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Spatial distribution of physical attributes of a clayey Latosol under different management systems

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Abstract

The use and management of the soil cause occasional changes in its physical properties; thus, altering its spatial variability. This work aimed to show the spatial distribution of physical attributes of a clay latosol under different management systems, through thematic maps of spatial distribution for values of these attributes. The experimental area consisted of three treatments: scarified no-tillage at 0.3 m depth (T1), no-tillage with 3 t ha^{-1} of plaster applied to the surface (T2) and; the control as traditional no-tillage system (T3). The attributes such as density, macroporosity, and microporosity in three soil layers were evaluated: 0-0.1; 0.1-0.2; and 0.2-0.3 m. The analysis of the experimental results indicates that all physical attributes presented spatial dependence between the data, with higher density values (values ranged from 0.95 to 1.37 Mg m^{3}) and lower macroporosity in areas with T1 (SPD with scarification) and T2 (SPD gypsum) management systems. However, in all treatments, the Macro values presented a volume above 10.51%, which is above the limit value for good aeration and water movement in the soil. Treatment T3 (traditional SPD) showed favorable physical soil conditions, even after compaction.

Keywords: No-tillage system; porous space; density; spatial variability; thematic maps.

Abbreviations: C_0 _ Nugget effect; C_1 _ Contribution; $C = C_0 + C_1$ _ Landing; *a* _ Range; LVdf _ typical Dystroferic Red Latosol; Iapar _ Agronomic Institute of Paraná; Embrapa _ Brazilian Agricultural Research Corporation; SPD _ No-tillage system; Lafis _ Laboratory of soil physics; Unioeste _ Western Paraná State University; D_s _ Soil density; MSS _ Dry soil mass; VT _ Total volume; PT _ Total porosity; D_p _ Particle density; Micro _ Microporosity; Macro _ Macroporosity; GD _ Degree of spatial dependence; S _ Standard deviation; S^2 _ Variance; CV _ Coefficient of variation; C_0 _ Nugget effect; C_0+C_1 _ Landing; FD _ Dependency Range; EPP _ Pure nugget effect

Introduction

The soil has natural variability, given its formation and intrinsic characteristics. The use and management can also promote point changes, increasing the spatial variability of its attributes (Bottega et al., 2013), intensifying this heterogeneity. For these cases, classical statistics are not satisfactory to explain the influence of management on soil attributes, and geostatistics has proven to be an appropriate alternative to characterize and measure the spatial variation of soil properties (Bottega et al., 2013; Neto et al., 2015).

The knowledge of the diversity of an area enables the use of precision agriculture when the necessary corrective and management actions are pinpointed, reducing operating costs and the traffic of machines on the ground (Bottega et al., 2013), as a sustainable proposal.

Among the physical attributes of the soil, density, total porosity, macroporosity, and microporosity have certain spatial variability, either as a consequence of machine traffic, trampling animals or even by actions of the weather. Lima et al. (2015) studied the spatial variability of soil physical attributes in hillside areas under degradation, finding spatial dependence for all the attributes analyzed: water infiltration, soil density, and texture. According to the authors, the results found are important for the experimental planning of the studied area and should be taken into consideration in terms of the proposal for its management.

Silva et al. (2015) evaluated the variability of physical and chemical attributes of the soil and the production of beans. They concluded that among the attributes assessed the physical ones, such as the density and total porosity can best explain the spatial variability of bean production.

The study of the spatial variability of these attributes is also important, because they are directly related to the hydraulic properties of the soil (Mesquita and Moraes, 2004; Fonseca et al., 2017), such as the hydraulic conductivity of saturated soil (Almeida et al., 2018) and water infiltration (Lima et al., 2015).

In geostatistics, the study of spatial variability is carried out through a sampling plan, in which a number of points are previously defined and the minimum spacing between samples are collected. For the study of variability, the semivariogram is usually being used, which measures the dependence between the sampling points, scattered in a reference space. Its objective is to perform the interpolation of values necessary for the construction of contour maps and surfaces employing kriging (Isaaks and Srivastava, 1989). The main components of a semivariogram are the nugget effect (C_0), the contribution (C_1), the landing ($C = C_0 + C_1$), and the range (a).

There are three types of semivariogram, the true, which expresses the real dependence; the experimental, which is a result of the sampling points; and the theoretical one, which is adjusted according to some theoretical model (Guerra, 1998). Among the theoretical models, the spherical, Gaussian and exponential models stand out.

Based on the choice of the theoretical models with better data adjustment, the data is interpolated to determine the values of the measured variable in non-sampled points of the same area. Kriging is a data interpolation method that estimates the values of a certain random variable Z(x) for non-sampled sites, enabling the construction of maps of a space S. According to Cressie (1992), this technique minimizes the estimated variance using an adjusted semivariogram and taking into account the stochastic dependence between the spatially distributed data.

Cross-validation consists of evaluating estimation errors, which allow comparing the estimated values with those sampled (Isaaks and Srivastava, 1989). This validation enables choosing the estimated model closest to the semivariance. The method consists of temporarily discarding a set of data, and for the same location estimation of a new set from the rest of the sample by Krigage. This procedure is repeated with all sets, comparing the estimated value with the sample value (Carvalho et al., 2012).

The final result of kriging is the interpolated surface of each variable, with its respective spatial distribution enabling the identification, location and coverage of extreme values, the degree of area homogeneity and the directions of the greater gradient. Based on the generated map, the presence of patterns or behaviors is feasible to infer (Guimarães et al., 2016).

Due to the importance of studying the spatial variability of soil attributes, this study aimed to evaluate the spatial dependence of density, macroporosity, and microporosity, through thematic maps of these attributes.

Results and discussion

Descriptive statistics of treatments

Tables 2, 3 and 4 present the results of descriptive statistics for the treatments evaluated. The Ds presented mean values between 1.02 and 1.17 Mg m^3, similar to those found by Faraco et al. (2008). On the other hand, in T3 treatment (Table 4) we found lower Ds values, when compared to T1 (Table 2) and T2 treatments (Table 3), which may reveal that traditional no-till farming did not impose significant negative changes in soil structure. This effect is contrary to expectations, since recent experiments have shown a deterioration of the structure of soils managed with no-till for long periods (Cássaro et al., 2011; Suzuki et al., 2013; Didoné et al., 2014; Soracco et al., 2018). The non-occurrence of an increase in the value of Ds can be explained by the fact that these are experimental plots, in which cover species called "structural recoverers" were cultivated since this is a long-term experiment.

The attribute with the highest coefficient of variation in all layers was Macro, with a higher CV of 27.23% in the second layer of T2 treatment, as shown in Table 3. This result was similar to that found by Drescher et al. (2016), with higher CV values for the same attribute. The first layer with 43.8% of CV takes into account all the treatments analyzed in the experiment. Guimarães et al. (2016) explained that the greater variability of this attribute may be a result of the methodology used in its calculation since its value is obtained by the difference between the PT and the Micro. For Ds and Micro, the coefficient of variation presented results close to or below 10%, results similar to those found by Reichert et al. (2016).

The asymmetry values, close to zero, as well as the values found for kurtosis, reveal that the data are close to a normal distribution. This statement is confirmed by the Shapiro-Wilk test, with some exceptions, such as what occurred in the second layer of T3 treatment for Ds and Micro (Table 4). However, this is not a requirement for the application of geostatistical methods.

Attributes of Soil Density (Ds), Macroporosity (Macro) and Microporosity (Micro) of the soil

Table 5 presents the results of the spatial statistics for the soil attributes Ds, Macro and Micro in the three layers analyzed of the evaluated management system areas T1 (SPD with scarification), T2 (SPD gypsum) and T3 (SPD traditional).

The nugget effect (C0) represents the discontinuity of the semivariogram, whereas its value should be zero in theory. The nullity of C0 was occurred in some layers of the evaluated treatments. For example, it can be observed in all T2 depths of the variable Micro, besides values close to zero for the Ds, as can be observed in this experiment.

In the first and third layers of the Micro T1 treatment, the so-called pure nugget effect (PDP) was occurred. This result may indicate the non-detection of the structure of spatial variability at distances smaller than the shortest sampling distance (Kamikura et al., 2013).

The range value (a) varied from 6 to 14 meters, and Micro showed lower range values. The Ds had a range of 10.1 to 14 meters, similar to that observed by Grego and Vieira (2005) and greater than those found by Kamikura et al. (2013) in the first two layers evaluated in the experiment.

Based on the degree of dependence classification by Mello et al. (2008), the Ds and Macro presented moderate to strong spatial dependence in almost all layers of the three treatments, except for Ds of the first layer of T3, with GD equal to 20.69% and the second layer of Micro of T15 treatment with GD of 23.91%. The Micro did not show a degree of spatial dependence in layers 1 and 3 of the T1 treatment, while Kamimura et al. (2013) found strong dependence for this variable in all layers.

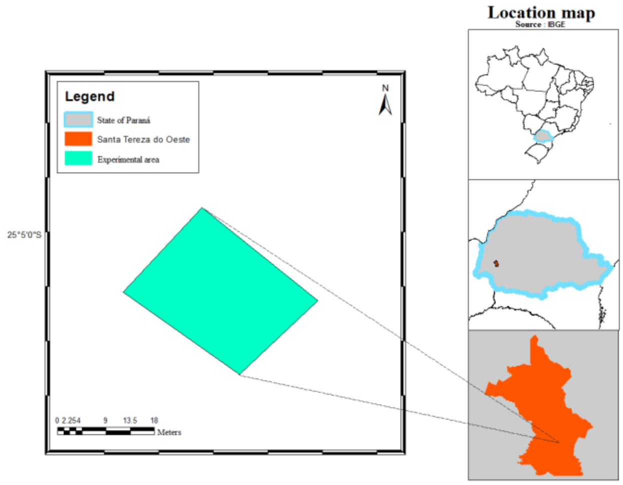

Fig 1. Location map of T1 treatment (25º 05' 6,65" S and 53º 35' 12,98" O).

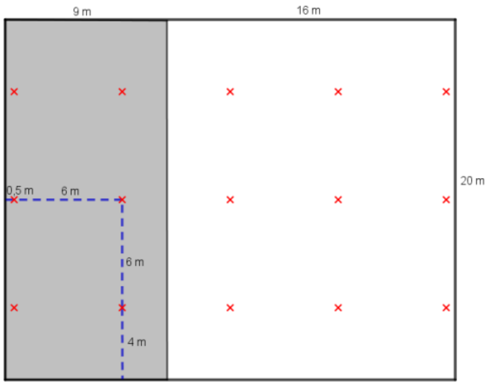

Fig 2. Point spacing breakdown for spatial variability analysis (gray stripe received three passes from of compacting roller in order to cause a density gradient in the soil).

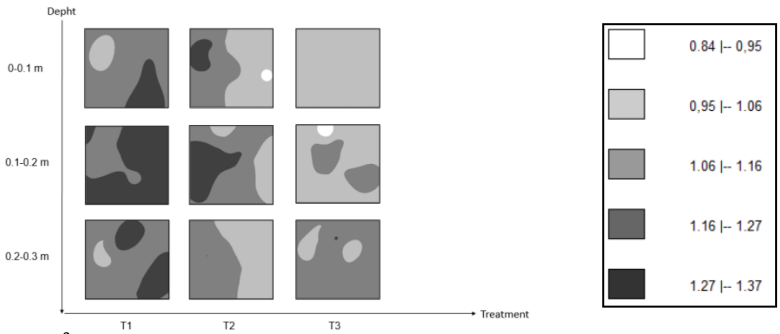

Fig 3. Surface maps of soil density, Ds (Mg m^3), for the three treatments, in the 0-0.1 layers; 0.1-0.2 and 0.2-0.3 m. The colors in the image correspond to the Ds values (Mg m^3), ranging from white (0.84 Mg m^3) to dark grey (1.37 Mg m^3).

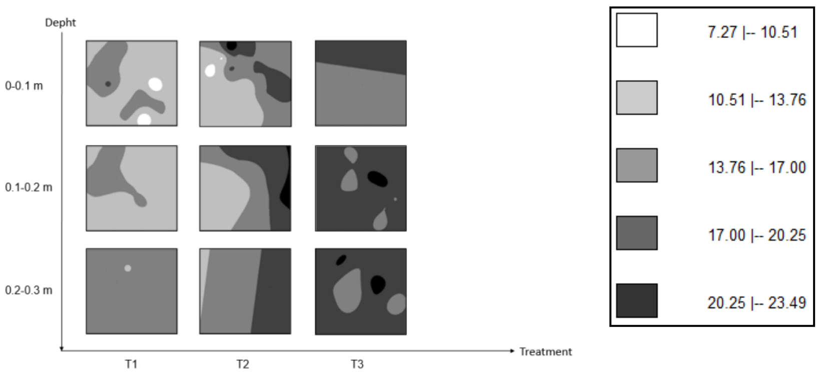

Fig 4. Surface maps of soil macroporosity, Macro (%), for the three treatments, in the 0-0.1 layers; 0.1-0.2 and 0.2-0.3 m. The colors in the image correspond to the Macro values (%), ranging from white (7.27%) to dark grey (23.49%).

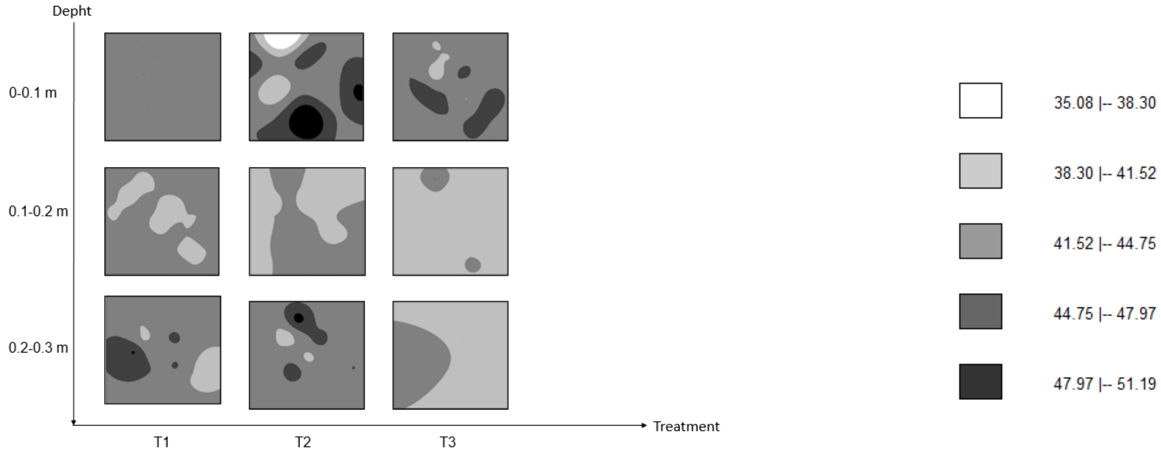

Fig 5. Surface maps of soil microporosity, Micro (%), for the three treatments, in the 0-0.1 layers; 0.1-0.2 and 0.2-0.3 m. The colors in the image correspond to the Micro values (%), ranging from white (35.08%) to dark grey (51.19%).

Figs 3, 4 and 5 present the kriging maps for the three layers of the three treatments analyzed. Figure 3 shows the spatial variability of the soil (Ds). The T1 treatment presented higher Ds values, followed by the T2 treatment, in all layers, when compared to the T3 treatment. The temporary effect of scarification explains this behavior in the case of T1 treatment. On the other hand, the higher Ds of T2 treatment concerning T3 treatment can be explained by the neutralization, in part, of aluminum ions that in this type of soil promote the dispersion of existing aggregates (Costa et al., 2007).

Besides, it is possible to observe a higher value of Ds in the 0.1-0.2 m layer in T1 and T2 treatments (Fig 3). It is in the subsurface layers that occur the greatest effects of the traffic of agricultural machinery and implements, especially in soils managed with the SPD (Nunes et al., 2014). In the T3 treatment, there was a slight increase in Ds along the layers, contrary to what was observed by Faraco et al. (2008) also in no-till farming.

The T2 treatment concentrated more Ds in all layers of the west side of the studied region, where there was the passage of the roller compactor. In the other treatments, deformation by the passage of the roller compactor was not clear. Variations in the Ds can be explained by intrinsic variables, as a result of natural changes in the soil or extrinsic such as machine traffic over the soil (Kamimura et al., 2013).

A similarity was observed between the Ds map of the second layer of T1 with the Macro map of this treatment. In the region where the highest Ds are concentrated, a lower volume of Macro was observed (Fig 4), highlighting the relationship between these important attributes. The result is similar to what observed by Santos et al. (2012) in the first layer (0-0.1 m), in Red Latosol with a texture similar to our study.

The T3 treatment presented the highest values of Macro in all layers, which may be related to the lowest values of Ds in this treatment (Reichert et al., 2007). However, in all treatments, the Macro values presented a volume above 10.51%, which is above the limit for good aeration and water movement in the soil. Exceptions were the small regions in the first layer of T1 and T2 treatments, which had a value between 7.27 and 10.51%.

The results presented in Fig 5 indicate that Micro remained constant in the soil profile for the three treatments, with a small decrease in the last two layers of T3. Reichert et al. (2007) stated that this attribute is not sensitive to deformations due to soil compaction. In Fig 5, it is also possible to identify the lower spatial continuity of this attribute, especially in the first layer of T2 treatment.

Materials and methods

Experimental area

The experiment was performed in the experimental area of the Agronomic Institute of Paraná, Iapar, in the regional center of Santa Tereza do Oeste, Paraná, Brazil, located at latitude 25º 05' 6.65" S and longitude 53º 35' 12.98" O. In the region, the climate is characterized as humid subtropical mesothermal, according to the classification of Köppen, Cfa (Caviglione, 2000), with an annual average rainfall of 1840 mm and relative air humidity between 75 to 80% (Iapar, 2000).

Soil characterization and climatological data

According to the Brazilian Agricultural Research Corporation [Embrapa] (2018), the soil in the region is classified as typical Dystroferic Red Latosol, LVdf. The area has gently undulating slopes with values ranging from 0.21% to 5.41%. Table 1 shows the granulometric analysis, indicating the texture class as very clayey.

Characterization of treatments and plant materials

The experimental work was carried out in the 2017/2018 harvest with soybean (The soybean cultivar used was the Lance IPRO with sowing of 15 seeds per linear meter and spacing of 45 centimeters between rows and fertilization of 300 kg ha^{-1} of the formulation 08-22-08 + 6% Ca + 9% S) cultivation and is part of a long-term experiment in an area, where management systems are evaluated. The experimental area consisted of three treatments: scarified no-tillage at 0.3 m depth (T1), no-tillage with 3 t ha-1 of plaster applied to the surface (T2) and the control, traditional no-tillage system (T3). Fig 1 shows the map of the location of one of the treatments. The others were located in the same experimental area.

In each of the areas analyzed, 15 georeferenced points were marked, from which undeformed soil samples from layers 0-0.1, 0.1-0.2 and 0.2-0.3 m were collected. The spacing between points was determined considering a number of points for a better representation of the area, as shown in Figure 2, with each area measuring 20 x 25 m. The T2 and T3 treatments received three passes of compacting roller in part of their area (20 x 9 m) (Fig 2), to cause a density gradient in the soil.

The undeformed samples were collected with stainless steel volumetric rings, with a volume of approximately 98 cm³ (5 cm in diameter and 5 cm and height), being allocated in aluminum cans and taken to the Laboratory of Soil Physics, Lafis, located in Unioeste, Cascavel, Paraná. In the laboratory, the samples were properly adjusted to the volume of the ring, removing the excess soil from the upper and lower parts of the ring, and then placed in trays for saturation for an approximate period of 24 hours. After saturation, they were placed in a sand column at a tension of 0.6 meters of water column for the removal of water from the macropores (Reinert and Reichert, 2006). Then, the samples were taken to a kiln with a temperature of 105ºC until reaching a constant mass to extract the water in the micropores.

The soil density (Ds) was determined using the volumetric ring method, resulting from the ratio of dry soil mass (MSS) already discounted to the mass of the ring, by the total volume (VT) of the ring (Embrapa, 1997), according to the expression:

$$Ds\ (Mg\ m^{-3}) = \frac{MSS}{VT} \quad (1)$$

In turn, total porosity (PT) was evaluated through Ds and particle density (Dp) by the equation below proposed by Vomocil (1965):

$$PT(\%) = \left(1 - \frac{Ds}{Dp}\right) \times 100 \quad (2)$$

The expression was used to obtain the microporosity value (Micro):

$$Micro(\%) = \frac{MSU - MSS}{MSS} \times 100 \quad (3)$$

For the calculation of macroporosity (Macro), we used the equation:

$$Macro(\%) = PT - Mi \quad (4)$$

The particle density was determined by the volumetric flask method with alcohol.

Statistical analysis

The data were subjected to descriptive and spatial statistical analysis, with the assistance of software R (R Core Team, 2016). The Matheron semi-variate estimator (Matheron, 1962) was used to assess the existence and shape of the spatial dependence between the samples. After the construction of the experimental semivariograms, with a cutoff of 50% of the maximum distance between the sampled points, the theoretical models were adjusted by the ordinary least squares method and parameters C_0, C_1, C, and range *a* were determined.

To determine the degree of spatial dependence (GD), the ratio between the structural variance and the level was used as follows (Mello et al., 2008):

$$GD = \frac{C_1}{C_0 + C_1} \times 100 \quad (5)$$

The classification of these values was according to Mello et al. (2008), and GD < 25% denotes weak spatial dependence, 25% < GD < 75% representing moderate spatial dependence, and GD > 75% is configured as strong spatial dependence.

The thematic maps of the variables were generated by observing the dependence, through Krigagem, which estimates unbiased values for the nearby regions with minimum variance (Vieira, 2000).

Conclusion

The analysis of the experimental results indicates that all physical attributes presented spatial dependence between the data, with higher density values and lower macroporosity in areas with T1 (SPD with scarification) and T2 (SPD gypsum) management systems. Treatment T3 (traditional SPD) showed favorable physical soil conditions, even after compaction.

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