SPATIAL VARIABILITY OF AGGREGATES AND ORGANIC CARBON UNDER THREE DIFFERENT USES OF INDIAN BLACK EARTH IN SOUTHERN AMAZONAS

VARIABILIDADE ESPACIAL DE AGREGADOS E CARBONO ORGÂNICO SOB TRÊS DIFERENTES USOS DE TERRA PRETA DE ÍNDIO NO SUL DO AMAZONAS

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ABSTRACT: Indian Black Earths (IBEs) are distributed throughout the Amazon. They are characterized by their high chemical fertility and agricultural potential. IBEs have high organic carbon, favouring the improvement of soil structure. This work aimed to evaluate the aggregates and organic carbon (OC) spatial variability in different IBEs in southern Amazonas. We evaluated the organic carbon spatial variability, mean weight diameter (MWD), soil bulk density (ρ_b) and aggregate classes under three uses of soil: pasture, cocoa, and coffee. We collected 528 soil samples in a point grid according to its use at two depths: 0.0-0.05 m and 0.10-0.20 m. Results were subjected to variance, descriptive, and geostatistical analyses. We concluded that the soil use influenced the IBEs physical attributes soil behavior, concentrating the higher values of CO, aggregates > 2.00 mm, and MWD at 0.0-0.05 m in relation to ρ_b and aggregates < 2.00 mm where the higher values were the ones at 0.10-0.20 m. Aggregates < 2.00 mm (0.10-0.20 m) and OC (0.0-0.05 m) did not show spatial dependence, while the class of aggregates > 2.00 mm was the only attribute which represented to be a natural characteristic of the soil, with a strong spatial dependence, independently the land use and depth. There was no spatial relationship between the attributes studied and the geomorphic diversity.

KEYWORDS: Spatial dependence. Aggregate classes. Soil aggregation. Land use.

INTRODUCTION

Spatial variability of soil physical attributes occurs naturally due to factors and processes of soil formation and geomorphic expressions (CAMARGO et al., 2010). In the case of Indian Black Earths (IBEs), several factors contributed to the spatial discontinuity of physical attributes such as burial and burning of ceramic artifacts and animal bones. In addition, this discontinuity was conditioned by the trampling of indigenous peoples who inhabited these sites (AQUINO et al., 2014a; OLIVEIRA et al., 2015).

Besides the natural variability, land use and management in agriculture play an additional source of variation (OLIVEIRA et al., 2013). This use and management influence carbon distribution in different soil fractions and cause short and/or long-term changes (MARQUES et al., 2015). Deforestation and agriculture change soil properties, such as the aggregate stability (CAMPOS et al., 2013), altering porous space, aggregate size, water movement, and soil density (VIEIRA et al., 2011). Several studies have identified that the smaller the organic carbon content, higher the soil disintegration (CAMPOS et al., 2011).

Another factor that influences spatial variability of soil physical attributes is the curvature of land surface (CAMARGO et al., 2010). This curvature conditions the movement of water and the mass flow in the soil along the landscape. In this aspect, it is necessary to use methodologies to identify spatial discontinuity allowing soil characterization for sustainable use and management (CAJAZEIRA; ASSIS JÚNIOR, 2011). In this aspect, geostatistics allows the detection and a better understanding spatial variability (VIEIRA, 2000).

The State of Amazonas has a great territorial extension and geomorphological diversity. Thus, the use of geostatistics becomes an extremely viable practice due to its low cost and high representativeness of local conditions. Despite its applicability, few studies using geostatistics were carried out in the Amazonian soils, where some of them can be highlighted like the Campos et al (2011), Aquino et al. (2014a), Oliveira et al. (2015), and Alho et al. (2016). Thus, there is a need to characterize the soil and its use in the Amazon

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region. In this way, the objective of this work was to evaluate the spatial variability of aggregates and organic carbon in Terra Preta de Indio (Indian Black Earth) under different land uses in southern Amazonas.

MATERIAL AND METHODS

The study was carried out in the southern part of the Amazonas State, in Apuí and Manicoré at the roadside BR 230, the Transamazônica highway. Three areas of Indian Black Earth (IBE) were selected where cocoa, coffee, and pasture were growing. The IBE area with pasture (7 years of pasture growth) is located in Manicoré (Latitude 7º 59' 22" S, Longitude 61º 39' 51.2" W). This pasture is characterized by the use of brachiaria (*Brachiaria brizanta*) which supports one animal unit per hectare in an extensive system (Figure 1). The soil from this area was classified as Eutrophic Red-Yellow Argisol (Embrapa, 2013) or Red Ultisol (Soil Survey Staff, 2014), where the region primary ecosystem is Dense Tropical Forest. This type of soil developed geologically from sandstones of the Içá Formation.

The IBEs areas where cocoa and coffee were growting in Apuí (Latitude 7º 12' 05" S, Longitude 59º 39' 35" W). This soil was classified as Eutrophic Yellow Argisol, according to Embrapa (2013) or Yellow Ultisol (Soil Survey Staff, 2014). This soil is composed of sandstones of the Beneficial geological formation, which presents a clayey tertiary package and primary covered with Dense Tropical Forest.

The IBE area with cocoa (8 years of cocoa growth) was previously grown with rice, corn, beans, and watermelon (Figure 1). The area of IBE with coffee (6 years of coffee growth) was previously under pasture. Cocoa and coffee were manually cultivated.

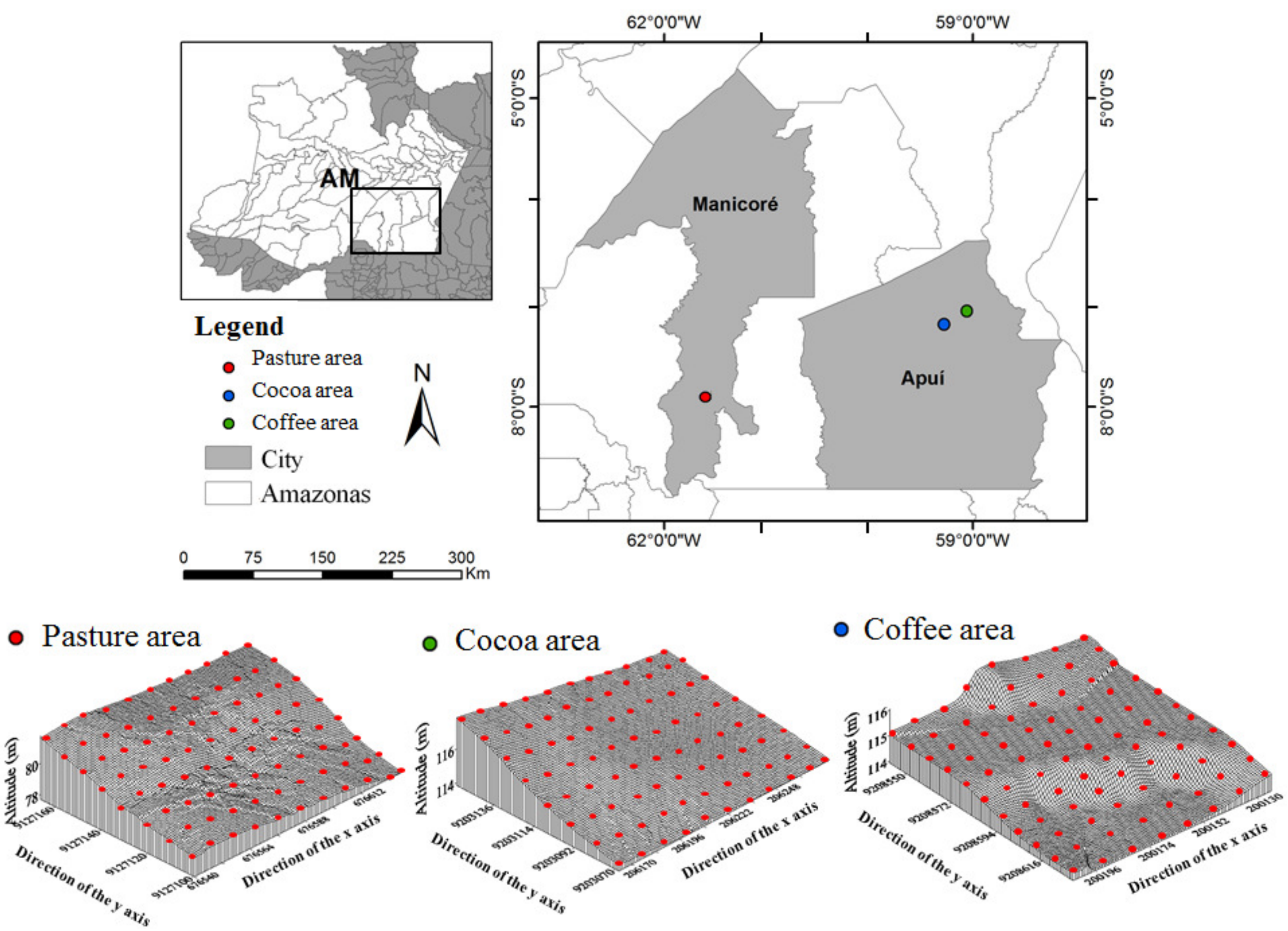

Figure 1. Map of location and digital elevation model of the studied areas in Manicoré and Apuí, AM.

Soil samples from the study areas were collected in a grid (Figure 1). The sampled pasture area was 4,480 m^2 (56 x 80 m), in a grid of 88 points spaced 6 x 8 m. The sampling area in both coffee and cocoa areas was 4,228 m^2 in a grid of 88 points spaced 8 x 8 m. Soil samples were collected at two depths in small trenches at depths 0-0.05 m and 0.10-0.20 m. At total, we collected 528 soil samples. The points of the sample grids were georeferenced to construct the digital elevation model. The equipment used in the georeferencing was the GPSMAP 76CS (Garmin International, USA) with accuracy of <10 m.

Texture analysis was performed using 0.1 mol L^{-1} NaOH solution as a chemical dispersant and mechanical stirring in high-speed apparatus for 15 min. Clay fraction was determined by the pipette method, the sand, by sieving, and the silt calculated by the difference (Embrapa, 1997). The results are presented at Table 1.

Table 1. IBE areas soil texture under different managements.

Layers	Coffee			Cocoa			pasture		
	g kg^{-1}								
	Sand	Silt	Clay	Sand	Silt	Clay	Sand	Silt	Clay
Superficial	364.65	617.37	17.98	221.10	572.83	204.52	711.13	235.49	51.18
Sub superficial	344.32	638.52	17.16	187.97	537.86	274.23	713.76	205.94	73.91

Superficial = 0.0-0.05 m, Sub superficial = 0.10-0.20 m

Soil bulk density (ρ_b) was determined in cylinders of 5.57 cm of diameter and 4.1 cm in height. Colected soil samples were oven-dried at 105-110 ºC for 48 hours (Embrapa 1997). Organic carbon (OC) was determined by the Walkley-Black method, modified by Yeomans and Bremner (1998).

Soil samples for aggregate determination were removed in blocks, which were air dried and passed through 9.52 mm and 4.76 mm sieves. Then, the aggregates retained at 4.76 mm sieve were used in the wet aggregates stability analysis, placed on a set of sieves with 2.0 mm, 1.0 mm, 0.5 mm, 0.25 mm, 0.105 mm, and 0.053 mm sieving, subjecting them to vertical oscillations. After fifteen minutes or 15 min, portions retained in each sieve were transferred to aluminum pots with the aid of water jets, and then dried at 105 °C for 24 hours for later weighing (KEMPER; CHEPIL, 1965). Results were expressed as Mean Weight Diameter (MWD), percentage of aggregates greater than 2 mm (% > 2 mm) and percentage of aggregates smaller than 2 mm (% < 2 mm).

Results were submitted to analysis of variance and Tukey's mean separation test ($p < 0.05$). We also did the descriptive analysis (mean, median and coefficient of variation) of these results and the evaluation of their normality, by using the Kolmogorov-Smirnov test. Finally, spatial variability was evaluated using geostatistics. For this evaluation, the experimental semivariogram was estimated according to equation (1).

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

Where: $\gamma(h)$ – semivariance value to a “h” distance; N(h) – number of pairs involved in the semivariance calculus; $Z(x_i)$ – value of Z at x_i; $Z(x_i+h)$ – value of Z separated by a distance “h” at x_i.

Both spherical and exponential mathematic models were adjusted to the semivariograms. This adjustment was made based on the number of pairs involved in the semivariogram, sum of the square of the residuals (SQR), presence of the plateau (BURROUGH; McDONNEL, 2000) and coefficient of determination (R^2). Then, the cross-validation (CV) technique was used to obtain the correlation coefficient (VIEIRA, 2000). Subsequently, the degree of spatial dependence (DSD) was succeeded by the relation between the nugget effect (C_0) and semivariogram plateau (C_0+C_1). Attributes were considered with strong DSD when the relation was [$C_0/(C_0+C_1) \leq 25\%$], moderate DSD [($C_0/(C_0+C_1)$ between 25 and 75%] and weak DSD when [($C_0/(C_0+C_1)$> 75% (CAMBARDELLA et al., 1994). Finally, we performed variable value distribution estimates to points not sampled in the grid by kriging.

Descriptive and variance analyzes were performed using the Minitab program, while the geostatistical analysis using the Surfer program (Golden Software Inc., 1999).

RESULTS AND DISCUSSION

The results referring to the descriptive statistical analysis and soil attributes mean test are shown in Table 2. The studied variables values of mean and median were similar among each other at the different soil use systems. This closeness indicated a normal distribution of data (CRUZ et al., 2010; CAMPOS et al., 2013a). No. However, the normality was only observed in all variables at 0.10-0.20 m in the soil grown with cocoa. We also observed that only the aggregates > 2.00 mm class presented normal distribution in all soil uses, regardless of depth. The normality of results obtained in this study was similar to other researches that studied soils with pastures (OLIVEIRA et al., 2015).

In general, the behavior of physical attributes evaluated in pasture and coffee areas were closer than the ones observed in soil where cocoa was grown (Table 2). At the three soil uses both Mean Weight Diameter (MWD) and aggregates class > 2.00 mm, obtained the highest values and they did not differ statistically at 0.0-0.05 m, evidencing few influence in this attributes influence. However, the decreased of MWD and aggregates > 2.00 mm at 0.10-0.20 mm was due to the smaller amount of CO, given that the magroaggregates genesis is closely associated to the CO content, mainly up to a 0.05-0.20 m depth (Garcia et al., 2010; Oliveira et al., 2015; Silva et al., 2016).

Soil bulk density (ρ_b) and aggregates class < 2.00 mm were the most sensitives physical atributes to the soil use type, mainly at 0.0-0.05 m, where we could found statistical difference to the adopted management (Table 2). The ρ_b was higher at pasture due to the livestock and intensive animal trampling, corroborating with Oliveira et al. (2015) and Silva et al. (2016) results. The smaller ρ_b in the cocoa and coffee soil is due to the big amount of cultural residues, like branches, leaves, and fruits, added to the soil in each crop cycle (Silva et al., 2016). In this sense, Steinbeiss et al. (2009) affirm the lower soil density in these areas happen not only due to the high amount of carbon, but also due to the intense biologic activity (fauna and roots).

Table 2. Mean and descriptive statistics test of Mean Weight Diameter (MWD), organic carbon (OC), soil density (ρ_b), aggregate class greater than 2 mm (> 2 mm), aggregate class smaller than 2 mm (< 2 mm) in Indian Black Earth (IBE) areas under different managements.

Attributes	Statistics	Pasture	Coffee	Cocoa	Pasture	Coffee	Cocoa
		Surface (0.0 – 0.05 m)			Sub-surface (0.10 – 0.20 m)		
MWD (mm)	Mean	3.14 A	3.14 A	3.14 A	3.01 A	2.90 A	2.53 B
	Median	3.16	3.14	3.15	3.07	2.91	2.63
	CV (%)$^{(1)}$	3.14	3.18	4.45	6.55	4.82	17.39
	d$^{(2)}$	0.03	0.20*	0.09*	0.01	0.20*	0.20*
OC (g kg^{-1})	Mean	34.26 B	38.96 B	55.62 A	33.46 A	33.83 A	31.66 B
	Median	34.25	37.25	54.71	33.50	35.19	32.35
	CV (%)$^{(1)}$	4.06	29.85	17.70	1.56	19.59	17.37
	d$^{(2)}$	0.15*	0.03	0.20*	0.15*	0.20*	0.15*
ρ_b (Kg dm^{-3})	Mean	1.29 A	1.08 B	0.89 C	1.17 A	1.20 A	0.93 B
	Median	1.30	1.09	0.89	1.16	1.23	0.92
	CV (%)$^{(1)}$	9.03	9.25	11.23	9.29	19.16	8.42
	d$^{(2)}$	0.15*	0.20*	0.02	0.15*	0.001	0.20*
> 2.00 mm (%)	Mean	91.96 A	90.60 A	90.51 A	86.54 A	81.58 B	76.91 C
	Median	92.49	91.26	90.72	88.59	81.74	76.59
	CV (%)$^{(1)}$	4.43	4.95	5.80	8.91	8.05	13.27
	d$^{(2)}$	0.14*	0.08*	0.20*	0.12*	0.20*	0.20*
< 2.00 mm (%)	Mean	5.57 B	7.56 AB	9.48 A	11.04 B	13.83 B	23.08 A
	Median	4.45	6.65	9.28	9.49	12.95	23.41
	CV (%)$^{(1)}$	67.99	53.04	55.37	59.51	50.25	44.23
	d$^{(2)}$	0.17*	0.01	0.20*	0.11*	0.20*	0.20*

Means followed by the same capital letter in the same depth line do not differ statistically from each other by the Tukey test ($p < 0.05$). [1]CV: coefficient of variation. [2]d: Kolmogorov-Smirnov normality test ($p < 0.05$).

According to the classification proposed by Warrick and Nielsen (1980), only aggregates < 2.00 mm in pasture presented high coefficient of variation (CV) at 0.0-0.05 m, while MWD, ρ_b, and aggregates > 2.00 mm presented low variability in the three soil uses. However, the variability was moderate for the MWD and aggregates > 2.00 mm in the coffee area and for ρ_b in the soil cultivated with cocoa. The OC observed in the pasture at the two studied depths presented low variability, while the variability was mild in the areas with coffee and cocoa. The decrease of ρ_b, MWD and OC in pasture was also observed in Alho et al. (2016) articles. Campos et al. (2013b) reported low variability for aggregates > 2.00 mm in Red Argisol, while Aquino et al. (2015) found low and medium variability for aggregates < 2.00 mm when the depth increased.

We observed a spatial dependence between depth and land use in most of the studied attributes (Table 3). This dependence can be observed in the semivariograms of Figure 2.

Table 3. Geostatistical parameter estimates to Mean Weight Diameter (MWD), organic carbon (OC), soil density (ρ_b), aggregate class greater than 2 mm (> 2 mm), aggregate class smaller than 2 mm (< 2 mm) in Indian Black Earth (IBE) areas under different managements.

Attributes	Parameters	Pasture	Coffee	Cocoa	Pasture	Coffee	Cocoa
		Surface (0.0 – 0.05 m)			Sub-surface (0.10 – 0.20 m)		
	Model	Exp	Exp	Sp	Sp	Exp	Sp
	Nugget effect	0.00007	0.002	0.02	0.001	0.003	0.08
	Plateau	0.0007	0.01	0.05	0.03	0.03	0.26
MWD (mm)	Reach (m)	23.00	22.80	39.40	16.60	18.90	38.10
	R^2	0.88	0.87	0.97	0.73	0.92	0.99
	SDD (%)	10.44	20.00	40.00	3.00	10.00	30.76
	CV	0.77	1.00	0.88	0.98	0.72	0.92
	Model	Sp	Exp	PNE	Sp	Exp	Exp
	Nugget effect	0.84	86.40	-	0.14	25.47	3.70
	Plateau	1.64	172.90	-	0.28	56.46	40.25
OC (g kg^{-1})	Reach (m)	41.80	31.50	-	43.80	37.30	14.70
	R^2	0.97	0.74	-	0.97	0.91	0.95
	SDD (%)	51.00	49.97	-	50.00	45.11	9.19
	CV	0.97	0.90	-	0.97	0.95	0.77
	Model	Exp	Exp	Exp	Exp	Exp	Exp
	Nugget effect	0.001	0.005	0.00001	0.001	0.002	0.0028
	Plateau	0.01	0.01	0.009	0.01	0.01	0.0099
ρ_b (Kg dm^{-3})	Reach (m)	25.80	48.90	17.80	21.90	15.60	25.80
	R^2	0.91	0.96	0.97	0.82	0.71	0.98
	SDD (%)	10.00	50.00	0.11	10.00	20.00	28.28
	CV	0.98	0.95	1.00	0.99	0.70	0.99
	Model	Exp	Sp	Exp	Exp	Exp	Sp
	Nugget effect	0.01	0.89	6.10	4.30	6.30	0.10
	Plateau	12.10	25.51	50.11	54.30	62.14	96.00
>2.00 mm (%)	Reach (m)	25.00	14.30	28.80	11.50	19.80	12.40
	R^2	0.86	0.76	0.92	0.92	0.90	0.73
	SDD (%)	0.08	3.48	12.07	7.92	10.13	0.10
	CV	0.78	0.76	0.81	0.76	0.75	0.73
	Model	Exp	Exp	Exp	PNE	Exp	Exp
	Nugget effect	0.01	6.74	6.50	-	35.90	8.10
	Plateau	8.80	17.15	51.17	-	94.16	92.92
<2.00 mm (%)	Reach (m)	16.00	25.70	28.50	-	38.50	21.60
	R^2	0.97	0.86	0.92	-	0.89	0.93
	SDD (%)	0.11	39.90	12.70	-	38.12	8.71
	CV	0.75	0.93	0.79	-	0.74	0.91

PNE: Pure Nugget Effect; Exp: Exponential; Sp: Spherical; R^2: coefficient of determination; SDD%: spatial dependence degree, and CV: Crossed validation.

The exponential model was predominant for all attributes, depths and soil uses (Table 3). Only the exponential model adjusted to the spatial dependence for ρ_b and aggregates < 2.00 mm, regardless land depth and use. However, there is an exception done to aggregates < 2.00 mm in the soil use with pasture at 0.10-0.20 m, where it was observed absence of spatial dependence (pure nugget effect – PNE), behavior also verified to OC at 0.0-0.05 m in the cocoa area. It is worth noting the absence of spatial dependence in these variables does not necessary means absence of variance, but the incapability of adjustment the semivariogram model (CAMBARDELLA et al., 1994; Vieira, 2000).

The evaluated attributes presented range values superior to the sampling mesh (8 m), indicating that the variables are spatially related and they allow interpolations (VIEIRA, 2000).The highest range values were found for ρ_b (48.90 m) at 0.0-0.05 m in soil grown with coffee, while aggregates > 2.00 mm presented the lowest reach value (11.50 m) at 0.10-0.20 m in soil grown with pasture. The range values for all variables were smaller as deeper, in this way the obtained results indicated greater spatial continuity of soil attributes in the superficial layers. This behavior corroborates with results observed by Souza et al. (2001).

The spatial dependence degree (SDD) was classified as strong for almost all soil uses, except in the area with cocoa, where the MWD presented moderate SDD. Moderate dependence was also found for the class of aggregates < 2.00 mm in coffee use, and ρ_b in both coffee and cocoa areas regardless of depth. In turn, strong SDD was observed for OC in soil use with cocoa at 0.10-0.20 m, however, the aggregate class > 2.00 mm presented strong SDD at all evaluated depths and soil uses. The Strong spatial dependence observed is due to the native anthropic activities, ended up with IBEs formation (AQUINO et al., 2015), while the mild spatial dependence reflected the nowadays soil use alterations, mostly at 0.0-0.05 m, the depth easilier affected by the soil management (CAMBARDELLA et al., 1994).

The isolines, surface and three-dimensional isoline maps obtained by interpolation of Kriging data presented similar values for the following variables: MWD, aggregates (> 2.00 <mm), ρ_b and OC at different depths and soil uses (Figure 2). However, maps allowed to illustrate spatial variability as a function of land use, which cannot be clarified with classical statistics. In pasture soil use, it was observed that the MWD and the class of aggregates (< 2.00> mm) presented greater spatial continuity at 0.0-0.05 m, this behavior was evidenced by the greater distance between the isolines and indicated a more defined behavior for these variables. The reduction of MWD values in aggregates > 2.00 mm coincided with the increase in the class of aggregates < 2.00 mm at 0.10-0.20 m. This relation of decrease and increase of aggregates of different classes reflected influence of the management in the properties of the soil.

The pasture soil use ρ_b maps of were closer due to the greater access and permanence of the cattle in the pasture. These maps characterize the compaction of this environment caused by animal trampling, which caused the destruction of the larger aggregates and ρ_b elevation to up to 0.05 m (AQUINO et al., 2014a; CAJAZEIRA; ASSIS JUNIOR 2011). However, ρ_b and compaction observed in this study did not compromise root development in the different uses due to the high organic matter content observed in IBEs (CAMPOS et al., 2012).

The landscape and soil shape in pasture and cacao areas were similar, but soil attributes presented distinct aspects due to differences in cultural habit, use, and type of soil. At 0.0-0.05 m, it was not possible to capture the spatial variability (Figure 2), considering the sampling distance used (McBRATNEY; WEBSTER, 1986), due to the greater uniformity of the soil surface provided by cacao cultivation, which covers the soil with remains and where conditions a more homogeneous environment. These plant remains favored the maintenance of organic matter, reflecting in the highest values of OC (0.10-0.20 m) when compared to the other types of soil uses.

In a general way, soil under coffee cultivation, due to the diversity of geomorphological expressions (linear, concave and convex pedoforms), presented greater spatial discontinuity in the class of aggregates < 2.00 mm and in the WMD at 0.0-0.05 m. This discontinuity can be observed on the map, where there is the predominance of erratic isolines at close range (Figure 2), in the case, the spatial variability was a natural consequence of the landscape configuration, since maps at depth 0.10-0.20 m are spatially more uniform for these attributes. Other studies have also reported the influence of landscape shape on soil physical properties (ALHO et al., 2015).

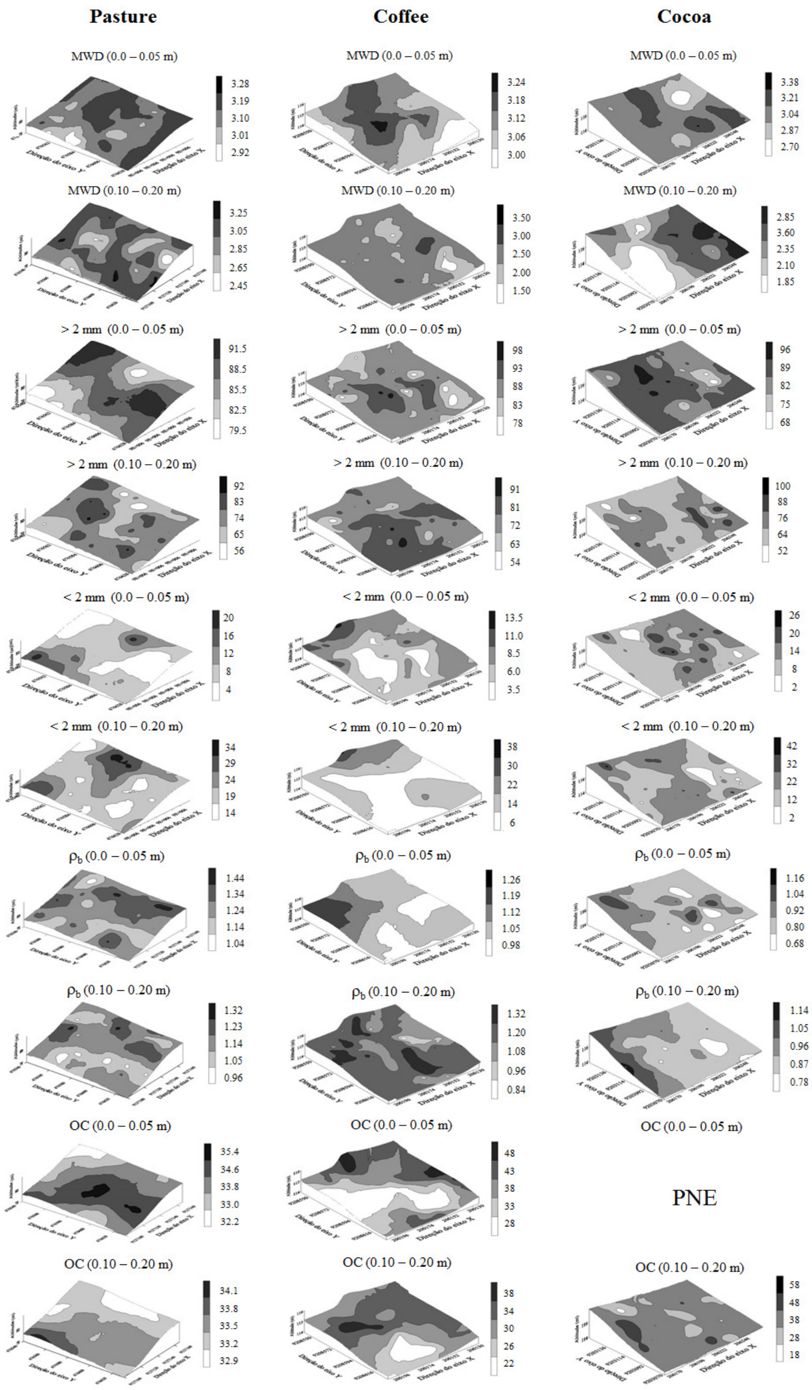

Figure 2. Isoline Maps of Mean Weight Diameter distribution (MWD, mm), aggregate class higher than 2 mm (> 2 mm), aggregate class smaller than 2 mm (< 2 mm), Bulk density (ρ_b, kg dm^{-3}), and organic carbon (OC, g kg^{-1}) at two depths.

The results did not identify correlation between the soil physical attributes and the existing geomorphic expressions. However, other studies observed such correlation (SILVA et al., 2016). It was not observed due to the scale used in the studied areas. However, it was possible to observe a more homogeneous behavior for the physical attributes at 0.10-0.20 m regardless both soil use and type, confirming the deeper, the less affect the adopted management to the soil attributes in IBEs.

CONCLUSIONS

The soil use influenced the soil physical attributes behavior in IBEs, where the higher values of CO, aggregates > 2.00 mm, and MWD at 0.00-0.05m in relation to ρ_b and aggregates < 2.00 mm increased at 0.10-0.20 m.

Aggregates < 2.00 mm (0.10-0.20 m) and OC (0.0-0.5 m) did not show spatial dependence, while the aggregates class > 2,00 mm was the only soil attribute characterized as natural with a strong spatial dependence, regardless the soil use and depth.

There was no spatial relationship between the attributes studied and the geomorphic diversity.

RESUMO: As Terras Pretas de Índio (TPIs) encontram-se distribuídas por toda a Amazônia. Elas são caracterizadas pela alta fertilidade química e potencial agrícola. As TPIs possuem alto carbono orgânico, favorecendo a melhoria da estrutura do solo. Este trabalho teve como objetivo avaliar a variabilidade espacial dos agregados e do carbono orgânico (CO) em diferentes usos de TPIs no sul do Amazonas. Foi avaliado a variabilidade espacial do carbono orgânico, diâmetro médio ponderado (DMP), densidade do solo (ρb) e as classes de agregados sob três usos do solo: pastagem, cacau e café. Nas áreas estudas construiu-se um grid regular de pontos, de acordo com o uso do solo e nas profundidades, 0-0,05 m e 0,10-0,20 m, totalizando 528 amostras de solo. Os resultados foram submetidos à análise de variância, descritiva e geoestatística. O uso do solo influenciou o comportamento dos atributos físicos das TPIs, concentrando os valores mais altos de CO, agregados > 2.00 mm e DMP na profundidade 0,0-0.05 m em relação a ρb e agregados <2.00 mm, que assumiram valores mais altos na profundidade 0,10-0,20 m. Agregados < 2,00 mm (0,10-0,20 m) e CO (0,0-0,05 m) não apresentaram dependência espacial, enquanto a classe de agregados > 2,00 mm foi o único atributo que representou uma característica natural do solo, com forte dependência espacial, independentemente do uso e profundidade do solo. Não houve relação espacial entre os atributos estudados e a diversidade geomórfica.

PALAVRAS CHAVE: Dependência espacial. Classes de agregados. Agregação do solo. Uso da terra.

REFERENCES

ALHO, L. C.; CAMPOS, M. C. C.; MANTOVANELLI, B. C.; SILVA, D. M. P.; SOUZA, Z. M.; CUNHA, J. M.; SOARES, M. D. R. Physical and geospatial attributes of inceptisols and ultisols under native vegetation in Humaitá, Am, Brazil. **Bioscience Journal**, Uberlândia, v. 32, n. 2, p. 422–430, 2016. http://dx.doi.org/10.14393/BJ-v32n2a2016-32656.

ALHO, L. C.; CAMPOS, M. C. C.; SILVA, D. M. P.; MANTOVANELLI, B. C.; SOUZA, Z. M. Variabilidade espacial da estabilidade de agregados e estoque de carbono em Cambissolo e Argissolo. **Pesquisa Agropecuária Tropical**, Goiânia, v. 44, n. 3, p. 246–254, 2014. http://www.scielo.br/pdf/pat/v44n3/a01v44n3.pdf

AQUINO, R. E.; CAMPOS, M. C. C.; MARQUES JÚNIOR, J.; OLIVEIRA, I. A.; MANTOVANELLI, B. C.; SOARES, M. D. R. Geoestatística na avaliação dos atributos físicos em Latossolo sob floresta nativa e pastagem na Região de Manicoré, Amazonas. **Revista Brasileira de Ciência do Solo**, Viçosa, v. 38, n. 2, p. 397–406. 2014a. http://dx.doi.org/10.1590/S0100-06832014000200004.

AQUINO, R. E.; CAMPOS, M. C. C.; MARQUES JÚNIOR, J.; OLIVEIRA, I. A.; TEIXEIRA, D. B.; CUNHA, J, M. Uso de semivariogramas escalonados no planejamento amostral de atributos físicos do solo em ambientes na região Sul do Amazonas. **Revista Brasileira de Ciência do Solo**, Viçosa, v. 39, n. 1, p. 21–30. 2015. http://dx.doi.org/10.1590/01000683rbcs20150524.

AQUINO, R. E.; CAMPOS, M. C. C.; OLIVEIRA, I. A.; MARQUES JÚNIOR, J.; SILVA, D. M. P. Variabilidade espacial de atributos físicos de solos antropogênico e não antropogênico na região de Manicoré, AM. **Bioscience Journal**, Uberlândia, v. 30, n. 4, p. 988–997, 2014b.

BRASIL. Ministério de Minas e Energia. **Projeto Radambrasil**. 17. ed. Rio de Janeiro: Folha SB. 20, Purus, 1978.

BURROUGH, P. A.; McDONNELL, R. A. **Principles of geographical information systems:** Spatial information systems and geostatistics. New York: Oxford University Press, 2000. 333 p.

CAJAZEIRA, J. P.; ASSIS JÚNIOR, R. N. Variabilidade espacial das frações primárias e agregados de um Argissolo no Estado do Ceará. **Revista Ciência Agronômica**, Fortaleza, v. 42, n. 2, p. 258–267, 2011.

CAMARGO, L. A.; MARQUES JÚNIOR, J.; PEREIRA, G. T. Spatial variability of physical attributes of an Alfisol under different hillslope curvatures. **Revista Brasileira de Ciência do Solo**, Viçosa, v. 34, n. 4, p. 617–630, 2010. http://dx.doi.org/10.1590/S0100-06832010000300003.

CAMBARDELLA, C. A.; MOORMAN, T. B.; NOVAK, J. M.; PARKIN, T. B.; KARLEM, D. L.; TURCO, R. F.; KONOPA, A. E. Field scale variability of soil properties in central Iowa soil. **Soil Science Society American Journal**, Madison, v. 58, n. 4, p. 1501–1511, 1994. http://dx.doi.org/10.2136/sssaj1994.03615995005800050033x

CAMPOS, M. C. C.; AQUINO, R. E.; OLIVEIRA, I. A.; BERGAMIN, A. C. Variabilidade espacial da resistência mecânica do solo à penetração e umidade do solo em área cultivada com cana-de-açúcar na região de Humaitá, Amazonas, Brasil. **Agrária**, Recife, v.8, n.2, p.305-310. 2013b. http://dx.doi.org/10.5039/agraria.v8i2a2091.

CAMPOS, M. C. C.; RIBEIRO, M. R.; SOUZA JÚNIOR, V. S.; RIBEIRO FILHO, M. R.; SOUZA, R. V. C. C.; ALMEIDA, M. C. Caracterização e classificação de terras pretas arqueológicas na região do Médio Rio Madeira. **Bragantia**, Campinas, v. 70, n. 4, p. 598–609. 2011. http://dx.doi.org/10.1590/S0006-87052011000300016.

CAMPOS, M. C. C.; SANTOS, L. A. C.; SILVA, D. M. P.; MANTOVANELLI, B. C.; SOARES, M. D. R. Caracterização física e química de terras pretas arqueológicas e de solos não antropogênicos na região de Manicoré, Amazonas. **Revista Agro@mbiente**, Boa Vista, v. 6, n. 1, p. 102–109, 2012. http://dx.doi.org/10.18227/1982-8470ragro.v6i2.682.

CAMPOS, M. C. C.; SOARES, M. D. R.; SANTOS, L. A. C.; OLIVEIRA, I. A.; AQUINO, R. E.; BERGAMIN, A. C. Variabilidade espacial dos atributos físicos em um Argissolo Vermelho sob floresta. **Comunicata Scientia**, Bom Jesus, v. 4, n. 2, p. 168–178, 2013a. http://dx.doi.org/2-s2.0-84880071446.pdf?sequence=1

CRUZ, J. S.; ASSIS JÚNIOR, R. N.; MATIAS, S. S. R.; CAMACHO-TAMAYO, J. H.; TAVARES, R. C. Análise espacial de atributos físicos e carbono orgânico em Argissolo vermelho-amarelo cultivado com cana-de-açúcar. **Ciência e Agrotecnologia**, Lavras, v. 34, n. 2, p. 271–278, 2010. http://dx.doi.org/10.1590/S1413-70542010000200001.

EMBRAPA. Empresa Brasileira de Pesquisa Agropecuária – Centro Nacional de Pesquisa de Solos. **Manual de métodos de análise de solo**. 2. ed. Rio de Janeiro: Embrapa, 1997. 167 p.

EMBRAPA. Empresa Brasileira de Pesquisa Agropecuária – Centro Nacional de Pesquisa de Solos. **Sistema brasileiro de classificação de solo**. 3. ed. Brasília: Embrapa, 2013. 263 p.

GARCIA, R. A.; ROSOLEM, C. A. Agregados em um Latossolo sob sistema plantio direto e rotação de culturas. **Pesquisa Agropecuária Brasileira**, Brasília, v. 45, n. 6, p. 1489–1498, 2010.

KEMPER, W. D.; CHEPIL, W. S. Aggregate stability and size distribution. In: BLACK, C. A. (Ed.) **Methods of soil analysis**. Madison: American Society of Agronomy, 1965. p. 499–510.

MARQUES, J. D. O.; LUIZÃO, J. L.; TEIXEIRA, G. T.; SARRAZIN, M.; FERREIRA, S. J. F.; BELDINI, T. P.; ARAÚJO MARQUES, E. M. Distribution of organic carbon in different soil fractions in ecosystems of Central Amazonia. **Revista Brasileira de Ciência do Solo**, Viçosa, v. 39, n. 1, p. 232–42, 2015. http://dx.doi.org/10.1590/01000683rbcs20150142.

McBRATNEY, A. B.; WEBSTER, R. Choosing functions for semi-variograms of soil properties and fitting them to sampling estimates. **Journal Soil Science**, Medford, v. 37, n. 3, p. 617–639, 1986. http://dx.doi.org/10.1111/j.1365-2389.1986.tb00392.x

MINITAB RELEASE 14.1. **Statistical Software**. US/Canadá, 2000.

OLIVEIRA, I. A.; CAMPOS, M. C. C.; SOARES, M. D. R.; AQUINO, R. E.; MARQUES JÚNIOR, J.; NASCIMENTO, E. P. Variabilidade espacial de atributos físicos em um Cambissolo Háplico, sob diferentes usos na região Sul do Amazonas. **Revista Brasileira de Ciência do Solo**, Viçosa, v. 37, n. 4, p. 1103–1112. 2013. http://dx.doi.org/10.1590/S0100-06832013000400027.

OLIVEIRA, I. A.; MARQUES JÚNIOR, J.; CAMPOS, M. C. C.; AQUINO, R. E.; FREITAS, L.; SIQUEIRA, D. S.; CUNHA, J. M. Variabilidade espacial e densidade amostral da suscetibilidade magnética e dos atributos de Argissolos da região de Manicoré, AM. **Revista Brasileira de Ciência do Solo**, Viçosa, v. 39, n. 4, p. 668–681, 2015. http://dx.doi.org/10.1590/01000683rbcs20140496.

SILVA, D. M. P.; CAMPOS, M. C. C.; FRANCISCON, U.; ALHO, L. C.; SANTOS, L. A. C.; PAULA NETO, P.; BERGAMIN, A. C.; SOUZA, Z. M. Spatial variability of soil properties in archeological dark earth sites under cacao cultivation. **Revista Brasileira de Ciência do Solo**, Viçosa, v. 40, p. 816–828, 2016. http://dx.doi.org/10.1590/18069657rbcs20140816.

SOIL SURVEY STAFF. **Keys to soil taxonomy**. 12. ed. Washington, DC: United States Department of Agriculture, Natural Resources Conservation Service, 2014.

SOUZA, Z. M.; SILVA, M. L. S.; GUIMARÃES, G. L.; CAMPOS, D. T. S.; CARVALHO, M. P.; PEREIRA, G. T. Variabilidade espacial de atributos físicos em um Latossolo Vermelho distrófico sob semeadura direta em Selvíria (MS). **Revista Brasileira de Ciência do Solo**, Viçosa, v. 25, n. 3, p. 699–707. 2001. http://dx.doi.org/10.1590/S0100-06832001000300019.

STEINBEISS, S.; GLEIXNER, G.; ANTONIETTI, M. Effect of biochar amendment on soil carbon balance and soil microbial activity. **Soil Biology and Biochemistry**, Oxford, v. 41, n. 6, p. 1301–1310, 2009. https://doi.org/10.1016/j.soilbio.2009.03.016.

SURFER FOR WINDOWS. Realese 7.0. **Contouring and 3D surface mapping for scientist's engineers.** User's guide. NY/Estados Unidos: Golden Software, 1999.

VIEIRA, S. R. Geoestatística em estudos de variabilidade espacial do solo. In: NOVAIS, R. F.; ALVAREZ, V. H.; SCHAEFER, G. R. (Eds.) **Tópicos em Ciência do Solo**. Viçosa: Sociedade Brasileira de Ciência do Solo, 2000. p. 1–54.

VIEIRA, S. R. Variabilidade espacial de atributos físicos e químicos relacionados com o estado de agregação de dois Latossolos cultivados no sistema de semeadura direta. **Bragantia**, Campinas, v. 70, n. 2, p. 185–195, 2011. https://doi.org/10.1590/S0006-87052011000100025.

WARRICK, A. W.; NIELSEN, D. R. Spatial variability of soil physical properties in the field. In: HILLEL, D. (Ed.) **Applications of soil physics**. New York: Academic Press, 1980. 400 p.

YEOMANS, J. C.; BREMNER, J. M. A rapid and precise method for routine determination of organic carbon in soil. **Communication Soil Science Plant and Analisys**, New York, v. 19, n. 2, p. 1467–1476, 1988. http://dx.doi.org/10.1080/00103628809368027.