Acta Iguazu
ISSN: 2316-4093

Spatial dependence of soil attributes in natural field and forest areas, Humaitá, AM

Igor Hister Lourenço[1], Milton Cesar Costa Campos[1], Leandro Coutinho Alho[2], Jose Mauricio da Cunha[1], Bruno Mantovaneli[3], Douglas Marcelo Pinheiro da Silva[1]

[1]Universidade Federal do Amazonas - IEAA, Rua 29 de Agosto, 786, 69.800-000 – Humaitá/AM/Brazil
[2]Instituto Federal de Educação, Ciência e Tecnologia do Amazonas, Rua 22 de outubro, s/nº, Vila Falcão. Lábrea/AM. CEP: 69830-000.
[3]Universidade Federal de Santa Maria. Santa Maria, Rio Grande do Sul, Brasil, CEP:97105-900.

E-mail autor correspondente: igorhisteragro@gmail.com

Artigo enviado em 11/11/2017, aceito em 20/11/2018.

Abstract: The great geological diversity in Amazonas region generates a variety of soils. Among the various vegetation types in the Amazon, we have in the Southern region, toposequences of natural fields and forests, which includes since grasslands with alternated small trees, to isolated forest galleries along streams. The aim of this study was to use scaled semivariograms in spatial dependence of soil attributes in areas of natural fields and forest in Humaitá, AM region. Sampling networks were established with 64 points, with dimensions of 70 x 70 m and regular spacing of 10 m. The soil was sampled at depths of 0 – 0.05; 0.05 – 0.10 and 0.10 – 0.20 m for the following determinations: macroporosity, microporosity, total porosity, soil moisture, soil resistance penetration (SRP), bulk density, organic carbon, storage carbon and soil organic matter. All variables showed a strong spatial dependence structure in both areas and layers, reaching upper ranges than those established in the mesh. Bulk density (BD) and soil resistance penetration (SRP) in natural field area, can yet cause agricultural problems.

Keywords: soil management, Southern Amazon, geostatistics.

Dependência espacial dos atributos do solo em áreas naturais e florestais, Humaitá, AM

Resumo: A grande diversidade geológica na região do Amazonas gera uma variedade de solos. Entre os vários tipos de vegetação na Amazônia, temos na região Sul, topossequências de campos e florestas naturais, que incluem desde pradarias com pequenas árvores alternadas, até galerias florestais isoladas ao longo de córregos. O objetivo deste estudo foi utilizar semivariogramas escalonados na dependência espacial de atributos do solo em áreas de campos naturais e floresta em Humaitá, AM. Redes de amostragem foram estabelecidas com 64 pontos, com dimensões de 70 x 70 me espaçamento regular de 10 m. O solo foi amostrado em profundidades de 0 - 0,05; 0,05 - 0,10 e 0,10 - 0,20 m para as seguintes determinações: macroporosidade, microporosidade, porosidade total, umidade do solo, penetração da resistência do solo (PPR), densidade do solo, carbono orgânico, carbono armazenado e matéria orgânica do solo. Todas as variáveis apresentaram forte estrutura de dependência espacial em ambas as áreas e camadas, atingindo faixas superiores às estabelecidas na malha.

Densidade a granel (BD) e penetração da resistência do solo (SRP) na área de campo natural, ainda podem causar problemas agrícolas.

Palavras-chave: manejo do solo, Sul da Amazônia, geoestatística.

Introduction

As world population grows, so grows the need for food production, and, consequently, agricultural land changes. According to Barona et al. (2010), the role of soybean and pasture cultivation, may still be one of the major underlying causes of deforestation in the Legal Amazon. This information matches with recent soy investments in Southern Amazonas region, as shown by SEPROR (2017). However, the area where this investment happened, do not correspond to forest areas, but to natural fields, more commonly known as "*Campos de Puciari-Humaitá*", which includes since grasslands with alternated small trees to isolated forest galleries along streams (Braun & Ramos, 1959). This phenomenon covers a Southern and Eastern portion of the Amazonas, West of Rondônia and Northern Roraima (FREITAS et al., 2006) with savanna characteristics associated with forest mosaics, conditioned to local soil factors (CAMPOS et al., 2010).

This makes us reflect about a few questions. Should soy and pasture production really be considered a taboo in Amazon? Can these areas be a good alternative to slow down the deforestation process by occupying non-forested areas? And, for last, and the main aim of this work, are the soil physical conditions in these areas favorable for crops development?

The Southern Amazonas region is located at the Amazonian Craton, which has a large pedologic and geomorphologic diversity, justifying the wide variety of soils and environments. With dominance of Ultisols (51%), Oxisols (27.4%), Entisols (8.5%), among others, it is an area with well-drained and deeply weathered soils (SCHAEFER, 2013).

The physical behavior of the soil is closely related to characteristics of its pore space (macroporosity, microporosity and total porosity), especially as regards its distribution, continuity in the soil profile and its stability over time (BRAIDA, 2011). The retention and availability of water in the soil for the plants are essential production factors to the development of crops (REICHERT et al., 2011). These production factors, in its turn, has straight relation with other soil properties such as: bulk density, soil resistance penetration, soil organic matter (OM), among others, as shown in recent studies of natural and transformed environments (CAMPOS et al., 2015).

Braida (2011) also states that the organic matter has implications on the physical behavior of soil, either by acting directly on some of its physical processes, or by its indirect effects. These effects are related to the soil organic matter capacity to form complexes with the clay fraction, influencing some physical properties (DEXTER et al., 2008). Some authors suggest that changes in the levels of soil organic matter can cause implications for water retention forces on the ground and their availability (COSTA et al., 2003). Making the soil organic carbon (OC) essential to understand the soil operation and maximize the benefits of management practices in tropics (LAL, 2005).

Taking in consideration that

terrain micro-variations can promote geospatial variation of soil attributes (AQUINO et al., 2015; CAMPOS et al., 2007), the use of geostatistical techniques shows useful in the study of soil attributes and its spatial dependence, aiming to evaluate distribution, reduce risks of environmental contamination and increase crops development (CAVALCANTE et al., 2007). The most commonly method used for predicting soil properties variety is kriging (WEBSTER and OLIVER, 2007). In other words, extra statistical analyses are good tools to measure these variations (SOUZA et al., 2006).

That way, seen the expanding agriculture over this region and in order to contribute with the knowledge construction over these areas for possible investments. The objective of this study was to use the statistics and geostatistics to determine the spatial dependence, ideal sampling space and other useful information about soil physical attributes in a natural field and a forest area in Southern Amazonas region.

Materials and Methods

The study area (Figure 1) is located in 54º Brazilian Army Jungle Infantry Battalion (7º 30'24 "S and 63º 04'56" W), on surroundings of BR 230, in the municipality of Humaitá, AM. The climate is type Am, rainy tropical according to Köppen classification, with a dry period of short duration, with temperatures ranging between 25°C and 27°C and average annual rainfall of 2,500 mm, with the rainy season starting in October and extending until June.

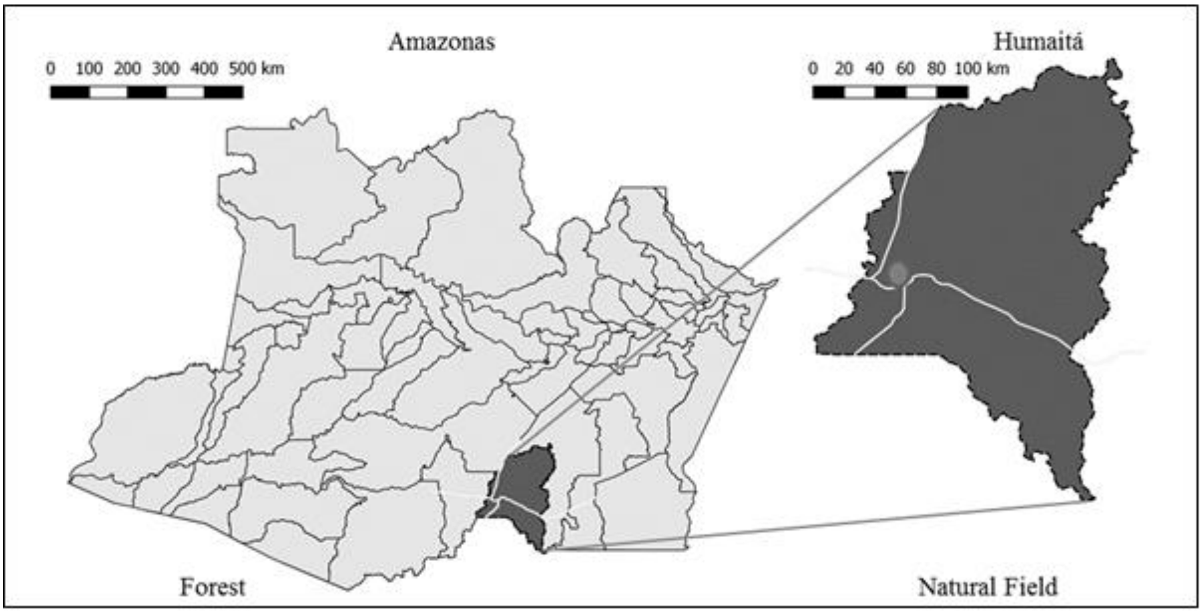


Figure 1. Location map.

According to Braun and Ramos (1959), the region presents relief similar to the "board" type, with very small gaps and slightly bulging lips. It also presents geology formed by ancient alluvial undifferentiated referred to Holocene. Sediments of this formation are from two sedimentation cycles, the first of lower sandy banks, representing pluvio-fluvial sedimentation, and the second of upper argillaceous sediments, indicating lacustrine sedimentation.

The common vegetation in this region are the natural fields, which includes since grasslands with alternated small trees, to isolated forest galleries along streams (BRAUN and RAMOS, 1959). These areas make up some mosaics with the surrounding forests, and the contact between these vegetations in some places occurs abruptly, and others more gradually. These soils, according to Embrapa and adapted to United States Department of Agriculture (EMBRAPA, 2013; USDA, 2010), in natural field area is a *Cambissolo Háplico Alítico Plíntico* (Inceptsol, USDA Soil Taxonomy) and in the forest, an Argissolo Vermelho Alítico Plíntico (Ultisols, USDA Soil Taxonomy), both classified by Campos et al. (2012).

The soil samples were taken in March and October 2013, respectively in the areas of natural field and forest, collected in sampling grid scheme established in each environment, with dimensions of 70 x 70 m, 10 m between points, and three layers: 0.0-0.05 m; 0.05-0.10 m and 0.10-0.20 m, totalizing 64 samples per layer. Each sample point was georeferenced with a GPS model GPSMAP 76CS and altitude measured with precision level for the construction of digital elevation model (DEM) (Figure 2).

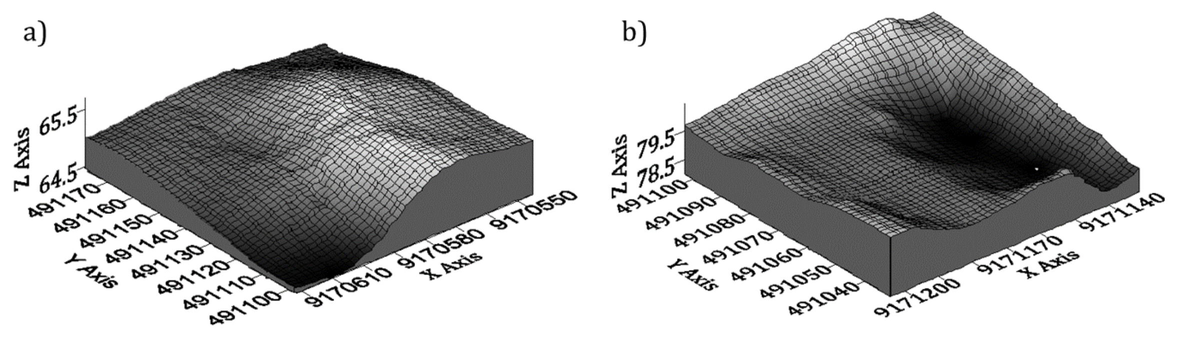


Figure 2. Digital Elevation Model (DEM) of Natural Field (a) and Forest (b) areas.

The total porosity was determined by the saturation method, which consists in the saturation of the samples until they are taken to the tension table. For the quantification of the macroporosity (MaP), the balance of the set (ring-soil) after applying a tension of -6 kPa in tension table. Microporosity (MiP) was obtained after subtraction of the weight of the ring-soil set balanced at -6 kPa and its respective oven dried weight at 105° C. The Soil Moisture (SM) was obtained by the difference between the soil mass and the dry soil mass in drying oven at 105°C for 24 h (EMBRAPA, 2011). The determination of the Bulk Density (BD) was performed by the volumetric ring method, with sample collect in a preserved structure, in cylinders with an average volume of 98.33 cm^3.

The soil resistance penetration (SRP), was measured using an electronic penetrometer Model MA-933 Marconi ™, equipped with a 200 N load cell, with cone shaft 4 mm base diameter and half top angle of 30º. The constant speed of penetration is 0.1667 mm s^{-1}, and a receiver interface coupled to a computer registered the readings by means of an exclusive equipment software. The samples from the upper and lower 5 mm were discarded in order to eliminate the effect of the periphery of the sample (Bradford, 1986).

The total organic carbon (OC)

was determined by Walkley-Black method modified by Yeomans & Bremner (1988). The organic matter (OM) in turn was estimated based on the OC. The storage carbon (Sto C) was determined in all areas and layers studied and calculated by the expression of Weldkamp (1994):

$$\text{Storage C} = \frac{\text{OC x BD x e}}{10} \qquad (1)$$

where: C Storage = is soil storage carbon (mg ha^{-1}), OC = is soil organic carbon (g kg^{-1}), BD = is bulk density (kg dm^{-3}) and e = is thickness of the considered layer (cm).

Data were submitted to descriptive analysis to determine the mean, median, maximum and minimum values, skewness and kurtosis, Kolmogorov-Smirnov test at 5% probability, and coefficient of variation (CV) using the statistical software SPSS Statistics, (2012) where the CV was classified according to Warrick & Nielsen (1980), where: CV<12%; 12%<CV<24%; and 24%<CV, represents low, moderate and high variation, respectively. After that we proceeded to the spatial dependence analysis, which has been achieved by geostatistics (Vieira et al., 1983) in theory of intrinsic hypothesis, and the semivariogram estimated from the following equation:

$$\gamma(\mathrm{h}) = \frac{1}{2\,\mathrm{N(h)}} \sum_{\mathrm{i=1}}^{\mathrm{N(h)}} \{[\mathrm{Z(x)} - \mathrm{Z(x+h)}]^2\,\}\} \qquad (2)$$

where: γ(h) = is the semivariogram, $N(h)$ = is the number of pairs involved in calculation of semivariance, $Z(x)$ = is value of the variable in x point, $Z(x+h)$ = is the variable value at the point $(x+h)$ and h = the distance between the points x and $(x+h)$.

For this calculation, the program GS+ (Gamma Desing, 2002) were used. The algorithm implemented in GS+ selects the model that has lower amount of residual square in setting. The fit of the mathematical model data defines semivariogram parameters, which are: Nugget Effect (Co), which is the γ value when h= 0; range (R) from which γ is the constant; level (C + Co), whose value is approximately equal to the variance of the data (if it exists) obtained by adding the nugget (Co) and structural variance (C).

To construct the scaled semivariograms the average distance and the average standardized semivariance values from each attribute at its respective layer were obtained from the standardized variograms proposed for the GS+ program and applied to the equation proposed by McBratney and Webster (1986):

$$\gamma(\mathrm{h}) = \mathrm{Co} + \mathrm{C}\left[1 - \mathrm{e}^{\left(\frac{-3\mathrm{h}}{\mathrm{a}}\right)}\right] \qquad (3)$$

where: h = is the separation distance between points, a = is the range (m), C = is the structural variance and Co = is the nugget effect.

After the confection of the scaled semivariograms, for the determination of how many samples would be needed in a future sampling grid, the range values obtained where applied to the following equation (Oliveira et al., 2015):

$$\mathrm{N} = \frac{\mathrm{A}}{(\mathrm{a})^2/10000} \qquad (4)$$

where: N = minimum number of samples required to determine a sampling grid, A is the total area (ha) and $(a)^2$ is the semivariogram’s range (m).

Results and Discussion

The results of the descriptive statistics are shown in Table 1. In both areas, mean and median presented close values for all variables (Table 1), indicating symmetrical distribution of data according to Marques Junior et al. (2008), who state that in a symmetric distribution, mean and median values are coincident and, in contrast, variations between the values of mean and median, cause larger variations of skewness and kurtosis with respect to the central zero value.

Table 1. Descriptive statistics of soil properties in natural field and forest areas in Humaitá region, AM, Brazil.

Natural Field	OC	OM	Sto C	MaP	MiP	TP	SM	SRP	BD
	g kg-^{1}		mg ha-^{1}	----------------------m^{3} m-^{3}----------------				KPa	Mg m-^{3}
				0.00 – 0.05 m					
Mean	29.80	51.38	20.34	0.08	0.37	0.44	0.37	1.98	1.37
Median	29.71	51.22	20.26	0.08	0.37	0.45	0.37	1.99	1.37
Maximum	33.57	57.87	22.92	0.16	0.41	0.51	0.41	2.73	1.51
Minimum	26.49	45.67	17.81	0.02	0.31	0.38	0.31	1.12	1.21
VC (%)	5.33	5.33	5.83	47.05	6.32	7.22	6.32	19.91	5.70
Skewness	0.25	0.25	-0.18	0.35	-0.23	-0.01	-0.23	-0.31	-0.05
Kurtosis	-0.04	-0.04	-0.79	-0.77	-0.43	-0.54	-0.43	-0.52	-0.92
d	*	*	*	0.03	0.01	*	0.01	*	*
				0.05 – 0.10 m					
Mean	26.42	45.56	19.84	0.05	0.35	0.40	0.35	2.11	1.50
Median	26.65	45.95	19.36	0.05	0.35	0.41	0.35	2.18	1.50
Maximum	30.87	53.23	24.00	0.09	0.40	0.45	0.40	2.61	1.63
Minimum	21.99	37.91	16.50	0.02	0.30	0.37	0.30	1.28	1.37
VC (%)	7.67	7.67	9.59	40.26	6.14	5.96	6.14	15.46	4.68
Skewness	0.07	0.07	0.41	0.52	-0.03	0.10	-0.03	-0.61	-0.04
Kurtosis	-0.68	-0.68	-0.43	-0.59	-0.12	-1.13	-0.12	-0.15	-0.84
d	*	*	*	0.01	0.03	*	*	*	*
				0.10 – 0.20 m					
Mean	23.29	40.15	17.76	0.05	0.24	0.29	0.24	2.00	1.53
Median	23.00	39.64	17.77	0.04	0.24	0.28	0.24	1.99	1.53
Maximum	26.81	46.23	20.58	0.13	0.27	0.38	0.27	2.90	1.68
Minimum	20.10	34.65	14.87	0.01	0.22	0.24	0.22	1.26	1.35
VC (%)	6.98	6.98	7.12	64.14	5.68	11.36	5.68	18.34	5.50
Skewness	0.44	0.44	0.03	0.97	0.25	1.04	0.25	0.34	-0.35
Kurtosis	-0.14	-0.14	-0.05	0.12	-0.95	0.71	-0.95	0.07	-0.54
d	*	*	*	0.01	0.01	0.01	0.01	*	*
Forest	OC	OM	Sto C	MaP	MiP	TP	SM	SRP	BD
	g kg-^{1}		mg ha-^{1}			m^{3} m-^{3}		KPa	Mg m-^{3}
				0.00 – 0.05 m					
Mean	29.88	51.52	20.53	0.14	0.37	0.51	0.37	0.78	1.16
Median	29.84	51.45	20.68	0.14	0.37	0.50	0.37	0.79	1.15

Maximum	32.12	55.38	23.78	0.19	0.41	0.56	0.41	1.25	1.31
Minimum	27.68	47.61	17.69	0.10	0.33	0.44	0.33	0.40	1.02
VC (%)	3.02	3.02	6.74	15.30	5.13	4.87	5.32	26.92	5.60
Skewness	-0.03	-.0.03	0.06	0.21	0.07	-0.13	0.11	0.26	0.05
Kurtosis	0.43	0.43	-0.63	-0.55	-0.22	0.08	-0.20	-0.46	-0.11
d	*	*	*	*	0.01	0.01	0.01	*	*
0.05 – 0.10 m									
Mean	25.72	44.35	19.19	0.14	0.37	0.51	0.37	0.77	1.21
Median	25.63	44.19	19.26	0.14	0.37	0.51	0.37	0.79	1.22
Maximum	30.11	51.91	22.64	0.21	0.40	0.56	0.40	1.32	1.34
Minimum	21.35	36.80	15.48	0.10	0.33	0.47	0.33	0.30	0.99
VC (%)	7.33	7.33	8.37	19.66	4.57	4.52	4.57	27.54	6.72
Skewness	-0.01	-0.01	-0.09	0.53	-0.07	0.20	-0.07	0.22	-0.63
Kurtosis	-0.17	-0.17	-0.62	-0.45	-0.51	-0.86	-0.51	0.23	0.03
d	*	*	*	0.03	0.01	0.01	0.01	*	*
0.10 – 0.20 m									
Mean	23.66	40.78	18.09	0.13	0.37	0.50	0.37	0.89	1.28
Median	23.66	40.79	18.34	0.13	0.37	0.50	0.37	0.87	1.28
Maximum	26.53	45.74	20.79	0.17	0.40	0.53	0.40	1.42	1.44
Minimum	21.11	36.39	15.39	0.09	0.33	0.46	0.33	0.44	1.15
VC (%)	4.80	4.80	7.42	14.48	4.11	3.63	4.11	29.91	5.80
Skewness	0.19	0.19	-0.30	0.30	-0.35	0.01	-0.35	0.14	0.25
Kurtosis	0.31	0.32	-0.46	-0.19	-0.14	-0.97	-0.14	-0.84	-0.77
d	*	*	0.04	0.01	0.00	0.01	0.01	*	*

OC: organic carbon; OM: organic matter; Sto C: Storage Carbon; MaP: macroporosity; MiP: microporosity; TP: total porosity; SM: soil moisture; SRP: soil resistance penetration; BD: bulk density; VC: variation coefficient; d: Kolmogorov-Smirnov test at 5% probability; * significant at 5% probability.

The Kolmogorov-Smirnov test (Table 1) presented normality distribution for most of the attributes. In natural field, the variables that did not present normal distribution were MaP and MiP in all layers, TP in 0.10 - 0.20 m layer and SM in 0.00 - 0.05 and 0.10 - 0.20 m layers. In forest, the variables that did not present normality were MiP, TP and SM in all layers, the MaP in layers 0.05 - 0.10 and 0.10. - 0.20 m and Sto C at layer 0.10 - 0.20 m. That way, the information generated by the exploratory analysis allows us to state that the variables are in a sufficiently symmetrical distribution to use the geostatistical analysis.

Regarding the CV (Table 1), proposed by Warrick & Nielsen (1980), it was observed that most of the studied attributes showed low variability, except in natural field for the variables: SRP (moderate variability in all layers) and MaP (moderate variability in 0.00 - 0.10 m layer and high variability in 0.10 - 0.20 m layer). Similar results were found by Oliveira et al. (2013) who studied an Inceptsol under different uses in the Southern Amazon region, what evidences the moderate variability of attributes in this soil class even in natural environments. Yet in forest area MaP and SRP presented moderate variability, agreeing with Campos et al. (2013) who studied spatial variability of physical attributes in Ultisols under forest. These higher MaP values found in forest area are probably product of more extensive root mass and greater number of borrowing organisms (GREGORICH et al., 1997), what explains the higher CV as well.

The mean values of OM, OC and Sto C (Table 1), in both areas, showed similar behavior, tending to decline with the deepening of the layers, with values ranging between: 23.29 - 29.88 g kg^{-1} for OC; 40.15 - 51.52 g kg^{-1} for OM and 17.76 - 20.53 mg ha^{-1} for Sto C. The influence of these variables over the other soil attributes can only be analyzed by a chemical fractionation of organic forms, once Alho et al. (2014) found similar texture between these environments, and the mean OM values found in the present study did not vary greatly between areas. Bosatta and Ângren (1997) studying the influence of texture over soil organic matter dynamics, stated that abiotic factors, such as temperature, can affect the OM functions in soil. This information is crucial to understand the relation of OM with soil physic in natural field, which is uncovered, and receive direct sunlight and consequently have higher temperatures.

The natural field area showed average values of BD ranging from 1.37 - 1.53 Mg m^{-3} (Table 1), increasing concomitantly to the deepening of layers, corroborating with results obtained by Alho et al. (2016), who associated this behavior to the natural densification processes (ARAUJO et al., 2007; CARDOSO et al., 2011). This increase of BD can be a limiting factor for the depth development of roots, as stated by Silva et al. (2011), who assessed soil physical attributes under different crops, and found that BD values greater than 1.30 Mg m^{-3} can generate constraints to root growth. Jones et al. (1983), also established some critical values for BD, where the higher and lower critical values were 1.52 and 1.26 Mg m^{-3}, thus, justifying the predominance of undergrowth vegetation species instead of trees in this area. In the forest, the average values of BD showed similar behavior to natural field with the deepening of layer, but with much lower values, ranging from 1.16 - 1.28 Mg m^{-3}, favoring the development of roots in depth.

BD also seemed to influence SRP mean values (Table 1). In natural field area, SRP values were higher compared to the forest, behavior justified by the higher BD mean values in that area. Consequently, this relationship is also seen in the forest area, but with lower SRP mean values reflected by a lower BD. Some authors affirm that the BD is influenced by natural densification processes or management practices (ARAÚJO et al., 2007; CARDOSO et al., 2011). In this case, for the natural field, this behavior can be associated to the natural densification processes duo to its soil morphological attributes, such as angular and subangular blocks as stated by CAMPOS (2012). These kind of morphological structure as some authors suggest (FERREIRA, 2010; CAMPOS et al., 2010; CAMPOS et al., 2012; ALHO et al., 2014), may cause the densification due to the packing of granular partially cemented sediments, which makes soils with blocks-like structure to be usually more densely packed. Seen the relation of BD and SRP with the SM, as some authors suggest (BENGHOUGH and MULLINS, 1990; OLIVEIRA et al., 2004), this can imply in water infiltration problems or even generate water stagnation on the lower areas, as proved by the presence of Gleissolos Háplicos (Aqualf, Aquult ou Aquox, USDA Soil Taxonomy) around these areas (CAMPOS, 2012).

For the forest, however, this behavior may be occasioned by the rhizosphere factor and the cumulative intake of organic matter (littering), common in forest soils, which may decrease BD and consequently SRP (MARTINS et al., 2006; SILVA et al., 2008; CARDOSO et al., 2011; ALHO and NASCIMENTO, 2015).

In geostatistical analysis (Table 2), based on the SDD proposed by Cambardella et al. (1994) all variables showed a strong spatial dependence. According to this same author, strong spatial dependence structure is influenced by the intrinsic soil properties. BRAUN and RAMOS (1959), by analyzing representative soil samples in these areas, evidenced little variation in the number, arrangement and characteristics of the horizon's physical and chemical attributes, which allowed them to group these soils in a single large pedological group, explaining thus, the strong spatial dependence found in these areas. This way, the different soil types found in that region, as stated by Campos (2012), has direct relation with the relief, which conditions the water draining and the groundwater level, what requires double attention when applying any intake over these areas.

The attributes were adjusted to the exponential model, agreeing with Aquino et al. (2015) who emphasize that this is one of semivariogram adjustment patterns often found for the soil properties.

The range (R) values, varied between 14.48 - 53.70 m (Table 2), highlighting that they were higher than the spacing used in the sampling grid, indicating that the samples are spatially related, allowing to make interpolations (VIEIRA, 2000).

Table 2. Semivariograms models and parameters in natural field and forest areas in different layers in the region of Humaitá, AM, Brazil.

Natural Field	OC	OM	Sto C	MaP	MiP	TP	SM	SRP	BD
					0.00 – 0.05 m				
Model	Exp.	Exp.	Exp.	Exp.	Exp.	Exp.	Exp.	Exp.	Exp.
Co	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
C+Co	2.99	7.65	1.49	0.00	0.00	0.00	0.00	0.13	0.00
R	35.00	17.58	35.00	25.05	37.80	14.48	22.80	15.80	23.08
$^1R^2$	0.86	0.72	0.79	0.78	0.86	0.71	0.86	0.81	0.96
^{2}SDD (%)	0.00	0.13	0.00	0.00	0.00	0.00	0.00	0.00	0.00
^{3}VC	0.79	0.92	0.84	1.00	1.0	0.97	1.00	1.00	0.75
					0.05m – 0.10 m				
Model	Exp.	Exp.	Exp.	Exp.	Exp.	Exp.	Exp.	Exp.	Exp.
Co	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
C+Co	4.69	13.44	3.89	0.00	0.00	0.00	0.00	0.12	0.00
R	35.00	35.00	26.59	30.00	35.00	16.43	35.00	30.00	17.69
$^1R^2$	0.78	0.71	0.73	0.83	0.79	0.87	0.94	0.86	0.70
^{2}SDD (%)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
^{3}VC	0.86	0.88	1.00	0.86	0.77	0.75	0.76	0.86	0.77
					0.10 – 0.20 m				
Model	Exp.	Exp.	Exp.	Exp.	Exp.	Exp.	Exp.	Exp.	Exp.
Co	0.38	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
C+Co	4.52	13.4	2.55	0.00	0.00	0.00	0.00	0.23	0.00

		6							
R	40.20	35.00	45.00	42.47	22.50	41.70	21.00	29.10	22.86
[1]R^2	0.87	0.87	0.82	0.84	0.85	0.94	0.83	0.88	0.73
[2]SDD (%)	8.41	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
[3]VC	0.92	0.90	0.95	0.94	0.93	0.89	0.98	1.00	0.97

Forest	OC	OM	Sto C	MaP	MiP	TP	SM	SRP	BD
0.00 – 0.05 m									
Model	Exp.	Exp.	Exp.	Exp.	Exp.	Exp.	Exp.	Exp.	Exp.
Co	0.01	0.04	0.15	0.00	0.00	0.00	0.00	0.00	0.00
C+Co	2.38	7.24	2.76	0.00	0.00	0.00	0.00	0.04	0.00
R	20.40	23.10	20.10	45.00	47.70	20.98	45.00	36.00	45.00
R^2	0.87	0.91	0.81	0.92	0.92	0.72	0.92	0.86	0.94
SDD (%)	0.42	0.55	5.43	0.00	0.00	0.00	0.00	0.00	0.00
VC	0.91	0.98	0.96	0.88	0.96	0.91	0.82	0.85	0.90
0.05m – 0.10 m									
Model	Exp.	Exp.	Exp.	Exp.	Exp.	Exp.	Exp.	Exp.	Exp.
Co	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00
C+Co	4.63	13.78	3.39	0.00	0.00	0.00	0.00	0.05	0.01
R	45.90	45.90	29.40	50.00	50.00	27.00	47.10	45.00	50.00
R^2	0.82	0.82	0.73	0.85	0.81	0.71	0.86	0.77	0.87
SDD (%)	0.21	0.07	0.29	0.00	0.00	0.00	0.00	0.00	0.00
VC	0.80	0.80	1.00	0.87	0.89	0.90	0.89	0.77	0.85
0.10 – 0.20 m									
Model	Exp.	Exp.	Exp.	Exp.	Exp.	Exp.	Exp.	Exp.	Exp.
Co	0.15	1.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00
C+Co	2.07	6.37	2.36	0.00	0.00	0.00	0.00	0.10	0.01
R	50.00	45.00	36.60	53.40	50.00	45.30	45.00	53.70	35.70
R^2	0.88	0.86	0.75	0.98	0.72	0.91	0.71	0.90	0.96
SDD (%)	7.24	15.69	0.00	0.00	0.00	0.00	0.00	10.00	0.00
VC	0.90	0.85	0.95	0.88	0.90	0.80	0.85	0.89	0.92

OC: organic carbon; OM: organic matter; Sto C: Storage Carbon; MaP: macroporosity; MiP: microporosity; TP: total porosity; SM: soil moisture; SRP: soil penetration resistance; BD: bulk density; Co: nugget effect; Co+C: level; R: range; R^2: residual square; SDD: spatial dependence degree; VC: crossed validation.

It is worth noting that the range values increased with the deepening of layers, what ensure that the attributes tend to homogenize in the lower layers of the profile. In the forest area, the higher ranges were obtained, which may indicate a more stable area and less variation of attributes.

The range (R) values found for BD (Table 2) represent a higher variability of this attribute in the first two layers, justified by the increase in depth, which tends to produce higher surface pressure on the subsurface, as explained by Campos et al. (2012), who justified the consolidation of these soils due to granular structure in subangular blocks and medium texture silt loam.

These range (R) values also provide information regarding to the spatial distribution heterogeneity of the studied properties in each area (Trangmar et al., 1985), and consequently, providing help to determine the ideal sampling procedure (Mcbratney & Webster, 1986). That way, for further analyses in these areas, it is possible to specify the optimal number of samples needed to evaluate the distribution of soil characteristics, giving another important purpose to the semivariogram use (Souza et al., 2009).

Table 3. Sampling density and ideal spacing values based on geostatistical analysis estimated range in natural field and forest.

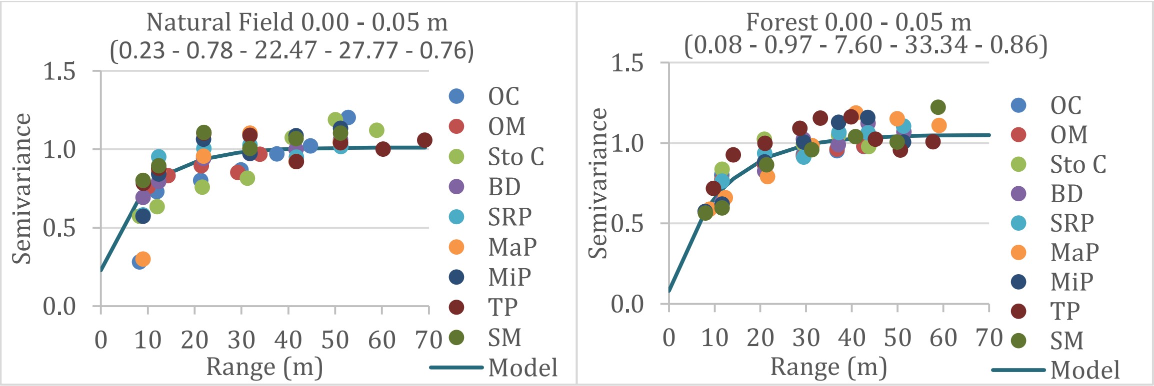
Physical Attributes	Sample Planning			
	Natural Field (0.00 - 0.05 m)		Forest (0.00 - 0.05 m)	
	Sample Density (p/ha)	Spacing (m)	Sample Density (p/ha)	Spacing (m)
OC	8	35	25	20
OM	31	18	19	23
Sto C	8	35	25	20
MaP	16	25	5	45
MiP	7	38	4	48
TP	44	15	23	21
SM	19	23	5	45
SRP	39	16	8	36
BD	19	23	5	45
Physical Attributes	Natural Field (0.05 - 0.10 m)		Forest (0.00 - 0.10 m)	
	Sample Density (p/ha)	Spacing (m)	Sample Density (p/ha)	Spacing (m)
OC	8	35	5	46
OM	8	35	5	46
Sto C	14	27	12	29
MaP	11	30	4	50
MiP	8	35	4	50
TP	39	16	14	27
SM	8	35	5	47
SRP	11	30	5	45
BD	31	18	4	50
Physical Attributes	Natural Field (0.10 - 0.20 m)		Forest (0.10 - 0.20 m)	
	Sample Density (p/ha)	Spacing (m)	Sample Density (p/ha)	Spacing (m)

OC	6	40	4	50
OM	8	35	5	45
Sto C	5	45	7	37
MaP	6	42	4	53
MiP	21	22	4	50
TP	6	42	5	45
SM	23	21	5	45
SRP	12	29	3	54
BD	19	23	8	36

OC: organic carbon; OM: organic matter; Sto C: carbon stock; MaP: macroporosity; MiP: microporosity; TP: total porosity; SRP: soil resistance penetration; BD: bulk density;

As shown in Table 3, the forest requires bigger spacing between points, showing that this area tends to have a bigger spatial continuity for its attributes. With exception of the chemical attributes OC, OM, Sto C in the first layer, what, once again, can be explained for the cumulative intake of organic matter, common in forest environments, generating more variability in the upper layers for these specific attributes. However, this cumulative intake of organic matter also seems to be homogenizing the evaluated soil physical attributes, as reflected by the bigger ranges (R) found in that area. These results corroborate with other authors who also found approximated spacing needed in forest environments to determine spatial variability of soils attribute (Aquino et al., 2014; Alho et al., 2016), what characterizes the forest as more stable environment comparing to the natural field.

For the scaled semivariograms adjust (Figure 3), it was verified similar results to the individual attributes semivariogram. Once again, according to the SDD (Cambardella et al, 1994), the adjusted models showed strong spatial dependence, what suggests that the processes that regulate the soil physical attributes in each area are similar. The individual adjusted models in forest showed higher ranges (R), compared to natural field, tending to stabilize in the deeper layers, behavior also observed in the scaled semivariogram, where range values tended to increase with the deepening of layers, thus, suggesting a higher spatial continuity for the soil attributes in forest area.



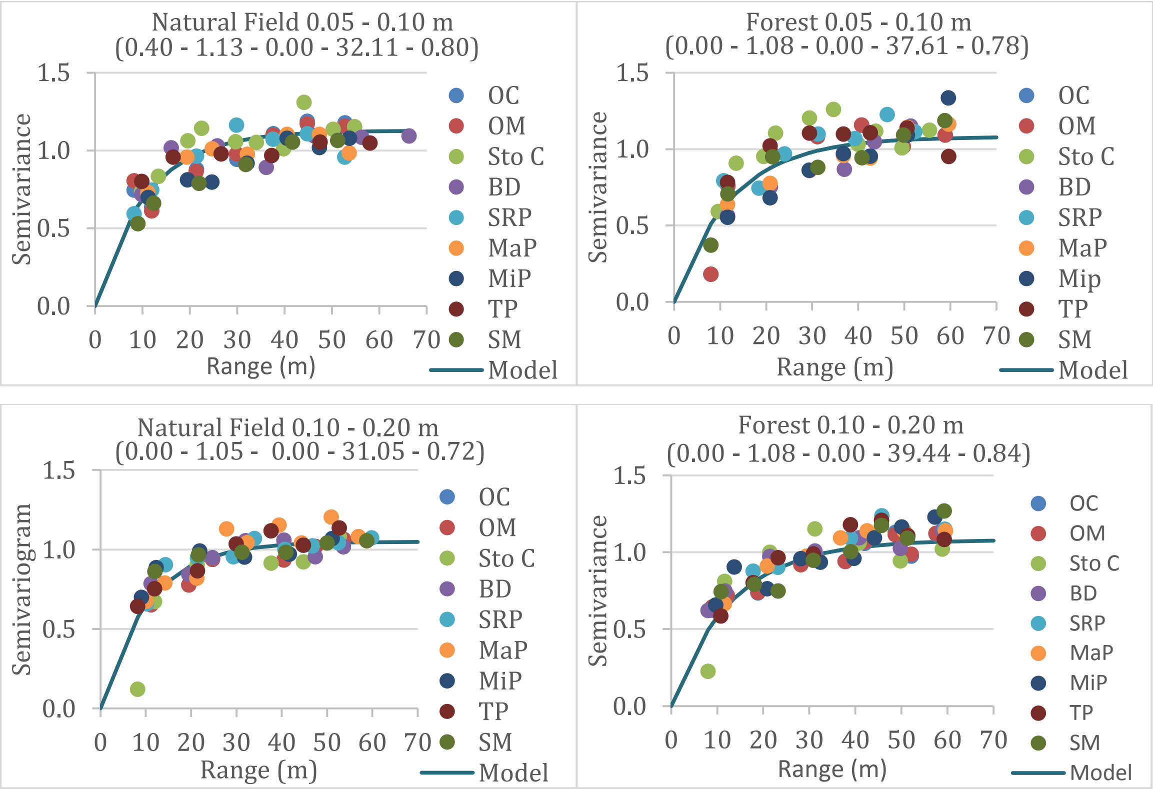


Figure 3. Adjusted scaled semivariograms models in natural field and forest areas in different layers in the region of Humaitá, AM, Brazil. (nugget effect – level – SDD – range – R^2). SDD = spatial dependence degree; R^2 = residual square.

With the mean range values obtained from the scaled semivariograms it is possible to determine the ideal sampling density for a future sampling grid in that area. For natural field, the ideal sampling density is 11 points ha^{-1} (30 m between points). In forest, the ideal sampling density is 7 points ha^{-1} (37 m between points). Once again suggesting a higher spatial continuity for forest area compared to natural field.

Conclusions

All attributes presented strong spatial dependence in both areas, evidencing that these attributes are influenced by the soil intrinsic properties, common in natural areas.

The use of individual and scaled semivariograms have shown being useful for the studied environment for determining the ideal sampling density of 11 points ha^{-1} for natural field and 7 points ha^{-1} for forest, permitting the usage of these database in future soil studies in Amazon Southern region.

The high BD and SRP levels in natural field area can cause problems to root development and water accumulation in the lower areas.

OM, OC and Sto C presented similar values in both areas, however, with different influences over soil's analyzed attributes (BD, SRP, MaP, MiP, TP and SM), requiring further studies with chemical fractionation of organic forms.

Acknowledgements

The authors would like to thank

to CNPQ (Conselho Nacional de Desenvolvimento Tecnológico), and FAPEAM (Fundação de Amparo à Pesquisa do Amazonas).

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