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ORIGINAL ARTICLE

Spatial variability of physical attributes in Alfissol under agroforestry, Humaitá region, Amozonas state, Brazil

Variabilidade espacial dos atributos físicos de um Argissolo Vermelho sob agrofloresta

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ABSTRACT: In this research, we aimed to evaluate the spatial variability of soil properties in Alfissol under agroforestry in the Humaitá region, Amazonas state, Brazil. Mapping of an agroforestry growing area was performed in 70 × 70 m sampling grid design. In the mapped area, soil samples were collected at regular 10 m spacing at 0.0-0.1 m depth layer, totaling 64 sampling sites. The following physical analyses were carried out: texture, soil bulk and particle density, macro and microporosity, total porosity and stability of aggregates in water. Descriptive and geostatistical analyses were conducted. After these steps, it was possible to observe that all physical attributes were spatially dependent and that most ranges were greater than those initially established in the sampling grid, except for variables related to aggregates, which must have denser sampling grid. Empirical semivariograms followed the adjustment trends for attributes in the field of Soil Science: exponential model for sand, particle density and microporosity; spherical model for the other physical variables.

RESUMO: *O objetivo deste trabalho foi avaliar a variabilidade espacial dos atributos físicos de um Argissolo Vermelho Alítico plíntico sob agrofloresta, na região de Humaitá-AM. Foi realizado o mapeamento de uma área sob uso agroflorestal, delimitando-se uma malha de 70 × 70 m. Na malha, foram coletadas amostras de solos em espaçamentos regulares de 10 em 10 metros, na profundidade de 0,0-0,10 m, totalizando 64 pontos amostrais. Foram realizadas análises físicas, como: textura, densidade do solo e de partícula, macroporosidade, microporosidade, porosidade total e estabilidade dos agregados em água. Foram realizadas análises estatísticas descritivas e geoestatísticas. Após essas etapas, verificou-se que todos os atributos físicos estudados apresentaram dependência espacial e que a maior parte dos alcances foi superior aos estabelecidos incialmente na malha de amostragem, com exceção das variáveis relacionadas aos agregados, que deverão ter a malha de amostragem mais adensada. Os semivariogramas empíricos seguiram as tendências de ajuste para os atributos na área da Ciência do Solo, sendo o modelo exponencial para areia, densidade de partícula e microporosidade, e o modelo esférico para as demais variáveis físicas.*

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1 Introduction

In the Amazon region, family farming is developed within traditional subsistence agricultural systems deployed in indigenous, mestizo and riparian communities (CASTRO et al., 2009). These traditional production systems are characterized by an assembly of woody perennial plant species (trees, shrubs and palms) and herbaceous plant species (crops and/or forages) associated or not with animals in the same management unit, favoring a time-spatial arrangement with high species diversity and ecological interactions - they are called agroforestry systems (ABDO; VALERI; MARTINS, 2008).

According to Carvalho, Goedert and Armando (2004), these agricultural production systems are an alternative because they minimize the effect of human intervention in natural systems. Castro et al. (2009) claim that these alternatives promote sustainable use of the land, and consequently generate multiple use species. Furthermore, they allow the recovery of degraded areas, as highlighted by Fávero, Lovo and Mendonça (2008) working with recovery of degraded areas with agroforestry in Vale do Rio Doce, Minas Gerais state. Carvalho, Goedert and Armando (2004) evaluating soil quality under agroforestry found lower density, higher porosity, lower penetration resistance and greater aggregate stability, when compared to soils under conventional tillage.

Currently, the use of mathematical modeling tools, e.g. geostatistics, has been of essential importance because it allows prediction of spatial dependence of the attributes assessed, aiming increased crop productivity and reduced risk of environmental contamination (CAVALCANTE et al., 2007). Thus, studies on soil spatial variability have become important, as agriculture information on soil structure is fundamental to the understanding of physical-hydric and chemical processes, which are dynamic; and based on this information, make inferences about practices of crop and soil management (SOUZA; MARQUES JÚNIOR; PEREIRA, 2009). Moreover, according to Grego and Vieira (2005), understanding the variability of soil properties and crops in space and time is currently considered a basic principle for the precise management of agricultural areas, whatever their scale. Therefore, in this study, we aimed to evaluate the spatial variability of soil properties in Alfissol under agroforestry in the Humaitá region, Amazonas state, Brazil.

2 Materials and Methods

The study area is located in the Humaitá region, southern Amazonas state, at the following geographic coordinates: 7° 30’ 24” S latitude and 63° 04’ 56” W longitude. The region presents vegetation of contact between Fields/Forests, which is characterized by having several grasslands; low grass-woody vegetation is dominant, alternating small isolated trees and forest galleries along the rivers. According to the Köppen classification, the study region presents tropical rainy climate with short dry period (Am), temperatures ranging between 25 and 27 °C and 2,500 mm average annual rainfall, rainy season starting in October and extending until June, and relative humidity ranging from 85 to 90% (BRASIL, 1978).

Mapping of an agroforestry growing area was performed in 70 × 70 m sampling grid (Figure 1). Soils were sampled at the crossing points of the grid at regular 10 m spacing, totaling 64 sampling sites. These sites were georeferenced with a GPS device and then soil samples were collected at 0.0-0.10 m depth layer.

Particle size analysis was performed by the pipette method using NaOH 0.1 N solution as chemical dispersant and high-speed mechanical stirring for 15 minutes. Clay fraction was separated by sedimentation, coarse and fine sands by sieving, and silt was calculated by difference. Soil particle density (PD) was determined by the rubber-balloon method according to methodology by Embrapa (2011).

Samples of undisturbed soil were collected in volumetric rings. They were then saturated by a gradual increase in water depth until reaching approximately 2/3 of the ring height. Total porosity (TP) was obtained by the difference between the mass of saturated soil and the mass of soil oven-dried at 105 °C for 24 h. Microporosity of soil was determined by the tension table method (limit between macropores and micropores at 6 kPa), according to methodology by Embrapa (2011). Macroporosity was obtained by the difference between total porosity and microporosity. Soil bulk density (BD) was calculated by the ratio between the dry weight at 105 °C for 24 h of the soil sample of the volumetric cylinder and the volume of the same cylinder (EMBRAPA, 2011).

Samples of undisturbed soil were collected at 0.0-0.10 m depth layer at the crossing points of the sampling grid to determine stability of soil aggregates. Samples were dried in shade, slightly fractionated manually, and passed through a 9.51 mm sieve and then retained on sieves of 4.72 mm diameter mesh for analysis of soil aggregates. Separation and stability of aggregates were determined according to Kemper and Chepil (1965), with modifications in the following diameter classes >2.0, 2.0 to 1.0 and <1.0 mm. Soil aggregates were initially moistened and then placed in contact with water on a 2.00 mm sieve for fifteen minutes, the mass of material retained on each sieve was placed in oven at 105 °C. Results were expressed as percentage of aggregates in the >2.0, 2.0 to 1.0 and <1.0 mm sieves; aggregation indices corresponding to geometric mean diameter (GMD) and weighted mean diameter (WMD) were also calculated.

First, we evaluated the exploratory data analysis by calculating the mean; median; standard deviation; variance; maximum and minimum coefficient of variation; coefficient of skewness; and coefficient of kurtosis. Hypothesis of normality of data was verified by the Kolmogorov-Smirnov test, using the statistical software Minitab 14 (MINITAB, 2000).

Geostatistical analysis (ISAAKS; SRIVASTAVA, 1989) was used to characterize spatial variability. Under the intrinsic hypothesis theory, the experimental semivariogram was estimated by the classic method using the semivariance estimator (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: $\hat{\gamma}(h)$ – value of the semivariance at distance/lag h; N(h) - number of pairs involved in the calculation semivariance; Z(x_i) - value of the attribute Z at the position

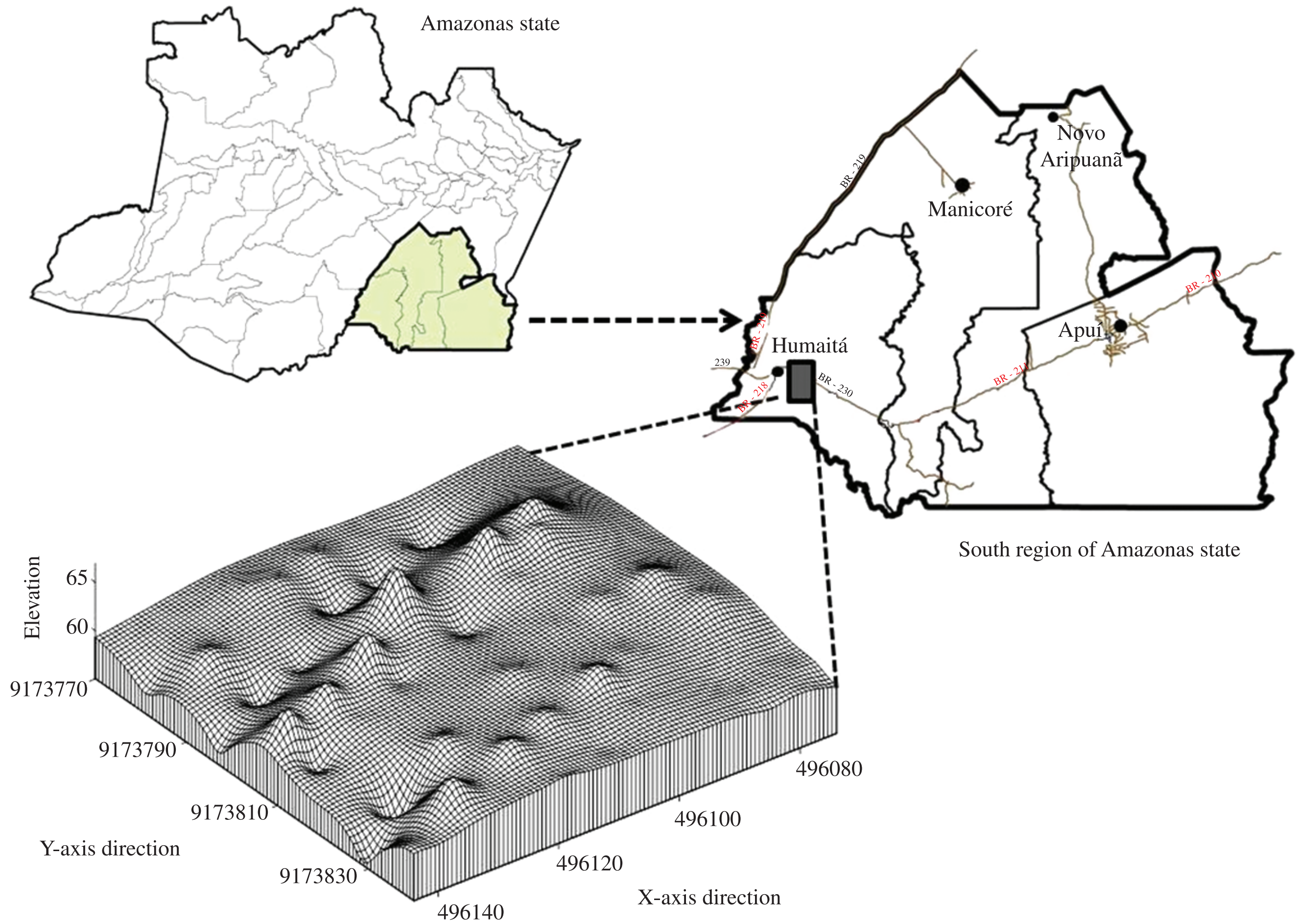

Figure 1. Map of the state of Amazonas, south region of Amazonas state and Digital Elevation Model of the agroforestry area in Humaitá.

x_i.; $Z(x_i+h)$ - value of the attribute Z separated by distance/lag h from the position x_i.

Coefficients of the theoretical model for the semivariogram are defined from the fitting of a mathematical model to the values calculated of $\hat{\gamma}$ (h): Nugget effect (C_0); Sill (C_1); Spatial Lag Dependence ($C_0 + C_1$) and Range (a). Nugget effect is the semivariance value at the origin (0 lag) and it is the component of the random variation; sill is the semivariance value at which the semivariogram levels off; range is the lag distance at which the semivariogram (or semivariogram component) reaches the sill value, autocorrelation is essentially zero beyond the range.

For the analysis of spatial lag dependence (percent ratio of nugget effect (C_0) over sill (C_0+C_1)) of the variables studied, we used the classification by Cambardella et al. (1994), where values of $[(C_0/(C_0+C_1)]$ smaller than 25% are considered strongly correlated, values of $[(C_0/(C_0+C_1)]$ between 25 and 75% indicate moderate correlation, and values of $[(C_0/(C_0+C_1)]$ greater than 75% are weakly correlated.

In order to determine whether spatial dependence existed, we used the elaboration and examination of semivariograms through the GS+ program (ROBERTSON, 1998). In the event of more than one model for the same semivariogram, our choice was based on the highest correlation coefficient and the best determination coefficient (r^2). After adjustment of permissible mathematical models, data interpolation was performed by kriging (or stochastic simulation) and then isoline maps were generated in software Surfer 8.00.

3 Results and Discussion

Mean and median values are similar for all variables, as well as coefficient of skewness and coefficient of kurtosis values are close to zero, which indicates symmetric distribution of data (Table 1).

Results for the Kolmogorov-Smirnov test indicated normality for all the variables studied. Although normality of data is not a requirement of geostatistics, distribution should not present very elongated tails or should not be very asymmetric, which could compromise stochastic simulation estimates, which are based on mean values (ISAAKS; SRIVASTAVA, 1989). Gonçalves and Folegatti (2002) found normality for the variable clay working with regular grid sampling. Similar results for the variable silt were also observed by Campos, Marques Júnior and Pereira (2010).

According to the classification proposed for CV by Warrick and Nielsen (1980), variability for classification of soil variables is low when CV is lower than 12%, medium when CV ranges from 12 to 60% and high when CV is higher than 60%. We observed that values of microporosity, particle density, bulk density and total porosity showed low variability of data, that is, CV < 12%; similar results were found by Passos, Sorrato and Freddi (2002) in Dystrophic Red Latosol and Campos et al. (2007) in Spodosol in Zona da Mata, Pernambuco state. The variable macroporosity showed high CV (CV> 60%), probably because this attribute is very sensitive to soil management. On the other hand, particle size analysis presented moderate CV values except for clay, which showed low values for this variable. Campos et al. (2007) also found low CV in a study carried out in Spodosol. High values of CV may be considered early indicators of the existence of heterogeneity in data.

Results of the geostatistical analysis (Table 2 and Figure 1) showed that all variables presented spatial dependence. The values of R^2 were considered in the selection of semivariogram models, the spherical model was the one that best fitted the variables silt, clay, macroporosity, total porosity and bulk density; while the exponential model was the most adequate for sand, microporosity and particle density (Table 2). According to Carvalho, Silveira and Vieira (2002), the spherical mathematical model is predominant in works in soil science; on the other hand, Souza, Marques Júnior and Pereira (2009) pointed out that the models of semivariogram fitted to soil properties most commonly found are the spherical and exponential ones.

For the analysis of spatial dependence of physical attributes (Table 2), we used the classification by Cambardella et al. (1994) for spatial lag dependence SLD < 25%; 25% < SLD > 75%; and SLD> 75%, regarding strong, medium and weak correlation, respectively. The variables studied showed moderate correlation (26-76%), except for microporosity, which showed weak spatial correlation. The distribution of physical attributes is not random, because all of them showed moderate values for the degree of spatial correlation, except for microporosity.

The correlation adjustment coefficients of the semivariogram (r^2) were fitted to all variables studied with values ranging from 0.81 to 0.99 (Table 2 and Figure 2). However, it is worth considering that microporosity, bulk density and macroporosity obtained low values of nugget effect (C_0), which indicates a greater representation of the spatial variability of these attributes for the study area; on the other hand, sand and silt were the variables that clearly showed the worst semivariograms.

According Cambardella et al. (1994) and Vieira (1997), high nugget effect (C_0) values correspond to variability not detected during the sampling process. The lower the proportion of nugget effect over sill of the semivariogram, the higher the

Table 1. Descriptive statistics of particle size attributes (sand, silt and clay), macro (Macro) and microporosity (Micro), total porosity (TP), bulk density (BD) and particle density (PD) of Alfissol in agroforestry area in the region of Humaita, Amazonas state.

Descriptive statistics	Sand	Silt	Clay	Macro[4]	Micro[5]	TP[6]	BD[7]	PD[8]
	g kg^{-1}			m^3 m^{-3}			kg dm^{-3}	
Mean	220.79	230.11	549.10	2.94	30.93	33.87	1.31	2.67
Median	210.29	228.69	558.87	2.68	31.68	34.40	1.31	2.67
Minimum	144.15	110.54	402	–4.03	23.04	26.65	1.07	2.50
Maximum	404.49	396.64	680	9.28	43.05	39.02	1.58	2.68
SD[1]	50.10	59.61	65.52	2.030	3.600	3.11	0.094	0.091
Variance	2510.34	3553.72	4293.71	4.120	13.020	9.70	0.008	0.008
CV[2]	22.69	25.90	11.93	69.06	11.66	9.19	7.20	3.14
Kurtosis	2.687	0.74	–0.40	4.79	0.98	–0.06	0.49	–0.33
Skewness	1.46	0.57	–0.44	0.24	–0.06	–0.79	0.10	–0.02
d[3]	0.15	0.12	0.11	0.18	0.15	0.14	0.05	0.04

SD[1]= standard deviation; CV[2]= coefficient of variance; d[3] = significant at 5% probability by the Kolmogorov-Smirnov test; [4]Macro = macroporosity, [5]Micro = microporosity, [6]TP = total porosity, [7]SD = soil density, [8]PD = particle density.

Table 2. Parameters of the estimated models of semivariograms for particle size attributes (sand, silt and clay), macro (Macro) and microporosity (Micro), total porosity (TP), bulk density (BD) and particle density (PD) of Alfissol in agroforestry area in the region of Humaita, Amazonas state**.**

Statistics	Sand	Silt	Clay	[3]Macro	[4]Micro	[5]TP	[6]BD	[7]PD
Model	[1]Exp.	[2]Sph.	Sph.	Sph.	Exp.	Sph.	Sph.	Exp.
C_0	625.47	845.75	2253.62	1.21	0.39	3.51	0.006	0.004
C_1+C_0	2357.84	3187.04	3474.68	2.50	13.08	8.50	0.008	0.007
r	68.31	18.26	33.27	61.18	69.51	67.90	45.50	22.60
r^2	0.92	0.81	0.85	0.99	0.99	0.98	0.96	0.88
SLD	73	73	35	50	97	58	27	38

C_0: nugget effect; C_1: structural variance; *r*: range; r^2: correlation coefficient; SLD: spatial lag dependence between samples ; [1]Exp:Exponential; [2]Sph:Spherical. [3]Macro = macroporosity, [4]Micro = microporosity, [5]TP = total porosity, [6]BD = bulk density, [7]PD = particle density.

spatial correlation presented by the attribute (LIMA et al., 2006); therewith, the greater the phenomenon continuity, the lower the estimate variance and the greater the confidence in the estimated value.

Range (*a*) of spatial dependence is another important parameter in the study of semivariogram; it sets the limit distance/lag to which a sampling point influences another, that is, the maximum spatial correlation distance/lag between variables. Because the range of an attribute ensures that all points within a circle with radius of equal value are so similar that can be used to estimate values for any point between them (MACHADO et al., 2007). In addition, range values concerning semivariograms have considerable importance in determining the limit of spatial dependence and they can also indicate the interval between sampling grid units (GREGO; VIEIRA, 2005).

Souza et al. (2006) recommend the use of semivariogram range to determine the amount of samples to be collected for soil property analyses, according to the scale of the study. To ensure spatial dependence, points must be collected at a distance equal to half the range. When spatial dependence cannot be maintained, points must be collected at a distance equivalent to twice the range. The variables analyzed showed different ranges (Table 2 and Figure 2): variables sand, macroporosity, microporosity and total porosity showed ranges over 55 m, these attributes maintained higher spatial continuity because they presented higher values; whereas silt, clay, bulk density and particle density showed range values shorter than 46 m.

Through kriging maps (Figure 3), regarding particle size attributes (sand, silt and clay), it was possible to verify that greater clay contents were found in the upper part of the area assessed,; whereas in the lower part, where the slope was more pronounced, greater amounts of total sand were observed due to the removal of finer fractions. Campos, Marques Júnior and Pereira (2010) stated that variation in relief itself can significantly influence the determination of sediment transport and deposition, so as to cause spatial variability in soil attributes.

Results for the Kolmogorov-Smirnov test indicated normality for all studied variables (Table 3). Although normality of data is not a requirement of geostatistics, distribution should not present very elongated tails, which could compromise kriging, which is based on mean values (ISAAKS; SRIVASTAVA, 1989).

We observed a higher percentage of aggregates in class size > 2.00 mm, with values above 80% (Table 3), indicating greater resistance to disaggregation. According to Souza, Marques Júnior and Pereira (2004), aggregation can be considered an index of soil quality, because structure stability improves aeration and water infiltration and reduces erodibility percentage. High values of WMD were observed indicating high stability of soil aggregates, results similar to those found by Carvalho, Goedert and Armando (2004) when studying soil quality physical attributes in soil under agroforestry, where the authors attributed as probable causes, the presence of large amount of organic matter in different stages of decomposition and the higher biological activity, thus contributing to the formation of more stable aggregates. According to Le Bissonnais, Cros-Cayot and Gascuel-Odoux (2002), high WMD values indicate high stability of aggregates.

Adopting the classification criteria for CV proposed by Warrick and Nielsen (1980) to measure dispersion values, it was possible to note medium and high values (CV), (12% <CV> 60%) and (CV> 60%), respectively. The variable GMD presented medium CV (12% < CV > 60%), results similar to those found by Souza, Marques Júnior and Pereira (2004) studying aggregate stability and organic matter in soils of different reliefs and by Vieira et al. (2011), studying stability of aggregates by means of classic statistics, who reported medium CV for GMD. The variable WMD presented moderate CV (12% < CV > 60%); similar results were found by Souza, Marques Júnior and Pereira (2009). Moderate CV value was noted for the variable >2.00 mm, corroborating Souza, Marques Júnior and Pereira (2009). However, the variable 2.00 to 1.00 mm showed CV > 60%.

Results of geostatistical analysis showed that all variables presented spatial dependence (Table 4 and Figure 4). The spherical model was the best fit for data to define semivariogram parameters (Table 4). This selection is in accordance with Souza, Marques Júnior and Pereira (2009); they adjusted the spherical model to the WMD when studying

Table 3. Descriptive statistics for the geometric mean diameter (GMD), weighted mean diameter (WMD) and percentage of soil aggregates in classes > 2.00, 2.00-1.00, and <1.00 mm of Alfissol in agroforestry in the region of Humaita, Amazonas state.

Descriptive statistics	GMD (mm)	WMD (mm)	>2.00 (%)	2.00-1.00 (%)	<1.00 (%)
Median	2.09	2.87	82.04	3.39	12.43
Mean	2.03	2.76	80.79	4.03	14.79
Minimum	0.10	0.16	53.96	0.52	–1.3
Maximum	3.91	3.38	98.31	14.88	40.46
[1]SD	0.71	0.53	10.13	2.70	8.23
Variance	0.50	0.28	102.65	7.32	67.84
[2]CV (%)	34.89	19.30	12.54	67.06	55.67
Kurtosis	0.91	14.04	–0.24	3.01	0.81
Skewness	–0.34	–3.37	–0.66	1.51	0.96
[3]d	0.08	0.19	0.11	0.16	0.13

[(1)]SD= Standard deviation; [(2)]CV= Coefficient of variance; [(3)]d= Kolmogorov-Smirnov test.

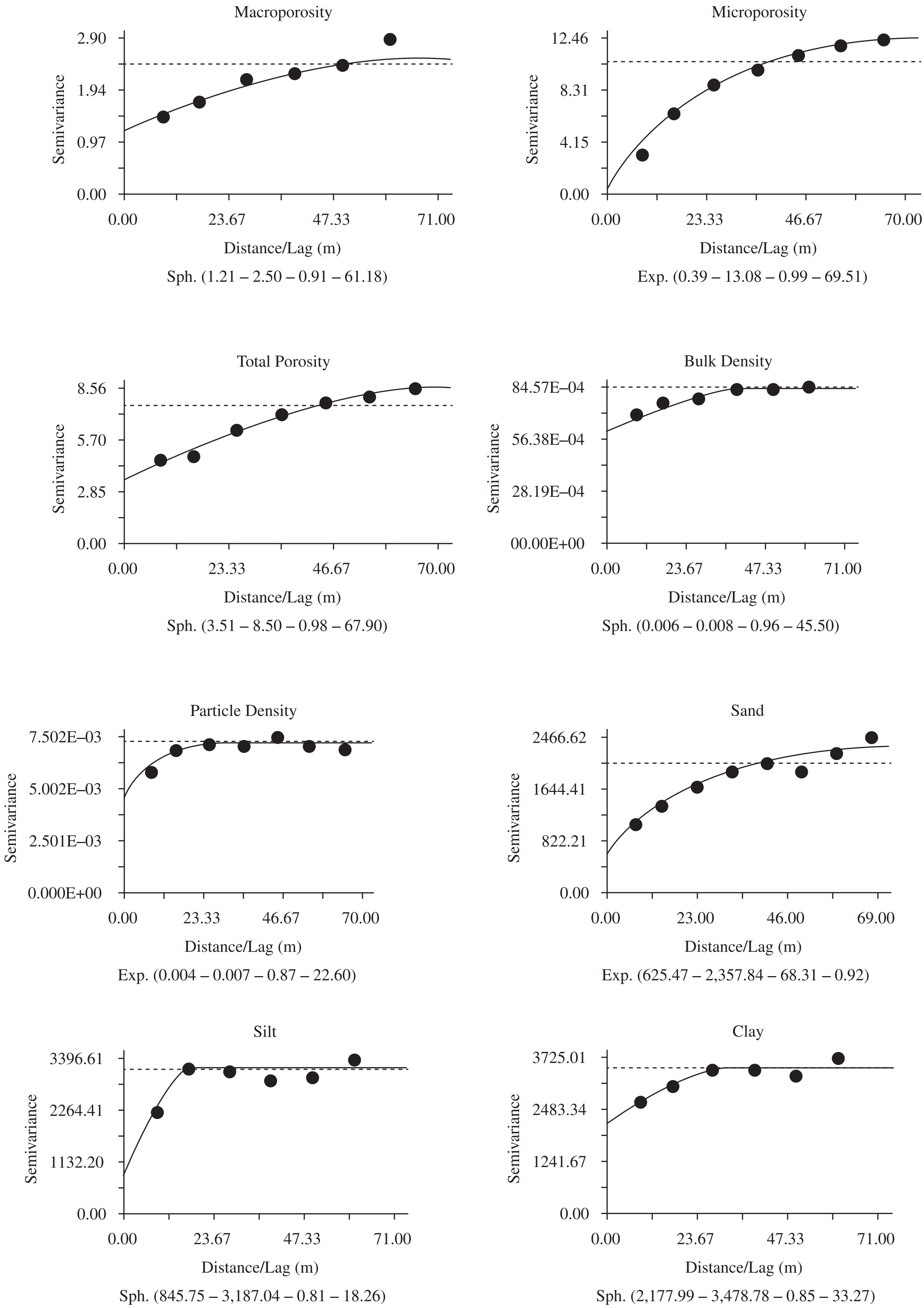

Figure 2. Experimental semivariograms of particle size attributes (sand, silt and clay), macro (Macro) and microporosity (Micro), total porosity (TP), bulk density (BD) and particle density (PD) of Alfissol in agroforestry in the region of Humaita, Amazonas state. Sph. = Spherical model, Exp = exponential model.

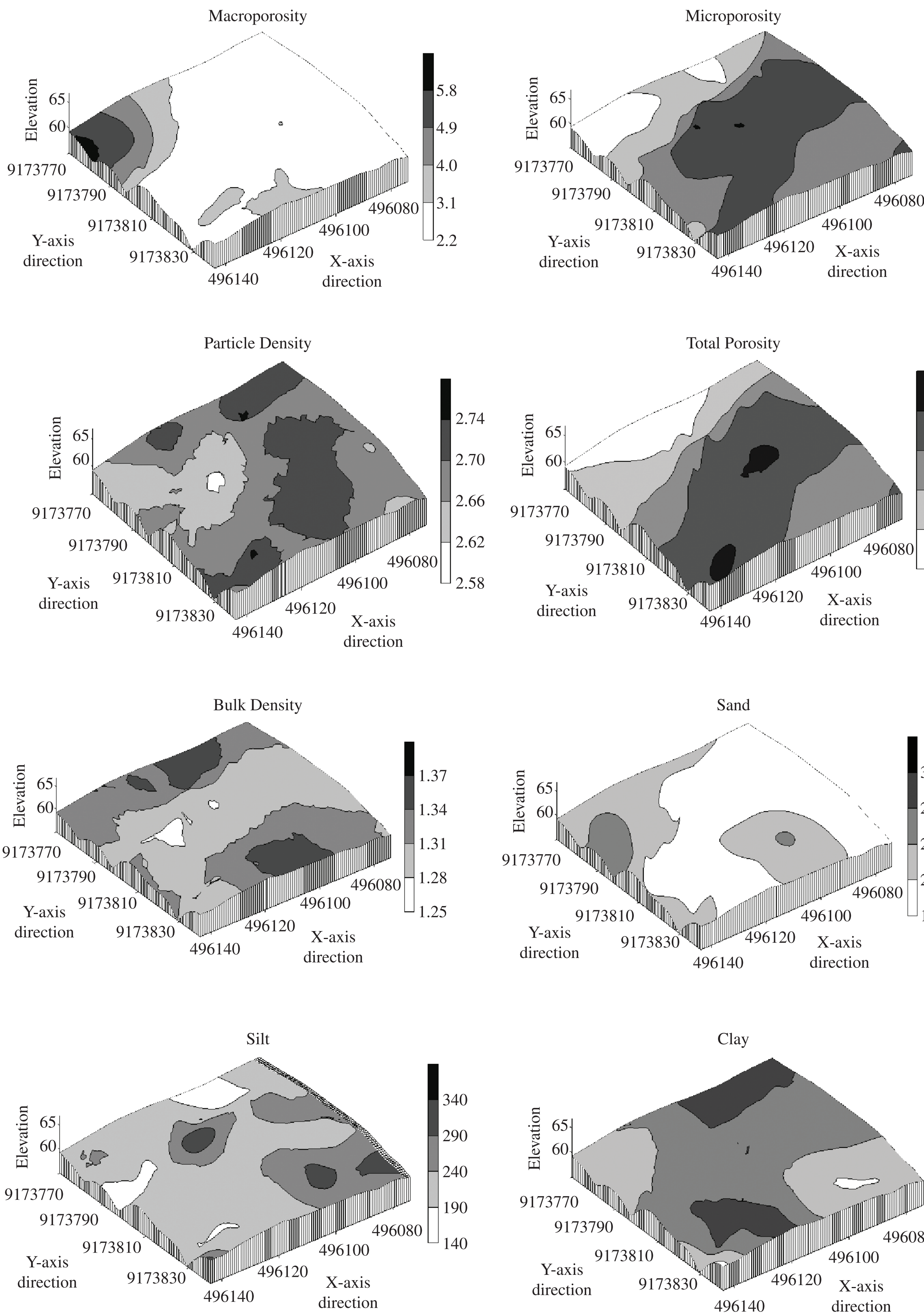

Figure 3. Kriging maps of particle size attributes (sand, silt and clay), macro (Macro) and microporosity (Micro), total porosity (TP), bulk density (BD) and particle density (PD) of Alfissol in agroforestry in the region of Humaita, Amazonas state.

Table 4. Parameters of the estimated models of semivariograms for geometric mean diameter (GMD), weighted mean diameter (WMD) and percentage of soil aggregates in classes >2.00, 2.00-1.00 and <1.00 mm of Alfissol in agroforestry area in the region of Humaita, Amazonas state.

Variables	Model	C_0	C_1+C_0	*r*	r^2	SLD(%)
GMD (mm)	Spherical	0.10	0.43	16.07	0.94	75
WMD (mm)	Spherical	0.04	0.18	19.48	0.96	75
>2.00 (%)	Spherical	44.90	89.81	29.60	0.99	50
2.00-1.00 (%)	Spherical	0.44	7.22	15.83	0.75	93
<1.00 (%)	Spherical	24.74	63.16	23.35	0.97	60

C_0: nugget effect; C_1: structural variance; *r*: range; r^2: correlation coefficient; SLD: spatial lag dependence between samples.

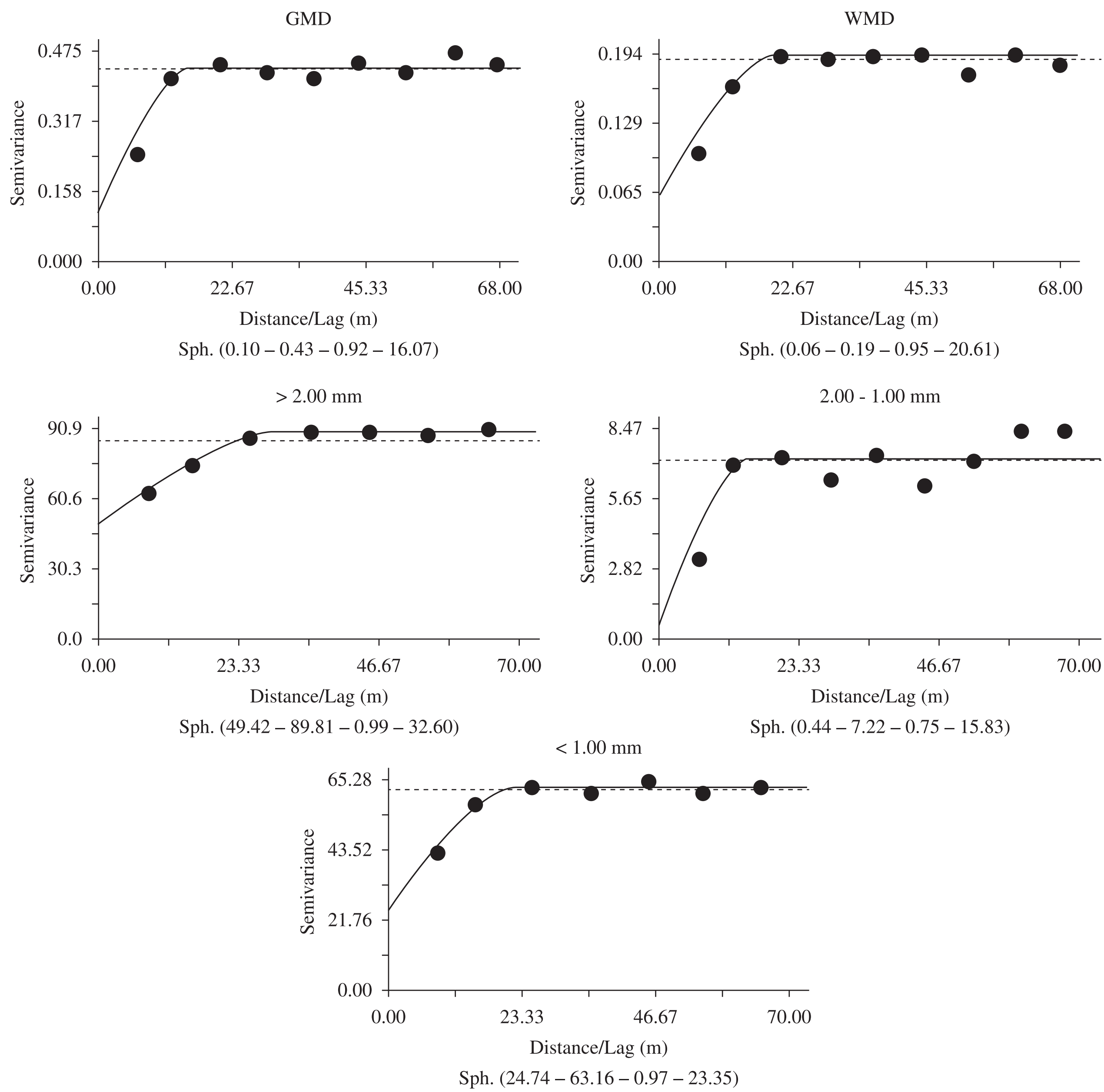

Figure 4. Experimental semivariograms for geometric mean diameter (GMD), weighted mean diameter (WMD) and percentage of soil aggregates in classes >2.00, 2.00-1.00 and <1.00 mm of Alfissol in agroforestry area in the region of Humaita, Amazonas state. Sph. – spherical model; Exp. – exponential model.

spatial variability of aggregate stability in Distroferric Red Latosol, as well as Vieira et al. (2011) analyzing two Latosol areas cultivated under no-tillage. Souza, Marques Júnior and Pereira (2004) adjusted the spherical model for the variables GMD and > 2.00 mm. The choice for the spherical model coincides with other studies that describe this model as the one that best fits the parameters of soil and plant (GREGO; VIEIRA, 2005). In general, the exponential model and the

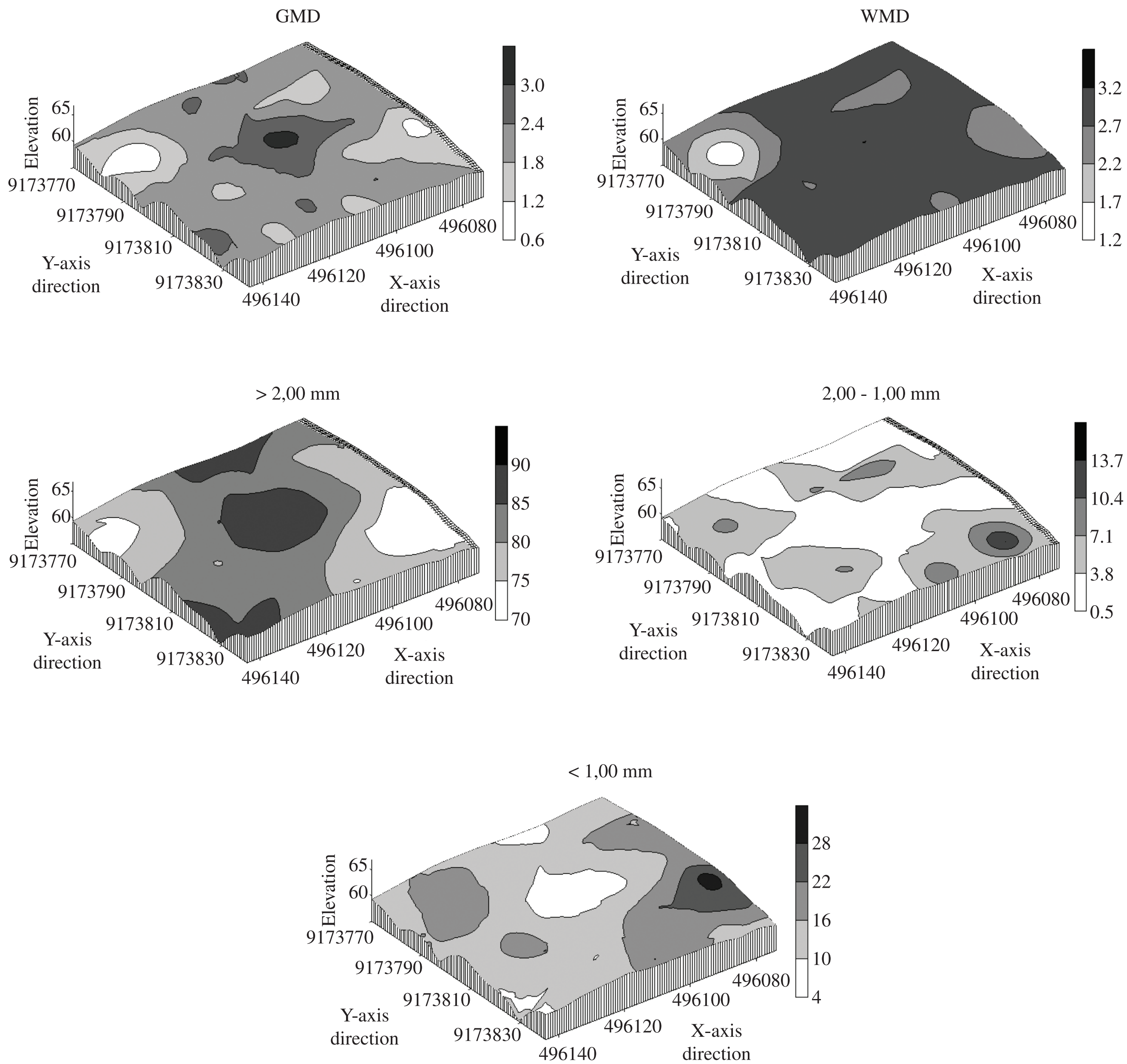

Figure 5. Kriging maps for geometric mean diameter (GMD), weighted mean diameter (WMD) and percentage of soil aggregates in classes >2.00, 2.00-1.00 and <1.00 mm of Alfissol in agroforestry area in the region of Humaita, Amazonas state.

spherical model represent, respectively, low and medium spatial variability continuity. These adjustments are explained by the ease of change of soil structure.

Regarding spatial dependence, we observed (Table 4) that the variables GMD, WMD, >2.00 and <1.00 presented moderate spatial lag dependence, except for the variable 2.00-1.00 mm, which showed weak spatial dependence. Souza, Marques Júnior and Pereira (2004) obtained similar results for the variables GMD and > 2.00 mm. For Cambardella et al. (1994), variables that exhibit strong spatial dependence are more influenced by intrinsic properties of the soil (derived from factors of soil formation), thereby the attributes studied suffer moderate influence of the intrinsic characteristics of the soil. The distribution of variables GMD, WMD, > 2.00 and <1.00 mm are not random, because all soil attributes studied showed moderate spatial dependence, except for aggregate class between 2.00 and 1.00 mm, which presented weak spatial dependence.

Range (r) varied among the soil properties analyzed, reaching values of 29.90 m for the aggregate class > 2.00 mm and 19.48 m for WMD, similar result was obtained by Souza, Marques Júnior and Pereira (2004) in Distroferric Red Latosol for WMD, and the lowest value was obtained for the class of aggregates between 2.00-1.00 mm (r = 15.83 m). Range is the distance at which sampling points are spatially dependent on each other (JOURNEL; HUIJBREGTS, 1991), that is, points located in an area of radius shorter than or equal to the range are more similar.

Range values concerning semivariograms have considerable importance in determining the limit of spatial dependence and they can also indicate the interval between sampling grid units (TRANGMAR et al., 1985; SOUZA; MARQUES JÚNIOR; PEREIRA, 1997). The lower the range, the faster the independence between samples is obtained, because range is the spatial dependence limit distance. The extrinsic variability concerning soil management practices contributes to reduced range. Low range values may negatively influence the quality of estimates, because few points are used to perform the interpolation to estimate values at non-measured sites (CORÁ et al., 2004).

We observed that part of the range (r) values was smaller than that established by the sampling grid (Table 4 and Figure 4), thus indicating continuity in the spatial distribution of aggregates, demonstrating that, for these variables, samples are not spatially correlated. According to Souza, Marques Júnior and Pereira (2009), range values can be used to set the spacing of data collection. Nevertheless, we should bear in mind that range (r) value varies according to the different soil attributes (SIQUEIRA; VIEIRA; DECEN, 2009).

Mapping for the variables geometric mean diameter (GMD), weighted mean diameter (WMD) and aggregate classes: > 2.00, 2.00-1.00, and <1.00 mm, are shown in (Figure 5). We verified that GMD and WMD showed values from 0.6 to 3.48 and 1.0 to 3.28 mm; while the aggregate classes > 2.00, 2.00-1.00 and <1.00 mm presented percentage from 69.0 to 91.0, 0.5 to 13.7 and 4.0 to 30.8%, respectively.

Apparently, existence of spatial correlation between GMD, WMD and > 2.00 and <1.00 mm classes of aggregates can be suggested, in sites of lower concentrations of WMD there was lower prevalence of GMD. There was increase of aggregates in class > 2 mm and reduction of aggregates in class <1 mm in the central area. According Le Bissonnais, Cros-Cayot and Gascuel-Odoux (2002), who found correlation between landscape position and spatial variability of aggregate stability, in flatter areas, aggregate stability behavior is more evident than in areas of higher slope. On the other hand, Bird et al. (2002) and Le Bissonnais, Cros-Cayot and Gascuel-Odoux (2002) found correlation between stability of aggregates at different positions in the landscape. Campos, Marques Júnior and Pereira (2010) reports that soil attribute variability is influenced by its location in the landscape or on the slope, even if little pronounced.

4 Conclusions

All physical attributes studied presented spatial dependence and most ranges were greater than those initially established in the sampling grid.

Empirical semivariograms followed the adjustment trends for attributes in the field of Soil Science: exponential model for sand, particle density and microporosity; spherical model for the other physical variables.

Sampling grid must be denser for the variables related to aggregates.

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