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SPACIAL VARIABILITY AND SAMPLING DENSITY OF CHEMICAL ATTRIBUTES IN ARCHAEOLOGICAL BLACK EARTH AND NATIVE FOREST SOIL IN MANICORÉ, AM

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Abstract

Considering the lack of information about spatial behavior of the soil attributes in areas of archaeological black earth and native forest, the objective of this study was to evaluate the spatial variability of chemical attributes and determine the sampling density in soil with archaeological black earth and native forest in the region of Manicoré, AM. The study was conducted in a rural property located in the community of Santo Antônio do Matupi, at the margins of BR 230, Trans-amazon highway, in the region of Manicoré, AM. In these areas were established grids of 70 m x 70 m, with regular spacing of 10 x 10 m, totaling 64 points, then soil samples were collected at a depth of 0.0-0.20 m and 0 , 40 - 0,60 m. Chemical attributes were determined (pH, OM, P, K, Ca, Mg, SB, CTC, V% and H + Al). Data were analyzed using descriptive statistical techniques and geostatistics. Sampling density was determined basing on CV and on the range of the semivariograms. It was verified that the studied attributes showed spatial variability and the area of archaeological black earth presented greater spatial variability than the native forest. Its greater sampling density was determined basing on the range of the adjusted semivariograms.

Keywords: Indian black earth; attributes of soil; geostatistics.

Resumo

Variabilidade espacial e densidade amostral de atributos químicos em solo de terra preta arqueológica e floresta nativa em Manicoré, AM. Considerando a falta de informações sobre o comportamento espacial dos atributos do solo em áreas de terras pretas arqueológicas ou terras pretas de índio e floresta, o objetivo deste trabalho foi avaliar a variabilidade espacial de atributos químicos e determinar a densidade amostral em solo com terra preta arqueológica e floresta nativa na região de Manicoré, AM. O estudo foi realizado em uma propriedade rural localizada na comunidade de Santo Antônio do Matupi, às margens da BR 230, rodovia Transamazônica, região de Manicoré, AM. Nestas áreas foram estabelecidas malhas de 70 m x 70 m, com espaçamento regular de 10 x 10 m totalizando 64 pontos e em seguida, coletadas amostras de solos na profundidade de 0,0-0,20 m e 0,40 - 0,60 m. Foram determinados os atributos químicos (pH em água, MO, P, K, Ca, Mg, SB, CTC, V% e H+Al). Os dados foram analisados utilizando-se técnicas de estatística descritiva, geoestatística e determinado a densidade amostral com base no CV e no alcance dos semivariogramas. Verificou-se que os atributos estudados apresentaram variabilidade espacial e a área de terra preta arqueológica apresentou maior variabilidade espacial em relação à floresta nativa, apresentando maior densidade amostral baseados no alcance dos semivariogramas ajustados.

Palavras-chave: Terra preta de índio; atributos do solo; geoestatística.

INTRODUCTION

The southern region of Amazonas is characterized by great soil variability, represented by Acrisols, Latosols, Cambisols, Neosols, Plintosols and Spodosols (CAMPOS, 2009) and in some areas of the region all these soils are characterized by the peculiar presence of an anthropic A horizon, known as Archaeological Black Earths (ABE), or Indian Black Earths (IBE). Those are soils with great natural fertility, found in the whole Amazon region (PETERSEN *et al*., 2001; LEHMANN *et al*., 2003; GLASER *et al*., 2004; GLASER, 2007; WOODS *et al*., 2009), and normally associated to water sources or to higher lands. Their peculiar characteristics are the darkish color and the presence of ceramic and/or lithic fragments, embedded in the matrix of the surface horizons (KAMPF; KERN, 2005).

In contrast with these soil characteristics, adjacent forests with low fertility soils have an important role in the improvement of nutritional quality and physical characteristics of the soil attributes. The study of these attributes becomes essential when rational management, sustainable productivity and prediction of forest ecosystems are the desired objectives, since both forest and soil are interconnected (WOJCIECHOWSKI *et al*., 2009).

Seen in these terms, the different behavior of soil attributes in different landscape locations may be understood by the characterization of their spatial variability. This can be achieved using geostatistical techniques, which help to identify similarities between locations of the landscape. This spatial knowledge of the attributes of a soil in a determined area is important for the evaluation of its environmental quality, as it is important to define the necessary sampling density to achieve a reliable characterization (CARVALHO *et al*., 2010; VIEIRA, 2000).

Those sampling strategies are important to map the spatial variability of soils and their attributes, because creation of more consistent maps is possible only starting from the mentioned modeling techniques. Besides, there are studies indicating that the correct characterization of IBEs according to the taxonomic classification of the Brazilian System of Soil Classification (EMPRESA BRASILEIRA DE PESQUISA AGROPECUARIA (EMBRAPA), 2013), whose parameters are established by a committee, will require some modifications to this classification system.

Thus, information on variability of the attributes may help this committee to make these changes. Minasny and Mcbratney (2007) also propose the use of numeric classification models for a better mapping and identification of these soil limits and their attributes in field.

In this context, the great difficulty encountered during studies on soil spatial variability is the determination of the ideal sampling density, which in some situations hinders the use of precision agriculture techniques. Thus, studies on soil sampling methods, with the intent to subsidize the use and recommendation of these techniques in different environments, has been a constant challenge for researchers (WEBSTER; OLIVER, 1990; VAN GROENIGEN *et al*., 1999; LARK, 2000, MONTANARI *et al*., 2005). Works like Souza *et al*. (2006), developed on Latisols and considering the soil-embossment aspects and using sampling density, showed to be efficient to estimate the chemical attributes, reducing the minimum number of samples to be collected.

Objective of this study was to determine spatial variability and sampling density of the chemical attributes, in Indian Black Earths and adjacent soils, of a native forest in the municipality of Manicoré, AM.

MATERIAL AND METHODS

The study was conducted in an estate, located in the southern Amazonas state, close to the community of Santo Antonio de Matupi, alongside the Transamazon Highway BR 230 in the region of Manicoré, AM. The IBE area below a cultivated Red Acrisol, with corn cultivations, is located in the geographical coordinates 07º55’02,1” S and 61º31’45,2” W, at an average altitude of 102 m. Adjacent soil (Red Acrisol) is near the IBE area, under a native forest located in the geographical coordinates 7º54’44,5” S and 61º31’44,7” W, at an average altitude of 140 m above sea level (Figure 1).

The original material was generated by alterations in granites of Rondonia type, of the Early Pre-Cambrian geological period, and is formed by colluvial sediments, laying in the lower parts of the landscape, known as tertiary clay plains (BRASIL, 1978). Climate of the region, according to Köppen classification, is tropical rainy, with a short dry period (Am) and temperature variations between 25 °C and 27 °C. Rainfall is between 2,250 and 2,750 mm, with concentrations in the period from October to June (BRASIL, 1978).

Two grids of 70m x 70m were established, with approximately 0.49 hectares area, being one grid per each area, and soil was sampled with regular 10 by 10 m spacing between crossing points, totalizing 64 sampling points per each grid (Figure 1). These points were georeferenced with a Garmin Etrex GPS equipment (South American 69). Next, soil samples collection took place at 0.0-0.20m and 0.40-0.60m depth, to determine the chemical attributes, totalizing 128 soil samples from each grid. Particle size characterization values of the IBE area were 434.14 g kg^{-1} of sand, 444.36 g kg^{-1} of silt e 121.50 g kg^{-1} of clay at 0.0-0.20 m depth, and 426.26 g kg^{-1} of sand, 297.99 g kg^{-1} of silt and 275.75 g kg^{-1} of clay at 0.40-

0.60 m depth. The adjacent soil under native forest gave 358.81 g kg^{-1} of sand, 313.24 g kg^{-1} of silt and 327.94 g kg^{-1} of clay at 0.0-0.20 m depth, and 251.35 g kg^{-1} of sand, 355.71 g kg^{-1} of silt and 392.94 g kg^{-1} of clay at 0.40-0.60 m depth.

The following chemical analyses were conducted on the soil samples, according to methodologies suggested by EMBRAPA (2011): 1) exchangeable calcium, magnesium and aluminum, extracted by KCl; 2) available potassium and phosphorus extracted by Mehlich-1; 3) potential acidity (H+Al) extracted by pH 7.0 calcium acetate solution. Basing on results of the chemical analyses, the Sums of Bases (SB), cation exchange capacity (T) and saturation by bases (V%), were then calculated.

Having obtained the analytic results, evaluation of chemical attributes of IBE and native forest adjacent soils began initially with the explorative analysis of data, calculating mean, median, variance, coefficient of variation, asymmetry coefficient, coefficient of kurtosis and test of normality. The Coefficient of Variation (CV) was calculated basing on the criterion of Warrick and Nielsen (1980), which classifies its value low if CV < 12%, medium from 12% to 60% and high if CV > 60%. Hypothesis of normality was verified by the Kolmogorov-Smirnov test, using the statistical software Minitab 14.

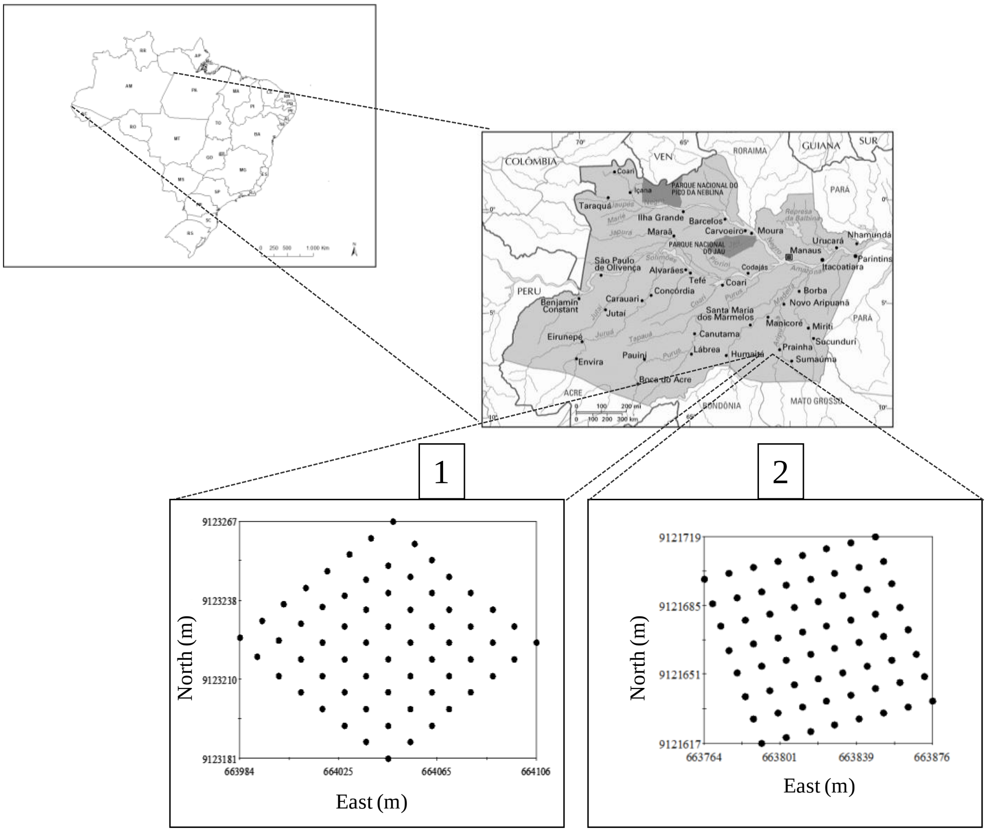

Figure 1. Location of areas: 1: Area with adjacent soil under forest; 2: Area with corn cultivated IBE.

Figura 1. Localização das áreas: 1: Área com solo adjacente sob floresta; 2: Área com TPI cultivada com milho.

The pH was determined with a potentiometric method, using the ratio soil:water of 1:2.5, according to EMBRAPA (2011). Organic carbon was determined by the method of Walkley-Black, modified by Yeomas and Brenner (1988), and the organic matter was estimated basing on the values of organic carbon

To characterize the spatial variability, a geostatistical analysis based on studies by Matheron (1963), Vieira *et al.* (1983) and Isaaks *et al.* (1989), was used. The experimental semivariogram, under the "intrinsic hypothesis" theory, was estimated by the following equation:

$$\hat{\gamma}(h) = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} \left[Z(x_i) - Z(x_i + h) \right]^2 \qquad (1)$$

where: $\gamma(h)$ = value of semivariance for a given h distance
N(h) = number of pairs involved into calculation of the semivariance
$Z(x_i)$ = value of the attribute Z in a given position x_i;
$Z(x_i + h)$ = value of the attribute Z at a distance h from the x_i position.

Coefficients of the theoretical model for the semivariogram are defined from the adjusting of a mathematical model to the calculated $\gamma\hat{}$ (h) values (nugget effect, C_0; structural variance, C_1; sill, $C_0 + C_1$; and range, a). Nugget effect is the value of the semivariance at zero distance and represents the component of random variation; sill is the value of semivariance where the curve stabilizes above a constant value; range is the distance from the origin to where sill reaches stable values, expressing the distance limit above which samples are not spatially correlated any more (VIEIRA *et al*., 1983; TRANGMAR *et al*., 1985). Semivariograms were analyzed using the GS^+ program (ROBERTSON, 1998), to determine if spatial dependence existed or not. In case of doubts between more models for the same semivariogram, the best R^2 was considered (coefficient of determination).

To analyze the degree of spatial dependence between the studied variables (Table 2), the classification method proposed by Cambardella *et al*. (1994) was used. In this method, values of $[(C_0/(C_0+C_1)]$ lower than 25% are considered with strong spatial dependence, values of $[(C_0/(C_0+C_1)]$ between 25 and 75% indicate a moderate spatial dependence and values of $[(C_0/(C_0+C_1)]$ above 75% are considered with weak spatial dependence.

The number of sub-samples needed to create a composed sample and estimate mean value of the variables was determined basing on the coefficient of variation using the formula described by Cline (1944):

$$\mathbf{n} = \left(\frac{\mathbf{t_\alpha . CV}}{\mathbf{D}} \right)^2 \qquad (2)$$

where: n = minimum number of samples to define a sampling mesh;
$t\alpha$ = value of Student's t distribution (at 95% of probability);
CV = coefficient of variation
D = percentage of variance starting from mean value (5%).

The number of sub-samples was also determined basing on the range values obtained in the geostatistical analysis, according to equation 3.

$$\mathbf{N} = \frac{A}{(a^2)/10000} \qquad (3)$$

where: N = minimum number of samples needed to determine a sampling grid ;
A = total area in hectares
a = range of the semivariogram in meters

RESULTS AND DISCUSSIONS

Mean values and median values of almost all the studied variables, as it can be observed, are very close each other, highlighting that variables are approximating to a normal distribution and indicating that data follow symmetrical distributions (Table 1 and 2). These values are justified by asymmetry and kurtosis values close to zero. Exceptions can be observed for K (0.0 – 0.20 m and 0.40 – 0.60 m) and Mg (0.40 -0.60 m) in the IBE area, and H+Al, K, Mg, SB (0.0 – 0.20 m), Ca, K, P and V% (0.40 – 0.60 m) in the adjacent soil under forest, which presented mean and median values slightly distant, highlighting that in this case they may be influenced by extreme values.

Consequently, values of asymmetry and kurtosis farer from zero can be observed, affirming the fact that these variables are not following an asymmetry or are not following a standard curve of distribution. About data of asymmetry and kurtosis, Cortez *et al.* (2011) affirm that the closer data are to zero, the higher is their normality, and thus they are not necessary for application of geostatistics. However, information about these parameters make the “visual adjustment” easier.

Comparing mean values of the chemical attributes of Archeological Black Earths with adjacent soil under native forest, differences are observable between attributes in different soils (Table 1 and 2). Values of chemical attributes of IBE are, in general, far greater than the one of soils under native forest, highlighting a greater fertility and better quality of these soils. Greater Organic Matter content (OM), Sum of Bases (SB) and saturation per bases values (V%) are observable in the Archeological Black Earths (ABE), together with greater values of the attributes pH, P, Ca, Mg and greater T; on the other hand, forest present greater potential acidity in both depths and greater K at 0.40 – 0.60 m depth, with 74.92, 59.55 and 1.39 mmol kg^{-1}, respectively.

This fact explains the great fertility of ABEs compared to adjacent soils, since according to Kern and Kämpf (1989), Lehmann *et al.* (2003) and Glaser (2007), these soils generally present great natural fertility, with great P, Ca, Mg, Zn, Mn contents, and with great content of stable organic matter. On the other hand, Cunha *et al.* (2007) affirm that the great natural fertility of these soils is strongly related to the molecular characteristics of the alkaline soluble fraction of the organic carbon, and these authors found that A horizons of anthropogenic soils of the Amazons presented greater total carbon content compared to adjacent not-anthropogenic soils, which did not present A anthropic horizon.

Table 1. Descriptive statistics of chemical attributes in archeological black earth area.
Tabela 1. Estatística descritiva dos atributos químicos em área de terra preta de índio.

Attributes	**Descriptive statistics**										
	Un.	**Mean**	**Median**	**Min.**	**Max**	**SD**	**Var.**	**CV%**	**Kurt.**	**Asym.**	**d**
					Depth 0.0 - 0.20 m						
pH	H_2O	6.27	6.20	5.70	7.10	0.29	0.08	4.71	0.48	0.58	0.09^{ns}
H+Al	mmol kg^{-1}	28.29	29.50	13.00	42.00	6.64	44.08	23.46	-0.51	-0.08	0.06^{ns}
MO	g dm^{-3}	68.19	68.00	29.00	94.00	13.54	183.33	19.86	0.31	-0.26	0.06^{ns}
P	mg dm^{-3}	309.4	298.5	165.0	547.0	86.4	7465.2	27.93	-0.02	0.53	0.07^{ns}
K	mmol kg^{-1}	1.72	1.40	0.70	10.20	1.41	2.00	82.30	24.46	4.66	0.26*
Ca	mmol kg^{-1}	166.02	164.50	85.00	214.00	26.72	714.08	16.10	0.49	-0.51	0.06^{ns}
Mg	mmol kg^{-1}	29.45	30.00	17.00	47.00	6.49	42.12	22.04	-0.12	0.27	0.05^{ns}
SB	mmol kg^{-1}	197.19	195.20	103.80	252.60	29.18	851.70	14.80	0.58	-0.46	0.09^{ns}
T	mmol kg^{-1}	225.49	227.65	128.80	274.40	27.74	769.48	12.30	1.15	-0.61	0.08^{ns}
V	%	87.20	86.80	78.10	93.70	3.58	12.86	4.11	-0.46	-0.20	0.08^{ns}
					Depth 0.40 - 0.60 m						
pH	H_2O	5.90	5.90	5.20	6.8	0.31	0.090	5.30	0.77	0.66	0.11*
H+Al	mmol kg^{-1}	30.55	31.00	18.00	47.00	5.98	35.76	19.57	0.25	0.03	0.04^{ns}
MO	g dm^{-3}	24,11	22.00	15.00	39.00	5.34	28.61	22.19	-0.23	0.67	0.13*
P	mg dm^{-3}	252,4	238.0	114.0	746.0	95.0	9022.5	37.64	10.69	2.46	0.15*
K	mmol kg^{-1}	0.74	0.50	0.20	8.60	1.04	1.09	141.74	53.01	7.02	0.31*
Ca	mmol kg^{-1}	75.90	73.00	39.00	121.00	17.12	292.96	22.55	0.68	0.67	0.08^{ns}
Mg	mmol kg^{-1}	14.01	13.00	7.00	30.00	4.16	17.30	29.68	3.66	1.62	0.12*
SB	mmol kg^{-1}	92.88	87.50	46.20	161.30	23.46	550.54	25.26	0.51	0.85	0.13*
T	mmol kg^{-1}	123.44	118.60	84.20	189.30	22.82	520.61	18.48	0.47	0.94	0.12*
V%	%	74.50	74.20	54.90	85.90	6.70	45.00	9.00	0.63	-0.59	0.06^{ns}

Un.: Unit; SD: Standard Deviation; Var.: Variance; CV: Coefficient of Variation; Kurt.: Kurtosis; Asyim.: Coefficient of Asymmetry; d: test of Normality, *significant by the test of Kolmogorov-Smirnov.

Considering the limits of coefficient of variation proposed by Warrick and Nielsen (1980), values of CV for the classification of pH and V% variables in ABE and pH in forest were low (CV < 12%), which can be a sign of low variability (Table 1 and 2), similarly to results found by Vieira et al. (2010) in a Red-Yellow Acrisol cultivated with grain legumes. On the opposite, K variables for ABE in both depths and K, Ca, SB and V% (0.0 – 0.20 m), presented greater coefficients of variation, indicating great data variability in the area (CV > 60%). In this way, the other variables presented moderate variability (12% < CV < 60%). High CV values are an estimate of greater heterogeneity of the attributes, indicating a greater variability. In this context, greater heterogeneity can be observed in the ABE area than in the native forest. According to Carvalho *et al*. (2003), results of the analysis of soil attributes usually present high values in the coefficient of variation.

Results referred to the Kolmogorov-Smirnov test indicated normality for the variables K (0.0 – 0.20 m), pH, MO, P, K, Mg, SB, CTC and V% (0.40 – 0.60 m), in the IBE. On the opposite, in native forest, only the variables P and K (0.0 – 0.20 m), and pH and Mg (0.40 – 0.60 m) did not present normality of data. However, according to Cressie (1991), normality of data is not mandatory in geostatistics. Although normality of data is not fundamental in geostatistics, it is important to have a distribution without very long tails, which could hinder the estimates of kriging, since they are based on the mean values (ISAAKS; SRIVASTAVA, 1989).

In both the studied areas there was predominance of the adjusted spherical model, according to Isaaks and Srivistava (1989), exponential models fit better with erratic phenomena in small scale, while spherical models describe properties with great spatial continuity, or less erratic in short distances (Tables 3 and 4). Spherical and exponential models have been proposed as the most common theoretical models for soil attributes. The choice of spherical model for the majority of the attributes coincide with other works which describe this model as the one that fits better with plant and soil parameters (SALVIANO *et al*., 1998; BERTOLANI; VIEIRA, 2001; CAVALCANTE *et al*., 2007; VIEIRA *et al*., 2011). The majority of the adjusted models presented high values of the coefficient of determination, expressed by the values of R^2, thus justifying the models that were adjusted to the chemical variables.

Table 2. Descriptive statistics of chemical attributes in native forest area in Manicoré, AM.
Tabela 2. Estatística descritiva dos atributos químicos em área de floresta nativa em Manicoré, AM.

Attributes	**Descriptive statistics**										
	Un.	**Mean**	**Median**	**Min.**	**Max**	**SD**	**Var.**	**CV%**	**Kurt.**	**Assim.**	**d**
Depth 0.0 - 0.20 m											
pH	H_2O	3.97	3.90	3.70	4.60	0.19	0.03	4.79	0.25	0.74	0.11*
H+Al	mmol kg^{-1}	74.92	88.00	34.00	109.00	22.04	485.85	29.42	-1.54	-0.21	0.15*
MO	g dm^{-3}	18.66	20.50	6.00	31.00	6.58	43.34	35.29	-1.21	-0.28	0.13*
P	mg dm^{-3}	6.09	5.50	2.00	10.00	2.20	4.848	36.13	-0.84	0.49	0.08^{ns}
K	mmol kg^{-1}	1.66	1.50	0.30	7.80	1.12	1.248	67.25	14.13	2.97	0.14*
Ca	mmol kg^{-1}	4.77	3.00	2.00	34.00	4.86	23.61	101.96	23.35	4.50	0.28*
Mg	mmol kg^{-1}	2.52	2.00	1.00	6.00	1.27	1.61	50.58	2.53	1.80	0.15*
SB	mmol kg^{-1}	8.94	7.05	3.30	41.20	6.18	38.15	69.08	13.08	3.27	0.27*
T	mmol kg^{-1}	83.86	93.95	39.50	115.80	21.94	481.15	26.16	-1.37	-0.37	0.19*
V	%	11.11	8.40	5.40	49.50	7.59	57.66	68.34	11.17	2.99	0.26*
Depth 0.40 - 0.60 m											
pH	H_2O	4.11	4.10	3.80	4.50	0.13	0.017	3.18	0.31	-0.16	0.06^{ns}
H+Al	mmol kg^{-1}	59.55	52.00	42.00	88.00	14.43	208.09	24.23	-0.53	0.87	0.13*
MO	g dm^{-3}	14.05	11.50	7.00	27.00	5.44	29.60	38.73	-0.54	0.90	0.20*
P	mg dm^{-3}	6.50	6.00	5.00	12.00	1.78	3.17	27.41	0.23	1.06	0.14*
K	mmol kg^{-1}	1.39	1.20	0.40	4.40	0.78	0.61	56.24	3.44	1.61	0.10*
Ca	mmol kg^{-1}	3.44	3.00	2.00	13.00	1.88	3.52	54.58	10.41	2.76	0.16*
Mg	mmol kg^{-1}	1.98	2.00	1.00	8.00	1.18	1.38	59.21	10.44	2.64	0.09^{ns}
SB	mmol kg^{-1}	6.81	5.90	3.40	25.40	3.57	12.75	52.41	11.24	2.79	0.17*
T	mmol kg^{-1}	66.36	60.50	46.50	100.40	15.30	234.14	23.06	-0.61	0.86	0.18*
V%	%	10.34	9.00	5.50	37.70	4.97	24.73	48.11	14.01	3.11	0.20*

Un.: Unit; SD: Standard Deviation; Var.: Variance; CV: Coefficient of Variation; Kurt.: Kurtosis; Asyim.= Coefficient of Asymmetry; d: test of Normality, *significant by the test of Kolmogorov-Smirnov.

Through the analysis of semivariograms it is observable, in both areas, that pH was the attribute of soil which presented the smaller nugget effect when compared to remaining chemical attributes studied, and also the smaller CV (Table 3 and 4). In this way, through descriptive statistical methods and geostatistics, it is possible to predict soil attributes which variability values were not detected by the sampling scheme, because of greater discontinuity between samples. According to Cavalcante *et al.* (2007), denser samplings may reveal greater spatial continuity of the analyzed chemical attributes.

The Degree of Spatial Dependence (DSD), expressed by the ratio between nugget effect (C_0), and sill ($C_0 + C_1$) (CAMBARDELLA *et al.*, 1994), was classified as moderate for most of the studied chemical attributes in the IBE area, while, in forest area, strong DSD predominance is observable (Table 3 and 4). According to Cambardella *et al.* (1994), variables with strong spatial dependence are more influenced by intrinsic soil properties, that is to say by factors related to soil formation, whereas moderate spatial dependence would be due to soil homogenization, as the extrinsic factors are considered with weak dependence.

Table 3. Models and estimated parameters of semivariograms of chemical attributes in IBE area in the region of Manicoré, AM.

Tabela 3. Modelos e parâmetros estimados dos semivariogramas dos atributos químicos em área de TPI na região de Manicoré, AM.

Attributes	**Unit**	**Model**	C_0	C_0+C_1	***a*** **(m)**	R^2	**DSD**
			Depth 0.0 - 0.20 m				
pH	H_2O	Sph	0.0235	0.0555	32.7	0.65	0.423
H+Al	mmol kg^{-1}	Sph	7.21	31.92	22.6	0.87	0.226
MO	g dm^{-3}	Sph	38.4	117	33.1	0.77	0.328
P	mg dm^{-3}	PNE	-	-	-	-	-
K	mmol kg^{-1}	Sph	0.063	0,2	23.86	0.94	0.315
Ca	mmol kg^{-1}	Sph	215	589	31	0.94	0.365
Mg	mmol kg^{-1}	Sph	16.7	38.94	35.04	0.54	0.429
SB	mmol kg^{-1}	Exp	318	853	40.2	0.61	0.373
T	mmol kg^{-1}	Sph	1.00	402	22.3	0.96	0.002
V	%	Sph	4.07	8.66	44.4	0.96	0.47
			Depth 0.40 – 0.60 m				
pH	H_2O	Sph	0.039	0.098	24.2	0.73	0.398
H+Al	mmol kg^{-1}	Sph	11.64	32.08	26.3	0.77	0.363
MO	g dm^{-3}	Exp	12.22	25.18	40	0.51	0.485
P	mg dm^{-3}	Sph	1754	4716	59.1	0.96	0.372
K	mmol kg^{-1}	Sph	0.0054	0.10	23.7	0.96	0.053
Ca	mmol kg^{-1}	Sph	101.2	208.1	40	0.97	0.486
Mg	mmol kg^{-1}	Sph	2.69	8.26	20.6	0.43	0.326
SB	mmol kg^{-1}	Exp	58.00	586.2	36.3	0.91	0.099
T	mmol kg^{-1}	Sph	264.5	571	50.3	0.91	0.463
V	%	Sph	11.59	35.747	25.13	0.51	0.324

C_0: Nugget Effect; C_0+C_1: Sill; DSD: degree of spatial dependence; R^2: Coefficient of Determination; Exp: exponential; Sph: spherical; PNE: pure nugget effect.

The range of spatial dependence is an important parameter of the semivariogram since indicates the influence zone of a sample, that is to say the value of this parameter indicates a radius where values within it present great similarity and are correlated. The greatest and smallest range values of the variability models were 44.4 and 22.3 m at 0.0-0.20 m depth and 59.1 and 23.7 at 0.40-0.60 m depth in the IBE area. In native forest, at 0.0-0.20 m depth, values were 73.0 and 25.1 m and at 0.40-0.60 m depth were 92.0 and 50.16 m, respectively (Tables 4 and 5). All range values were greater than planned for the grid and were in accordance with Souza *et al.* (2007).

These range values provide information about heterogeneity of spatial distribution of the studied properties in each management system (TRANGAMAR *et al.*, 1985). The forest area revealed range values of the spatial variability structure of the chemical attributes greater than values found the IBE area, indicating much more homogenous distribution of these attributes in the native forest area.

Hence, using the coefficient of variation when studying variability of soil attributes allows to calculate the minimum number of sub-samples needed to estimate the value of an attribute in a given area. Thus, using the formula proposed by Cline (1944), the minimum number of samples needed to estimate chemical attributes of both areas is determinable (Table 5). In the same way, geostatistics based on the "range" parameter also allows to estimate the minimum number of samples to properly determine the soil attributes (Table 6).

Table 4. Models and estimated parameters of semivariograms of chemical attributes in native florest area in the region of Manicoré, AM.

Tabela 4. Modelos e parâmetros estimados dos semivariogramas dos atributos físicos em área de floresta nativa na região de Manicoré, AM.

Attributes	**Unit**	**Model**	C_0	C_0+C_1	***a* (m)**	R^2	**DSD**
			Depth 0.0 - 0.20 m				
pH	H_2O	Sph	0.01	0.03	38.70	0.97	0.319
H+Al	mmol kg^{-1}	Sph	131.00	594.20	72.70	0.98	0.220
MO	g dm^{-3}	Sph	7.60	51.27	63.50	0.98	0.148
P	mg dm^{-3}	Sph	0.70	3.81	25.10	0.59	0.185
K	mmol kg^{-1}	Sph	0.24	0.652	31.80	0.58	0.367
Ca	mmol kg^{-1}	Sph	0.08	1.70	41.70	0.94	0.049
Mg	mmol kg^{-1}	Sph	0.69	1.67	55.70	0.89	0.417
SB	mmol kg^{-1}	Exp	1.52	13.87	48.00	0.96	0.110
T	mmol kg^{-1}	Sph	75.00	598.00	73.00	0.98	0.125
V	%	Exp	3.70	14.62	35.70	0.76	0.253
			Depth 0.40 - 0.60 m				
pH	H_2O	Exp	0.0009	0.0126	50.16	0.95	0.071
H+Al	mmol kg^{-1}	Gau	64.00	272.40	84.18	0.98	0.235
MO	g dm^{-3}	Sph	0.10	50.31	92.00	0.99	0.002
P	mg dm^{-3}	Sph	0.01	3.87	79.20	0.95	0.003
K	mmol kg^{-1}	PNE	-	-	-	-	-
Ca	mmol kg^{-1}	Sph	0.52	1.79	72.30	0.97	0.289
Mg	mmol kg^{-1}	Sph	0.19	1.033	60.80	0.98	0.188
SB	mmol kg^{-1}	Sph	1.30	5.49	63.30	0.91	0.237
T	mmol kg^{-1}	Sph	1.00	342.00	78.80	0.99	0.003
V	%	PNE	-	-	-	-	-

C_0: Nugget Effect; C_0+C_1: Sill; DSD: degree of spatial dependence; R^2: Coefficient of Determination; Exp: exponential; Sph: spherical; Gau: Gaussian; PNE: pure nugget effect.

Thus, considering that the minimum number of soil sub-samples is directly proportional to the coefficient of variation, the greater the CV, the greater will be the number of sub-samples to be collected (SOUZA *et al*., 2006). In this study was observed that the variables pH, T and V% (0.0-0.20 m and 0.40-0.60 m) for IBE and only pH (0.0-0.20 m and 0.40-0.60 m) (Table 6) for soil under native forest required a smaller number of samples for the same error around mean value, consequently, the other variables for both areas had a greater density than what established in the sampling grid.

Consequently, basing on CV of the attributes, the means of sampling density were greater when range was smaller than established in the grid for both areas in both assessed depths. On the other hand, using the semivariogram range, diminution is observable in the number of samples to be collected to evaluate all the physical attributes, as per the formula of Cline (Tables 5 and 6). With these data is possible to estimate a range mean value of 31.80 m and 50.20 m at 0.0 - 0.20 m depth, and 34.50 and 72.50 m at 0.40 – 0.60 m depth, for IBE and native forest, respectively, which could facilitate future studies in IBE areas and forest management areas with similar characteristics to this study. Specifically, greater variability is observable at 0.40 – 0.60 m for IBE basing on geostatistics, opposite to what found under native forest.

These information may facilitate works in field, since several studies on sampling have been conducted aiming to reduce variability of soil characteristics: influence of the sampling collection instrument (auger, blade, hoe etc.) (GUARÇONI *et al*., 2007; OLIVEIRA *et al*., 2007); necessary number of samples to form a composite (BRUS; NOIJ, 2008; WEINDORF; ZHU, 2010); effect of cultural traits (OLIVEIRA *et al*., 2007; PAULETTI *et al*., 2009); and effects of landforms (MONTANARI *et al*., 2005; SANCHEZ *et al*., 2009). However, these studies generally do not consider variability of the sub-samples to build up the composed sample, neither the way tracts of land are defined.

Table 5. Values of sample density and ideal spacing according to the Cline formula (% CV) for chemical attributes of IBE and native forest area in the city of Maricoré, AM.

Tabela 5. Valores de densidade amostral e espaçamento ideal de acordo com a fórmula de Cline (CV%) para os atributos químicos em área de TPA e floresta nativa no Município de Maricoré, AM.

Attributes	**Sample planning - CLINE**			
	IBE		**Forest**	
	Sample density (points/ha)	**Spacing (m)**	**Sample density (points/ha)**	**Spacing (m)**
Depth 0.0 - 0.20 m				
pH	12	29	13	28
H+Al	304	6	478	5
MO	218	7	687	4
P	430	5	720	4
K	3738	2	2496	2
Ca	143	8	5737	1
Mg	268	6	1412	3
SB	121	9	2633	2
T	83	11	378	5
V	9	33	2577	2
Mean	533	11	1713	6
Depth 0.40 - 0.60 m				
pH	16	25	6	42
H+Al	211	7	324	6
MO	272	6	828	3
P	782	4	415	5
K	11087	1	1745	2
Ca	281	6	1644	2
Mg	486	5	1935	2
SB	352	5	1516	3
T	188	7	293	6
V	45	15	1277	3
Mean	1372	8	1142	7

CONCLUSIONS

- The coefficient of variation gave mean sampling densities greater than initially established by the sampling grid, for both areas at both studied depths.
- Mean spatial range of 31.80 m and 50.20 m at 0.0 – 0.20 m depth and 34.50 and 72.50 at 0.40 – 0.60 m depth for IBE and for soil under native forest, respectively, reveal that for greater distances than the above mentioned, data must be treated as independent. These results suggest that when soil sampling is to be defined, samples can be distant each other up to those distances to be properly treated as spatially dependent.
- These results may assist future studies on spatial variability mapping in IBE and native forest, aiming preservation or sustainable management projects in these areas.

Table 6. Values of sample density and consequent ideal spacing based on the estimated range in geostatistical analysis for chemical attributes of IBE and native forest area in the city of Maricoré, AM.

Tabela 6. Valores de densidade amostral e espaçamento ideal de acordo com base no alcance estimado na análise geoestatística para os atributos químicos em área de TPA e floresta nativa no município de Maricoré, AM.

Attributes	**Sample planning - Geoestatistics**			
	IBE		**Forest**	
	Sampling density (points/ha)	**Spacing (m)**	**Sampling density (points/ha)**	**Spacing (m)**
	Depth 0.0 - 0.20 m			
pH	9	33	7	39
H+Al	20	23	2	73
MO	9	33	2	64
P	18	24	10	32
K	10	31	6	42
Ca	8	35	3	56
Mg	6	40	4	48
SB	20	22	2	73
CTC	5	44	8	36
V	9	33	7	39
Mean	11.4	31.80	5.1	50.2
	Depth 0.40 - 0.60 m			
pH	17	24	4	50
H+Al	14	26	1	84
MO	6	40	1	92
P	3	59	2	79
K	18	24	-	-
Ca	6	40	2	72
Mg	24	21	3	61
SB	8	36	2	63
CTC	4	50	2	79
V	16	25	-	-
Mean	11.6	34.5	2.12	72.5

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