SPATIAL DEPENDENCE OF THE AGGREGATE STABILITY AND ORGANIC MATTER IN A CAMBISOL UNDER SUGAR CANE CULTIVATION[1]

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ABSTRACT: The soil management system can modify the natural distribution of the soil attributes and, consequently, the variability of the soil aggregation and organic matter content. Thus, the aim of this work was to evaluate the aggregate stability and organic matter content spatial distribution on a Haplic Cambisol under sugar cane cultivation in the Southern Amazonas State, Brazil. A 70 x 70 m square mesh, with regular 10 meters intervals, was designed over the cultivation area, resulting in 64 sample points. Soil blocks with preserved structure were collected at 0.0-0.2 m depth in order to analyze the aggregate stability and organic matter content. The data were submitted to the descriptive and geostatistical analysis. The soil attributes presented a spatial dependence structure and the greater range was observed for the mean weighted diameter and aggregate class <1.00 mm. Also, there is a spatial relation among the mean geometric diameter, mean weighted diameter and aggregate classes (> 2.00 and 2.00-1.00 mm).

Keywords: Geostatistics. Soil physical attributes. Soil aggregation.

DEPENDÊNCIA ESPACIAL DA ESTABILIDADE DE AGREGADOS E MATÉRIA ORGÂNICA DO SOLO EM CAMBISSOLO SOB CULTIVO DE CANA DE AÇUCAR

RESUMO: O sistema de manejo pode modificar a distribuição natural dos atributos do solo e consequentemente, a variabilidade da agregação e matéria orgânica do solo. Assim, o objetivo deste trabalho foi avaliar a distribuição espacial da estabilidade de agregados e matéria orgânica em um Cambissolo Háplico sob cultivo de cana-de-açúcar na região Sul do Amazonas. Na área de cultivo foi delimitado uma malha de 70 x 70 m, com intervalos regulares de 10 m, perfazendo um total de 64 pontos de amostragem. Foram coletados blocos de solo com estrutura preservada na profundidade 0,0-0,20 m para determinação da estabilidade de agregados e teor de matéria orgânica. Os dados foram submetidos à análise estatística descritiva e geoestatística. Os atributos do solo apresentaram estrutura de dependência espacial, sendo o maior alcance observado para os teores de matéria orgânica. Há relação espacial entre o diâmetro médio geométrico, diâmetro médio ponderado e classes de agregados (> 2,00 e 2,00-1,00 mm).

Palavras-chave: Geoestatística. Atributos físicos do solo. Agregação do solo.

INTRODUÇÃO

The soil physical and chemical attribute modifications, which proceed from different management techniques, have great importance in the plant growth analysis. From a practical point of view, it is interesting to study those modifications because they are crucial in the agricultural potential recovery and maintenance (MARQUES JUNIOR et al., 2008), becoming a starting point of any production system.

An important physical attribute in the soil quality evaluation is the aggregates stability. The aggregates are joint by physical forces and linking mechanisms via chemical elements or molecules that act over the aggregation and stabilization of the aggregates (SOUZA et al., 2004a). According to Neves et al. (2006) the aggregate structure maintenance facilitate the aeration and water infiltration, reducing the soil erosion. On the other hand, the soil aggregation is subject to change due to natural and anthropogenic phenomena as use and management (SOUZA et al., 2009a; VIEIRA et al., 2011), and also being influenced by a variety of other soil, as attributes besides being influenced by various soil properties such as texture, density, penetration resistance, organic matter content, pH, cation exchange capacity, available water, total porosity, macroporosity and soil moisture (TAVARES-FILHO et al., 2012)

Another component not least in the stabilization and aggregation of soil aggregates is the organic matter (SOUZA et al. 2004a), that is not only responsible for the structure, proper functioning sustainability of the ecosystem (ROZANE et al., 2010), but also promotes improvement in other attributes as soil bulk density, hydraulic conductivity, total porosity, water infiltration and plant nutrient supply (VASCONCELOS et al., 2010).

In the face of the technological advances in the agricultural production, quantifying the spatial and temporal variation of the soil attributes that affect the crop yield is to be essential, as the use of the resources has to be at low cost (CARVALHO et al., 2002). 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 et al., 2009b). As observed by Grego and Vieira (2005), the knowledge of the soil attributes variability and crops, in the space and time, is the beginning point for the accurate management of agricultural areas, in any scale. In this respect, the geostatistical analysis allows the detection of variability and spatial distribution, becoming an important tool for the detailed description of the soil attributes (SOUZA et al., 2004b; CAMPOS et al., 2007). Therefore, the aim of this work was to evaluate the spatial dependence of the aggregates stability and organic matter from a Cambisol under sugar cane cultivation in the Southern Amazonas.

MATERIAL E MÉTODOS

The study was performed in Humaitá County, Southern Amazonas State, Brazil. The site is located at 7° 30' 24" S and 63° 04' 56" W. The region climate, according to the Köppen classification, is of "Am" type, rainy tropical (monsoon rains), presenting a short dry period, with temperatures ranging from 25 to 27 °C and average annual rainfall of 2,500 mm, with the wet period beginning in october to june, and air relative humidity between 85 to 90%.

The soil was classified as Plinthic Alithic Haplic Cambisol, of medium-texture (366 g kg^{-1} of sand, 450 g kg^{-1} of silt and 184 g kg^{-1} of clay) (EMBRAPA, 2006) which, according to Braun and Ramos (1959), was developed from indistinct or old alluvial sediments that are chronologically originated from Holocene. These authors mentioned that the region was characterized by tablelands with small slopes and slightly rounded edges.

The survey area covers approximately 10.5 hectares and has been used for sugar cane cultivation over the past five years. Harvesting is carried out through the burning process. The soil samples were collected at 0.00-0.20 m depth, at the crossing points of a regular square mesh of 70 x 70 m, with 10 m intervals, totalizing 64 sample points over an area of 0.49 hectares (Figure 1). These points were georeferenced by a GPS receptor, Promark 2 model, with differential correction.

Soil blocks with their preserved structure were collected at 0.00-0.20 m depth, air-dried and sieved through 9.52 and 4.76 mm meshes for the determination of the aggregate distribution. The aggregates retained on the 4.76 mm mesh were used for the analysis of the aggregate stability in water according to Kemper and Chepil (1965), which was performed by placing the samples on 2.0; 1.0; 0.5; 0.25; 0.125 and 0.063 mm meshes and submitting them to vertical oscillations for fifteen minutes, with 32 oscillations per minute. As stability indexes, the >2 mm, 2-1 mm and <1 mm aggregate classes were adopted, as well as their mean geometric diameter (MGD) and mean weighted diameter (MWD).

The total organic carbon content was determined via the oxidation method in water, with external heating (YEOMANS; BREMNER, 1988), and the organic matter content was estimated based on the first.

Soil variability was primarily evaluated by the exploratory data analysis. The mean, median, minimum and maximum values were calculated, as well as the standard deviation, variance and coefficients of variation, asymmetry and Kurtosis. The coefficient of variation (CV%) was calculated on the basis of the criterion of Warrick and Nielsen (1980) that

classifies the CV as low < 12 %, average of 12% to 60% and high > 60 %. The data normality hypothesis was tested by the Kolmogorov-Smirnov test using the Minitab 14 statistical software (MINITAB®, 2000).

For the characterization of the spatial variability, the geostatistical analysis was used (Vieira *et al.* 1983). According to the intrinsic hypothesis, the experimental semivariogram was estimated through the equation:

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

where: $\gamma(h)$ – the semivariance value for an h distance; $N(h)$ – number of pairs used to calculate the semivariance; $Z(x_i)$ – Z attribute value at the x_i position; $Z(x_i+h)$ – Z attribute value separated by an h distance from the x_i position. From the mathematical model adjustment to the ($\hat{y}$) h calculated values, the theoretical model coefficients are estimated for the semivariogram (nugget effect, C_0; landing, C_0+C_1; and range, a). The semivariogram models were the spherical, exponential, linear and Gaussian and were adjusted by the GS+ 8.0 software (ROBERTSON, 1998).
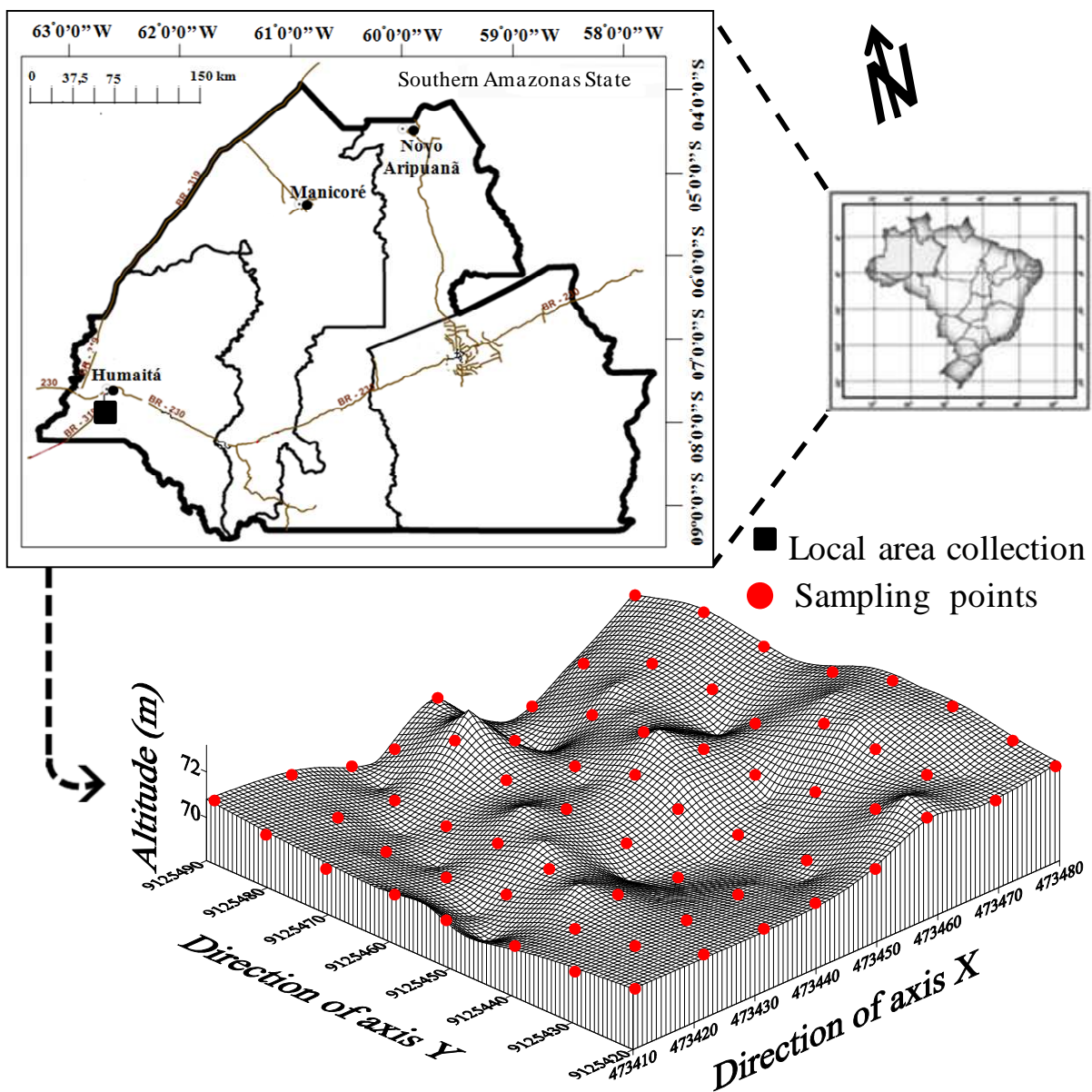

Figure 1. Digital elevation model of the survey area under sugar cane cultivation.

The Cambardella et al. (1994) classification was used to analyze the spatial dependence degree of the studied attributes, from which the semivariograms are considered strong when they have a nugget effect that is lower or equal to 25% of the landing; moderate when it falls between 25 and 75%; and weak when it is higher than 75%.

When more than one model was obtained for the same semivariogram, the one with the highest correlation coefficient derived from the cross-validation technique was chosen, as well as the one with the best coefficient of determination (R^2).

RESULTS AND DISCUSSION

The results referring to the descriptive analysis show that the organic matter, GMD, WGMD and the aggregate classes presented similar values of mean and median (Table 1), which shows a symmetric distribution, thereby corroborating with Marques Junior et al. (2008) results, studying spatial variability of the soil attributes in a Latosol under sugar cane cultivation. Due to Cambardella et al. (1994), it is an indicative that the measures of central tendency are not dominated by atypical values in data distribution

Table 1. Descriptive statistics for the geometric mean diameter (GMD), weighted geometric mean diameter (WGMD), organic matter (OM) and aggregate percentage for >2,00, 2,00–1,00 and<1,00 mm classes in an Haplic Cambisol under sugar cane cultivation.

Descriptive Statistic	OM (g kg^{-1})	MGD (mm)	MWD (mm)	>2.00 (%)	2.00-1.00 (%)	<1.00 (%)
Median	29.53	2.61	3.11	90.57	1.91	7.49
Mean	29.80	2.54	3.07	89.64	2.11	8.24
Minimum	11.02	2.71	1.71	74.03	0.11	1.20
Maximum	40.55	3.10	3.29	97.82	5.83	20.13
[1]SD	5.42	0.34	0.02	5.70	1.36	4.41
Variance	29.43	0.11	4.66	32.59	1.85	19.52
[2]CV (%)	18.37	13.18	31.10	6.12	6.42	53.62
Kurtosis	1.18	-0.59	-0.11	-0.10	-0.2	-0.01
Asymmetry	-0.55	-0.47	-0.69	-0.68	0.64	0.71
[3]d	0.08	0.11	0.11	0.11	0.12	0.12

[1]SD= Standard Deviation; [2]VC= Variation Coefficient; [3]d= Kolmogorov-Smirnov test.

and according to Souza et al. (2009b), when the soil attribute results are close to a normal distribution, implies that are suitable to geostatistical use.

A greater percentage of aggregates was verified in the >2.00 mm class, with values exceeding 89% (Table 1), indicating a superior resistance to disaggregation, what corroborates with Cajazeira and Assis Júnior (2011) findings. For the area of sugar cane, the increase in the size of the aggregates may have been due to a higher pressure received by the soil as result of mechanization (Oliveira et al., 2013).

For all the studied variables, the Kurtosis coefficients varied from -0.59 to 1.18 while the asymmetry ones ranged between -0.69 and 0.71 presenting, thus, values close to zero, what indicates symmetry for these variables. As Marques Júnior et al. (2008) reported, the asymmetry coefficient is more sensitive to extreme values than the mean and standard deviation, since a single value could strongly influence it, as the deviations between each value and its mean are raised to the third power.

The Kolmogorov-Smirnov test resulted in normality for all studied variables. According to Marques Junior et al. (2008), the data normality is not a Geostatistics request, but the distribution must not be very asymmetric as it could compromise the analysis. Souza et al. (2004c), when studying the aggregate stability in areas under sugar cane cultivation, found a normal distribution, whereas Carvalho et al. (2003) did not obtain it for the organic matter.

All the studied variables presented moderate

values of variability except for the >2.00 and 2.00-1.00 mm aggregate classes, which had low values (Table 1), corroborating with Lemos Filho et al. (2008), Vieira et al. (2011), Souza et al. (2004a) and de Souza et al. (2009b). Although the variation's coefficients allow us to compare the variability between samples in different units, it does not allow analyzing the spatial variability of soil attributes and it's spatial pattern (Camargo et al. 2008).

For this reason, the soil chemical attributes were submitted to geostatistics analysis. These showed spatial dependence, expressed by adjusted semivariograms models (Table 2 and Figure 2).

The organic matter, MGD and <1.00 mm aggregate class showed a spherical semivariogram model while the other variables regarding the soil aggregate distribution adjusted to the exponential model (Table 2 and Figure 2). As found by Carvalho et al. (2002), the mathematical spherical is the predominant model in soil science researches. However, Souza et al. (2009b), when studying Red Latosols under sugar cane cultivation, found an exponential model for the MGD. On the other hand, Souza et al. (2004a), when studying the spatial variability in different landforms, obtained an exponential model for the 2.00-1.00 mm aggregate class. Vieira et al. (2011), when working with two no-till Latosols, verified that the OM showed a similar spherical model to this research.

The soil aggregate distribution and organic matter did not present a pure nugget effect (C_0)

(Table 2 and Figure 2), which is resulted from a random allocation of the data, and could be caused by measurement error or attribute variations that might not be detected over the scale sample (SOUZA et al. 2009a). According to Vieira (2000) the parameter nugget effect is important to the semivariogram and indicates the unexplained variability when considering the adopted sample distance. Lemos Filho et al.

(2008) while studying the sugar-cane areas, did find any random variability (C0) for the MO and aggregate stability.

The range (a) varied among the studied attributes, reaching 20.80 m for the OM, which is the lowest value, and 59.40 m for the >1.00 mm aggregate class, corroborating with results found by Souza et al. (2009b) in Distrofic Red Latosols in Guariba region, São Paulo State, Brazil.

Table 2. Experimental semivariograms models and parameters to the geometric mean diameter (GMD), weighted geometric mean diameter (WGMD), organic matter (OM) and aggregate percentage for the classes >2,00, 2,00–1,00 and<1,00 mm in a Haplic Cambisol under sugar cane cultivation.

Variables	Model	C_0	C_1	a	r^2	RD (%)
OM (g kg^{-1})	Spherical	4.85	29.91	20.80	0.91	83
MGD (mm)	Exponential	0.02	0.12	41.40	0.97	82
MWD	Spherical	0.00	0.02	59.40	0.98	60
>2.00 (%)	Exponential	6.41	32.50	44.10	0.94	80
2.00-1.00 (%)	Exponential	0.74	1.95	37.00	0.95	61
<1.00 (%)	Spherical	8.33	22.49	59.40	0.97	63

C_0: nugget effect; C_1: structutal variance; a: reach; r^2: correlation coefficient; RD: ratio-dependence among samples.

The range values (a) were higher than those established by the mesh (Table 2 and Figure 2), what shows a better continuity in the spatial distribution of the aggregates and organic matter in the soil under sugar cane cultivation, highlighting the spatial correlation among samples. As it was underlined by Montanari et al. (2005), this fact allows the interpolation in larger meshes than those used in this work. According to Souza et al. (2004c), the knowledge on the range is important for the definition of the sampling rate, aiming at reducing labor, mean standard errors and sample representativeness increase.

The range, as described by Grego and Vieira (2005), represents the distance among the sampling points, that is, the sample points that are located in an area with a similar radius to the range (a) are more homogeneous among themselves. The range values related to the semivariograms have a considerable importance on the determination of the spatial dependence limit, what could also be an indicative of the distance among soil mapping units.

The evaluation of the ratio of spatial dependence among samples (RD) for the soil aggregate distribution and organic matter showed that the MGD for the 2.00-1.00 and <1.00 mm aggregate classes had a moderate spatial dependence, while the organic matter, MGD and >2.00 mm aggregate class had a weak one (Table 2 and Figure 2), which corroborate with the studies developed by Souza et al. (2009b) and Vieira et al. (2011), when studying the spatial variability of the soil organic matter and aggregates in São Paulo State. For Cambardella et al. (1994), the variables that present a strong spatial dependence are

more affected by the soil intrinsic properties (those originated from soil formation factors), so the studied attributes are moderately affected by them.

The adjustment correlation coefficients of the semivariogram (R^2), which values reached above 0.91, showed a good adjustment for all the studied variables (Table 2 and Figure 2). However, it is worth to state that the MWD, MGD and aggregate percentages at the 2.00-1.00 mm class obtained the lowest C_0 values, indicating a higher spatial variability representativeness of these attributes.

The krigging maps of the soil attributes are presented in Figure 3. It was observed that the OM had values that ranged from 14 to 40 g kg^{-1}. The MGD and MWD ranged from 1.85 to 2.97 mm and 2.82 to 3.18 mm, respectively, while the >2.00, 2.00-1.00 and <1.00 mm aggregate classes showed values that varied from 78 to 96, 0.6 to 4.4 and 4.5 to 15.7%, respectively.

There was a spatial correlation of the MGD, MWD and aggregate percentage from the >2.00, 2.00-1.00 and <1.00 mm classes (Figure 3). These results could be assigned to the crop management over the soil attributes, as highlighted by Abreu et al. (2003), or to the studied area location in the landscape because the variability of the soil attributes is influenced by its location in the landscape or slope, even in small scale (CAMPOS et al., 2007).

Generally, the OM contents were high and strongly related to the >2.00 mm aggregate class that presented the highest aggregate percentage, demonstrating its influence on those OM contents in the stability aggregate.
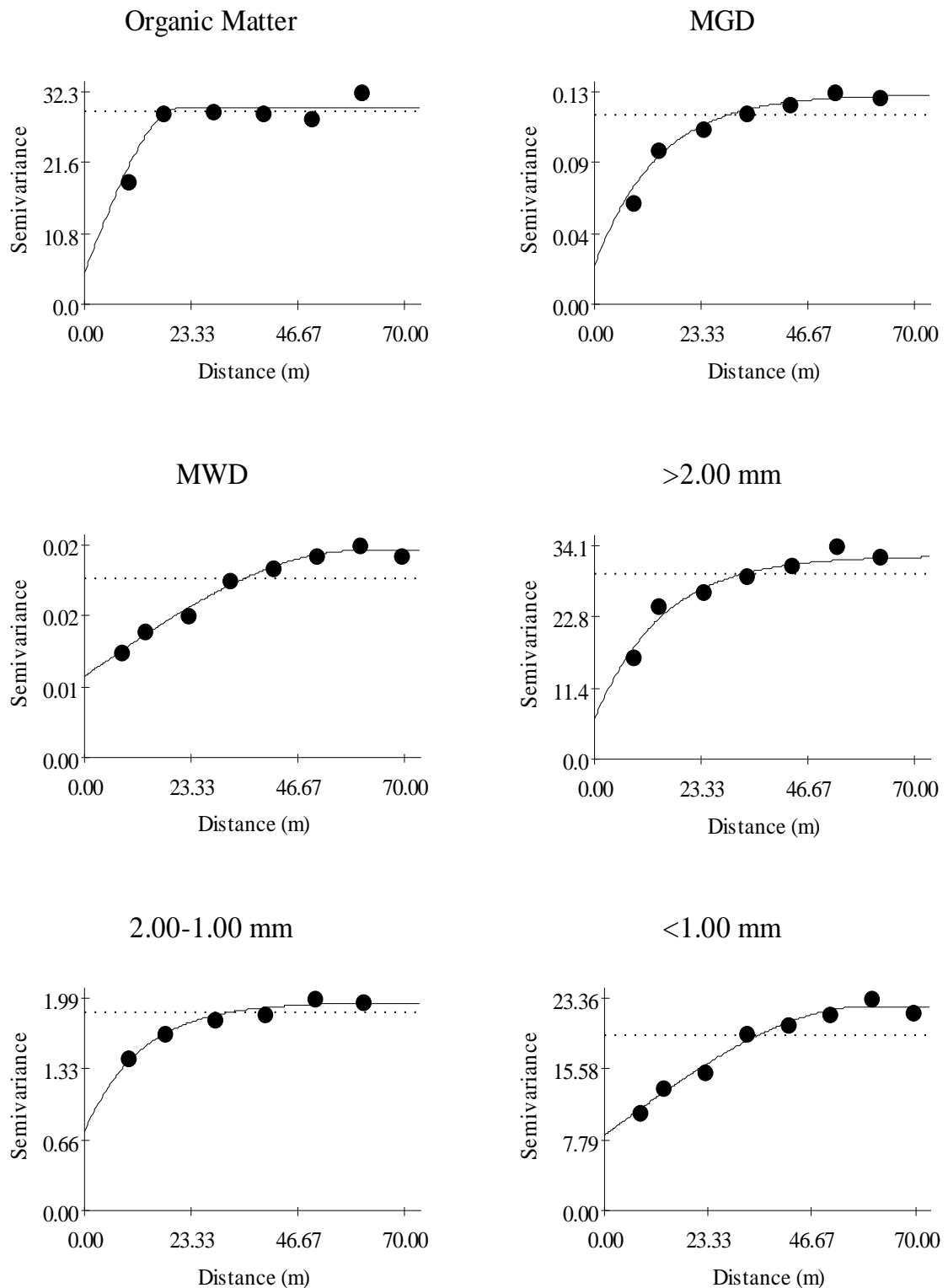
Figure 2. Experimental semivariograms of the variables: organic matter (OM); geometric mean diameter (GMD); weighted geometric mean diameter (WGMD);and aggregate percentage at >2.00, 2.00–1.00 and<1.00 mm classes in a Haplic Cambisol under sugar cane cultivation.
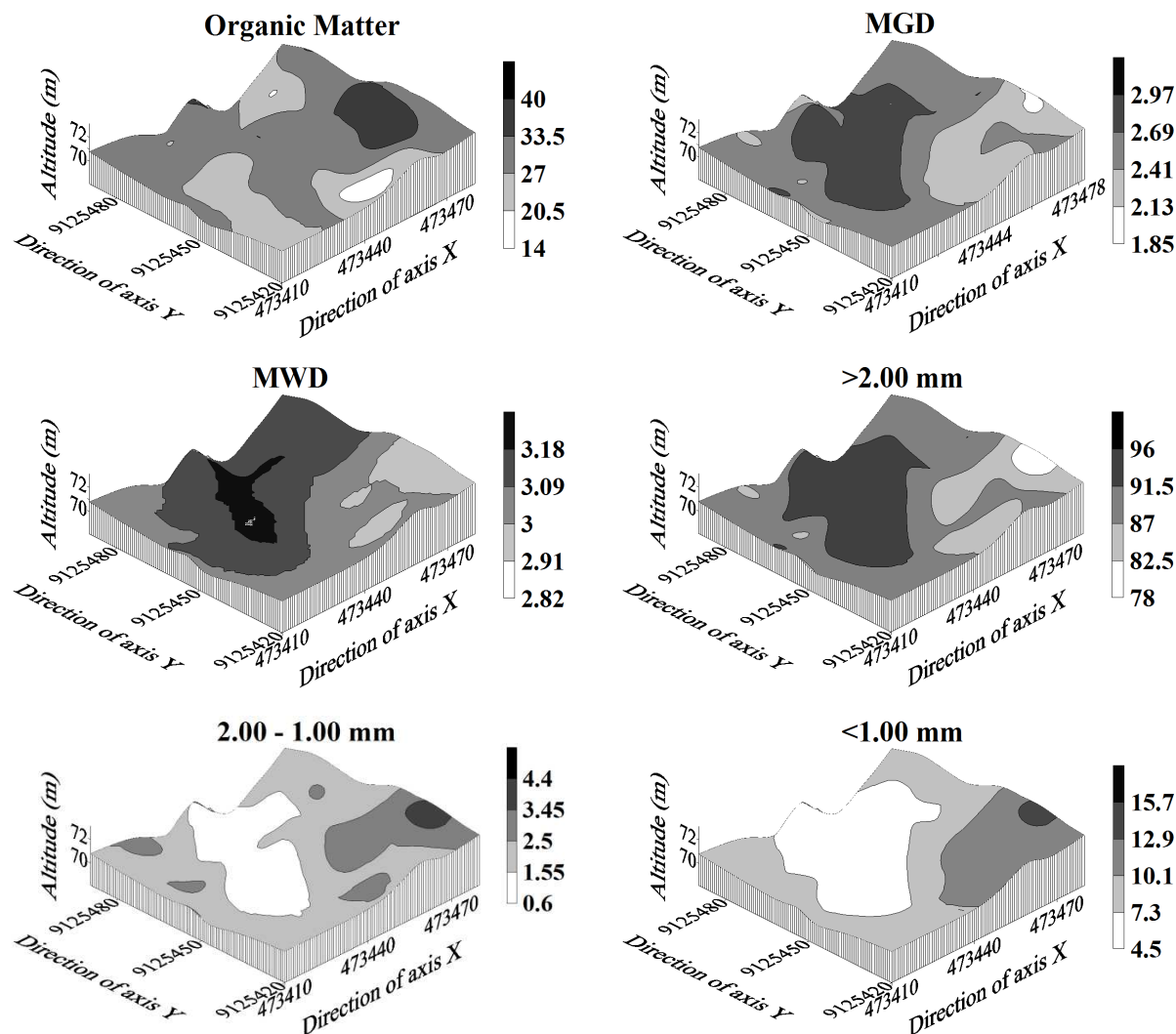
Figure 3. Krigging maps for organic matter (OM), geometric mean diameter (GMD), weighted geometric mean diameter (WGMD) and aggregate percentage at >2.00, 2.00–1.00 and <1.00 mm classes in an Haplic Cambisol under sugar cane crop.

CONCLUSION

The soil attributes presented structure of spatial dependence, and the highest reach was observed for GMD and <1.00 mm aggregate class;

The organic matter did present spatial distribution similar to the aggregate stability;

It was observed a spatial correlation among geometric mean diameter, weighted geometric mean diameter and the aggregate percentages at >2.00 e 2.00-1.00 classes, due to their similarity to the spatial distribution.

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