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Mapping of Physical-Water Attributes in an Oxisol Under Sugarcane Cultivation in Ceres Municipality, Goiás State (GO), Brazil

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Abstract**—** *This paper aimed to determine and spatialize physical-hydric attributes in the sugarcane area at the Sugarcane Research Unit in Ceres (GO) in Cerrado (vegetation of the Brazilian interior),. The experiment comprised an area of 285 x 60 m with a 15 m sampling grid, in which a deformed and undisturbed soil sampling was carried out from January 2020 to January 2021. The evaluated attributes were: (a) clay ; (b) sand; (c) silt; (d) soil density (SD); (e) particle density (PD); (f) total porosity (TP); (g) macroporosity (macro); (h) microporosity (micro); (i) water retention in field capacity (FC); (j) water retention in the permanent wilting point (PWP); and (k) total water availability (TWA). All physical attributes showed moderate to strong spatial dependence with adjustments to Gaussian models predominantly for granulometry and exponential, and spherical for the others, ranging from 15.4 to 191.9 m. Results of TWA spatial variability allow defining two management units and show that the soil under study has low water retention in the available water range. This study provides information that enables decision-making in irrigation management and soil decompaction..*

Keywords**— *Soil physics. Soil water. Spatial variability. Saccharum officinarum.***

I. INTRODUCTION

Brazil is among the 10 countries with the largest irrigated land area in the world. About 80% of the Brazilian irrigated area is concentrated in Minas Gerais, Goiás, São Paulo and Bahia. In Goiás, the main technology deployed for irrigation is the central pivot, however, other sprinkler systems are also found, including conventional and self-propelled sprinklers[1].

Currently, the application of new technologies in the agricultural sector has been assisting the sustainable intensification of crops. Precision agriculture treats the planting area taking into account the spatial and temporal variability of soil attributes[2]. To this end, the use of remote sensing, global positioning system aerophotogrammetry, topography, among others, comprises geotechnologies employed for the correct analysis of the variation of soil attributes.

The spatial variability of soil physical properties within or between agricultural fields is inherent to nature, occurring due to geological and pedological factors of soil formation, as well as some of the variability can be induced by the type of tillage and management practices adopted[3].

Knowledge of the spatial variability of physical soil attributes in crops such as sugarcane, which are highly technological, is essential to reduce the costs associated with production systems[4].

Thus, geostatistical techniques allow quantifying the existence of spatial variations of the various soil physical and water attributes, such as soil density, moisture, porosity and penetration resistance, enabling a detailed description of these properties in time and space [5].

Based on the above, the study of the variability of soil attributes in small areas helps in determining the range of variations, thus allowing geostatistics to be applied in large agricultural fields in order to provide physical-hydric parameters necessary for irrigation management and good crop development.

Thus, the objective of the work was to determine and evaluate indicators of physical quality, characterize the spatial dependence and spatialize attributes evaluated in a Red Distrofic Latosol under sugarcane in Ceres - GO, aiming to contribute to soil management and irrigation.

II. MATERIAL AND METHODS

The area studied is located in the municipality of Ceres (GO) in the Sugarcane Research Unit of the Instituto Federal Goiano - Campus Ceres in partnership with CRV Industrial, and is located between the geographical coordinates 15º20'42``S and 49º36'19``W with 561 m altitude, belonging to the Barro Alto Complex geological formation. The local climate is Aw according to the Köppen and Geiger classification, characterized by a mild, dry winter and a hot, rainy summer. The soil of the study area was classified as dystrophic Red Latosol according to the Brazilian Soil Classification System [6].

The sugarcane crop was implemented (reform) in April 2018 with conventional soil management in an area of 30 ha and received "rescue irrigation", provided by self-propelled sprayer, with application of 60 mm of water in September of the same year. The experiment comprised an area of 285 x 60 m in the implanted crop, totaling 1.71 ha.

For soil sampling, we used a sampling grid with spacing between points of 15 x 15 m, totaling 100 sampling points, Fig. 1. Some points of the grid were georeferenced with precision coordinates and calculated for all other points. The coordinates were determined in the Universal Transverse Mercator System (UTM) to perform the linear measurements.

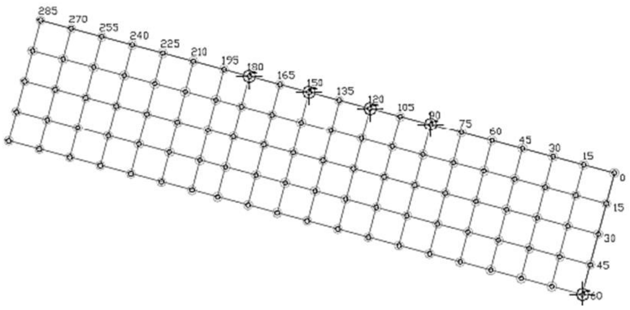


Fig.1: Sample grid used in soil collection

Samples were collected with deformed and undeformed structures at depths of 0-0.2 m (deformed and undeformed) and 0.2- 0.4 m (deformed) at each point. The physical and hydric characteristics evaluated were: granulometry (sand, silt and clay), soil density (SD), particle density (PD), total porosity (TP), macroporosity, microporosity (6 kPa), water retention at field capacity (33 kPa)(FC), water retention at permanent wilting point (1500 kPa) and total water availability (TWA). Particle size and PD attributes were determined for the 0-0.2 and 0.2-0.4 m layers, and the others, for 0-0.2 m.

Particle size was determined by the pipette method, with soil dispersion in 0.1 mol L^{-1} sodium hydroxide. The analysis of SD was done by the volumetric ring method and PD by the volumetric balloon method, analyzed according to the methodology described by Teixeira[7]. Macro, microporosity, moisture at field capacity and permanent wilting point were done in Richards Extractor (Soil Mosture), in undeformed samples collected in duplicate with a volumetric ring of 48 mm diameter and 50 mm high. The calculation of total porosity, macro, micro and TWA was also done according to Teixeira [7].

With the use of geostatistical techniques for the evaluation of spatial variability and the making of maps of occurrence of soil patches, the spatial dependence of the points was analyzed through the semivariance (γ(h)), equation 1[8]. For this, the software Gamma Design Software 7.0 - GS+ [9]. was used, and the linear, Gaussian, exponential, spherical and pure nugget effect models (1) were tested.

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

Where: (h): semivariance estimated at a distance h; N(h): number of pairs of values [Z(xi), Z(xi+ h)] separated by a vector h; xi: spatial position of variable Z; and Z: Z(xi) the value of property Z at location xi, in space.

After obtaining the experimental semivariograms with the best fit to the data, the degree of spatial dependence (DSD) was evaluated using (2) [10]. This index refers to the ratio between the nugget effect (C0) and the plateau (C0+C), given in percentage, which classifies the result in strong spatial dependence (DSD < 25%), moderate (25% < DSD < 75%).

$$SDG = \frac{C_0}{C_0 + C} \qquad (2)$$

With the data interpolated by kriging of the physical-hydric variables studied, iso-occurrence maps were made in the study area, also using the software Gamma Design Software 7.0 – GS+ [9].

III. RESULTS AND DISCUSSIONS

Table 1 shows the descriptive statistical analysis of the data collected. It can be observed that the mean and median values (measures of central tendency) found for all the attributes are relatively close, and it can be inferred, therefore, that there was low data dispersion.

The coefficient of variation is used to determine the variability of the data. The attributes clay and particle density in both layers, sand from 0.20 to 0.40 m, moisture at field capacity, soil density and microporosity presented low coefficient of variation. On the other hand, silt and sand from 0 to 0.20 m, total porosity, moisture at permanent wilting point, total water availability and silt from 0.20 to 0.40 m showed medium coefficient of variation. Finally, it was found that macroporosity showed a high coefficient of variation, which may be related to variability in soil compaction because it showed high and negative significant Pearson correlation coefficients (r) for FC, SD and micro (r=0.80**, 0.91** and 0.85**, respectively; data not shown).

Table 1 - Descriptive statistics for physical-hydric attributes in Red Latosol under sugarcane at the Sugarcane Research Unit (CRV/IF Goiano Plant – Ceres Campus) in Ceres – GO

Variable	Minimum	Maximum	Average	Median	Sd	Kurtosis	Asymmetry	CV	Kolmogorov-Smirnov*
				0.00 – 0.20 m					
Clay(1)	367.10	578.30	490.20	494.50	47.97	-0.13	-0.39	9.78	0.068< 0.725N
Silt(1)	85.90	300.00	176.63	173.55	40.19	1.21	0.87	22.75	0.100< 0.248N
Sand(1)	239.20	457.10	333.17	328.35	41.81	0.32	0.42	12.55	0.067< 0.749N
SD(2)	1.00	1.74	1.45	1.48	0.16	0.19	-0.87	11.38	0.134< 0.050A
PD(2)	2.38	2.78	2.62	2.63	0.09	-0.02	-0.36	3.31	0.109< 0.175N
Micro(3)	0.29	0.51	0.36	0.37	0.03	4.18	0.62	8.67	0.096<0.306N
Macro(3)	-0.07	0.32	0.08	0.05	0.08	0.49	0.95	103.25	0.133< 0.054A
TP(3)	0.30	0.61	0.44	0.43	0.06	0.22	0.69	14.13	0.090< 0.380N
θ FC(3)	0.25	0.46	0.33	0.33	0.03	1.94	0.26	10.28	0.088< 0.407N
θ PWP(3)	0.18	0.42	0.28	0.28	0.04	1.65	0.43	13.58	0.087< 0.426N
TWA(4)	0.15	1.14	0.53	0.53	0.15	1.39	0.44	30.13	0.057< 0.897N
				0.20 – 0.40 m					
Clay(1)	411.70	628.80	523.16	534.50	50.51	-0.64	-0.34	9.66	0.099< 0.26 N
Silt(1)	95.70	288.30	171.77	160.35	43.12	-0.29	0.50	25.10	0.122< 0.091A
Sand(1)	220.60	377.00	305.08	304.95	31.46	0.16	-0.36	10.31	0.078< 0.566N
Dp(2)	2.06	2.78	2.63	2.63	0.10	8.59	-1.96	3.86	0.159– 0.011A

Sd- Standard Deviation; CV - coefficient of variation; SD – soil density; PD – particle density; Micro - microporosity; Macro – macroporosity; TP – total porosity; θ – volumetric humidity; FC – field capacity; PWP – permanent wilting point; TWA – total water availability in the soil. * Kolmogorov-Smirnov test at 5% probability; A: Asymmetric distribution; N: Normal distribution; (1): g kg^{-1}; (2): kg dm^{-3}; (3): m^3 m^{-3}; (4): mm cm^{-1}.

When evaluating the clay, silt and sand contents, the averages obtained show an increase in clay content from the 0-0.20 m layer (490.20 g kg^{-1}) to the 0.20-0.40 m layer (523.16 g kg^{-1}). Based on these values, the soil texture was classified as clayey in both layers[6].

Soil density ranged from 1.0 to 1.74, with an average of 1.45 kg dm^{-3}. For clayey soils as the case of the soil under study, values between 1.30 and 1.40 kg dm^{-3} can already be considered restrictive to root growth[11].

In relation to the density of the particles, there was little variation among the layers evaluated, with an average value of 2.62 kg dm^{-3}. This attribute is related to soil composition (mineral and organic) and its average value varies between 2.3 and 2.9 kg dm^{-3}[12].

As for the micro and macroporosity of the soil, we found average values of 0.36 and 0.08 m^3 m^{-3}, respectively. In clayey soils it is common for the amount of micropores to be greater than that of macropores[13], a fact verified in the results found.

For the total soil porosity variable, the results varied from 0.30 to 0.61, with an average of 0.44 cm^3 cm^{-3}. Soil considered ideal for agricultural production should present a total porosity of approximately 0.50 cm^3 cm^{-3}, divided into 34% of macro pores and 66% of micro pores[14].

Analyzing the physical-hydric attributes of moisture at the permanent wilting point and field capacity (layer from 0 to 0.20 m), averages of 0.33 cm^3 cm^{-3} and 0.28 cm^3 cm^{-3} were obtained, respectively.

High PWP values in clayey soils can be attributed to the higher water retention in the micropores[15]. the field capacity moisture in clayey soils with no-till farming, has an average of 0.31 cm^3 cm^{-3}, therefore verifying that the soil of the present study presents a slightly higher average[16]. However, the water retention in clayey Latosols, found in studies they presented FC and PWP with values of 0.32 and 0.23 cm^3 cm^{-3}, respectively, with a range of variation of 0.09 cm^3 cm^{-3}[17].

The total soil water availability (TWA) ranged from 0.15 to 1.14, and on average, it was 0.53 mm cm^{-1}. For Red Latosol this aspect in a 0.0-0.10 m layer, found an average value of 1.30 mm cm^{-1}, indicating that the results of the present study are about 60% below found in that work. The TWA is directly related to soil density, since soils with high density tend to have fewer pores for storage and availability of water and air to plants [18].

Table 2 presents the fits of the semivariogram models and parameters for the attributes studied. In the attributes referring to soil granulometry (clay, silt and sand), the spatial dependence for clay and sand was classified as strong, and for silt, moderate, at both depths. For these attributes in the 0-0.20 m layer, the model fitted for clay was the Gaussian model, while for the others it was the exponential model. For the 0.20-0.40 m depth, the exponential model was fitted to the granulometric attributes. The range varied from 23.35 m (clay) to 191.90 m (silt).

Soil density fitted the spherical model with a range of 155.50 m and DSD of 49.76%, which configures a moderate degree of spatial dependence. Studies about this attribute in a Red Latosol after agricultural cultivation with sugarcane, also obtained a fit to the spherical model, but with a range of 17.2 m, disagreeing with that found in this study[19].

For particle density, degrees of spatial dependence lower than 25% were found, thus classifying the attribute as strongly dependent. For this parameter, the Gaussian model was the one that best fitted the data from both layers. The smallest range reached by this variable was 25.29 m.

Table 2 - Parameters of the experimental adjustment and validation test for physical-water attributes of a Red Latosol soil under sugarcane in Ceres – GO

		Ajuste De Semivariograma								Validação Cruzada		
Attribute	Depth (m)	Model	C0	C0 + C	Range	R^2	SQR	DSD	SD	SE	R^2	RC
Clay	0.0-0.2	GAU	277.00	1690.00	23.38	0.70	$6.08E^4$	16.39	Strong	0.20	0.19	0.94
	0.2–0.4	EXP	592.00	2662.00	67.20	0.93	$1.03E^5$	22.24	Strong	0.18	0.31	1.00
Silt	0.0-0.2	ESF	722.00	1540.00	191.90	0.90	$6.85E^4$	46.88	Moderate	0.22	0.20	1.04
	0.2–0.4	EXP	1054.00	3100.00	150.00	0.91	$4.07E^6$	34.00	Moderate	0.18	0.30	0.97
Sand	0.0-0.2	ESF	307.00	1468.00	55.00	0.83	$1.18E^5$	20.91	Strong	0.12	0.35	0.73
	0.2–0.4	EXP	81.00	934.00	57.60	0.91	$1.74E^4$	8.67	Strong	0.23	0.26	1.12
SD	0.0-0.2	ESF	0.01	0.02	155.50	0.86	$1.66E^{-5}$	49.76	Moderate	0.23	0.16	0.95
PD	0.0-0.2	GAU	0.00	0.01	28.06	0.85	$1.02E^{-6}$	17.23	Strong	0.16	0.16	0.68
	0.2–0.4	GAU	0.00	0.01	25.29	0.62	$3.51E^{-6}$	1.49	Strong	0.14	0.21	0.69
Micro	0.0-0.2	ESF	0.00	0.00	54.30	0.85	$1.14E^{-8}$	39.07	Moderate	0.21	0.32	1.19
Macro	0.0-0.2	EXP	0.00	0.01	42.00	0.63	$2.14E^{-6}$	12.93	Strong	0.33	0.11	0.97
TP	0.0-0.2	GAU	0.00	0.00	158.31	0.93	3.30E-7	49.87	Moderate	0.23	0.22	1.00
θ PWP	0.0-0.2	ESF	0.00	0.00	15.40	0.00	$4.27E^{-8}$	1.06	Strong	0.52	0.11	1.51
θ FC	0.0-0.2	GAU	0.00	0.00	21.82	0.57	$2.42E^{-8}$	8.29	Strong	0.25	0.20	1.18
TWA	0.0-0.2	ESF	0.01	0.03	73.90	0.78	$6.63E^{-5}$	31.01	Moderate	0.34	0.22	1.51

C0 - pepita effect; C0+C - plateau; R^2 - Coefficient of determination; SQR - Sum of squares of residuals; DSD - Degree of spatial dependence (%); SD - Spatial dependence; GAU - Gaussian; EXP - Exponential; ESF - Spherical; RC - Regression coefficient; SE - Standard error.

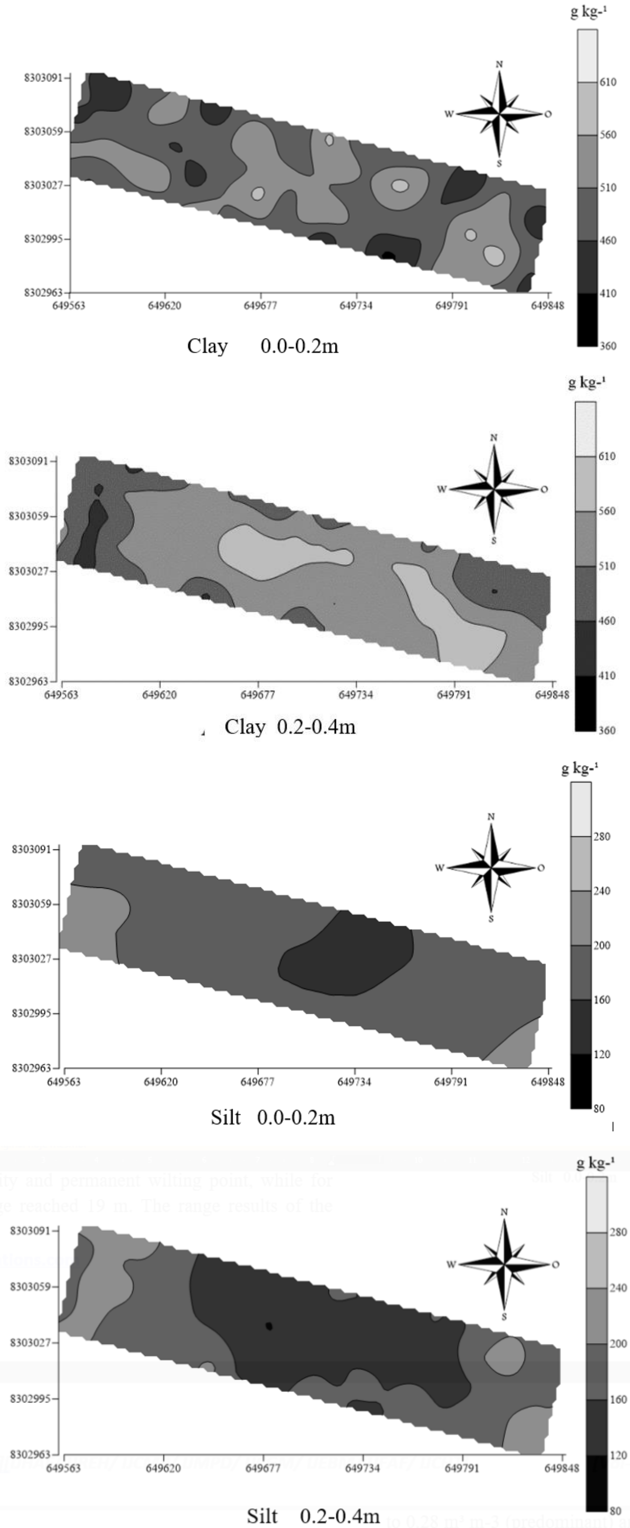
Regarding soil porosity, the data were fitted to spherical, exponential and Gaussian models, with ranges of 54.30 m, 42.00 m and 158.31 m, respectively, for microporosity, macroporosity and total porosity. These fits corroborated those of other studies, who, when studying soil macro and microporosity, obtained a better fit to the exponential model, with a range of 45 m[20].

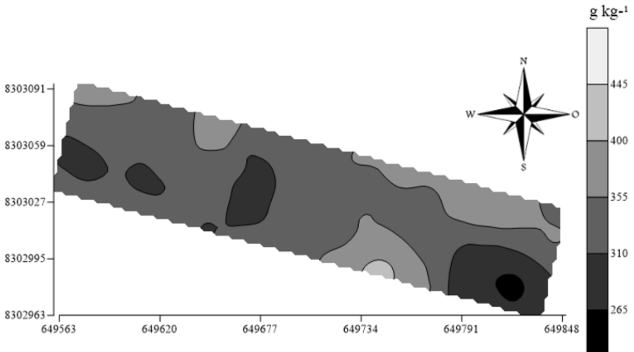
As for the water retention in the soil at the permanent wilting point and at field capacity, the degree of spatial dependence was strong for both attributes, with adjustment to spherical and Gaussian models, with ranges of 15.40 and 21.82 m, respectively. In general, the coefficients of determination (R^2) of the models were high, except for θPMP.

When studying water retention in a Red Latosol at a depth of 0.0 to 0.15 m, Authors found fits to the spherical model for both soil moisture and total water availability[21]. The range verified was approximately 10 m for field capacity and permanent wilting point, while for TWA, the range reached 19 m. The range results of the present study were relatively close to the mentioned study for PWP and FC and far apart for TWA.

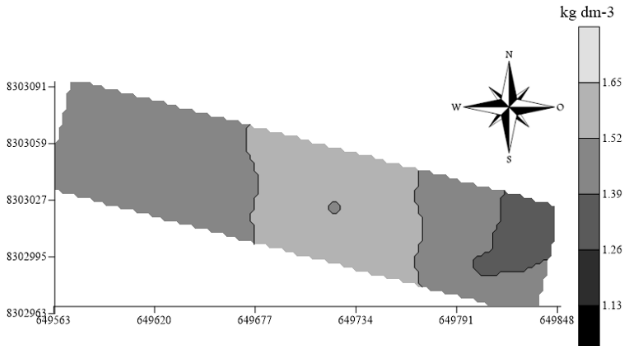
Iso-occurrence maps are a useful tool for visualizing the variability of attributes in the study area[22]. In this way, it is possible to understand the distribution of the variation of the attributes and even compare them at different depths. Fig.2 shows the maps made for the study area.

For the clay attribute, in the 0-0.20 layer the 460-510 g kg^{-1} class followed by patches of the 510 to 560 g kg^{-1} class predominated throughout the study area. In the 0.20-0.40 m layer, the 510 to 560 class covers almost the entire area with central patches of 560-610 g kg^{-1} and patches of 460-510 g kg^{-1}, mainly in the western portion.

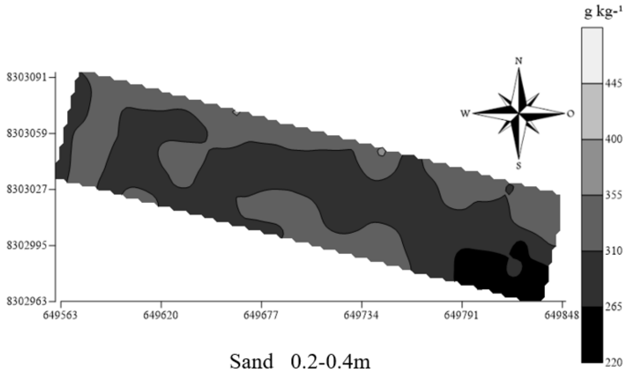




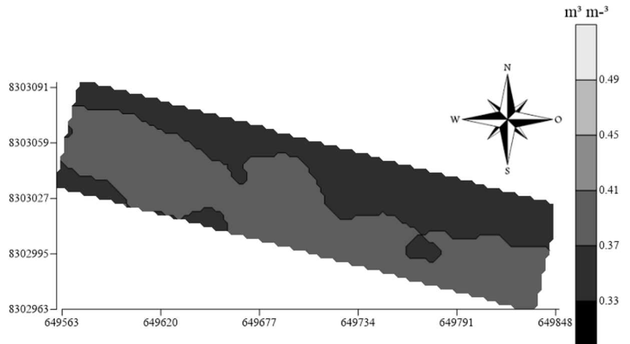
Sand 0.0-0.2m



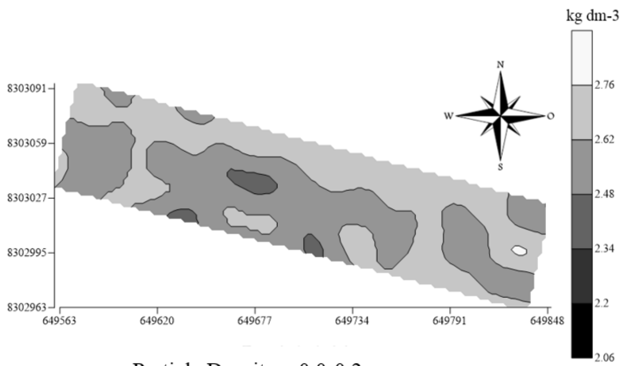
Soil Density 0.0-0.2m



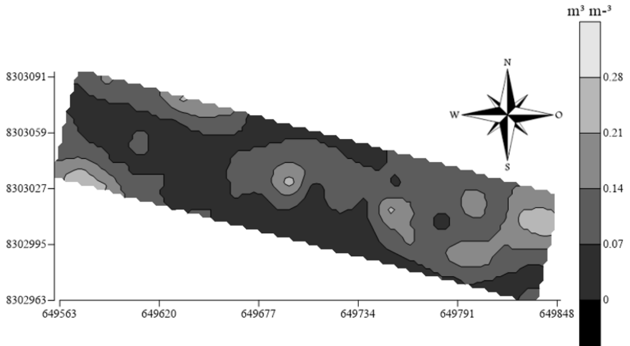
Sand 0.2-0.4m



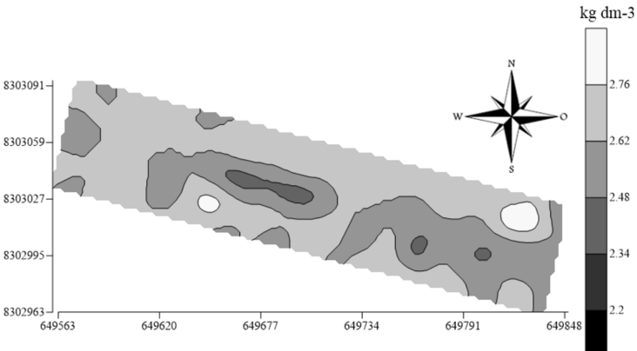
Microporosity 0.0-0.2m



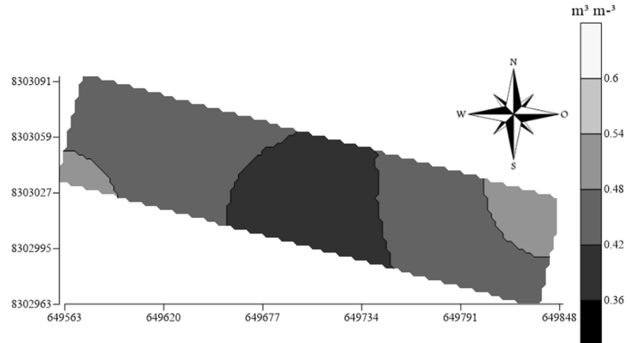
Particle Density 0.0-0.2m



Macroporosity 0.0-0.2m



Particle Density 0.2-0.4m



Total Porosity 0.0-0.2m

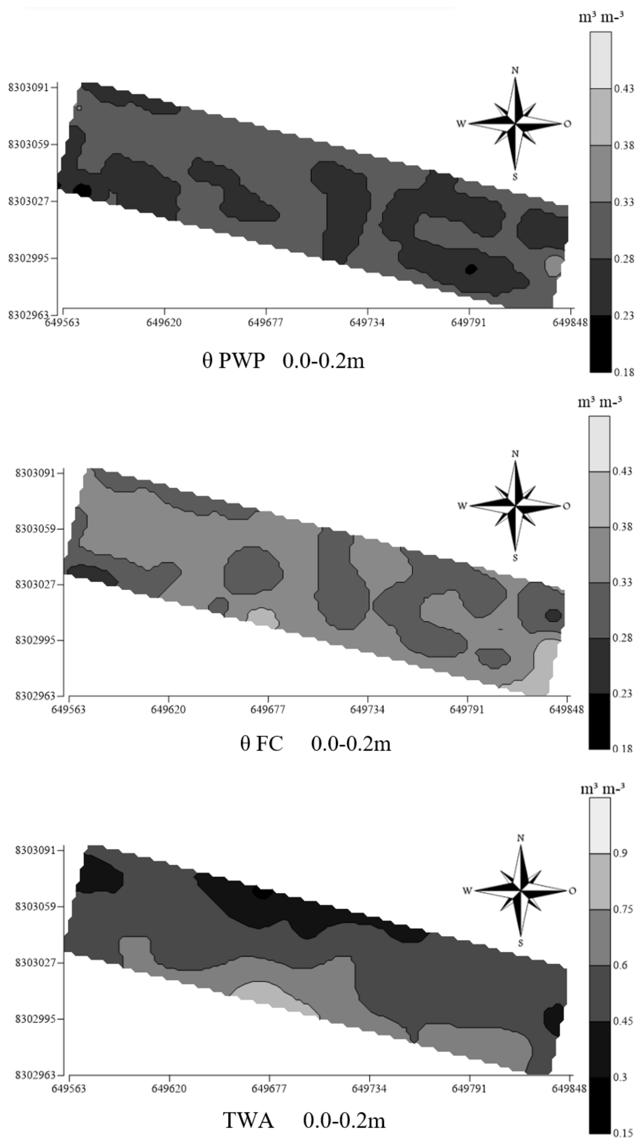


Fig.2: Maps of spatial distribution of soil attributes evaluated in the study area.

In all cases, the texture of the study area was within the clay class in both layers. Because of the larger area of the 510 to 560 g kg^{-1} class in the 0.20-0.40 m layer, a small increase in clay content was observed at depth. This was also observed in others papers, which was attributed to the influence of factors related to soil genesis[23].

In analyzing the silt attribute, the areas were more homogeneous than clay, especially in the 0-0.20 m layer, where the 160 to 200 g kg^{-1} class occurs in almost the entire area. Due to the intense weathering of the Cerrado Latosols lower silt contents are expected in this type of soil, as seen in the study area[24].

Conversely to the clay attribute, silt showed lower values in the 0.20-0.40 m layer. There were basically three classes of values, but predominating the classes 310 to 355 g kg^{-1} and 265 to 310 g kg^{-1} in the layers 0-0.2 m and 0.2-0.4 m, respectively, showing the expected behavior that clayey Latosols tend not to present large variations in the amounts of silt, having less weight than the others.

The density of the particles showed some similarity among the depths, ranging from 2.48 to 2.76 kg dm^{-3}. These values were consistent with those found for Brazilian soils highly weathered and rich in oxides are around 2.65 kg dm^{-3}[25].

The spatial distribution of the soil density variable (SD) is above the critical level, of 1.30 kg dm^{-3} for clayey soils[11]. In general, annual crops that develop in areas with clayey soils with average density higher than the critical level may have difficulties in root growth.

In the investigation of microporosity, it was found that in the vast majority of the experimental area the values are between 0.33 (south) and 0.41 cm³ cm^{-3} (north) (Fig.2). These values were higher than those considered ideal (0.33 cm³ cm^{-3}) [14].

Macroporosity, in turn, showed two predominant spatial distribution areas, being 0 to 0.07 and 0.07 to 0.14 m³ m^{-3}. The ideal for clayey soils like the one in this study is that macroporosity should be around 0.17 m³ m^{-3}. Low macroporosity together with high soil density, as occurs in the study area, indicate advanced soil compaction conditions, since this tends to be a result of the breakdown of macropores into micropores[14].

The ideal total porosity for clayey soils is in the range of 0.5 and 0.65 m³ m^{-3}[26]. Thus, the results of this attribute are less than ideal, reinforcing an indication of soil compaction.

For the variable permanent wilting point (tension 1500 kPa), there are basically two classes of values, from 0.23 to 0.28 m³ m^{-3} (predominant) and from 0.28 to 0.33 m³ m^{-3}. Areas under the latter class will imply a shorter irrigation shift, i.e., more frequent water replacement, because the difference between the wilting point and field capacity was smaller, as previously discussed.

As for the moisture at field capacity, the behavior of the spatial distribution is similar to the permanent wilting point attribute. Authors, when studying this variable in Latosols, found values of 0.35 m³m^{-3}, thus proving that the results found in this study are consistent with the literature[27].

With regard to the total soil water availability (TWA), there was a predominance of the range 0.45 to 0.6 mm cm^{-1} along the largest dimension of the area (east to west) and with a tendency to increase from south to north. Only in the southern region were the values found above 0.60 mm cm^{-1}. In general, the values for TWA, should be between

0.6 and 1.0 mm, with the soil under study being below the desired range[28].

Thus, considering the values determined for the available water (TWA) of the soil, it is possible to define irrigation shifts necessary for the adequate supply of water to the plants and, thus, to define the best irrigation method to be used. Likewise, with the results found, it is possible to assist works aimed at precision agriculture[29], in soils with characteristics similar to those of this study especially within the range of spatial dependence, as well as, in planning the sampling of physical attributes, decision-making related to irrigation and soil management.

IV. CONCLUSIONS

The analysis of the semivariograms showed that the physical-water attributes evaluated present spatial dependence with 40% moderate and 60% strong degree, indicating that the geostatistical interpolation is suitable for generating maps of spatial variability.

The study area presents higher spatial variability for the attributes clay, sand, Dp, macroporosity, FC, PWP and TWA, according to the so-occurrence maps.

The average moisture of the FC and PWP of the area is 0.33 and 0.28 m^3 m^{-3} under the conditions of the study, allowing calculation of irrigation blade and irrigation shift. The low results of TWA show that the reddystrophic red beta-solus in the study presents low water retention in the available water range.

The values of TWA present themselves relatively homogeneous in the direction of the largest dimension and increase from south to north and indicate the possibility of dividing the area into management units, and with this, application of irrigation blades at variable rate.

The results of soil density and macroporosity indicate that the study area presents soil compaction, probably caused by mechanized operations in humidity levels above the adequate, requiring preventive and corrective measures.

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