Original Article

CHEMICAL SOIL ATTRIBUTES EVALUATED BY MULTIVARIATE TECHNIQUES AND GEOSTATISTICS IN THE AREA WITH AGROFORESTRY AND SUGARCANE IN HUMAITÁ, AM, BRAZIL

ATRIBUTOS QUÍMICOS DO SOLO AVALIADOS POR TÉCNICAS MULTIVARIADAS E GEOESTATÍSTICAS EM ÁREA COM AGROFLORESTA E CANA-DE-AÇÚCAR EM HUMAITÁ, AM, BRASIL

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ABSTRACT: Studies on the spatial behavior of soil attributes in the Amazon region are still very incipient. In this sense, the objective of this work was to evaluate the chemical attributes through multivariate techniques and geoestatistics in the area with agroforestry and sugarcane in Humaitá, AM, Brazil. The study was carried out in a farm in Humaitá city, Amazonas State. The studied area was divided into 70.00 m x 70.00 m meshes with a regular spacing of 10 m, totaling 64 points and then, soil samples were collected at 0.0-0.2 m and 0.4-0.6 m depths. We performed chemical analyses of the attributes of soil. Then, it was applied descriptive statistics, multivariate and geostatistics. In conclusion, our findings suggest that for most of the chemical attributes was observed spatial dependence in both areas, with DSD varying from weak to moderate, with prevalence of the weak one. The multivariate analysis was efficient in the selection of chemical soil attributes that best represented the agroforestry environments and sugarcane. The results of this study will serve as a basis for further studies on these environments and other systems within the region; moreover serving as a basis for agricultural planning aiming a better environmental sustainability.

KEYWORDS: Spatial variability. Soil attributes. Southern Amazonas.

INTRODUCTION

Soil property variability is generated over time by intensity of soil forming processes (BURROUGH, 1993) and influenced by human activities (SILVEIRA et al., 2000). The knowledge on soil variability may allow a better understanding of relationships between the attributes and environmental factors (GOOVAERTS, 1998) and can help in determining specific management practices (PLANT, 2001); thus contributing to a better sustainable management and minimizing environmental impacts.

In this sense, the use of multivariate analysis technique you can explain as much intercorrelação between the variables and find out which ones contribute more to the characterization and, or, alteration of soil. Na análise simultânea de muitas informações, esta técnica torna-se a melhor ferramenta (CRUZ; REGAZZI 2001). Using set of multivariate techniques can assist in decision-making the use and proper management of soil, based on the behavior of its attributes, and indicate

the attributes that suffer greater change with the anthropic action (OLIVEIRA et al., 2015).

Spatial variability study through geostatistics enables the interpretation of the results based on natural variability structure of evaluated attributes, taking into account the spatial dependence within the sampling interval (SOUZA et al., 2008). However, it is necessary to provide an accurate and reliable sampling to avoid serious interpretation errors (CRUZ et al., 2010).

Nevertheless, there are few studies on spatial behavior of soil attributes in Northern Brazil. Being non-existent chemical attributes studies still in soils under regenerated areas with agroforestry systems. By contrast, it is observed in literature several studies of this variability in soils under sugarcane cropping throughout Brazil (PELUCO et al., 2015; AQUINO et al., 2014; MARQUES JR et al., 2014).

Chemical attribute spatial variability is not only conditioned by soil genesis factors, but also temporal events, different crops and applied treatments within a seemingly homogeneous area (CAON, 2012). Several studies show correlation or

spatial dependence of soil chemical attribute variability (PELUCO et al., 2013; DALCHIAVON et al., 2014; BOTTEGA et al., 2013).

In this context, considering the lack of studies on spatial behavior of chemical attributes in Amazonas region, the objective of this work was to evaluate the chemical attributes through multivariate techniques and geoestatistics in the area with agroforestry and sugarcane in Humaitá, AM, Brazil. The results may help further studies on studies of spatial variability characterization, mapping and cause and effect.

MATERIAL AND METHODS

The study was conducted at two farms located within Humaitá County, Amazonas State in Northern Brazil. Sugarcane area is located at 7º 54' 38" S and 63º 14' 27" W geographical coordinates with an average altitude of 70 m; and the agroforestry area is located at 7º 28' 29" S and 63º 02' 07" W geographical coordinates at an average altitude of 63 m above sea level (Figure 1).
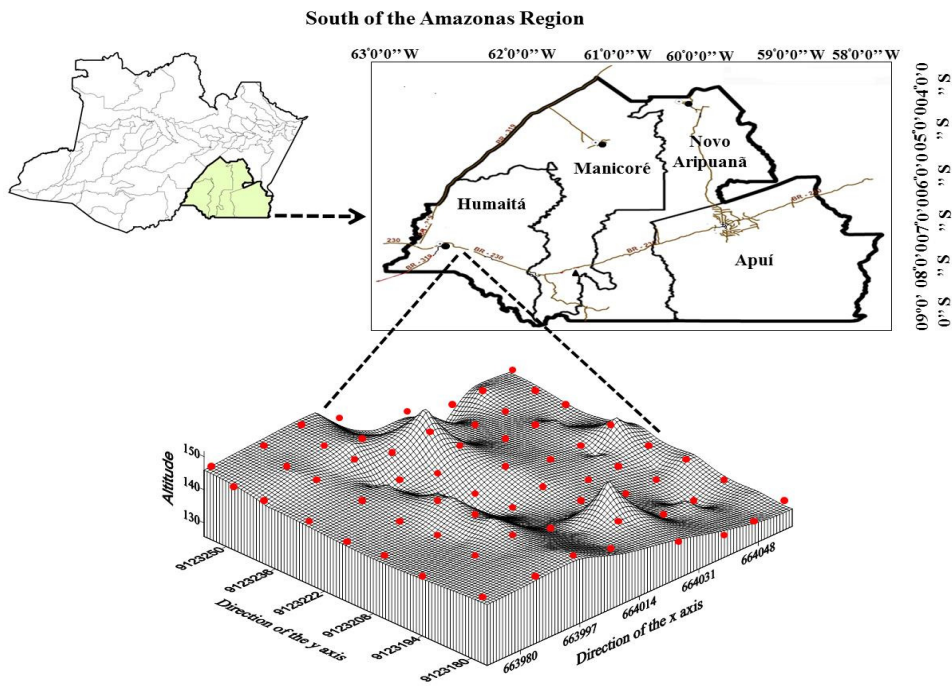

Figure 1. Model Digital Elevation and location of the area of sugar cane and area with agroforestry's in the region in Humaitá-AM.

According to Köppen Classification, local climate is a rainy tropical type (*Am*) (monsoon rain type). The temperatures range between 25 and 27 °C, average annual rainfall is 2,500 mm with a short dry period and rainy season from October to June, and relative humidity between 85 and 90%. In both areas the soil was classified as Alitic Plinthic Cambisol (CXalf) according to Embrapa (2013) (Inceptisol).

The area of sugarcane has more than eight years, with manual harvest after firing; last year, the Office performed the cutting and burning of the plants, for renewal of the crop. The area has approximately 17 years agroforestry cultivated with fruit Amazonian species (cacao, açaí, cupuaçu, bacaba, manga etc.); However, the area was

managed with implements manuals, running rough for invasive methods manuals, using machete and Scythe. Soils were sampled between May and July 2011.

Over these areas, seventy-square-meter meshes were established and soil samples were collected at mesh crossing-points, with regular spacing of each 10 meters, making 64 sampling points by mesh (Figure 1). These points were georeferenced using a Garmin 'Etrex' GPS receiver (South American´69). Next, soil sampling at 0.0-0.2 and 0.4-0.6 m for determination of granulometric and chemical attributes, totaling 128 soil samples in each mesh. Particle size characterization of the samples are shown in Table1.

Table 1. Granulometric Analyzes (g.kg^{-1}) for sugar cane and agroforestry in Humaitá, AM.

Clay	Silt	Sand	Clay	Silt	Sand
Depth 0.0-0.2 m			Depth 0.4-0.6 m		
Cane					
284.94	474.49	240.57	323.27	467.70	209.02
Agroforestry					
284.94	230.11	220.79	510.89	284.77	204.33

The chemical elements and values were extracted by the following techniques: exchangeable calcium, magnesium and aluminum by KCl; available phosphorus and potassium by Mehlich-1; potential acidity (H + Al) by buffered solution of calcium acetate at pH 7.0 (EMBRAPA, 1997). Based on the results of this chemical analysis, it was calculated the sum of bases (SB), cation exchange capacity (CEC) and base saturation (V%).

The pH was determined potentiometrically using a 1: 2.5 soil and water ratio. Total carbon was determined by Walkley-Black method, which Yeomans and Bremner (1988) changes; and organic matter content, in turn, was estimated based on organic carbon.

Particle size analysis was performed by the pipette method using a 0.1 mol L-1 NaOH solution as a chemical dispersant and mechanical shaking at high speed for 15 min as proposed by Embrapa (1997).

Factors were analyzed to relate a set of variables to be explained in terms of a limited number of new variables. We chose to use the principal component extraction (JEFFERS, 1978), which is calculated from the correlation matrix between variables. To facilitate interpretation, we used the method called orthogonal varimax rotation (HOFFMANN, 1992).

Factor analysis was complemented by a principal component analysis (PCA) to obtain a smaller set of linear combinations of the selected variables to analyze factors that have preserved most of the information provided by the original variables (SILVA et al., 2010) . This analysis makes it possible to assess how attributes interact qualitatively at the same time, whose original values were normalized to a mean of zero and variance equals to one to compose variables used in PCA. Components were selected by their eigenvalues, which had to be above 1.00 and be able to synthesize a cumulative variance above 70% (HAIR et al, 2005).

After data collection, we performed exploratory data analysis, calculating means, median, variance, coefficients of variation, skewness and kurtosis and normality test. The coefficient of variation (CV) was calculated as proposed by Warrick and Nielsen (1980), who classified it as low (CV <12%), medium (from 12% to 60%) and high (CV > 60%). The data normality hypothesis was tested using the Kolmogorov-Smirnov test through the Minitab 14 statistical software (Minitab, 2000).

Spatial variability characterization was made through geostatistics (ISAAKS and SRIVASTAVA 1989). On basis of intrinsic hypothesis theory, the experimental semivariogram was estimated by the following Equation (1):

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

(1)

wherein:
$\gamma(h)$ – semivariance value for sample sites separated by an **h** distance;
N(h) – number of pairs involved in semivariance calculation;
$Z(x_i)$ – value of Z attribute at **xi** site;
$Z(x_i+h)$ - value of Z attribute separated by an **h** distance from **xi** site.

From a mathematical model fit to the calculated values of $\gamma(h)$, the theoretical model coefficients are set for the semivariogram (nugget effect, C_0; structural variance, C_1; sill, $C_0 + C_1$; and range, a). The nugget effect is the semivariance value at zero distance and represents random variation component; sill is the semivariance value in which the curve is steady at a constant value; range is the distance from origin up to where sill reaches stable values, expressing distances beyond those in which samples are correlated (VIEIRA et al., 1983; TRANGMAR et al., 1985). In spatial dependence determination, we used the semivariogram exam through the GS$^+$ software (ROBERTSON, 1998). In case of doubt among more than one model for the same semivariogram, it was considered the best R^2 (coefficient of determination).

In the spatial dependence analysis of variables under study, we used the classification proposed by Cambardella et al., (1994), in which $[(C_0/(C_0+C_1)]$ values lower than 25% are considered strong, between 25 and 75% indicate moderate and higher than 75% poor spatial dependence.

RESULTS AND DISCUSSION

Based on knowledge of the variation of chemical attributes variation among management systems, we performed a factor analysis (Table 2).

This procedure helped in selecting attributes that had greater factor load by varimax method, wherein, it can be established which attributes had discriminatory power in common to the studied managements.

Table 2. Factors extracted by principal component analysis, emphasizing chemical attributes of factor load above 0.7 (module) for the studied managements in Humaitá – AM, Brazil.

Attributes	Depth 0-20 cm		Depth 20-40 cm	
	Factor 1	Factor 2	Factor 1	Factor 2
pH H_2O	0,650232	0,739210	-0,832283	0,316645
Potential acidity	-0,565528	-0,787364	-0,962788	-0,024864
Organic matter	0,958053	0,137539	0,383626	-0,916440
Organic Carbon	0,958053	0,137539	-0,440249	-0,894126
Phosphorus	0,185738	-0,885345	-0,256506	0,088058
Potassium	-0,361017	-0,788535	-0,987312	0,107913
Calcium	0,720740	0,668949	0,631169	0,559974
Magnesium	0,741923	0,612555	-0,789116	0,503560
Base sum	0,737543	0,640165	0,903290	0,242212
Cation exchange capacity	-0,508118	-0,797619	0,971143	0,115700
Base saturation	0,674863	0,707977	0,879777	0,205028
Eigenvalue s	8,627062	1,423419	7,148572	2,454421
% Total variance	78,42783	12,94017	64,98702	22,31292
Cumulative eigenvalue	8,62706	10,05048	7,14857	9,60299
% Cumulative	78,42783	91,36801	64,98702	87,29994

In the factor analysis it was found that the first two factors in the depth of 0-20 cm explained altogether 91.30% of the total variance of the data and showed that all attributes showed high factor loadings. OM, CB, Ca, Mg, and BS are the most important attributes for the determination of Factor 1 which explains 78.42% of the total variance. The pH, H + Al, P, K, CEC and BS is related to Factor 2, which explained 12.94% of the variance. In the depth of 20-40 cm explained as a whole 87.30% of the total variance of the data and showed that all attributes the exception of P and Ca showed high factor loadings. The pH H + Al, K, Mg, CEC and BS attributes are the most important factor for determining the one that explained 64.98% of the total variance. The OM and OC is related to Factor 2, which explained 22.31% of the variance.

Principal component analysis (PCA) was performed using high discriminatory-power variables (Figure 2 and 3). Using the ACP from the selected data in the 0-20 cm depth (Figure 2), it was possible to explain 91.36% of the total variance in the first two components (CP1 and CP2) and evaluate the interaction of attributes with the studied management.

A OC, OM, BS, V%, Ca, Mg e pH related to sugarcane occurs due to the continuous application of limestone and fertilizers that contribute to an increase of base content and the straw the contribution of sugarcane. It indicates that perhaps these attributes are the most sensitive to changes and, therefore better able to reflect local balance alterations than other attributes. This way, they can be considered indicators of environmental changes. The attributes P, K, CTC and H + Al are directly related to agroforestry environment. In agroforest, CEC and H + Al attributes are linked to organic material and plant waste decomposition, which forms water-soluble organic complexes of Ca and Mg with organic binders (MIYAZAWA et al., 1993), facilitating leaching of cations along the soil profile.

In the 20-40 cm depth, it was possible to explain 89.21% of the total variance in the first two components (CP1 and CP2), Figure 3, and evaluate the interaction of attributes with the studied management. The variables H + Al, CTC, K, OC, OM are related to the development environment, while the variables pH, Mg, SB and V% are related to the environment of sugar cane similar to that observed in depth of 0-20 cm.
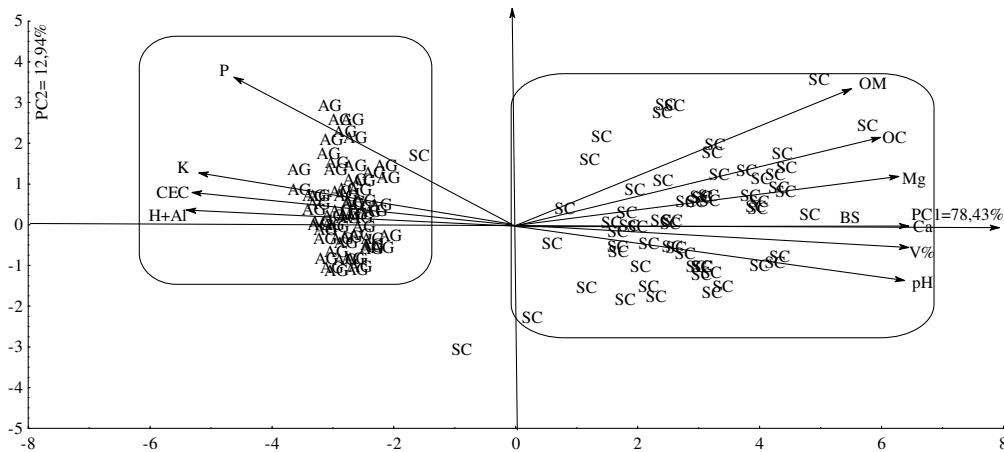
Figure 2. Principal component analysis (PCA) of soil chemical attributes with high discriminatory power for the studied managements in Humaitá County – AM, Brazil in deph 0-20 cm. SC= sugarcane; AG= agroforestry; Ca= calcium; Mg= magnesium, P= Phosphorus ; K=Potassium; OM= Organic matter; OC= Carbon Organic; BS= base sum; CEC= cation exchange capacity; V% = base saturation; pH; H+Al= Potential acidity.

Figure 3. Principal component analysis (PCA) of soil chemical attributes with high discriminatory power for the studied managements in Humaitá County – AM, Brazil in deph 20-40 cm. SC= sugarcane; AG= agroforestry; Ca= calcium; Mg= magnesium, P= Phosphorus ; K=Potassium; OM= Organic matter; OC= Carbon Organic; BS= base sum; CEC= cation exchange capacity; V% = base saturation; pH; H+Al= Potential acidity.
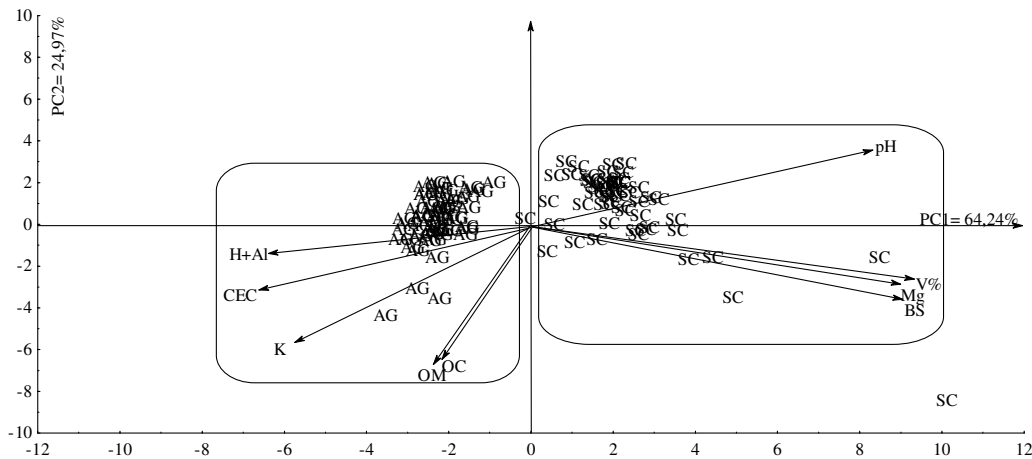
Chemical data frequency distribution in soil was evaluated using descriptive statistics, and it showed values close to mean and median of almost all studied variables. This fact demonstrate a distribution near to normal, which is justified by skewness and kurtosis values near to zero (Table 3 and 4).

Some data had no symmetric distribution, since they have mean and median values somewhat remote. This indicates influence by extreme values, being Ca, Mg, BS (0.0-0.2 and 0.4-0.6 m) and V% (0.4-0.6 m) in agroforestry area (Table 3); H+Al and CEC (0.0-0.2 m); H+Al, OM, Mg, BS, CEC and V% (0.4-0.6 m) in sugarcane area (Table 3). Consequently, it can be observed kurtosis and skewness values farther away from zero, which confirms the fact that these variables did not follow the pattern of this distribution curve being non symmetric. According to Silva (2010), the skewness coefficient is used to characterize how and how much the frequency distribution deviates from symmetry, if $Cs > 0$, there is a right asymmetrical distribution; $Cs < 0$, there is a left asymmetrical distribution; and when $Cs = 0$, the distribution is

symmetrical. Cortez et al., (2011) claim that as the asymmetry and kurtoses values are closer to zero, the greater the normality of the data. Therefore, the information of these parameters makes the adjustment "by feeling" of the semivariogram.

Table 3. Descriptive statistics of chemical attributes in area of agroforestry's in Humaitá, AM.

Attributes	Unit	Mean	Median	Mín	Máx	SD	Var.	CV%	Kurtosis	Skew.	d
					Depth 0.0 – 0.2 m						
pH	H_2O	3.78	3.80	3.60	3.90	0.06	0.00	1.53	0.80	-0.48	0.06^{ns}
H+Al	$mmol\ kg^{-1}$	189.52	185.00	150.00	228.00	17.54	307.78	9.26	-0.48	-0.51	0.05^{ns}
OM	g,dm^{-3}	20.58	20.50	14.00	30.00	3.19	10.15	15.48	0.63	0.79	0.09^{ns}
P	$mg\ dm^{-3}$	8.19	8.00	6.00	13.00	1.55	2.41	18.96	0.39	0.57	0.04^{ns}
K	$mmol\ kg^{-1}$	1.11	1.10	0.60	1.80	0.24	0.06	21.78	0.76	0.59	0.07^{ns}
Ca	$mmol\ kg^{-1}$	2.39	2.00	2.00	4.00	0.55	0.31	23.11	0.09	1.03	0.09^{ns}
Mg	$mmol\ kg^{-1}$	1.36	1.00	1.00	2.00	0.48	0.23	35.58	-1.69	0.60	0.10^{ns}
BS	$mmol\ kg^{-1}$	4.86	4.15	3.60	7.40	1.15	1.33	23.73	-1.29	0.67	0.28^{*}
CEC	$mmol\ kg^{-1}$	194.37	191.40	154.70	232.10	17.45	304.44	8.98	-0.54	-0.51	0.24^{*}
V	%	2.52	2.20	1.77	4.03	0.66	0.44	26.24	-0.80	0.75	0.18^{*}
					Depth 0.4 – 0.6 m						
pH	H_2O	3.81	3.80	3.70	3.90	0.05	0.002	1.23	1.74	0.23	0.06^{ns}
H+Al	$mmol\ kg^{-1}$	211.86	205.00	166.00	253.00	18.64	347.36	8.80	-0.81	-0.40	0.06^{ns}
OM	$g\ dm^{-3}$	10.66	10.50	7.00	19.00	2.39	5.69	22.38	1.81	1.02	0.06^{ns}
K	$mmol\ kg^{-1}$	0.64	0.60	0.40	1.00	0.10	0.01	16.43	2.48	0.95	0.06^{ns}
Mg	$mmol\ kg^{-1}$	1.02	1.00	1.00	2.00	0.13	0.02	12.31	64.00	8.00	0.05^{ns}
BS	$mmol\ kg^{-1}$	2.84	2.60	2.40	5.70	0.55	0.30	19.20	11.34	2.96	0.32^{*}
CEC	$mmol\ kg^{-1}$	214.70	208.75	168.50	255.60	18.80	353.57	8.76	-0.84	-0.41	0.27^{*}
V	%	1.33	1.25	1.02	2.44	0.23	0.05	17.30	7.77	2.16	0.11^{*}

Min.= Minimum; Max.= Maximum; SD = Standard deviation; Var. = Variance; CV = Coefficient of variation; Skew.= Skewness; d = normality test, * significant by the Kolmogorov-Smirnov test ($p \leq 0,05$).

Table 4. Descriptive statistics of chemical attributes in area of sugar cane in Humaitá, AM.

Attributes	Unit	Mean	Median	Mín	Máx	SD	Var.	CV%	Kurtosis	Skew.	d
					Depth 0.0 – 0.2 m						
pH	H_2O	4.43	4.50	3.90	4.70	0.15	0.02	3.39	1.07	-0.85	0.05^{ns}
H+Al	$mmol\ kg^{-1}$	89.64	80.00	64.00	205.00	21.09	444.68	23.52	13.43	2.96	0.15^{*}
OM	g,dm^{-3}	30.48	30.50	11.00	47.00	6.25	39.11	20.52	1.01	-0.05	0.07^{ns}
P	$mg\ dm^{-3}$	6.36	7.00	3.00	10.00	1.57	2.46	24.64	-0.60	-0.06	0.04^{ns}
K	$mmol\ kg^{-1}$	0.49	0.50	0.30	0.70	0.11	0.01	22.98	-0.77	0.02	0.04^{ns}
Ca	$mmol\ kg^{-1}$	14.58	15.00	4.00	27.00	4.17	17.42	28.63	0.41	0.07	0.03^{ns}
Mg	$mmol\ kg^{-1}$	8.06	8.00	3.00	16.00	2.84	8.06	35.21	0.32	0.75	0.07^{ns}

BS	mmol kg^{-1}	23.13	23.30	7.40	43.60	6.92	47.85	29.90	0.23	0.33	0.06 ns
CEC	mmol kg^{-1}	112.77	107.50	91.60	216.70	18.35	336.85	16.27	15.77	3.30	0.19 *
V	%	21.06	21.6	5.4	35.3	6.83	46.70	32.44	-0.45	-0.12	0.05 *
				Depth 0.4 – 0.6 m							
pH	H$_2$O	4.06	4.10	3.90	4.30	0.07	0.01	1.75	2.77	0.82	0.08 ns
H+Al	mmol kg^{-1}	126.66	121.00	80.00	185.00	19.44	378.10	15.35	2.86	1.03	0.10 ns
OM	g dm^{-3}	8.69	8.00	5.00	20.00	2.48	6.15	28.56	5.94	1.97	0.14 *
K	mmol kg^{-1}	0.40	0.40	0.20	0.60	0.09	0.01	23.31	0.46	0.31	0.03 ns
Mg	mmol kg^{-1}	2.16	2.00	1.00	7.00	0.98	0.96	45.42	12.19	3.02	0.10 ns
BS	mmol kg^{-1}	6.18	5.40	3.30	19.50	2.48	6.16	40.16	14.35	3.40	0.30 *
CEC	mmol kg^{-1}	132.83	126.40	94.50	190.50	18.52	342.82	13.94	2.95	1.42	0.23 *
V%	%	4.83	4.27	2.65	19.60	2.64	6.99	54.72	18.49	3.96	0.26 ns

Min.= Minimum; Max.= Maximum; SD = Standard deviation; Var. = Variance; CV = Coefficient of variation; Skew.= Skewness; d = normality test, * significant by the Kolmogorov-Smirnov test ($p \leq 0,05$).

Regarding the chemical attribute mean values for both areas (agroforestry and canesugar), it can be observed different values for both attributes (Table 3 and 4). The agroforestry had higher values for the area under sugarcane. However, higher CEC values for agroforestry area are observed, with 194.37 and 214.70 mmol/kg at 0.0-0.2 and 0.4-0.6 depths, respectively. Such fact may be due to the strong influence of potential acidity (H + Al) with 189.52 and 211.86 mmol/kg at 0.0-0.2 m and 0.4-0.6 m depths, respectively. In contrast, sugarcane presented CEC values of 112.77 and 132.63 mmol/kg at 0.0-0.2 m and 0.4-0.6 m depths, respectively, which were less influenced by potential acidity that showed values of 89.64 and 126.66 mmol/kg at both respective depths.

Considering the coefficient of variation limits proposed by Warrick and Nielsen (1980), pH, H+Al and CEC (at 0.0 – 0.2 and 0.4 – 0.6 m depths) only for agroforestry and singly pH (at 0.0 – 0.2 and 0.4 – 0.6 m depths) for sugarcane presented low coefficients (CV < 12 %), which is an indicative of low variability. Mg and V% (at 0.0 – 0.2 m depth) and P, Ca, Mg, BS and V% (at 0.0 – 0.2 m depth); OM, Mg, BS and V% (0.4 – 0.6 m depth) in grazing area presented high CV (CV >24.1%). The other variables presented moderate CV for both environments (CV > 12.1% < 24%). In this way, it is observed a greater predominance of moderate variability in the chemical attributes for both agroforestry and sugarcane, what demonstrate moderate to high heterogeneity of such attributes.

As stated by Camargo et al., (2008), the CV enables to compare variability between samples of different unit variables; however, it does not aid in the analysis of spatial variability of soil attributes neither the spatial pattern. Therefore, attribute variability encountered in our study can justify spatial dependence, what make easy to understand their occurrence pattern. Carvalho et al., (2003) asserted that results of soil attribute analysis are used to present high coefficient of variation values.

It was observed normality by Kolmogorov-Smirnov test for the attributes BS, CEC and V% at both depths in agroforestry. Likewise in sugarcane H+Al, CEC, V% at 0.0-0.2 m depth and OM, BS and CEC at 0.4 – 0.6 m. However, the other variables did not present data normality in any area.

The evaluated attributes undergone to semivariogram application to analyze their spatial dependence. Tables 4 and 5 show the semivariogram parameters. There was an exponential model fit for H+Al (0.0 - 0.2 m), pH and OM (0.4 - 0.6 m). In addition, P and CEC (0.0 - 0.2 m) and H+Al, Mg, BS, CEC, V% (0.4 - 0.6 m) were fit to the spherical model. For the other variables, there was no fit to any model (Table 5).

When the studied variable is spatially independent, the C_0 (nugget effect) is equal to the $C_1 + C_0$ (sill), which is known as a pure nugget effect (PNE). PNE is important and indicates random distribution, i.e., unexplained variability or undetected variation, and it may occur due to measurement, sampling errors or non-detected micro-variation, considering the used sampling space greater than required to detect spatial dependence (CAMBARDELLA et al., 1994).

In sugarcane area, there was spherical and exponential model fit, with predominance of spherical at 0.00 to 0.20 m depth; inversely, at 0.4 - 0.6 m depth, the exponential model was bet fit (Table 6).

Tabela 5. Models and parameters estimated semivariogram of the chemical attributes in agroforestry area in Humaitá AM.

Attributes	Unit	Model	NE (C_0)	Sill (C_0+C_1)	Reach (a)	R^2	DSD
				Geoestatistics			
			Depth 0.0 – 0.2 m				
pH	H_2O	PNE	-	-	-	-	-
H+Al	mmol kg^{-1}	Exp.	3.9E-004	7.1E-003	45.60	0.77	0.94
MO	g dm^{-3}	PNE	-	-	-	-	-
P	mg dm^{-3}	Sph.	0.08	2.47	84.64	0.95	0.96
K	mmol kg^{-1}	PNE	-	-	-	-	-
Ca	mmol kg^{-1}	PNE	-	-	-	-	-
Mg	mmol kg^{-1}	PNE	-	-	-	-	-
BS	mmol kg^{-1}	PNE	-	-	-	-	-
CEC	mmol kg^{-1}	Sph.	93.70	282.30	52.50	0.96	0.67
V	%	PNE	-	-	-	-	-
			Depth 0.4 – 0.6 m				
pH	H_2O	Exp.	1.18^{-004}	2.99$^{-00,3}$	37.60	0.82	0.60
H+Al	mmol kg^{-1}	Sph.	14.14	371.80	66.58	0.94	0.96
MO	g dm^{-3}	Exp.	0.30	5.70	29.10	0.74	0.94
K	mmol kg^{-1}	PNE	-	-	-	-	-
Mg	mmol kg^{-1}	Sph.	0.001	0.02	54.00	1.00	0.90
BS	mmol kg^{-1}	Sph.	0.13	0.20	44.75	0.88	0.34
CEC	mmol kg^{-1}	Sph.	9.31	382.73	68.17	0.95	0.97
V	%	Sph.	0.001	0.03	19.80	0.69	0.94

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.

Tabela 6. Models and parameters estimated semivariogram of the chemical attributes in cane area in Humaitá AM.

Attributes	Unit	Modelo	C_0	C_0+C_1	a (m)	R^2	DSD
				Estatística			
			Depth 0.0-0.2 m				
pH	H_2O	Sph.	0.00	0.01	17.40	0.83	0.77
H+Al	mmol kg^{-1}	Exp.	40.20	205.02	23.35	0.81	0.80
MO	g dm^{-3}	Exp.	8.11	40.40	26.10	0.97	0.79
P	mg dm^{-3}	Sph.	0.26	2.34	33.00	0.77	0.88
K	mmol kg^{-1}	Sph.	0.00	0.01	18.70	0.57	0.84
Ca	mmol kg^{-1}	Sph.	2.43	13.08	15.70	0.59	0.81
Mg	mmol kg^{-1}	Sph.	2.10	6.50	14.10	0.91	0.67
BS	mmol kg^{-1}	Sph.	0.01	0.07	18.50	0.81	0.77
CEC	mmol kg^{-1}	Exp	34.04	174.30	26.70	0.97	0.80
V	%	Sph.	0.02	0.12	13.90	0.81	0.75
			Depth 0.4-0.6 m				
pH	H_2O	Exp.	0.00	0.002	28.20	0.93	0.78
H+Al	mmol kg^{-1}	Exp.	29.32	285.27	28.65	0.82	0.89
MO	g,dm^{-3}	Exp.	1.08	3.82	27.30	0.90	0.71
K	mmol kg^{-1}	Sph.	0.004	0.008	31.00	0.93	0.50
Mg	mmol kg^{-1}	Exp.	0.07	0.22	47.40	0.98	0.82
BS	mmol kg^{-1}	Exp.	0.26	1.35	21.60	0.92	0.80
CEC	mmol kg^{-1}	Exp.	80.16	280.72	29.72	0.74	0.71
V	%	Sph.	0.02	0.80	34.20	0.96	0.71

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.

It is observed a spherical model predominance of the chemical attributes in both areas, similarly to other authors' results (MONTANARI et al., 2008; CARVALHO et al., 2010). For Trangmar et al., (1985), Cambardella et al., (1994), Carvalho et al., (2003) and Cavalcante et al., (2007), spherical and exponential models are considered as the most common theoretical models for soil and plant properties.

The nugget effect (C_0) is a crucial parameter to be considered as it represents the unexplained or random variance, which is constantly caused by measurement errors or variations of attributes that cannot be detected at sampling scale (VIEIRA, 2000). The lower the rate between nugget effect and sill of the semivariogram, the greater the spatial dependence presented by the attribute. With this, the greater the phenomenon continuity, the lower the estimation variance and the greater the confidence in the estimated value. As suggested by Cambardella et al., (1994), the chemical properties were classified according to spatial dependence magnitude, taking into account the nugget effect.

In agroforestry area, H+Al and P (0.0 - 0.2 m), pH, and BS (0.4 - 0.6 m) were classified as moderate DSD; however, the other variables were ranked as poor DSD for both depths. The same behavior is observed in sugarcane area, where we observed that only Mg and V% (0.0 - 0.2 m), OM, K, CEC and V% (0.4 - 0.6 m) were classified with moderate DSD, while the rest were weak. Some researches, such as Souza et al., (2006), and Campos et al., (2007) found an DSD range in sugarcane from strong to moderate.

The strong spatial dependence of soil attributes is commonly attributed to intrinsic factors, whereas extrinsic factors favor weak dependence (CAMBARDELLA et al., 1994). Thus, the moderate spatial dependence and weak would be due to soil homogenization from the different uses and management systems (CAVALCANTE et al., 2007).

An important parameter in semivariogram studies is the range. This parameter indicates the maximum distance at which the sampling points are correlated (VIEIRA et al., 1983), in other words, measurements performed at greater distances have randomized distribution, being therefore, independent from each other. It is an important measure for experimental planning and evaluation and may help to define sampling procedures with direct application in the sample plan.

It is noteworthy to mention that in agroforestry site, range values vary from 45.60 m to 84.64 m at first depth and from 19.80 m to 68.17 m at the second one. While in sugarcane area, these values range from 13.90 m to 33.00 m at 0.0 to 0.2 m depth and 21.30 m to 57.70 m at 0.4 to 0.6 m. It was noticed that in agroforestry area, the range of values are much higher when compared to sugarcane, indicating a higher spatial continuity in this area. Therefore, beyond vertical variation, there is also variability among the horizontal depths for both areas, since range was different for the variables at the different evaluated depths.

CONCLUSIONS

In conclusion, our findings suggest that for most of the chemical attributes was observed spatial dependence in both areas, with DSD varying from weak to moderate, with prevalence of the weak one.

The multivariate analysis was efficient in the selection of chemical soil attributes that best represented the agroforestry environments and sugarcane.

The results of this study will serve as a basis for further studies on these environments and other systems within the region; moreover serving as a basis for agricultural planning aiming a better environmental sustainability.

ACKNOWLEDGEMENTS

RESUMO: Existe uma carência de estudos enfocando o comportamento espacial de atributos químicos no Amazonas. Neste sentido o objetivo deste trabalho foi avaliar os atributos químicos do solo por meio de técnicas multivariadas e geoestatística em área com agrofloresta e cana-de-açúcar em Humaitá, AM, Brasil. O estudo foi realizado em uma propriedade rural em Humaitá, Amazonas. Nestas áreas foram estabelecidas malhas de 70,00 m x 70,00 m, com espaçamento regular de 10,00 x 10,00 m totalizando 64 pontos e em seguida, coletadas amostras de solos na profundidade de 0,0-0,20 e 0,40 – 0,60 m. Foram determinados os atributos químicos (pH, MO, P, K, Ca, Mg, SB, CTC, V% e H+Al). Utilizaram-se técnicas de estatística descritiva, multivariada e geoestatística. Em conclusão, nossos resultados sugerem que, para a maioria dos atributos químicos foi observada dependência espacial em ambas as áreas, com DSD variando de fraca a moderada, com prevalência de um fraco e a análise multivariada foi eficiente na seleção de atributos químicos do solo que melhor representou os ambientes de agrofloresta e cana de açúcar.

PALAVRAS-CHAVE: Variabilidade espacial. Atributos do solo. Sul do Amazonas.

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