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SPATIAL VARIABILITY OF SOIL PHYSICAL ATTRIBUTES IN FUNCTION OF THE USE AND OCCUPATION OF AGRICULTURAL LAND IN SÃO BENEDITO, CEARÁ

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ABSTRACT

With the modernization of agriculture, inadequate use and occupation of the soil and pedogenetic factors have led to spatial variability in physical attributes, which directly influence soil fertility and quality. Therefore, in agriculture, proper soil management is necessary for good plant development, which is only possible when the soil system and its dynamic interaction are understood. The aim was to evaluate the spatial variability of soil physical attributes in an agricultural area using geostatistical techniques. Soil samples were collected at a depth of 0 – 0.2 m at the Lagoon site in the rural area of the municipality of São Benedito-CE, on the Ibiapaba plateau, where 50 soil samples were collected, following a regular internal grid of 10 x 20 m equidistant, with georeferenced points as a way of demarcating the sampling area. The physical attributes assessed were: soil density, particle density, and total porosity. The data was submitted and analyzed using descriptive statistics and then submitted to geostatistics. The semi variogram model that fitted best was the spherical model, except for total porosity, which used the exponential model. The five variables analyzed in this study showed a strong degree of spatial dependence (nugget effect/pattern ratio < 25%). The maps made it possible to understand the influence of one variable on another.

kEYWORDS: geostatistics; Ibiapaba; thematic maps; regionalized variables.

VARIABILIDADE ESPACIAL DOS ATRIBUTOS FÍSICOS DO SOLO EM FUNÇÃO DO USO E OCUPAÇÃO DAS TERRAS AGRÍCOLAS EM SÃO BENEDITO, CEARÁ

RESUMO

Com a modernização da agricultura, o uso e ocupação inadequada do solo e os fatores pedogenéticos têm ocasionado a variabilidade espacial dos atributos físicos, que influenciam diretamente na fertilidade e qualidade do solo. Para tanto, na

agricultura é necessário um manejo adequado do solo para um bom desenvolvimento vegetal, que só é possível quando se compreende o sistema solo e sua interação dinâmica. Objetivou-se avaliar por meio de malha amostral a variabilidade espacial dos atributos físicos do solo em uma área explorada com agricultura, a partir das técnicas de geoestatística. Coletou-se amostras de solos na profundidade de 0 – 0,2 m no Sítio Lagoa, na zona rural do município de São Benedito-CE, na chapada da Ibiapaba, onde foram coletadas 50 amostras de solo, obedecendo a uma malha regular interna de 10 x 20 m equidistantes, com pontos georreferenciados como forma de demarcar a área amostral. Os atributos físicos avaliados foram: densidade do solo, de partículas e porosidade total. Os dados foram submetidos e analisados a partir da estatística descritiva e em seguida submetidos à geoestatística. O modelo de semivariograma que melhor se ajustou foi o esférico com exceção da porosidade total, que se utilizou do modelo exponencial, as cinco variáveis analisadas nesta pesquisa apresentaram um grau de dependência espacial forte (relação efeito pepita/patamar < 25%). Com os mapas foi possível compreender a influência de uma variável sobre a outra.
PALAVRAS-CHAVE: geoestatística; Ibiapaba; mapas temáticos; variáveis regionalizadas.

INTRODUCTION

Brazil was formed and organized based on the possession of large tracts of land that were given away to whoever would exploit them, generating major socio-environmental impacts. The environmental degradation that occurs in Brazil is directly associated with this process of over-exploitation of natural resources that dates back to the colonization period, which was based on political and economic interests that determined the occupation and use of this territorial space (FREITAS *et al*., 2012).

With the modernization of agriculture, the intense use of mechanization associated with the high rate of land use and occupation has led to several negative changes in the physical attributes of soils, which are excellent indicators of the environmental quality of an agricultural area. The physical and water attributes of the soil, together with other attributes, when negatively affected by management, influence the balance of natural resources and agricultural production.

In agriculture, areas with inadequate soil management result in erosion due to the removal of the soil's vegetation cover, consequently dragging sediment, causing siltation of rivers and water contamination due to the excessive use of agrochemicals and fertilizers. This attitude generates serious environmental problems, accompanied by a process of leaching and anthropogenic action, causing major changes in the agrosystem (SANTOS *et al.,* 2021).

By monitoring the physical properties of soils, it is possible to manage them as a result of their intensive use, including a decrease in organic matter, an increase in soil density, which contributes to water retention, the size of aggregates, a reduction in porosity and the infiltration rate, thus highlighting the importance of knowledge of spatial variability for correct soil management in agricultural areas.

The spatial variability of soil encompasses physical, chemical, and biological characteristics, regardless of whether the area is apparently uniform, generating complexities in the soil system since soil formation involves a series of processes that result in extremely heterogeneous end product in terms of its morphological characteristics and properties (CAJAZEIRA; ASSIS JÚNIOR, 2011).

The evolution of cultivation techniques with intense mechanization combined with the rate of land use has led to changes in the soil's physical attributes. Any change in these attributes can lead to negative changes, while the textural fractions are stable and change little over time, with a low coefficient of variation. Soil density is one of the physical attributes that stands out the most, as it indirectly reflects soil compaction conditions, which is a reflection of the management used (KLINKE NETO *et al.,* 2017), and can be high or low.

One of the tools that can be used to analyze spatial variability is geostatistics, which makes it possible to analyze the variation in properties that occurs from one location to another (LIMA *et al*., 2015). Among the various applications of geostatistics, one of the most widely used tools is the construction of thematic maps, which make it possible to evaluate the variable under study in space (LEMOS FILHO *et al*., 2008).

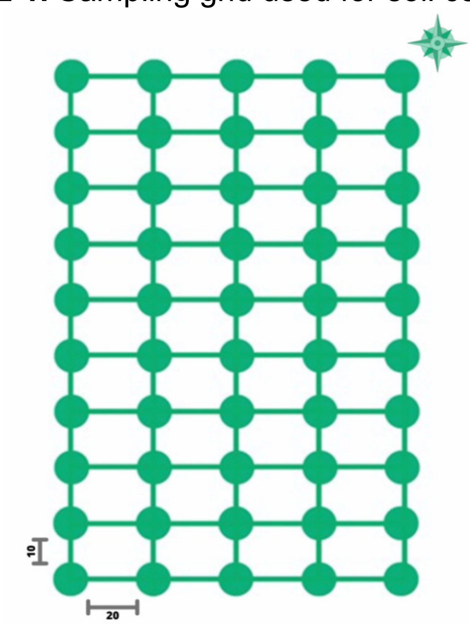
Therefore, the following hypothesis is put forward: there may be spatial variability in soil physical attributes caused by the use and occupation of land for agricultural purposes in the municipality of São Benedito, Ceará. The aim of this study was to evaluate the spatial variability of soil physical attributes in an agricultural area using geostatistical techniques.

MATERIAL END METHODS

The data was collected in an area used for agricultural purposes, belonging to the Instituto Agropolos do Ceará, Lagoon site, in the municipality of São Benedito-CE, under the geographical coordinates: 4º 02' 56" S and 40º 51' 54" W at 903 m altitude.

The soil samples were collected manually using a Dutch auger, at a depth of 0.00 to 0.20 m, in a Neossolo Quartzarênico according to Santos *et al*. (2018), following a regular internal grid of 10 x 20 m, totaling 50 samples as shown in Figure 1. The area where the soil was sampled is mostly occupied by ruderal plants, banana trees (*Musa spp*), and other secondary vegetation (species from the Caatinga biome), but has already been cultivated with fruit species such as apples (*Malus domestica* Borkh) and pears (*Pyrus* L.). Each point was geo-referenced using a GPS to demarcate the area.

FIGURE 1. Sampling grid used for soil collection.



Source: Authors (2023)

The samples were collected with a Dutch auger, the radius of which, at the georeferenced point, was approximately 500 g of soil, and packed in duly identified plastic bags. The samples were sent to the Soil Chemistry Laboratory at the Ieducare Faculty – FIED, in the municipality of Tianguá/CE. To characterize the physical attributes: soil density (ρs), particle density (ρp), and total porosity (α), all attributes were determined according to the method suggested by Teixeira *et al*., (2017).

All the data was submitted and analyzed using descriptive statistics, determining the values: mean, median, minimum and maximum value, standard deviation, coefficient of variation, kurtosis, asymmetry, and K-S test, for subsequent characterization. The data was submitted to the K-S test to analyze the normality of the data.

Spatial dependence was assessed by adjusting the semi variograms, which were represented in graphs in which the Gaussian, spherical, and exponential models were tested and, after analysis, the best adjustments were selected to represent the relationship between experimental semi variance and distance; the nugget effect (Co), plateau (Co+C) and range (Ao) parameters were also determined. Once spatial dependence had been detected, thematic maps of the spatial variability of the attributes analyzed were constructed using kriging, and the interpretation of the spatial variability was then carried out.

The SISVAR 5.6 software (FERREIRA, 2019) was used for the descriptive statistical analysis and the geostatistical analysis, as well as the semi variogram models of the soil attributes, were adjusted using the GS+ (Geostatistical for Environmental Sciences) computer program (ROBERTSON, 1998). Finally, thematic maps were constructed using Surfer software, version 8.0 (GOLDEN SOFTWARE, 2006).

RESULTS AND DISCUSSION

To use geostatistical techniques, it is necessary that the raw data, which is then tabulated and organized, has a normal frequency distribution, i.e. the mean, median, and mode position measures coincide or are at least close to each other.

It was noted that the mean and median values of the physical attributes of the soil under study are close to each other at a depth of 0.00 – 0.20 m, showing that the data has symmetry and a normal distribution (Table 1). To validate normality, we used Cajazeira (2007), who indicated that asymmetry values close to 0 (zero) were indicative of normality. The Kolmogorov-Smirnov (K-S) test at 5% probability showed that the attributes had a normal distribution (Table 1). The kurtosis coefficients in the sample density are close to zero, which reaffirms the trend toward symmetrical distribution. According to Diggle and Ribeiro (2007), both kurtosis and the asymmetry coefficient are more sensitive to high values when compared to the mean, median, and standard deviation, since a single value can have an extreme influence on kurtosis and the asymmetry coefficient, given that the deviations between each value and the mean are raised to the third power.

TABLE 1. Parameters for the soil physical attributes: particle density, soil density and soil porosity for the 0.00 to 0.20 m depth.

Parameters	Physical attributes		
	ρp (g/cm³)	ρs (g/cm³)	α (%)
Mean	2.29	1.26	44.99

Median	2.27	1.25	45.09
Standard deviation	0.06	0.06	3.11
Kurtosis	0.79	0.45	1.95
Asymmetries	0.21	-0.24	0.19
Minimum	2.13	1.08	36.55
Maximum	2.44	1.38	54.64
coefficient of variation (%)	2.54	4.97	6.90
Kolmogorov-Smirnov (K-S)	0.16	0.10	0.11

ρp – particle density; ρs – soil density; α – soil porosity. **Source:** Authors (2023).

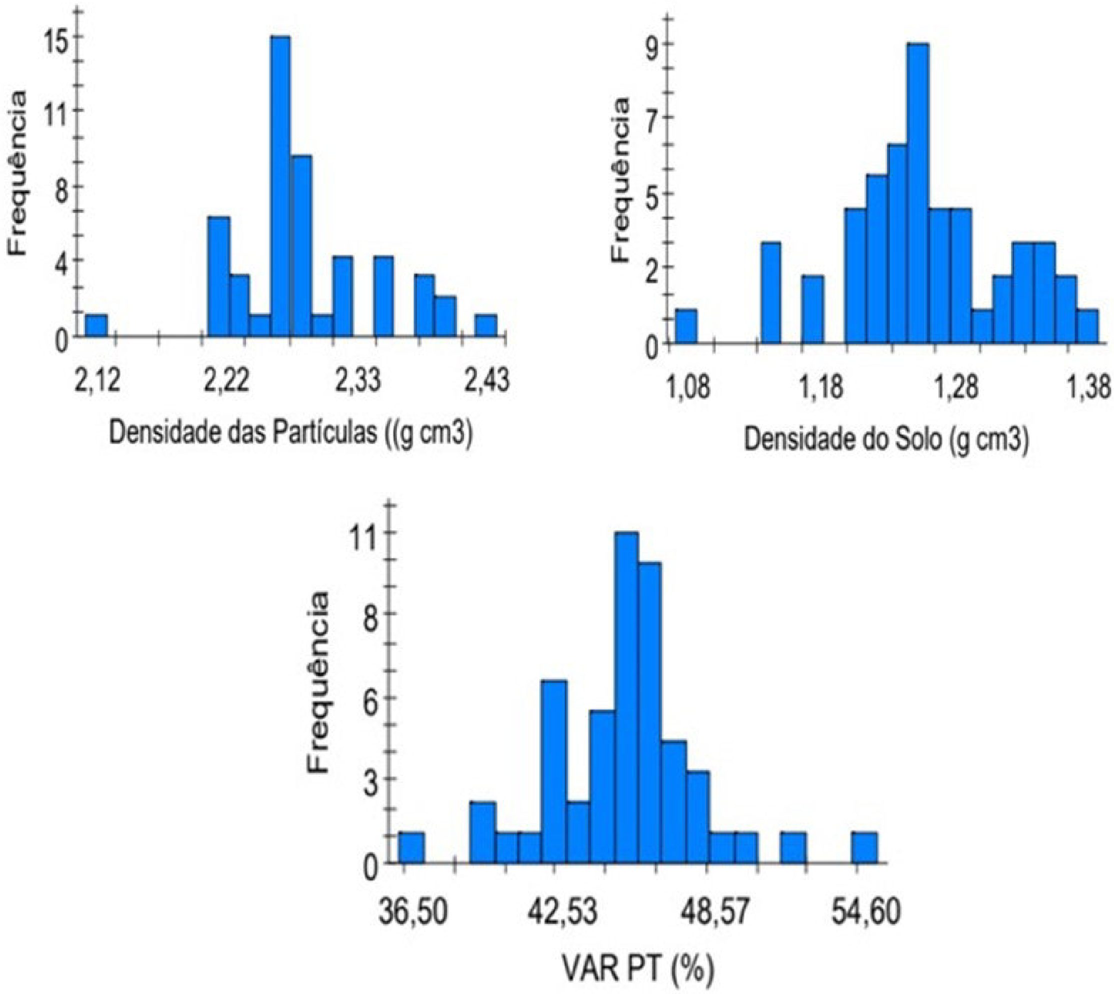
The coefficient of variation (CV), which refers to the extent of variability in the data, cannot be used as a metric to analyze the spatial dependence structure of soil properties, but rather geostatistical techniques. According to Warrick and Nielsen (1980), coefficient of variation values between 12% and 60% are classified as medium and high variability, respectively.

In this study, the values found were below those reported by those authors, in which case they were considered to be low variability: particle density (ρp), soil density (ρs), and total porosity (α) showed a CV below the average of 12% (Table 1). On the other hand, Santos *et al.* (2012) found similar results in their research for the same variables analyzed, particle density: 1.3%, soil density: 5.3%, and total porosity: 7.02%.

It was observed that the soil density variable showed a normal frequency distribution and a low coefficient of variation. The same was true of particle density (Table 1), which is to be expected given that it is associated with soil mineralogy. Total porosity, in turn, also showed a normal distribution, but with greater variability when compared to the other soil physical variables, something which justifies the higher coefficient of variation compared to the other attributes (Table 1).

The histograms of the variables analyzed can be seen in Figure 2, which shows that the three variables studied had a normal frequency, confirming the normality of the data using the test applied. According to Rodrigues (2010), physical attributes are more stable and suffer less spatial variability. According to Lima *et al*. (2006), the normality of the data is not an imposition of Geostatistics, so it is pertinent that in the normal distribution graph, the attribute does not have very elongated distribution extremities, as this can jeopardize the analysis.

FIGURE 2. Histograms relating to the stability of physical variables.



Source: Authors (2023)

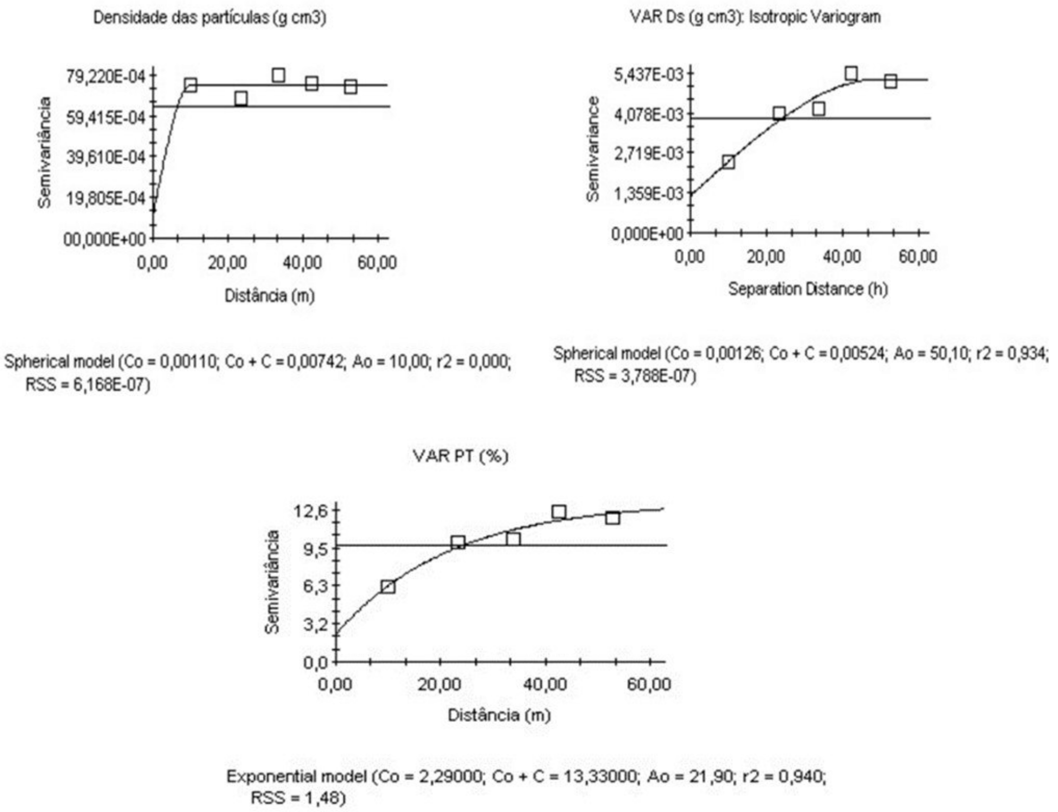
The attributes observed in this study showed differences in spatial dependence as determined by the semi variance analyses. The spherical and exponential models were used to define the variables (Figure 3). This selection is in line with Carvalho Filho *et al.,* (2010), who found these same models for spatial variability.

The model that best fitted the soil density (ρs) and particle density (ρp) variables was the spherical model. The exponential model was the best fit for the total porosity variable (α). According to Matias *et al*. (2019), the spherical semi variogram model is the best fit for soil attributes, which is because these attributes usually change abruptly in the environment.

The degree of spatial dependence was based on the ratio between the nugget effect and the plateau, which is classified as strong if the ratio is ≤ 25%, moderate when > 25% and < 75%, weak when ≥ 75% and < 100% and independent if the ratio is equal to 100% Cajazeira and Assis Júnior (2011). The three variables studied in this research showed a strong degree of spatial dependence (nugget effect/pattern ratio < 25%).

Most of the variables studied had a range equal to or within the 10 x 20 m study area. The variable that deviated from this pattern was soil density with a value of 50.10 m. This is due to several factors, such as the decrease in the thickness of the surface horizon, or some samples from the 0.0 – 0.20 m layer may be part of a more compacted soil zone, given that this area was cultivated, in which plowing and other agricultural mechanization operations took place.

FIGURE 3. Semivariograms correspond to the physical variables.



Source: Authors (2023)

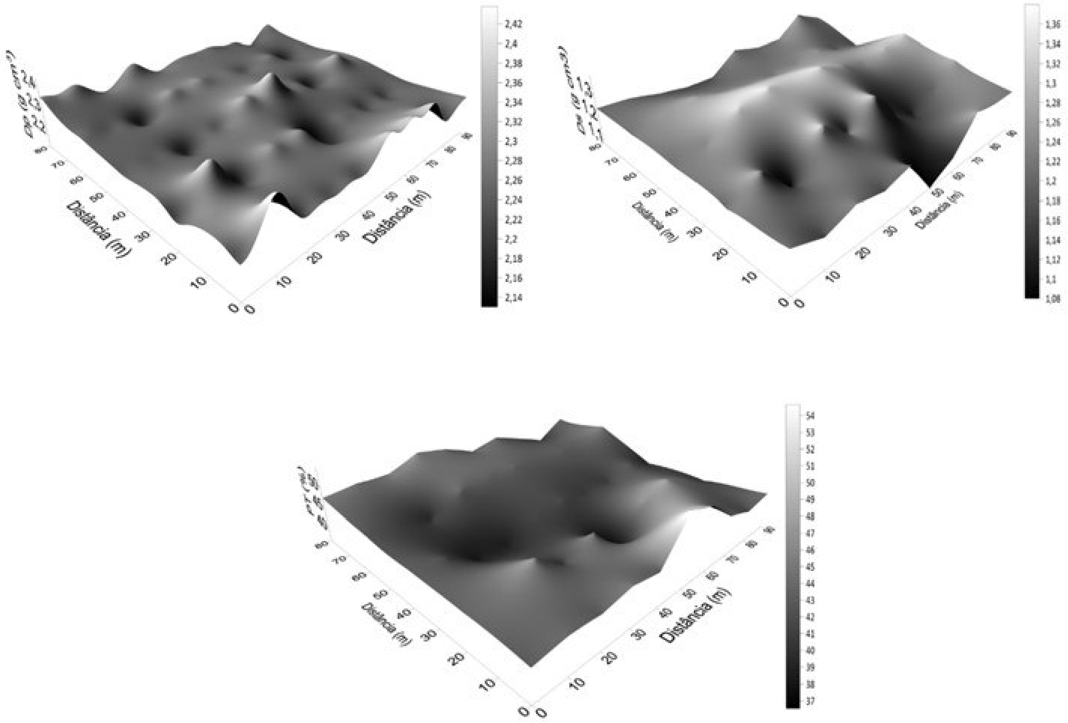
The thematic maps of the variables analyzed can be seen in Figure 4. With the semi variograms it was possible to show the spatial dependence, the semi variograms served as the basic tool for interpolating the data and then making the surface maps using the Surfer 8.0 software program. It was from the thematic maps that it was possible to study the behavior of the variables. The maps of the variable's particle density, soil density, and total porosity showed values between 2.14 and 2.42 g cm^{-3}; 1.08 and 1.36 g cm^{-3}, and 37 to 54%, respectively, as seen in (Figure 4).

Particle density was the variable that was most evenly distributed, with no large depressions. This is probably because the area was managed with little incorporation of organic matter, thus generating this uniformity, as well as something that is directly related to the mineralogical nature of the local soil (Neossolo). Soil density and total porosity showed an inversely proportional relationship, where there were peaks in one variable and troughs in the other, thus showing a correlation between these parameters.

This physical phenomenon occurs with soil compaction, because the more compacted the soil, the smaller the pore volume (macro and micropores), as shown in (Figure 4), where the ρs map shows a high density, there is a depression in the total porosity values, affected by the compaction present at the collection points.

According to Carvalho (2012), this correlation between physical variables is common, especially when it comes to the influence of soil density on total porosity, i.e. when one variable increases, the value of the other decreases.

FIGURE 4. Thematic maps correspond to the spatial distribution of physical variables.



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CONCLUSION

As a result of land use and occupation, there has been variability in the soil physical attributes.

There was a predominance of a strong degree of spatial dependence for the variables analyzed (nugget effect/pattern ratio).

Using the maps, it was possible to diagnose the influence of some parameters on others, especially soil density and total porosity.

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