which reveal the discontinuity in spatial distribution for trees with larger VOL between measurements, i.e, changing from the class 1.0 – 0.67 (light color) to the class 0.33 – 0.67 (dark color).

Within the time scale adopted, the rubber trees comprising the highest DBH and HGT also presented the largest VOL, as shown in the upper lateral right and in the lower regions of the area.

4. CONCLUSIONS

- In the early growth stage of rubber trees (Fx 3864 clone), the maximum tree height in the first and second measuring period displayed significant correlation with P and K levels from the 0 – 0.20 m layer and with the P level from the 0.20 – 0.40 m layer. Concerning the third measuring period, all rubber tree variables correlated with the K level from the 0 – 0.20 m layer.
- The soil chemical attributes P and K and the dendrometric parameters (height, volume and diameter) of the rubber tree (Fx 3864 clone) show spatial and temporal variability in different regions in the area for tree growth and soil fertility (P and K), these are indicators of rubber tree growth.
- Spatial and temporal analysis of dendrometric parameters and soil fertility should be carried out until the latex extraction phase to observe the effects of tree growth on production.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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