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PROBABILITY OF PARTICLE-SIZE FRACTIONS OCCURRENCE IN DIFFERENT LANDFORMS

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ABSTRACT

Knowing the variation of particle-size fractions, considering the relief forms, contributes for understanding the variation of other soil attributes. This work aimed to study the spatial distribution of the probability of particle-size fractions occurrence (clay, silt, very fine sand, fine sand, coarse sand, and total sand) in a clayey Oxisol with predominance of concave and convex curvatures. A sampling grid with 94 sampling points in 33x33m spacing at a depth of 0–0.20 m was built using a GPS. The spatial analysis was performed through indicator kriging. The spherical model was fit for all soil fractions, with ranges varying from 130 m to 280 m. In the region of convex curvature, the clay fraction presented the highest probability of occurrence (0.75 to 1.00), whereas in the concave region the coarse sand and total sand fractions presented the highest probability of occurrence. The very fine sand fraction and the silt did not present pattern of distribution in relation to the dominant curvatures of the relief.

Palavras-chave:
pedoforma
relevo
semivariograma

PROBABILIDADE DE OCORRÊNCIA DAS FRAÇÕES GRANULOMETRICAS EM DIFERENTES PEDOFORMAS

RESUMO

Conhecer a variação das frações granulométricas, considerando as formas do relevo, colabora no entendimento da variação de outros atributos do solo. Este trabalho teve como objetivo estudar a distribuição espacial da probabilidade de ocorrência das frações granulométricas (argila, silte, areia muito fina, areia fina, areia grossa e areia total) em um Latossolo Vermelho Amarelo, textura argilosa, com predomínio das curvaturas côncavas e convexas. Uma malha amostral com 94 pontos amostrais no espaçamento 33x33m, na profundidade de 0-0,20 m, foi construída com auxílio de um GPS. A análise espacial foi realizada pela krigagem indicatriz. Em todas as frações do solo se ajustou o modelo esférico, com alcances variando de 130 m a 280 m. Na região de curvatura convexa a fração argila apresentou maior probabilidade de ocorrência (0,75 a 1,00), enquanto que as frações, areia grossa e areia total com maior probabilidade de ocorrer na região côncava. A fração areia muito fina e o silte não apresentaram um padrão de distribuição em relação as curvaturas dominantes no relevo.

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INTRODUCTION

The landforms that are part of the landscape influence the dynamics of rainfall. The features of concave, linear, and convex landforms have direct effects on the convergence and dispersion of water in the runoff process, contributing in the modeling and spatial variability of the soil. The forms of relief may be indicators of variations in soil attributes, because this variability is caused by small changes in slope that affect pedogenic processes and transport and storage of water in the soil profile (SANCHEZ *et al*., 2009).

Guo *et al*. (2007) state that the forms of relief influence the display of source material, intensity, and direction of water flow in the soil profile. According to these authors, the adopted practices of soil management can intensify the variability of physical, chemical, and biological attributes, which, combined with the form of the landscape, result in imbalance of the natural and productive system.

Artur *et al*. (2014) researched the spatial variability of soil chemical properties and identified relations with microrelief, concluding that the highest mean values of the attributes occurred in concave landforms. Nizeyimana & Bicki (1992) observed higher mean values of cation exchange capacity (CEC) in concave terrain, attributing them to the drainage conditions of the area and to the convergent characteristics of relief's slope.

Among the methods that consider the spatial variability of soil attributes, there is the technique that works with indicator variables obtained by nonlinear transformation of data into binary variables, known as indicator kriging. This method is not influenced by discrepant values in the dataset and, according to Yamamoto & Landim (2013), it can be used to derive the conditional cumulative distribution function for estimating the probability of a certain value occurrence in a non-sampled point, according to a given value considered as the cutoff point.

Kriging indicator is a non-parametric method because, a priori, it does not consider any probability distribution for the transformation of continuous random variable into binary variable (ASSUMPÇÃO *et al*., 2007). This technique provides maps in which it is possible to evaluate the occurrence probability of the phenomenon under study, fostering the understanding of different phenomena inherent to the soil system (SILVA *et al*., 2011).

This study was conducted to determine the occurrence probability of different particle-size fractions in different landforms in an Oxisol.

MATERIAL AND METHODS

The study was conducted in a commercial area of 10.0 ha located in São José do Calçado-ES, in UTM coordinates, zone 24S: North 7,682,793.845 m; South 7,682,564.753 m; East 226,112.751 m; and West 226,620.572 m. The area altitude ranges from 577.35 to 708.96 m and is inserted in a micro-region that presents accumulated precipitation in the year of more than 1000 mm and average monthly temperature of 21ºC.

The predominant coverage in the area is pasture, with *Brachiaria brizantha* Hochst Stapf (capim-braquiária) and *Melinis minutiflora* P. Beauv. (capim-gordura) grass species. The existing forests, adjacent to the study area, fall within the Atlantic Forest domain, reflecting the use of original soil of the area.

As described by Embrapa (2006), the soil of the area is classified as Oxisol – type LVa9, which is characteristic of yellowish, deep, and poor soils, with moderate A horizon, low in nutrients and very rich in aluminum. The clay of these soils have low activity, which makes them poorer in nutrients.

The area consists of a relief with two prominent curvatures, one considered as concave-concave and the other convex-convex, according to criteria defined by Thoer (1965). The convex region is present at the top and right side of the area (C^+P^+) and by concave (C^-P^-) at the central part and the left side of the area (Figure 1).

Using a geodetic GPS, the altimetric quotas were determined and a regular grid with 94 sampling points with intervals between points of 33x33m was established. At each grid point, soil was collected in the 0.0–0.20 m layer with the aid of a stainless steel auger. After collection, the samples were placed into plastic bags, identified, air-dried, and passed in 2 mm sieves, forming the

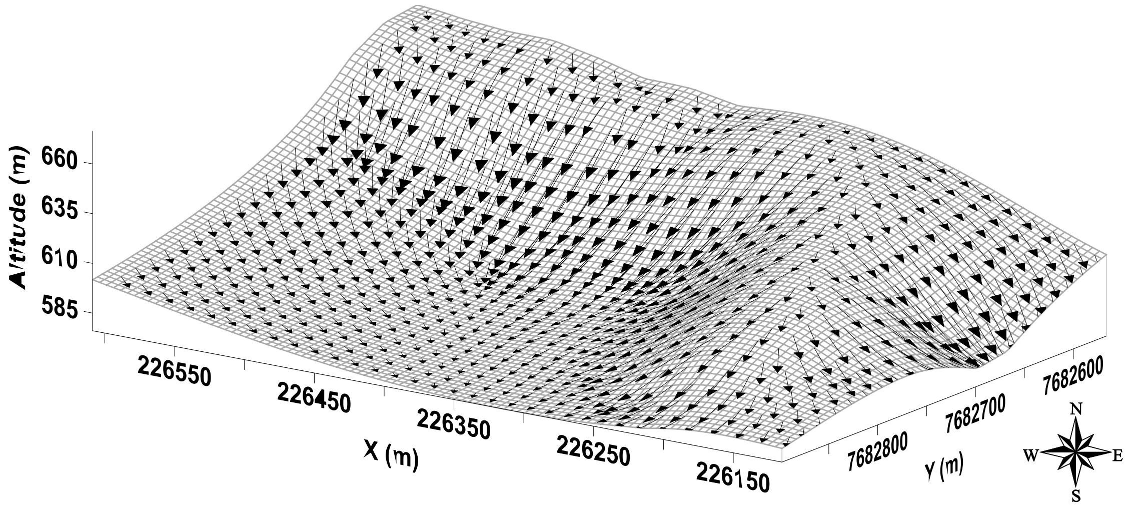

Figure 1. Digital elevation model (DEM) of the study area based on the sampling points.

air-dried fine earth (ADFE) for the determination of particle-size fractions by pipette method, with slow agitation, using NaOH (0.1M) as dispersant. The analyses of the particle-size fractions (clay, silt, very fine sand, coarse sand, and total sand) were performed according to the methodology presented by Embrapa (2011).

The fractions present the following values [mean; median (%)], considering all 94 sampling points: clay [50,0; 49,6], silt [6,2; 5,9], very fine sand [2,8; 2,7], fine sand [9,2; 9,0], coarse sand [31,8; 30,7], and total sand [43,8; 43,6]. The distribution of the soil fractions presents normality by the Kolmogorov-Smirnov test ($p \leq 0.05$) and asymmetrical distribution to the right.

Before the geostatistical analysis, the data of the particle-size fractions underwent a binary transformation, being coded to 0 or 1. In each soil fractions, the average data was adopted as the cutoff point: the values above or equal to this measure were coded with the value 1 and the values below it with 0. The transformation result generated a new set of data, composed of 0 and 1, which was subjected to geostatistical analyses, thereby obtaining the indicator semivariogram (equation 1), which reflects the pattern of spatial continuity for the predetermined cutoff value.

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

in which: N(h) is the number of experimental pairs of observations $Z(x_i)$, $Z(x_i+h)$, separated by a vector h. With the adjusted indicator semivariograms, the parameters were determined: nugget effect (C_0), sill (C_0+C), and range of spatial dependence (a). The choice of model was based on the lowest sum of squared residuals, in the R^2 of the adjustment, and in the correlation between the observed values and those estimated by cross-validation. For the spatial dependence degree (SDD), the classification proposed by Zimback (2001) was used, in strong for SDD $\geq$75%, moderate for 25%<SDD<75%, and weak for SDD $\leq$25%.

Indicative kriging requires that the attribute values should be modified in a non-linear transformation, which is called coding indication (OLIVEIRA & ROCHA, 2011). According to Yamamoto & Landim (2013), the kriging indicative requires a semivariogram of the variable indicator for various adopted cutoff values. Since the semivariogram function is calculated as average of the differences among points separated by a distance h, it is not always possible to obtain a semivariogram of the indicative, especially for cutoff values adopted at extremes of the data series. Thus, Journel (1983) states that the best semivariogram of each variable indicator corresponds to a cutoff value equal to the median of the data distribution, since half of the values is equal to 1 and the other half is equal to zero.

Once defined the semivariograms indicative, the method of indicative kriging was used for the construction of the thematic maps of the particle-size fractions occurrence probability with the aid of GS+ software program. According to Motomiya *et al*. (2006), these values correspond to the probability that the estimated values are above or below the cutoff point, i.e. the value expected in a non-sampled location is equivalent to the cumulative distribution of each variable under study.

RESULTS AND DISCUSSION

Table 1 presents the parameters and models of the semivariograms indicative adjustments, taking as cutoff the average of the data.

In the spatial analysis, the semivariograms indicative presented well-defined levels, revealing that the data do not have trend and minimally satisfy the intrinsic hypothesis of stationarity (ISAAKS; SRIVASTAVA, 1989). It was observed that the spherical model fitted the data series from all the particle-size fractions of the soil, as presented in Table 1. Lima *et al*. (2014) set the particle-size fractions of the soil to the spherical model for the construction of thematic maps by ordinary kriging (Figure 2).

Table 1. Parameters and models of isotropic semivariograms for the particle-size-fractions.

Fractions	Models	C_0	C_0+C	a (m)	SDD (%)	R^2 (%)
Clay	Sph	0.13	0.27	160	51	84
Silt	Sph	0.15	0.30	230	50	92
Total Sand	Sph	0.12	0.29	280	61	97
Coarse Sand	Sph	0.12	0.29	280	60	95
Fine Sand	Sph	0.13	0.29	160	50	88
Very Fine Sand	Sph	0.13	0.27	130	50	86

Sph: spherical model; C_0: nugget effect; C_0+C: sill; a: range of spatial dependence; SDD: spatial dependence degree; and R^2: coefficient of multiple determination of the adjustment.

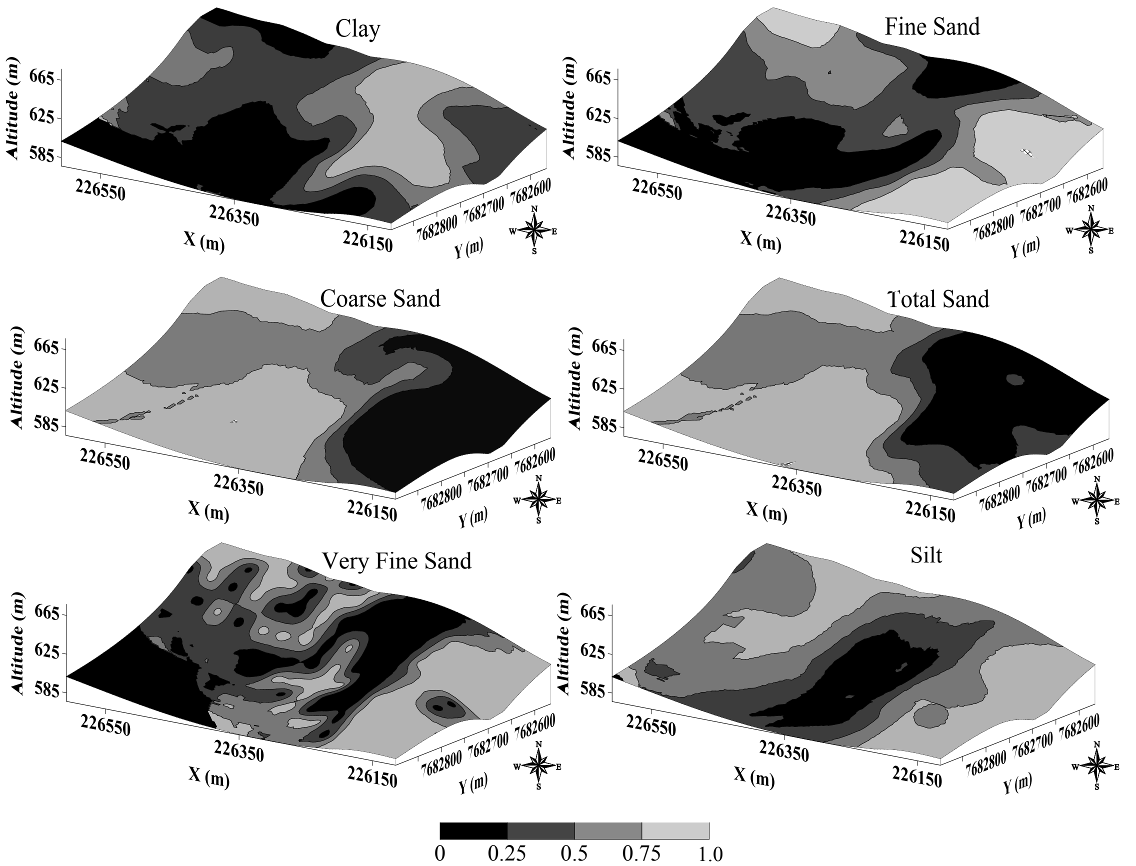

Figure 2. Spatial distribution of the particle-size fractions occurrence probability.

Considering the indicative semivariograms, the same pattern of spatial distribution of the occurrence probability is observed between the clay and fine sand fractions, with adjustments to the same model and the same ranges (160 m). For the fractions coarse sand and total sand, the same spatial distribution pattern is also observed, with ranges of spatial dependence of 280 m, with higher spatial continuity of the occurrence probability in the area. This fact is due to the fact that coarse sand fraction composes an average of 72.8% of total sand and the remaining 27.2% correspond to the fractions of fine sand and very fine sand. Andreotti (2002) states that the semivariograms indicative show patterns of spatial continuity that the semivariograms of the original data cannot show, due to the influence that the discrepant points have in defining the limit.

In analysis, the silt and very fine sand fractions do not present similarity in the spatial pattern with any other fractions. For the very fine sand, this fact may be related to its low contents in the soil, whereas concerning the silt, the process of determining in laboratory, which incorporates part of the existing variability in the sand and clay fractions, contributed to the observed. Silva *et al*. (2010) state that in addition to the issues regarding its means of determination, since it is devoid of load, the silt fraction generally presents high instability with behaviors of spatial distribution that do not follow specific patterns.

Soil cover is an important factor for the spatial behavior of texture attributes. The interference of soil cover on the surface runoff alters the translocation of solutes or prevents the movement of particles, retaining the water for a longer time in the growing area (PROCHNOW *et al*., 2005). The study area is cultivated with densely pasture, which, from the conservation point of view, significantly reduces soil loss caused by erosion (SILVA *et al*., 2007). According to these authors, in dense vegetation conditions, the effect of rainfall impact is invariant in the area with the flow dominated by the characteristics of the relief.

The spatial dependence degree (SDD) presents values ranging from 50% to 60%, which shows moderate dependence, according to the classification of Zimback (2001). The coefficients of multiple determination (R^2) of the theoretical semivariograms adjustment to the indicative experimental ones range from 84% to 97%, confirming the choice for unidirectional models, corroborated by the significant correlation between the observed and the estimated values, in accordance with cross-validation.

As expected, the silt/clay ratio of the soil under study is equal to 12.4%, indicating the high degree of weathering. Rezende *et al*. (2002) state that particles of the size of sand and silt, under weathering, are transformed into clay, which is generally tougher and less rich in reserves of nutrients than the material from which it originated. Then, resistant minerals remain in the size of sand and the silt fraction is the point of maximum instability, i.e. only the newest soils present high silt content, which is minimal in Latosols.

Soils with a high degree of weathering present low natural fertility, contrasting with the high stability of the aggregates, which results from the action of the oxides of aluminum and iron present in the clay fraction (OLIVEIRA *et al*., 2004), the low soil density, high volume of macroporosity, and high friability, which greatly favors its management. Lima *et al*. (2013) studied the probability of occurrence of average values of the attributes P and K in convex-convex landform in a Red-Yellow Latosol finding the greatest probabilities in a great part of the area.

The uniformity of vegetation cover, as discussed above, makes it possible to state that the clay fraction presents behavior highly influenced by landform and terrain slope. There is a higher probability of occurring values that are greater and equal to the median of the clay fraction (0.75 to 1.00) on the convex landform, a region of lower slope and less flow accumulated in the runoff. The lowest probability (0 to 0.25) occurs at the bottom portion of the concave landform and part of the upper left region, where there are small variations of the concave to the convex shape. In the region of the greatest slopes, the probability of occurrence ranges from 0.25 to 0.50. Montanari *et al.* (2010) state that the clay fraction is suffering the greatest influence from pedoenvironmental characteristics, mainly due to specificities of its crystallographic attributes. According to Ghidin *et al*. (2006), this factor, combined with the terrain slope, interferes the behavior of water flow in the soil and consequently in the transport and deposition of solids or materials in solution.

Sanchez *et al*. (2009) found that the magnitude of the variability of soil attributes is more influenced by the relief form than by erosion. Lima *et al*. (2013) in an Ultisol covered with natural vegetation, showed that water-dispersed clay presents increased concentration, when passing from convex to concave landform, which is due to runoff, according to the authors.

Souza *et al*. (2003), evaluating the soil physical properties in an Oxisol, observed higher spatial variability in the concave landform compared with other shapes of relief. Sanchez *et al*. (2009) found in an Ultisol indicating strong spatial dependence with the form of relief. Lima *et al*. (2009) studied the spatial distribution the particle-size fractions in pasture area, in one Ultisol, finding higher total sand concentration in the lowest area and clay at the top.

The probability of occurring values that are higher and equal to the average of fine sand fraction data (0.75 to 1.00) in the area occurs in the right and upper left region, where there are smooth changes in the convex landform to concave, region that presents low concentrations of clay.

The coarse sand and the total sand fractions, as expected, are highly spatial correlated, due to the contribution of coarse sand in the total sand fraction, as described previously. The maps are very similar in form, having the probability from 0.75 to 1.00, occurring the highest concentrations of the sand fractions in the lowest portion of the concave landform and upper left portion, where there are smooth changes of the convex landform to concave. The concave landform has greater removal at higher parts and higher accumulation in the lower areas, therefore, these different positions create different local situations (REZENDE *et al*., 2002). This is due to increased flow in the runoff, region of increased slope, carrying the fine fractions in the erosion process; as a result, the highest contents of coarse sand, by the residual enrichment of this fraction, occur in the region of lower altitudes. Lima *et al*. (2012), in a spatial study of soil fractions, state that contents of total sand and clay are negatively and positively correlated, respectively, with the altitude of the sampling sites, showing the influence of landscape configuration.

As discussed previously, the silt and very fine sand fractions show no similarity in the pattern of spatial distribution in the occurrence probability in the area. However, the highest probability of high values (0.75 to 1.00) for these two fractions occurs at the right and upper left parts of the area, where there are small changes from concave to convex curvatures and vice versa. Differently from Miqueloni & Bueno (2011), who concluded that very fine sand fraction tends to concentrate at the higher positions of the reliefs, following a reduction gradient in the direction of the lower quotas. In this work, at the convex landform, it was observed increased homogeneity of distribution of this fraction with predominance of occurrence probability values higher than 0.75.

In general, it is possible to affirm that the particle-size fractions presented less variation for the convex landform, which may be related to the direction of runoff in this area, where there is no predominance of water convergences and consequently accumulation of particles. Silva Junior *et al.* (2012) found variability for the chemical and physical attributes of soil, considering the convex landforms for Oxisol, less homogeneous groups, and linear for Ultisol, more homogeneous groups. Sanchez *et al*. (2009) observed that relief forms contribute as an indicator of variability of chemical and physical soil properties, with higher variation in concave landforms in relation to convex landforms. Regard to soil particle-size fractions for clay and silt, these authors observed higher average values for the convex landform, while total sand presented higher values for concave landform.

CONCLUSIONS

- The particle-size fractions presented less variation in probability for convex landforms compared to concave landforms.
- The clay fraction was the most influenced by the landforms and by the slope of terrain, with the highest probability of values being higher or equal to the median of fraction in convex landform and lower in concave landform.

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