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ANÁLISE DA VARIABILIDADE ESTRUTURAL DO SOLO UTILIZANDO GEOESTATÍSTICA EM CULTIVO DE SORGO FORRAGEIRO

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RESUMO: Entender como se dá a funcionalidade dos atributos físicos do solo é necessário para que haja um manejo apropriado para o cultivo. Deste modo, o presente estudo teve como objetivo avaliar diferentes interpoladores geoespaciais para a espacialização de atributos físicos do solo em área cultivada com sorgo (*Sorghum bicolor*). O experimento foi realizado no IFCE - *Campus* Iguatu, em um solo de classe textural Franco Arenosa. Foram coletados 56 pontos amostrais, em uma malha regular de 15,5 m em uma área de 1,2 ha e inferidas a densidade do solo (DS), a densidade de partículas (DP) e a porosidade total do solo (PTS). Os algoritmos foram avaliados pelo cálculo da raiz quadrada do erro médio (RMSE, do inglês *root mean squared error*), para recomendação do melhor algoritmo para cada atributo físico do solo, sendo o IDW (*Inverse Distance Weighting*) mais recomendado para a DS, o TIN (*Triangulated Irregular Network*) para a DP e a Krigagem ordinária para PTS. Por meio da geoestatística é possível visualizar áreas com necessidade de manejo, aplicando uma prática ao solo para melhorar a sua estrutura em um determinado ponto crítico afim de que se tenha uma boa produção, possibilitando um solo adequado para o cultivo.

Palavras-chave: Atributos físicos, *Sorghum bicolor*, interpolador.

SOIL STRUCTURAL VARIABILITY ANALYSIS USING GEOSTATISTICS IN FORAGE SORGHUM CULTIVATION

ABSTRACT: Understanding the functionality of soil physical attributes is necessary to provide appropriate management for cultivation. Thus, the present study aimed to evaluate different geospatial interpolators for the spatialization of soil physical attributes in an area cultivated with sorghum (*Sorghum bicolor*). The experiment was carried out at IFCE - Campus Iguatu, in a soil of textural class “Franco Arenosa”. Fifty-six sample points were collected in a regular 15.5 m mesh on 1.2 ha, and the soil density (SD), particle density (PD) and total soil porosity (TDP) were inferred. The algorithms were evaluated by calculating the root mean squared error (RMSE) to recommend the best algorithm for each physical attribute of the soil, with IDW (inverse distance weighting) being the most recommended for DS, TIN (triangulated irregular network) for DP and ordinary kriging for PTS. Through geostatistics, it is possible to visualize areas in need of management,

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applying a practice to the soil to improve its structure at a certain critical point to achieve good production, enabling a soil suitable for cultivation.

Keywords: Physical attributes, *Sorghum bicolor*, interpolator.

1. INTRODUCTION

Knowledge of the spatial distribution of soil properties is extremely important for determining the parameters responsible for crop yield and is essential for achieving sustainable agriculture (Weirich Neto *et al.*, 2006). In this context, geostatistics is already an established reality, being used in the analysis of soil pedogenetic processes to characterize and interpret soil properties within the scope of precision agriculture (Bernardi; Perez, 2014).

Spatial distribution maps are generated from mathematical modeling using interpolation methods, estimating values for nonsampled locations based on a certain number of points observed in the field (Souza *et al.*, 2010). It is necessary to compare interpolation methods, as the results obtained when generating maps may differ depending on the method used (Taghizadeh-Mehrjardi *et al.*, 2022). The interpolation methods used become essential tools, as the results generated can underestimate or overestimate the value of the attribute under study (Couto; Scaramuzza; Maraschini, 2002). In this sense, the quality of the estimation depends on the attributes under study as well as on the choice of the interpolation method indicated for particular characteristics.

Several researchers have sought to evaluate interpolation algorithms for creating thematic maps (Souza *et al.*, 2010; Mendes *et al.*, 2018; Kingsley *et al.*, 2019), obtaining promising results for the spatialization of soil physical attributes. Thus, understanding the variability of soil attributes and geostatistics helps to increase crop productivity and more assertively carry out the ideal management that each type of soil requires in heterogeneous areas, obtaining the correct spatial distribution for such attributes. It is relevant in agricultural planning with regard to the installation and management of crops (Silva *et al*., 2008). Soil that is not adequately managed to preserve its structure may cause compaction, interfering with the root system of crops. Several authors have cited and sought methods to solve problems generated by management outside technical standards.

Therefore, the present work aimed to evaluate different interpolators for the creation of thematic maps of soil physical parameters that assist in decision-making regarding appropriate agricultural management in a production area.

2 MATERIALS AND METHODS

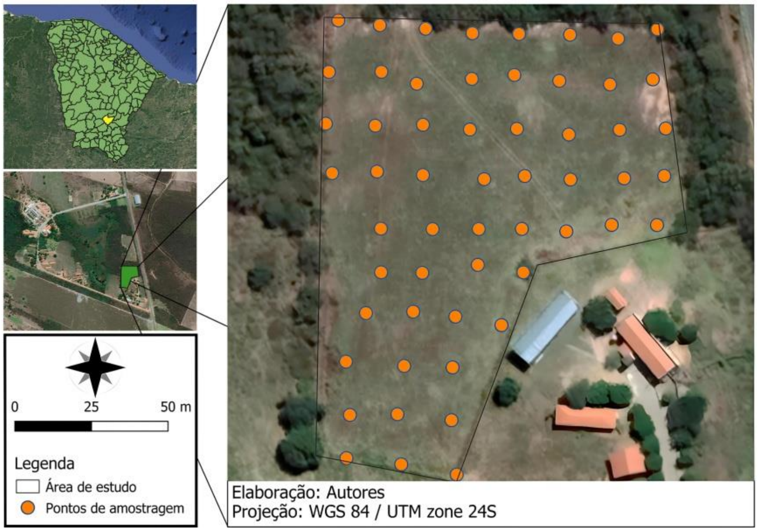
The study was carried out in an agricultural area of 1.2 ha in the municipality of Iguatu, Ceará, with an altitude of 214 m, whose central coordinates are 6°23'47.8”S and 39°15'52.2”W (Figure 1).

Fifty-six soil samples were collected on a regular mesh with a distance of 15.5 m between the trads during the cultivation of the forage sorghum (*Sorghum bicolor*) black tip. This species is cultivated in the area to produce silage to feed the animals, as it has high biomass production at low cost; is adapted to the northeastern semiarid region; is tolerant to drought, aluminum toxicity and soil acidity; and is tolerant to photoperiodism and disease resistance.

The undisturbed samples were collected at a depth of 0 to 10 cm from the soil profile using a Castelinho auger and georeferenced with a navigation GNSS (Figure 1).

To obtain the parameters of soil density (DS), particle density (DP) and total soil porosity (PTS), the volumetric flask method was used (Embrapa, 1997). Granulometric analysis was carried out with the surplus samples so that the sand, silt and clay contents could be obtained after drying in an oven at 105°C using the 2 mm mesh sieving method, dispersion and sedimentation. The soil in the area is classified as Red Yellow Argisol, whose textural class in the surface layer (0 - 10 cm) is classified as sandy loam.

Figure 1. Location of the sampling area and collection points



Source: prepared by the authors

The interpolators used were ordinary kriging, a spatial interpolation method used to estimate values in places where there are no measurements. Based on data observed at other points, IDW (*inverse distance weighting*) generates data by assigning weights to points, so the closer to the largest point will be the assigned weight and the TIN (*triangulated irregular network*), which generates values with a network of triangles with any sample value.

The calculation of the square root of the mean error (RMSE) was applied, which is responsible for measuring the difference between the predicted values and the actual values of a prediction or regression model under the interpolators.

$$RMSE = \sqrt{\sum_{i=1}^{n} \frac{\hat{y}_i - y_i}{n}} \qquad (1)$$

On what:

n- number of observations;
yi - real value of observation i;
ŷi - is the predicted value of observation i.

Of the 56 points sampled, 36 points were used for processing the evaluated algorithms, and 20 points were used for calculating the RMSE to obtain the interpolator that best represents the porosity, soil density and solid density.

RESULTS AND DISCUSSION

The RMSEs obtained in each of the geostatistical processes are presented in Table 1, in which the interpolators that showed greater accuracy in predicting values observed in the field for nonsampled locations were TIN for the density of solids, with a value of 0.0986; IDW for soil density, with a value of 0.0533; and ordinary kriging for soil porosity, with a value of 3.7574.

Table 1. RMSE values for all interpolated soil attributes in the forage sorghum production area, Iguatu, Ceará, Brazil.

Soil attributes	Kriging	TIN*	IDW**
Density of solids	0.1103	0.0986	0.1091
Soil density	0.0551	0.0642	0.0533

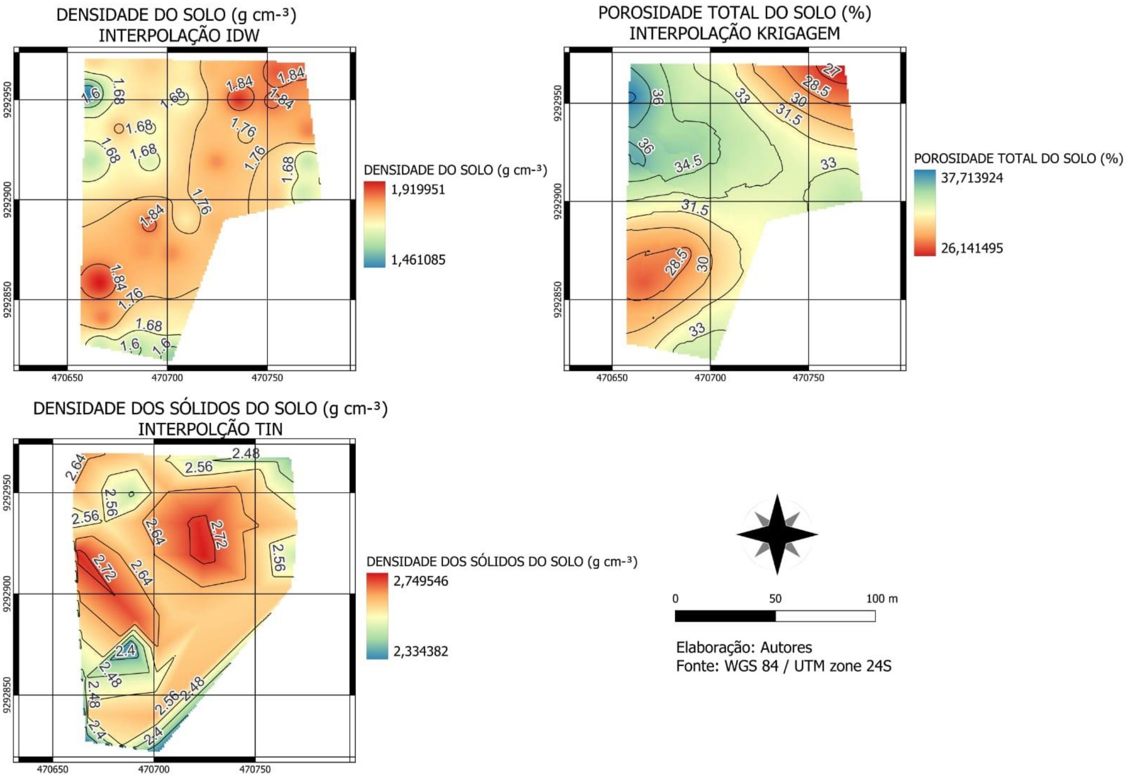
Soil porosity	3.7574	3.9918	3.8531

*: TIN (*triangulated irregular network*); **: IDW (*inverse distance weighting*);
Source: prepared by the authors

The prediction of soil physical attributes presented representative results within each spatial interpolation method (Mendes *et al.*, 2018). The quality of the estimate depends both on the choice of interpolation methods and on the appropriate application of methods indicated for the characteristics of the data under study (Souza *et al.*, 2010). The applicability of the RMSE to the different interpolators yielded values with estimates close to zero, with the exception of soil porosity, which presented higher errors, even for the interpolator that best represented it, ordinary kriging.

The three interpolation methods were efficient in estimating values for unsampled locations. Thus, all interpolators used in the present work presented values considered acceptable for use, with a low margin of error. The sampled points provided thematic maps of the physical attributes of the soil, which can better support decision-making and assist in agricultural management based on the composition of management areas, as shown in Figure 2.

Figure 2. Thematic maps of soil attributes represented by the algorithm that showed the best performance. Forage sorghum production, Iguatu, Ceará, Brazil



Source: prepared by the authors

Unlike the results obtained by Mendes *et al.* (2018), the interpretation of the linear regression analysis of the attributes measured in the field and predicted using interpolation methods allows us to infer that for all the attributes measured in their study, the IDW proved to be the best method, and consequently, the calculation of NC presented an RMSE ranging from 20 kg ha $^{-1}$ (IDW) to 270 kg ha $^{-1}$ (*simple kriging and random forest*). In their study, IDW presented the best response to the analyzed attributes, with high correlations in the regression and low mean squared errors, while the other interpolators presented higher values. Similarly, when submitting soil density data, where there was even a small difference, IDW managed to achieve a smaller margin of error than did the other interpolators (ordinary kriging and TIN).

For Souza *et al.* (2010), ordinary kriging presented a greater coefficient of determination of the semivariogram (R^2_{VC}) and the lowest mean absolute errors (EMAs) and mean relative errors (EMRs) for the three chemical attributes studied in relation to the inverse square of the distance (IDW). However, both interpolation methods were efficient in estimating values for nonsampled locations.

The sampled points provided detailed maps of the conditions in which the area is located (Figure 2), which can assist in making decisions in preparing this soil to receive the crop that will be planted. According to Singer and Ewing (2000), the plant will have effective rooting depth, total porosity, pore distribution and size, particle size distribution, soil density, soil resistance to root penetration, optimal water range, compression index and aggregate stability during soil preparation.

It is estimated that the total porosity of most soils typically ranges from 30% to 60% (Hillel, 1970; Kiehl, 1979). According to Libardi (2012), soil porosity is inversely related to soil density; that is, the higher this density is, the lower the porosity. The representative values of total soil porosity for the sandy textural class range from 32.1 to 47.2%. Because the soil studied is classified as sandy loam, the values are very close to those determined by Libardi (2012).

In general, the density of agricultural soils ranges from 0.9 to 1.8 g cm $^{-3}$, depending on the texture and organic matter content of the soil (Klein, 2014). According to Reichert, Reinert and Braida (2003), the critical density limit that is capable of providing an optimal water range for vegetables in sandy textured soil must be between 1.7 and 1.8 g cm $^{-3}$. According to Libardi (2012), in general terms, the density of natural mineral soil samples varies from 0.70 to 2.0 g cm $^{-3}$. For the authors, the density values of the surface layer representative of soils whose textural class is sandy vary between 1.3 and 1.8 g cm $^{-3}$.

Van Lier (2016) suggested that in most mineral soils, the density of solids varies from 2.6 to 2.7 g cm $^{-3}$, reflecting the dominant presence of quartz, whose particle density is 2.65 g cm $^{-3}$. For the author, the presence of iron oxides and heavy metals tends to increase the value, while organic matter, whose solid density is approximately 1.2 g cm $^{-3}$, contributes to its lowering, and in a given soil, the particle density values in the most superficial layers, which are rich in organic matter, are relatively lower than those in the superficial layers. Therefore, it is reasonable to admit that soil management may modify the density of solids over time if, with this management, there is a significant change in the organic matter content. According to Libardi (2012), for an average mineral soil, one can, as a first approximation, assume that the particle density is equal to 2.65 g cm $^{-3}$. This value increases when the soil contains a high percentage of minerals such as manganese dioxide and titanium dioxide and decreases when its organic matter content increases. According to this author, the density of organic matter varies from 1.30 to 1.50 g cm $^{-3}$.

The attributes studied are all within the limits dictated by some authors, taking into account that the profile studied is characterized as sandy loam. Based on this knowledge of the desirable limits for each attribute, it is possible to better define management zones that require agricultural practices for soil decompression operations, such as scarifiers and subsoilers, which are the most commonly used implements due to their greater penetration capacity and less soil disintegration, in relation to plows and disc harrows (Araújo *et al.*, 2001).

4 CONCLUSIONS

It was possible to spatialize the physical attributes of the soil as well as to assume the interpolators that best estimated the physical attributes of the soil at nonsampled points, knowing that for different attributes, the interpolators behave differently, where each of them was presented as the best option for at least one of the parameters studied, generating thematic maps of soil density (DS), particle density (DP) and total soil porosity (PTS), assisting in agricultural management in areas that are in a critical or adequate state in its structure.

Based on maps of this type, it is possible to propose management strategies, such as the adoption of soil conservation practices, such as cultivation through organic fertilization, mulching, crop rotation and direct planting, thus contributing to improving the production of sorghum forage in the studied area.

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