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SPATIAL VARIABILITY OF SOIL MOISTURE AND ELECTRICAL CONDUCTIVITY IN AN ALLUVIAL VALLEY USING GEOPHYSICAL TECHNIQUES

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Abstract

The methods of electromagnetic induction in precision agriculture have high potential in applications aimed at studying the spatial variability of soil salinity and moisture. The objective of this paper was to verify the performance of EM38® in an alluvial valley in the semiarid region for the purpose of application for precision agriculture, and to evaluate the dynamics and spatial dependence of soil moisture and electrical conductivity at different depths along the profile. The study area is located in the municipality of Parnamirim, Pernambuco State, on the Advanced Campus of Irrigated Agriculture in Parnamirim from the Federal Rural University of Pernambuco. Two regular meshes were adopted, one of 10 x 10 m for measuring the apparent soil electrical conductivity (ECa) estimated with the EM38® device and another of 20 x 10 m for soil sampling, to determine soil moisture, salinity, silt and clay contents in the 0-0.3 m, 0.3-0.6 m and 0.6-0.9 m layers. Direct and indirect information was used in geostatistical analysis, construction of semivariograms and map kriging. The Degree of Spatial Dependence of the evaluated attributes varied from strong to moderate. Higher soil moisture in the deepest layer was found, whereas the highest ECa was found in the 0.3-0.6 m layer. The EM38® proved to be efficient in estimating the soil electrical conductivity, and enabled the validation of a previously calibrated regression model for the same area, in a period of soil water restriction.

Keywords: geostatistics, precision agriculture, EM38®

VARIABILIDADE ESPACIAL DA UMIDADE E CONDUTIVIDADE ELÉTRICA DO SOLO EM VALE ALUVIAL UTILIZANDO TÉCNICAS GEOFÍSICAS

Resumo

Os métodos de indução eletromagnética na agricultura de precisão possuem alto potencial em aplicações voltadas para estudos da variabilidade espacial da salinidade e umidade do solo. O objetivo deste trabalho foi verificar o desempenho do EM38® em vale aluvial no semiárido para fins de aplicação de agricultura de precisão, e avaliar a dinâmica e dependência espacial da umidade e da condutividade elétrica em diferentes profundidades do solo. A área de estudo está localizada no município de Parnamirim, Pernambuco, no Campus Avançado de Agricultura Irrigada de Parnamirim da Universidade Federal Rural de Pernambuco. Duas malhas regulares foram adotadas, uma de 10 x 10 m para amostragem de condutividade elétrica aparente do solo (CEa) estimada com o aparelho EM38® e outra de 20 x 10 m para amostragem de solo, para determinação da umidade, salinidade, silte e argila nas camadas de 0-0,3 m, 0,3-0,6 m e 0,6-0,9 m. Informações diretas e indiretas foram utilizadas nas análises geoestatísticas, construção de semivariogramas e krigagem de mapas. O Grau de Dependência Espacial dos atributos avaliados variou entre forte e moderado. Maior umidade na camada mais profunda do solo foi constatada, as maiores CEa foram encontradas na camada 0,3-0,6 m. O EM38® mostrou-se eficiente na estimativa da condutividade elétrica do solo, e possibilitou a validação de modelo de regressão previamente calibrado na mesma área, em período com restrição hídrica no solo.

Palavras-chave: geoestatística, agricultura de precisão, EM38®

VARIABILIDAD ESPACIAL DE LA HUMEDAD Y CONDUCTIVIDAD ELÉCTRICA DEL SUELO EN UN

VALLE ALUVIAL UTILIZANDO TÉCNICAS GEOFÍSICAS

Resumen

Los métodos de inducción electromagnética en la agricultura de precisión poseen un alto potencial en aplicaciones destinadas a estudiar la variabilidad espacial de la salinidad y la humedad del suelo. El objetivo de este trabajo fue verificar el desempeño del EM38® en un valle aluvial en la región semiárida, con fines de aplicación de agricultura de precisión, y evaluar la dinámica y la dependencia espacial de la humedad y la conductividad eléctrica en diferentes profundidades del suelo. El área de estudio está localizada en el municipio de Parnamirim, Pernambuco, en el Campus Avanzado de Agricultura de Riego de Parnamirim de la Universidad Federal Rural de Pernambuco. Se adoptaron dos mallas regulares, una de 10 x 10 m para el muestreo de la conductividad eléctrica aparente del suelo (CEa) estimada con el aparato EM38® y otra de 20 x 10 m para el muestreo del suelo, para determinación de la humedad, salinidad, limo y arcilla en las capas de 0-0.3 m, 0.3-0.6 m y 0.6-0.9 m. Informaciones directas e indirectas fueron utilizadas en los análisis geoestadísticos, construcción de semivariogramas y kriging de mapas. El Grado de Dependencia Espacial de los atributos evaluados varió entre fuerte y moderado. Se verificó mayor humedad en la capa más profunda del suelo, los CEa más altos se encontraron en la capa de 0.3-0.6 m. El EM38® demostró ser eficiente en la estimación de la conductividad eléctrica del suelo, y permitió la validación de un modelo de regresión previamente calibrado en la misma área, en un período con restricción hídrica en el suelo.

Palabras-clave: geoestadística, agricultura de precisión, EM38®

1. INTRODUCTION

The spatial variability of soil attributes interferes in the agricultural practices, and in water availability, affecting the distribution of soil moisture and salinity. Montenegro et al. (2010) emphasize the high potential of alluvial valleys for the supply of water resources in the semiarid region, and warn of the susceptibility of such areas to degradation processes, due to salt accumulation. In this study, the authors successfully applied geophysical techniques to assess the spatial variability of soil salinity at different scales.

The use of electromagnetic measuring instruments, such as the EM38®, to investigate soil characteristics has already been the subject of several studies, in which wide applicability was observed, as in the example of Montenegro et al. (2010) and Lopes & Montenegro (2019a). In addition, the adoption of geophysical techniques in precision agriculture allows greater speed and cost reduction in the determination of soil physical-hydric variables, compared to direct methods (BRAMLEY & OUZMAN, 2019; LOPES & MONTENEGRO, 2019b).

Lopes & Montenegro (2019a) have developed geostatistical analysis using the EM38® in the same area which is object of this study, in a dry period and with lower soil water availability, confirming the adequate performance of some models in the spatial analysis of soil salinity and moisture, in particular of the model proposed by Rhoades & Corwin (1981).

Thus, the objective of this study was to expand the investigation of the EM38® performance for the application of precision agriculture, and to evaluate the dynamics and spatial dependence of soil moisture and electrical conductivity at different depths, in an alluvial area in the semiarid region, covering a period without soil water restriction.

2. METHODOLOGY

This study was developed in the first quarter of 2018, in an alluvial area inserted in the semiarid region of Pernambuco State. The study area is located in the municipality of Parnamirim-PE, on the Advanced Campus of Irrigated Agriculture of Parnamirim (EAIP) from the Federal Rural University of Pernambuco (Figure 1), inserted in the hydrographic basin of the Brígida River, in an alluvial valley, downstream of the Fomento Dam at geographic coordinates 08° 05'08" South latitude, 39° 34' 27" West longitude and 397 m of altitude.

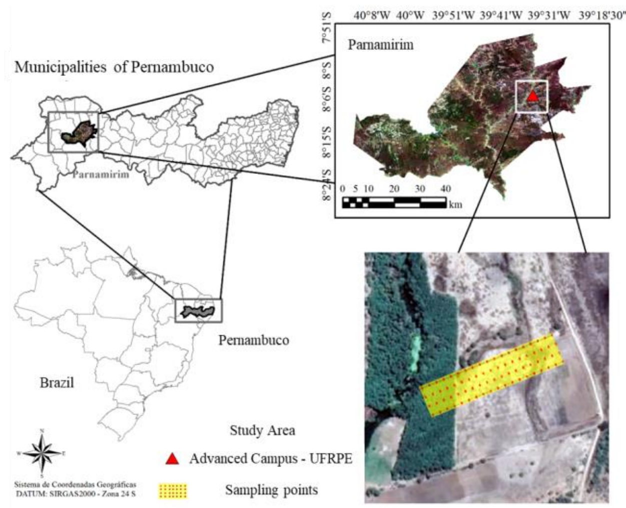

Figure 1 - Map of the location of the study area, in an alluvial valley of the Brígida River. Own authorship.

The region has a semi-arid BShw 'tropical climate, with the rainy season starting in November, and ending in April (ALVARES et al., 2013). The average temperature is of 26 ºC, average annual rainfall of 569 mm and potential evapotranspiration of approximately 1600 mm. In Figure 2, it is possible to observe the recorded rainfall from 1990 to 2018, as well as the accumulated rainfall of months prior to the experiment, which occurred from March 05 to 09, 2018. The accumulated rainfall prior to 90 days was of 230 mm.

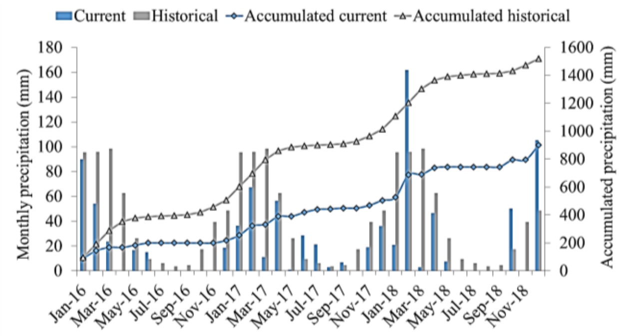

Figure 2 - Monthly and accumulated rainfall for the record and for the year of 2018. Own authorship.

A previous experiment, in the same study area, was developed by Lopes & Montenegro (2019a), in September 2016, during the dry season and with high water deficit. An accumulated rainfall of 500 mm and a potential evapotranspiration of approximately 2400 mm were observed during the period between experiments

The research area is inserted in the Caatinga biome. The municipality of Parnamirim has approximately 55% of the original forest cover from the Caatinga (RIBEIRO et al. 2015). The soil is a Fluvic Neosol with a clay loam texture.

Within the study area, two regular meshes were adopted, one of 10 x 10 m for measuring the apparent soil electrical conductivity (ECa), estimated with the EM38® device, totaling 148 measuring locations, and another mesh of 20 x 10 m for soil sampling for determining soil moisture, salinity and silt and clay content, totaling 74 samples. Such variables were sampled in three different layers (0-0,30 m; 0,30-0,60 m e 0,60-0,90 m).

Gravimetric soil moisture was obtained by the relation between the water mass and the soil dry mass (TEIXEIRA et al., 2017). The measurements of electromagnetic induction with the EM38® were carried out both in vertical and horizontal modes, positioning the equipment at different heights in relation to the ground level (0; 0.3; 0.6; 0.9; 1.2 m), as recommended by Rhoades & Corwin (1981). To evaluate the apparent soil electrical conductivity (ECa), the following regression functions were used:

1. Functions proposed by Rhoades & Corwin (1981) involving 5 heights of the EM38® (0; 0.3; 0.6; 0.9; 1.2 m), for the layers of 0-0.3 m, 3-0.6 m, 0.6-0.9 m, 0.9-1.2 m, expressed in the Eqs. 1a, 1b, 1c, 1d, respectively.

$$EC_a = -0.1285EM_0+0.1446EM_1+5.3878EM_2-17.4476EM_3+15.0549EM_4-0.1309 \quad (1a)$$

$$EC_a = -1.3259EM_0+4.8939EM_1+55.825EM_2-94.0405EM_3+47.4196EM_4-0.9169 \quad (1b)$$

$$EC_a = 9.1705EM_0-8.4116EM_1-18.3090EM_2+50.6298EM_3-42.5033EM_4-0.1224 \quad (1c)$$

$$EC_a = 1.1090EM_0-0.2352EM_1-23.3536EM_2+221.01EM_3-266.8789EM_4-3.5012 \quad (1d)$$

2. Functions proposed by Rhoades et al. (1989). based on the transformation of the fourth root. of the horizontal (EMH) and vertical (EMV) readings. considering the equipment positioned on the soil surface. presented in Eqs. 2a. 2b and 2c. for EMH ≤ EMV and in equations 2d. 2e and 2f for EMH> EMV.

$$EC^{0.25}_{a\,(0\text{-}0.3m)} = 2.539EM_H^{0.25} - 1.413EM_V^{0.25} - 0.068 \quad (2a)$$

$$EC^{0.25}_{a\,(0.3\text{-}0.6m)} = 2.092EM_H^{0.25} - 0.81EM_V^{0.25} - 0.179 \quad (2b)$$

$$EC^{0.25}_{a\,(0.6\text{-}0.9m)} = 1.894EM_H^{0.25} - 0.407EM_V^{0.25} - 0.292 \quad (2c)$$

$$EC^{0.25}_{a\,(0\text{-}0.3m)} = 1.164EM_H^{0.25} - 0.078EM_V^{0.25} \quad (2d)$$

$$EC^{0.25}_{a\,(0.3\text{-}0.6m)} = 0.640EM_H^{0.25} + 0.568EM_V^{0.25} - 0.114 \quad (2e)$$

$$EC^{0.25}_{a\,(0.6\text{-}0.9m)} = 1.367EM_V^{0.25} - 0.209 \quad (2f)$$

3. Functions proposed by Rhoades et al. (1999) using linear relations between the Neperian EMH logarithm and the difference between ln(EMH)–ln(EMV). in order to remove the collinearity between the horizontal and vertical reading of EM38®. detected by Lesche et al. (1992). To fit the profiles in regular. uniform or inverted type. the theoretical relation observed in Eqn. 3 was established.

$$EC_a = \ln(EM_H) - \ln(EM_V)\ 0.04334 + 0.03058\ \ln(EM_H) + 0.00836(EM_H)^2 \quad (3)$$

The three types of profiles were specified based on Eq. 3:

3.1) Regular profile. when the measurement ln(EMH)–ln(EMV) < 5% of the theoretical ln(EMH)–ln (EMV) (Eq. 3);

3.2) Uniform profile. when the measurement ln(EMH)–ln (EMV) is in the range ± 5% of the theoretical value ln(EMH)–ln (EMV);

3.3) Inverted profile. when the measurement ln(EMH) – ln(EMV)> 5% of the theoretical value ln(EMH)–ln (EMV).

The model choice with the best representation of the soil EC was based on the coefficient of determination R² between ECa and ECac (actual electrical conductivity of the soil). To determine the ECac the saturated paste method was used in 47 samples. as Teixeira et al. (2017).

The variables silt and clay. gravimetric moisture and ECa were analyzed using descriptive statistics (minimum. maximum. amplitude. mean. median. coefficient of variation. asymmetry. kurtosis and standard deviation). Coefficients of variation were analyzed according to Warrick & Nielsen (1998) who consider low variability when CV <15%; moderate to 15% ≤ CV <50% and high variability when CV ≥ 50%. The dispersion and distribution of data were subjected to the Kolmogorov-Smirnov's normality test (KS) at the level of 5% probability.

After the regression procedures. descriptive statistics and normality of the data. the spatial dependence analysis was performed using geostatistical techniques and semivariogram adjustments. The classic function for the semivariogram was used to describe the spatial dependence on texture. soil moisture and ECa at different depths. according to Vieira et al. (1981). The experimental semi-variances were estimated by Eqn. 4:

$$\gamma(h) = \frac{1}{2N(h)}\sum_{i=1}^{N(h)}[Z(X_i)-Z(X_i+h)]^2 \quad (4)$$

in which:

$\gamma(h)$ - semivariances;

N(h) - number of pairs at each separation distance (h).

The semivariograms and their respective fittings were obtained using the Geoeas® software. The gaussian. spherical and exponential models were tested. and the semivariograms models that showed the best fit were chosen. The cross-validation process (Jack-knifing method) was used. which consists of reassessing. by the estimator. the known sample values. removing them one by one. and recalculating them as if they were not known (VAUCLIN et al.. 1983).

The analysis of DSD (Degree of Spatial Dependence) was carried out according to Cambardella et al. (1994). based on the proportion in percentage of the nugget effect (C0) in relation to the level (C0 + C1) with the following classification: (a) strong dependence (< 25%); (b) moderate dependence (from 25 to 75%) and (c) weak dependence (> 75%).

The spatial distribution of soil texture. gravimetric moisture and the electrical conductivity was performed using the kriging interpolation algorithm for the individualized variables. thus generating the isoline maps.

3. RESULTS AND DISCUSSION

The model that showed the best performance was that of Rhoades & Corwin (1981) with a coefficient of determination R^2 of 0.82. as it can be seen in Figure 3A. then adopting the ECa calculated by this method for geostatistical analyzes. Similar results were obtained by Lopes & Montenegro (2019a) in the same area and in a period of high water deficit with an R^2 of 0.86 for the same method. The other tested methods presented R^2 of 0.12 and 0.14. for Rhodes et al. (1989) and Rhodes et al. (1999). respectively.

Figure 3B shows the relation between the ECa by Rhoades & Corwin (1981) and ECa also considering the measurements made in this study. and those obtained by Lopes & Montenegro (2019a). presenting a high coefficient of determination. and an angular coefficient of the regression line close to 1.

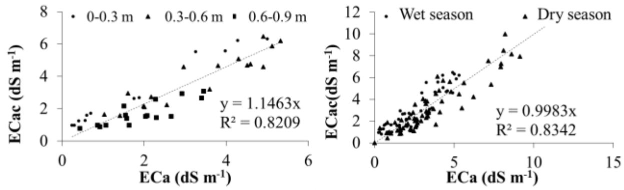

*Figura 3 - Performance of the Rhoades & Corwin's model (1981) for electrical conductivities at different depths (A) and in periods without water restriction and with water restriction considering Lopes & Montenegro (2019a) (B). (**. * - Significant at $p \leq 0.01$ and 0.05. respectively. by the F test.). Own authorship.*

Narjary et al. (2017) found relations of the estimated electrical conductivity with electromagnetic induction methods in vertical (EMV) and horizontal (EMH) readings. with the electrical conductivity of the soil saturation extract. presenting an R^2 determination coefficient of 0.77 for the profile 0-0.9 m. indicating that the EM38® instrument was reliable to characterize soil salinity. corroborating to the present study.

The performance of the regression functions may vary due to different physical and chemical soil conditions (such as texture. organic matter or soil moisture). which influence electromagnetic inductions (THIESSON et al.. 2014; SIQUEIRA et al.. 2016). Montenegro et al. (2010) when developing studies also in an alluvial valley in a semi-arid region. located in an irrigated perimeter. found low performance of the Rhoades & Corwin's method (1981). being the method by Rhoades et al. (1999) the one which presented the best performance. differing from this study possibly due to the difference in soil characteristics.

The "Box-Plots" for the variables analyzed - silt and clay. moisture and ECa of the soil - are shown in Figures 4A. B and C. for the layers 0-0.3 m. 0.3-0.6 m and 0 layers. 6-0.9 m

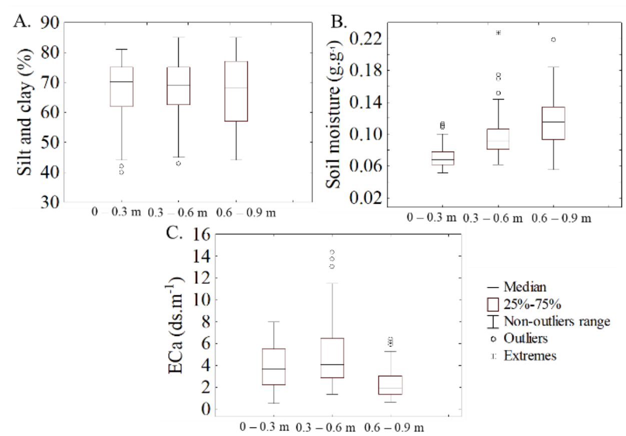

Figure 4 - Box-Plots for different layers of the silt and clay (A). Soil moisture (B) and ECa variables (C). Own authorship.

It can be seen in Figure 4A. that the surface layer and the 0.3-0.6 m intermediate layer present outliers in the range of 40% silt and clay content.

There was a homogeneity between the composition of silt and clay for the three depths. This similarity of texture (silt and clay) can be attributed to the management of the soil (plowing). mainly in the superficial layers. Schlindwein & Anghinoni (2000) mention that the frequent soil management in the conventional system such as plowing and harrowing causes a homogenization of the mobilized layer. Still regarding the "Box-Plots". in Figure 4B. it was found that the 0-0.3 m layer is the one with the lowest soil moisture values. and in Figure 4C. it is observed that the 0.3-0.6 m is the one with the highest EC values

The statistical analysis for the content of silt and clay. soil moisture and apparent electrical conductivity of the soil for all layers is shown in Table 1. It is possible to observe that the measures of central tendency as mean and median present approximate values. which suggests symmetric distribution. Thus. the results indicate that there is no dominance of outliers. In addition. all variables follow a normal distribution. according to the Kolmogorov-Smirnov's test at 5%. which is desirable for geostatistical analyzes of spatial dependence and construction of semivariograms.

Table 1 - Descriptive statistics of soil attributes for different soil depths. Own authorship.

Variable	Minimum	Maximum	Mean	Median	*CV (%)	Asymmetry	Kurtosis	*SD
Silt and clay (0.0-0.3 m)	40.04	81.04	67.88	70.29	15.03	-0.94	0.17	10.20
Silt and clay (0.3-0.6 m)	43.04	85.04	68.04	69.04	14.19	-0.61	-0.04	9.65
Silt and clay (0.6-0.9 m)	44.04	85.04	67.28	68.04	17.28	-0.25	-0.93	11.63
Soil moisture (0.0-0.3 m)	0.05	0.11	0.07	0.07	20.29	1.10	0.59	0.01
Soil moisture (0.3-0.6 m)	0.06	0.23	0.10	0.09	27.70	2.12	6.78	0.03
Soil moisture (0.6-0.9 m	0.06	0.22	0.12	0.12	26.18	0.35	0.95	0.03
ECa (0.0-0.3 m)	0.51	7.98	3.90	3.65	50.16	0.21	-1.18	1.96
ECa (0.3-0.6 m)	1.36	14.39	4.81	4.05	54.42	1.17	1.42	2.62
ECa (0.6-0.9 m)	0.62	6.39	2.31	1.95	54.57	1.04	0.59	1.26

**CV = coefficient of variation; *SD = Standard Deviation.*

Table 1 also shows that the values of ECa vary from 0.51 to 14.39 dS m^{-1} and have average values of 3.90. 4.81 and 2.31 dS m^{-1}. for the layers 0-0.3 m; 0.3-0.6 m and 0.6-0.9 m. respectively. In a period of water restriction. Lopes & Montenegro (2019a) reported EC values ranging from 0.3 to 10 dS m^{-1}. which are similar to those of the present study. Despite this study being in a period without water restriction. it is noticed that the potential evapotranspiration is greater than the accumulated rainfall in the interval between the referred studies. which contributes to limit salt leaching.

The variation coefficients for silt and clay showed moderate variability. except for the intermediate layer of 0.3-0.6 m. which presented low variability. Moisture showed moderate variability in all layers and ECa showed high variability for all depths. The variables were analyzed according to the Warrick & Nielsen's criterion (1998).

The parameters of the theoretical semivariograms adjusted to the soil attributes are shown in Table 2. while Figure 5 shows the semivariances for the layers of 0-0.3 m. 0.3-0.6 m and 0.6-0.9 m. The analysis of the DSD (Degree of Spatial Dependence) indicated a strong spatial dependence for silt and clay in the 0-0.3 m layer. for the soil moisture in the 0-0.3 m and 0.6-0.9 m layer for ECa in layers 0-0.3 m and 0.3-0.6 m. The spatial dependence was considered moderate for silt and clay in the 0.3-0.6 m and 0.6-0.9 m layers. for soil moisture in the 0.3-0.6 m layer and for ECa in the 0.6- 0.9 m. according to Cambardella et al. (1994).

Andrade et al. (2017) found weak spatial dependence for soil moisture and electrical conductivity in the 0-0.2 m and 0.2-0.4 m layers for clay content in the 0-0.2 m layer. while for the content of clay in the 0.2-0.4 m layer a moderate dependence was observed. partially corroborating this study

It is possible to observe in Table 2 that the adjusted semivariograms showed adequate results when passing the cross-validation test by the Jack-Knifing method. with an average of the residue ranging from -0.018 to 0.009 and the standard deviations of the residue ranging from 0.89 to 1.068.

Table 2 - Parameters of the theoretical models for the semi-variances of the analyzed variables and cross-validation (Jack-Knifing method). Own authorship.

Variable	Model	C0	C+C0	Range (A)	*DSD	R^2	*XVALID *Mean	*XVALID *SD
Silt and clay (0.0-0.3 m)	Spherical	11.5	83.35	49.30	0.14	0.96	0.009	0.890
Silt and clay (0.3-0.6 m)	Spherical	28.8	73.87	53.50	0.39	0.71	0.006	0.938
Silt and clay (0.6-0.9 m)	Gaussian	35.5	88.9	71.20	0.40	0.84	-0.005	0.964
Soil moisture (0.0-0.3 m)	Spherical	0.000033	0.000252	51.70	0.13	0.95	0.002	1.028
Soil moisture (0.3-0.6 m)	Spherical	0.000304	0.000872	39.30	0.35	0.66	-0.002	0.976
Soil moisture (0.6-0.9 m	Spherical	0.000227	0.001054	74.30	0.22	0.92	0.001	1.068
ECa (0.0-0.3 m)	Gaussian	0.51	5.029	235.4	0.10	0.97	-0.006	1.017
ECa (0.3-0.6 m)	Gaussian	1.89	9.789	268.8	0.19	0.99	-0.018	1.022
ECa (0.6-0.9 m)	Gaussian	0.499	1.788	155.2	0.28	0.99	-0.012	1.039

**DSD = degree of spatial dependence; * XVALID = cross-validation * Mean = mean of the residues; * SD = Standard deviation of residues.*

The models that best fit were spherical and gaussian for soil moisture and ECa respectively. and spherical and gaussian for silt and clay. It is observed in Figure 5 the semivariograms drawn from the parameters presented in Table 2. Rodrigues et al. (2017) evaluated the spatial variability of soil moisture and soil texture and found an exponential semivariogram model for all variables analyzed as having the best fit. differing from this study. For electrical conductivity. a semivariogram model was found for all layers. corroborating with Souza et al. (2008) and Montenegro et al. (2010). both in an irrigated alluvial valley.

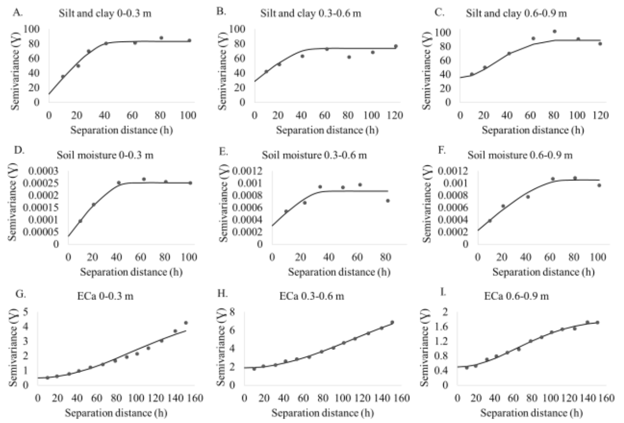

Figure 5 - Semivariograms of soil attributes adjusted for different depths. Separation distance (h) in meters. Own authorship.

It was possible to observe that all ranges were lower than the largest lengths of the study area. It is noticed that the sills of the semivariograms for silt and clay. for the 0.0-0.3 m and 0.3-0.6 m layers. Figure 5A and B. respectively. are similar. This result is attributed to the homogenization processes caused by soil management

There were lower sills for soil moisture in the 0-0.3 m and 0.3-0.6 m layers in the period without water restriction. when compared to Lopes & Montenegro (2019a). For ECa. there was also a reduction in ranges. in relation to those obtained by Lopes & Montenegro (2019a). which may be explained by rainfall events and spatially variable subsurface flows.

The isoline maps were produced and are shown in Figures 6A (silt and clay). 6B (Soil Moisture). 6C (ECa) and 6D (Residue from cross-validation for ECa). It is possible to observe in Figure 6A the low variability among soil layers for silt and clay. Figure 6B shows the spatial distribution of soil moisture. showing a rise with increasing depth. Higher moisture was found in the deepest layer southwest of the area. close to the banks of the Brígida River. both in the riparian forest strip and in the vicinity of the natural thalweg (Figure 1).

Andrade et al. (2017) found higher moisture in the surface layer of the soil. a condition that was attributed to irrigation. thus diverging from the results found in this study.

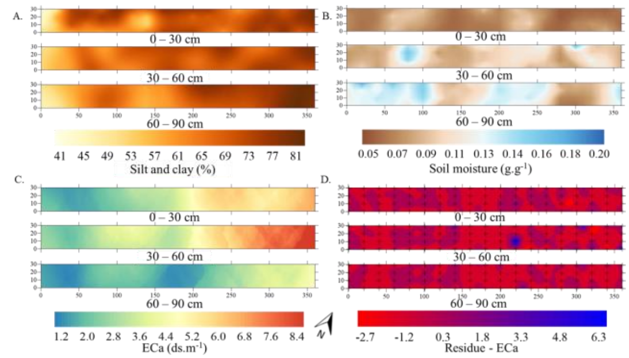

Figure 6 - Isoline maps for the attributes silt and clay of the soil (A). gravimetric moisture (B). ECa (C) and Residue of ECa (D).Own authorship.

In Figure 6C. it is observed that there is a higher ECa in the 0.3-0.6 m layer. corroborating with Lopes & Montenegro (2019a). which indicates that the rainy period did not significantly influence salt leaching. It is noted that the highest salinities occur at distances greater than 200 meters from the bank of the Brígida River. On the other hand. Andrade et al. (2017) found greater electrical conductivities for a more superficial layer. differently from the present study. as it is an area with agricultural cultivation.

According to Singh et al. (2016). spatially interpolated maps may present a close relation between soil properties and ECa. however such relation is not evident in this study. Instead. a strong inverse relation between soil moisture and ECa in the layer 0.6-0.9 m. near the Brígida River. is emphasized. The ECa residue map shown in Figure 6D clearly exhibits the randomness of the residue. which suggests that there is no trend in the data. Thus. a stationary domain is observed in terms of electrical conductivity. ensuring greater precision to the produced maps.

4. CONCLUSIONS

Geostatistical analyzes allowed to adequately assess the spatial dependence of soil attributes (silt and clay. soil moisture and electrical conductivity) for the alluvial region in the semiarid region. Soil management influenced heterogeneities of the sub-surface layers.

The cross-validation and kriging of the isoline maps allowed an adequate observation of the spatial distribution of soil attributes. detecting greater soil moisture in the deepest soil layer. especially in places close to the drainage lines.

The highest levels of electrical conductivity were observed in the intermediate layer. The relevance of the ecological function of the riparian forest is verified in the maintenance of high soil moisture and low salinity in the deepest layers of the soil.

In the alluvial area. the Rhoades & Corwin's method (1981) performed well. both for the period without water restriction. and for the dry period as previously verified. The EM38® allowed appropriate soil electrical conductivity estimations.

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