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SPACE DEPENDENCE OF SOIL MOISTURE AND SOIL ELECTRICAL CONDUCTIVITY IN ALUVIAL REGION[1]

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1 ABSTRACT

Spatial information on soil characteristics is essential to proper decision-making regarding to the environment and land use management. The objective of this work was the investigation of cross - variance between soil moisture and apparent soil electrical conductivity (CEa), under different land uses in an alluvial valley of Pernambuco. The study was developed at the Advanced Research Unit of Universidade Federal Rural de Pernambuco (UFRPE), located at Brígida River Basin, municipality of Panamirim-PE. Soil samples were collected in a regular mesh of 20 x 10 m, for soil moisture by gravimetric method and, following a regular 10 x 10 m mesh, CEa measurements were performed using EM38® device. Cross-semivariograms were assessed and spatial dependence was verified by geostatistical procedures. It was verified in geostatistical procedures low variation for soil moisture and intermediate variation for CEa. The use of geostatistics allowed identification of covariance between soil moisture and ECa, as well as spatial dependence for both variables, for agricultural areas. It was verified that soil moisture, even at levels close to residual, constitutes a relevant secondary component for increasing soil salinity maps precision, and hence to precision agriculture.

Keywords: geostatistics, semi-arid, precision agriculture

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2 RESUMO

Informações espaciais sobre as características do solo são essenciais para uma tomada de decisão adequada em relação ao meio ambiente e ao gerenciamento do uso do solo. O objetivo deste trabalho foi investigar a variância cruzada entre a umidade do solo e a condutividade elétrica aparente do solo (CEa), sob diferentes usos do solo em um vale aluvial de Pernambuco. O estudo foi desenvolvido na Unidade de Pesquisa Avançada da Universidade Federal Rural de Pernambuco (UFRPE), localizada na bacia do rio Brígida, município de Panamirim-PE. As amostras de solo foram coletadas em uma malha regular de 20 x 10 m, para a umidade do solo

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pelo método gravimétrico e, seguindo uma malha regular de 10 x 10 m, as medidas de CEa foram realizadas usando o dispositivo EM38®. Os semivariogramas cruzados foram avaliados e a dependência espacial foi verificada por procedimentos geoestatísticos. Verificou-se procedimentos geoestatísticos, uma baixa variação da umidade do solo e variação intermediária para CEa. O uso da geoestatística permitiu identificar a covariância entre a umidade do solo e o CEa, bem como a dependência espacial para ambas as variáveis, para as áreas agrícolas. Verificou-se que a umidade do solo, mesmo em níveis próximos ao residual, constitui um componente secundário relevante para o aumento da precisão do mapeamento da salinidade do solo e, consequentemente, para a agricultura de precisão.

Palavras-chave: geoestatística, semiárido, agricultura de precisão

3 INTRODUCTION

Spatial information on soil characteristics is essential to proper decision-making regarding to the environment and land use management, especially in the semi-arid (MONTENEGRO; MONTENEGRO, 2006; LOPES; MONTENEGRO, 2019).

Salt content in soils is dependent on the physical-hydric characteristics, and consequently requires management by zones, established through mapping (ALARCÓN-JIMÉNEZ; CAMACHO-TAMAYO; BERNAL, 2015). Hence, it is possible to qualitatively identify areas with higher susceptibility to salinization based on the soil physical characteristics and, therefore, allowing application of different management methods with higher precision (GAVIOLI et al., 2019).

In alluvial valleys of the Brazilian semiarid region, high potential for communal agriculture can be observed. However, these areas are susceptible to salt accumulation processes, both at the unsaturated and the saturated zone. Salt distribution is influenced, among other factors, by the hydraulic characteristics spatial distribution (MONTENEGRO; MONTENEGRO, 2006).

It was observed by Lima et al. (2015) that soils of the Pernambuco State semi-arid valley present reduced thickness and low hydraulic conductivity, limiting infiltration and drainage, and then enhancing salt accumulation.

The apparent electrical conductivity (ECa) can be easily evaluated, being related to nutrients spatial distribution and crop productivity, thus constituting a support tool for the decision making to maximize yields and minimize sampling efforts (SANCHES et al., 2019).

Studies have found that the spatial patterns of soil ECa have high temporal stability, being independent of the order of magnitude of electrical conductivity, whereas, variables such as soil temperature and soil moisture usually vary largely (MOLIN; RABELLO, 2011).

Thus, electromagnetic measuring instruments have been largely used to assess soil characteristics, with a wide applicability for several studies. However, such applications can only be adequately carried out if the instrument is properly calibrated (THIESSON et al., 2014; MONTENEGRO et al., 2010).

For precision farming, it is usually required a quantitatively large number of soil samples to reliably represent the variability structure, and the experimental semivariograms, for a geostatistical mapping (MONTENEGRO; MONTENEGRO, 2006).

Corwin and Lesch (2003) and Corwin (2005) highlight the potential use of the soil apparent electrical conductivity (CEa) (in particular measured with the

EM38® equipment) in precision agriculture, emphasizing its representativeness in applications oriented to studies of the spatial variability of salinity and soil moisture. Lopes and Montenegro (2019) successfully applied a geostatistical methodology for mapping soil salinity and soil moisture, combining local measuraments and EM38 readings.

Guimarães et al. (2010), Laborczi et al. (2015) and Lemos Filho, Bassoi and Faria(2016) also applied geostatistical analysis in precision agriculture, respectively for physical-hydric soil proprieties variability of an irrigated plot, for mapping topsoil texture, and for soil moisture variability of an irrigated sandy plot.

Despite several studies, field applications of the EM38® for the Brazilian semi-arid region and under conditions of severe water scarcity are still rare. Thus, the objective of this work was to verify the performance of EM38®, and the potential spatial covariance between CEa and soil moisture, under different uses in an alluvial valley of Pernambuco State.

4 METHODOLOGY

The investigation of CEa and soil moisture spatial variability was carried out at the Advanced Research Unit of Universidade Federal Rural de Pernambuco (UFRPE), located at an alluvial valley in the semi-arid region of Pernambuco State, with a BSh climate by Köppen methodology (1948), in the municipality of Parnamirim. Field activities were carried out from September to October 2016, in a period of extreme water scarcity in the region (LOPES et al., 2017).

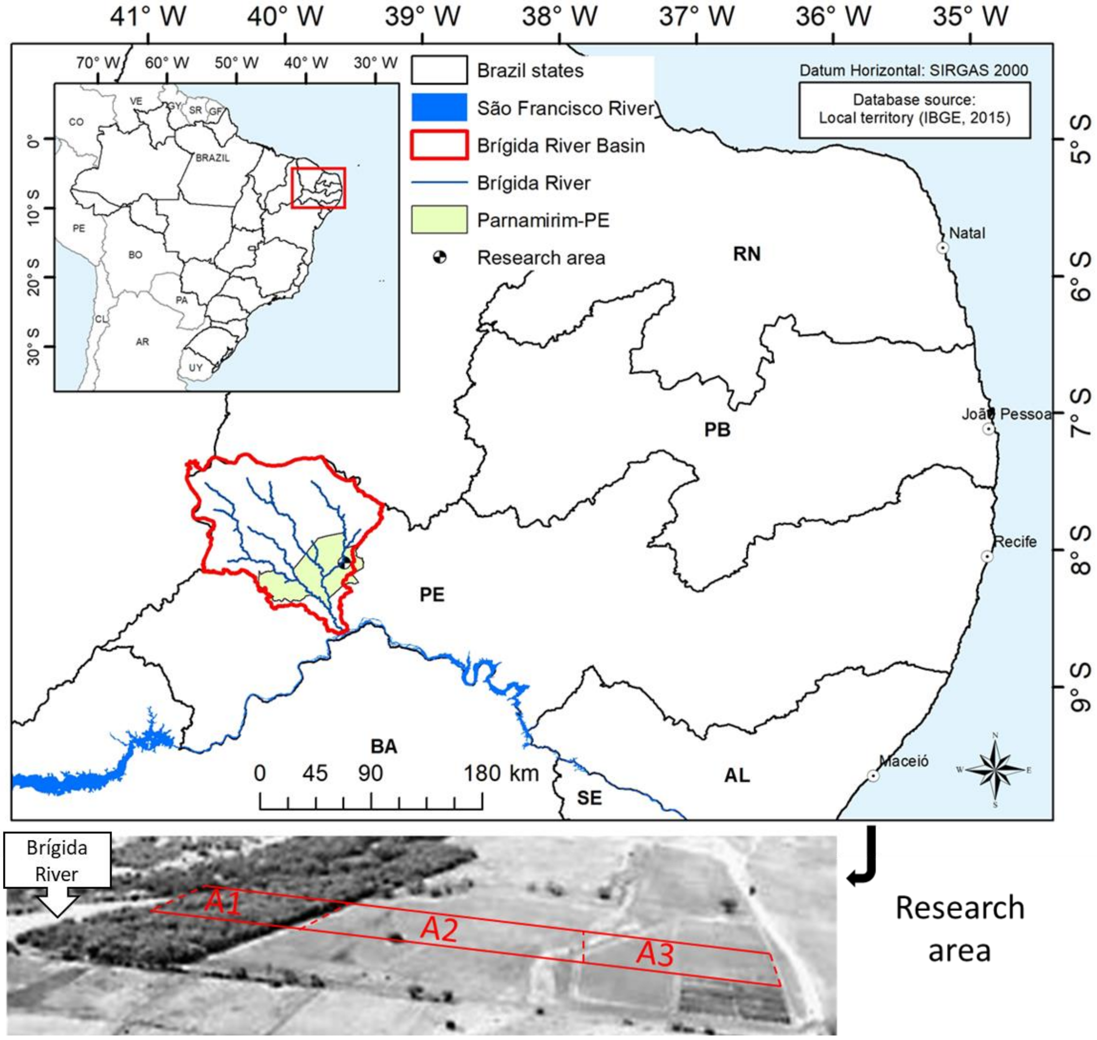
The study area is located in the Brígida River Basin, downstream of the Fomento Dam. Geographic coordinates are 08° 05' 08" south latitude and 39° 34' 27" west longitude, and elevation is approximately 654 m.

The selected area of 2.8 ha presented three different land uses / coverages, classified as:

- A1- Reserve area (Dense Caatinga);
- A2- Fallow area;
- A3- Plowing Area.

Such areas presented differences regarding the soil use and vegetation cover. Aerial view of the experimental area is shown in Figure 1.

Figure 1. Location and aerial view of the areas, in October 2016, with A1 being the reserve area, A2 the fallow area and A3 the plowing area.



Source: Adapted from IBGE (2018).

The soil of the study area is classified as a Fluvic Neosol of mean texture, for the 0-0.3 m layer, with a mean texture of 46.10, 28.90 and 25.00% sand, silt and clay, respectively. The 0.3-0.6 m and 0.6-0.9 m layers present, respectively, of 31.89; 44.51 and 23.60%, and 30.32; 42.35 and 27.33% of sand, silt and clay, for the same textural class sequence.

The near surface hydraulic conductivity surface (Ks) is 0.08 mm s^{-1}, assessed by the Beerkan method (HAVERKAMP et al., 1998), while the saturation soil moisture (USAT) is 0.694 g g^{-1}, the field capacity soil moisture (UCC) is 0.483 g g^{-1}, and the residual moisture (RH) is 0.085 g g^{-1}.

A regular mesh of 20 x 10 m was adopted for soil sampling (32, 44 and 36 points for areas A1 (0.8 ha), A2 (1.1 ha) and A3 (0.9 ha), respectively) and a regular 10 x 10 m mesh (64, 88 e 72 points for areas A1 (0.8 ha), A2 (1.1 ha) and A3 (0.9 ha), respectively) for CEa measurements, using the EM38® equipment, which has electromagnetic induction as its operating principle.

The soil texture, determination for the sand, clay and silt fractions, was by the Bouyoucos densimeter method, according to the methodology proposed by Embrapa

(2013). The soil samples were collected at the same locations adopted for CEa measurements.

For the soil moisture determination, disturbed soil samples were collected at the 0-0.3; 0.3-0.6 and 0.6-0.9 m layers and placed in hermetically sealed containers, for further measurements by the gravimetric method.

CEa measurements were performed both in vertical and horizontal modes with the EM38®, as recommended by Rhoades and Corwin (1981), positioned at different heights from the ground level (0, 0.3, 0.6, 0.9, 1.2 m). From the of vertical and horizontal readings at different heights, it is possible to obtain an equations system that allows evaluation of electrical conductivity profile by regression functions.

In this study, the following regression functions were adopted among CEa and the electromagnetic induction readings (EM38) according to Rhoades and Corwin (1981), as presented in Eqs 1, 2, 3 and 4.

$$\mathrm{EC}_{0.0-0.3m} = -0.1285\mathrm{EM}_0 + 0.1446\mathrm{EM}_1 + 5.3878\mathrm{EM}_2 - 17.4476\mathrm{EM}_3 + 15.0549\mathrm{EM}_4 - 0.1309 \quad (1)$$

$$\mathrm{EC}_{0.3-0.6m} = -1.3259\mathrm{EM}_0 + 4.8938\mathrm{EM}_1 + 55.8250\mathrm{EM}_2 - 94.0405\mathrm{EM}_3 + 47.4196\mathrm{EM}_4 - 0.9169 \quad (2)$$

$$\mathrm{EC}_{0.6-0.9m} = 9.1705\mathrm{EM}_0 - 8.4116\mathrm{EM}_1 - 18.3090\mathrm{EM}_2 - 94.0405\mathrm{EM}_3 - 42.5033\mathrm{EM}_4 - 0.1224 \quad (3)$$

$$\mathrm{EC}_{0.9-1.2m} = 1.1090\mathrm{EM}_0 + 0.2352\mathrm{EM}_1 - 23.3536\mathrm{EM}_2 + 221.0100\mathrm{EM}_3 - 266.8789\mathrm{EM}_4 - 3.5012 \quad (4)$$

Eqs. 1, 2, 3 and 4 proposed by Rhoades and Corwin (1981) involved 5 heights of EM38 above the soil surface: 0; 0.3; 0.6; 0.9 and 1.2 m, represented by the indexes 0, 1, 2, 3 and 4, respectively.

The descriptive statistics were applied to the data of CEa and soil moisture, evaluating the mean, median, quartiles, minimum and maximum values. For information about the dispersion, the amplitude, the variance and the standard deviation were obtained. Data normality test was performed by the Kolmogorov-Smirnov test (K-S), being:

$$\begin{cases} H0: The\ data\ follow\ a\ Normal\ distribution \\ H1: The\ data\ do\ not\ follow\ a\ Normal\ distribution \end{cases} \quad (5)$$

The CEa and soil moisture data were normal to 5% probability level.

In order to obtain the theoretical and experimental semivariograms, and the validation of the theoretical models, the GEO-EAS® software (ENGLUND; SPARKS, 1991) was applied. The cross-semivariograms were adjusted and the spatial dependence was then analyzed through geostatistics.

The classical function for the semivariance, according to Eq. 6 presented by Vieira, Nielsen and Biggar (1981), allows to analyze the spatial variability of the variables Z_1 and Z_2 between neighboring sites. For the cross variogram the range (a) represents the maximum spatial dependence distance between the two variables.

$$\gamma_{12}(\mathrm{h}) = \frac{1}{2\mathrm{N(h)}}\sum_{\mathrm{i}=1}^{\mathrm{N(h)}}[\mathrm{Z}_1(\mathrm{X}_\mathrm{i}) - \mathrm{Z}_1(\mathrm{X}_{\mathrm{i+h}})][\mathrm{Z}_2(\mathrm{X}_\mathrm{i}) - \mathrm{Z}_2(\mathrm{X}_{\mathrm{i+h}})] \quad (6)$$

Being:

γ_{12}(h) - Semivariogram between the primary and secondary variables;

$Z_1(X_i)$ - Value of the primary variable at point Xi;
$Z_1(X_{i+h})$ - Value of the primary variable at point Xi, adding a distance h;
$Z_2(X_i)$ - Value of the secondary variable at point Xi;
$Z_2(Xi+h)$ - Value of the secondary variable at point Xi, adding a distance h;
N is the number of pairs of points formed for a given distance h.

The cross-linked semivariograms and their respective adjustment parameters were also obtained through the GEO-EAS® software (ENGLUND; SPARKS, 1991). After the construction of the experimental cross-linked semivariograms, the gaussian, spherical and exponential models were tested. For the adjustment process of the theoretical models to the experimental values, the following parameters were estimated: the nugget effect (C_0); the threshold ($C_0 + C_1$); the range (a). The degree of spatial dependence (GD) was calculated using equation (7) (CAMBARDELLA et al., 1994).

$$GD = \left[\frac{C_0}{C_0 + C_1}\right] x100 \qquad (7)$$

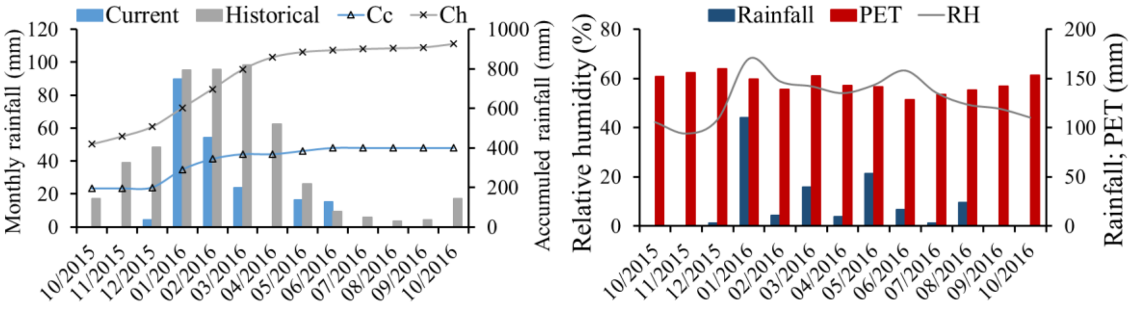
GD can be classified into strong (GD < 25 %), moderate (26 % < GD < 75 %), and weak spatial dependence (GD > 75 %), according to Cambardella et al. (1994).

5 RESULTS AND DISCUSSION

The region was undergoing a period of high water deficit, which can be observed in Figure 2, which shows the monthly and accumulated rainfall from October 2015 to the studied period and also data from the 1990-2016 historical series are presented. For the 2014 to 2016 years, a water scarcity period was also detected by Lopes et al. (2018).

The water budget can also be observed in Figure 2, by comparing rainfall alongside the potential evapotranspiration (PET).

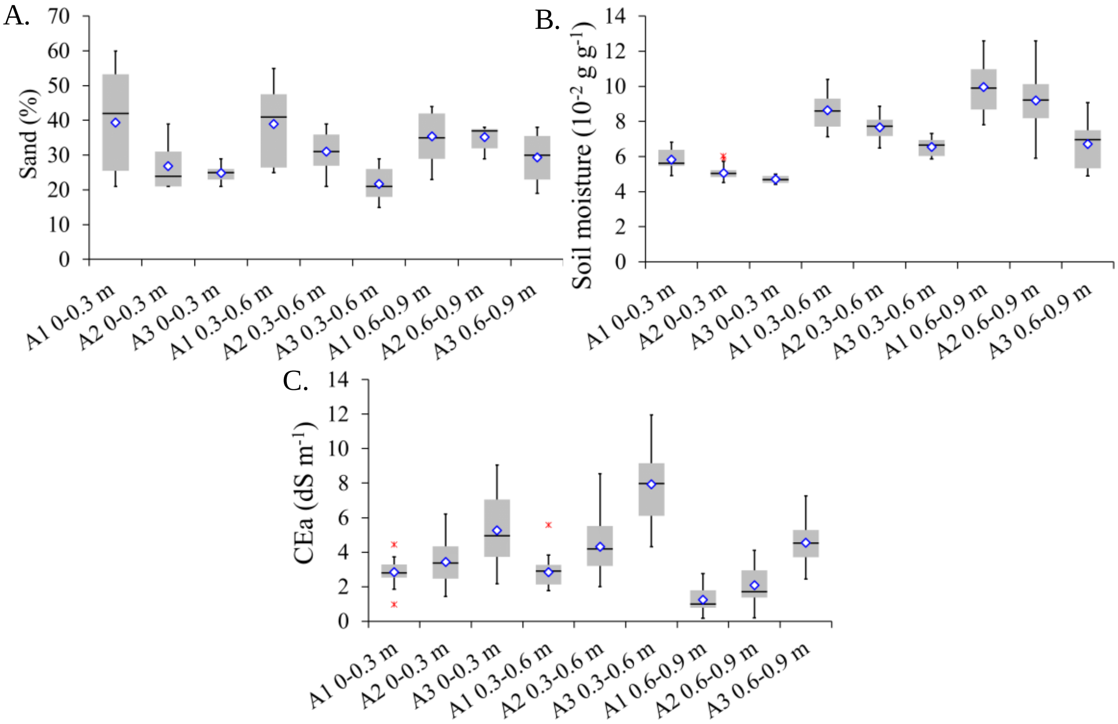
Figure 2. Precipitation for the 2015 year up to the measurements period. Water budget represented by PET and rainfall. Being: Current - the current month's rainfall; Historical - The historic rainfall for the month; Cc - Cumulative current rainfall; Ch - Cumulative historical rainfall; PET - potential evapotranspiration; RH - Relative Air Humidity.



Source: INMET (2018).

In Fig. 3A, 3B and 3C the Box-Plot for the texture (represented by sand), soil moisture and apparent electrical conductivity (CEa), are presented respectively, for the reserve areas (A1), fallow (A2) and Plowing (A3), and at 0-0,3; 0.3-0.6 and 0.6-0.9 m layers.

Figure 3. Box-Plot of the variable (A) Sand, (B) soil moisture and (C) CEa. Being (A1) reserve area, (A2) in fallow and (A3) Plowing area.



Source: Own authorship.

For texture, differences in soil profiles are observed for the three areas, which helps to understand the soil water movement processes and consequently the salts distribution. In area A1, there is a higher percentage of sand than in areas 2 and 3, although these areas presented high variability among layers of soils studied. As an alluvial valley area, it is expected to observe a high variation in soil texture, and the sand content decreases with increasing distance from the riverbed, that is, from A1 to A3.

In general, it can be observed that the land uses exhibit different patterns of soil moisture and CEa, that are influenced directly by the soil texture. In the areas of lower agricultural activity, higher soil moisture and lower salinity were observed, and the higher the use of the area, the lower the soil moisture, and the higher the salinity.

The outliers values, which were observed for moisture at A2 in the 0-0.3 m layer and CEa at A1 in the 0-0.3 and 0.3-0.6 m layers, were not removed for the semivariogram construction.

There were higher values of soil moisture at the three depths of area A1 and lower ones in area A3 (Figure 1A). For the upper layers, the difference was lower among the areas, and for the lower layers, the areas without cover (A2 and A3) presented residual values. A similar result was observed by Campos et al. (2013), with the difference between the vegetation area with caatinga and the uncovered areas being small, which was associated to the high evapotranspiration of the semi-arid zone (0.00-0.30 m).

It could be observed that the area A3 presented higher values of CEa than the other areas. It is also noted that the salinity of A2 is lower than at A1. The higher observation values for salt contents can be linked to external sources, like fertilizers. In addition, the A1 area is closer to the Brígida River bed, where the percolation and washing processes are more intense, and the texture is more sandy.

Table 1 shows the minimum (min), mean, median and maximum (max), besides the variance, standard deviation (sd), coefficient of variation (CV), asymmetry coefficient (A), kurtosis coefficient (K) and Kolmogorov-Smirnov (KS at 1%).

Table 1. Descriptive statistics for soil moisture and apparent electrical conductivity (CEa), for 0-0.3, 0.3-0.6 and 0.6-0.9 m layers, for (A1) reserve area, (A2) in fallow and (A3) Plowing

Variables	Mean	Median	Min	Max	Sd	CV	A	K	KS
A1									
Soil moisture (0.0-0.3 m)	5.81	5.61	4.91	6.82	0.56	9.71	0.28	-0.93	0.15
Soil moisture (0.3-0.6 m)	8.62	8.60	7.13	10.38	0.94	10.96	0.26	-0.91	0.08
Soil moisture (0.6-0.9 m)	9.96	9.89	7.81	12.57	1.48	14.88	0.19	-0.95	0.06
CEa (0.0-0.3 m)	2.75	2.82	0.97	4.43	0.73	26.73	-0.62	0.68	0.11
CEa (0.3-0.6 m)	2.65	2.41	1.61	5.57	0.78	29.19	1.21	2.54	0.14
CEa (0.6-0.9 m)	1.14	0.99	0.17	2.75	0.58	50.85	1.04	0.82	0.12
A2									
Soil moiture (0.0-0.3 m)	5.06	5.03	4.53	6.01	0.36	7.13	1.08	0.90	0.12
Soil moisture (0.3-0.6 m)	7.67	7.71	6.48	8.86	0.56	7.31	-0.15	-0.66	0.1
Soil moisture (0.6-0.9 m)	9.19	9.22	5.90	12.58	1.37	14.94	0.01	0.38	0.04
CEa (0.0-0.3 m)	3.33	3.28	1.01	6.21	1.31	39.36	0.18	-0.59	0.06
CEa (0.3-0.6 m)	4.26	4.19	1.96	8.54	1.52	35.36	0.70	0.17	0.09
CEa (0.6-0.9 m)	2.18	2.01	0.18	4.28	0.87	40.06	0.43	-0.31	0.12
A3									
Soil moisture (0.0-0.3 m)	4.69	4.68	4.41	5.01	0.19	4.24	0.09	-1.48	0.12
Soil moisture (0.3-0.6 m)	6.55	6.65	5.87	7.32	0.49	7.51	-0.01	-1.44	0.17
Soil moisture (0.6-0.9 m)	6.70	6.96	4.89	9.07	1.22	18.22	-0.01	-1.04	0.16
CEa (0.0-0.3 m)	5.12	4.88	1.19	10.50	2.09	40.84	0.49	0.18	0.06
CEa (0.3-0.6 m)	7.87	7.74	3.83	12.10	2.14	27.16	0.28	-0.14	0.09
CEa (0.6-0.9 m)	4.61	4.55	2.42	7.36	1.25	27.33	0.36	-0.34	0.07

All variables presented normality at 1% probability, thus, allowing non biased parameters of theoretical the semivariograms being obtained. The theoretical cross-linked semivariograms adjusted to the experimental data are shown in Table 2. The values of the nugget effect (C_0), sill ($C_0 + C$), range (A) and spatial dependency (GD) for the tested models (Gaussian , spherical and exponential) are presented.

Table 2. Parameters of theoretical models for cross-linked semivariograms of the soil variables measured. Being: C_0 - nugget effect, C_0 + C - sill, A - range and GD - spatial dependency

	Model	**C_0**	**C_0+C**	**C**	**A**	**GD***
			A1			
Soil moisture x CEa 0.0-0.3	EPP	---	---	---	---	---
Soil moisture x CEa 0.3-0.6	EPP	---	---	---	---	---
Soil moisture x CEa 0.6-0.9	EPP	---	---	---	---	---
			A2			
Soil moisture x CEa 0.0-0.3	Gaussian	0.0001	0.1542	0.1541	50.40	0.01
Soil moisture x CEa 0.3-0.6	Gaussian	0.0010	0.3680	0.3670	49.01	0.01
Soil moisture x CEa 0.6-0.9	Spherical	0.1000	0.2800	0.1801	34.04	0.35
			A3			
Soil moisture x CEa 0.0-0.3	Gaussian	0.0620	0.4200	0.3580	89.81	0.15
Soil moisture x CEa 0.3-0.6	Gaussian	0.1710	2.4520	2.2810	88.64	0.06
Soil moisture x CEa 0.6-0.9	Gaussian	0.0010	2.0110	2.0100	63.40	0.01

In the area A1 it was not possible to identify cross dependence between soil moisture and salinity. This fact may be related to variation of plant types, causing differences for the vegetation cover indexes, at their root zones, and consequently higher or lower evapotranspiration within the area.

When studied physico-hydraulic components, Lima et al. (2015) and Sabino Junior et al. (2014) observed that there is spatial dependence for the Caatinga area. However, when the seasonal factor is inserted, spatial dependence is affected, as observed in this study.

A condition that may explain the non-dependence between soil moisture and CEa in the area A1 was presented by Lopes and Montenegro (2017), being the sensitivity of soil moisture in response to rainfall events influenced by the soil cover condition. Indeed, interception/absorption processes by the trees or due to higher humidity contribute to the spatial independence among the points.

The semivariograms for the areas A2 and A3 presented spatial dependence (Table 2). It is noteworthy that, for the areas and depths modified by agriculture, it was possible to adjust covariance equations between soil moisture and ECa, due to the strong spatial dependencies.

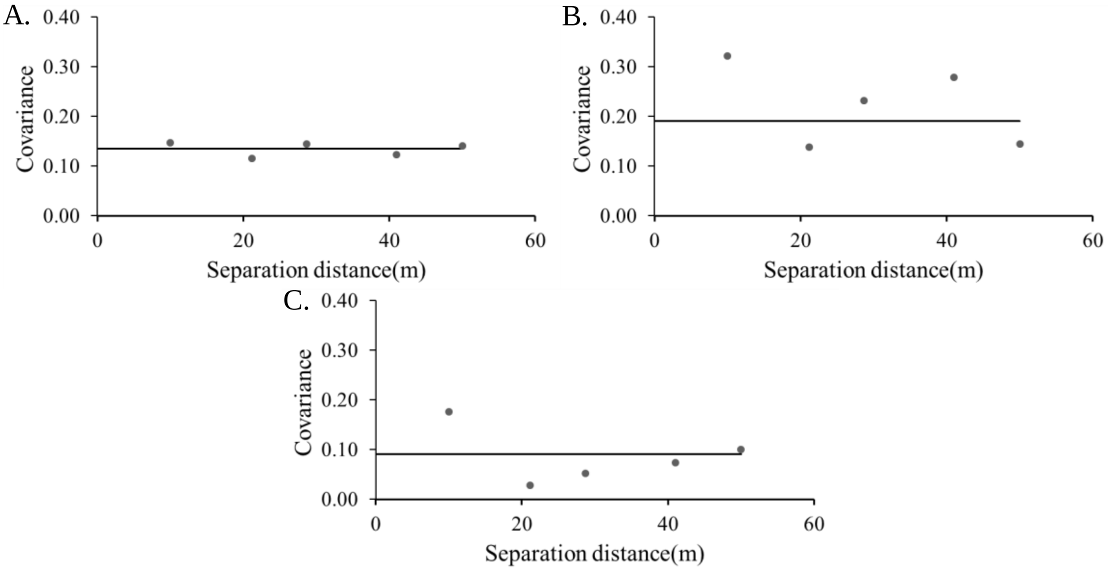
The obtained values of spatial dependence were classified as strong for soil moisture x CEa for A2, for 0.0-0.3, 0.3-0.6 m layers and for A3, for 0.0-0.3, 0.3-0.6 and 0.6-0.9 m layers. Only for A2 at the 0.6-0.9 m the dependence was classified as moderate.

For the areas A2 and A3, and studied depths, a high ECa variation is observed, and the effect of humidity is low, but it has a positive relation. The evaluation of the soil moisture through the ECa is not compromised (it presents high spatial dependence), allowing to obtain soil moisture values from the ECa measurements for points that were not sampled. The soil moisture estimation by ECa for sites that were not sampled was also obtained by Lopes and Montenegro (2019), for an alluvial region in the Pernambuco State.

It is worth mentioning the covariance of the soil moisture of the A3 for the three depths, with a range greater than 63 m, especially for the upper layers, showing the occurrence of spatial dependence even for at long distances (Table 2). This behavior, in which farmed areas presented high spatial dependence, is interesting, so that the information obtained quickly and easily (EM38®) can be used for managing zones (through differentiation), as also observed by Van Meirvenne et al. (2013), Tagarakis et al. (2012) and Valente et al. (2012), for other areas and parameters.

In Figures 4, 5 and 6 the experimental cross-linked semivariograms are presented.

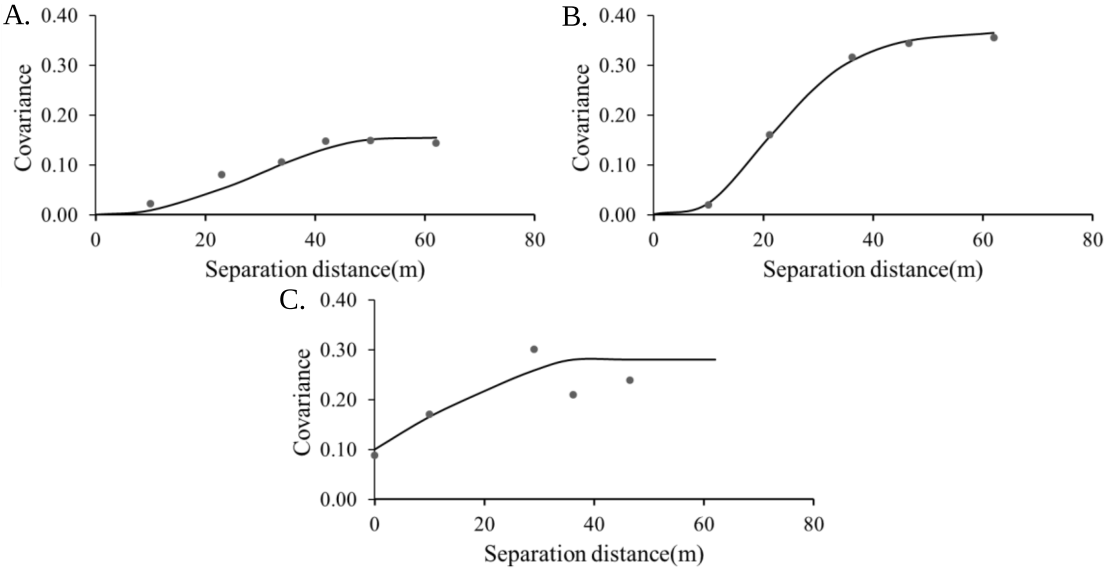
Figure 4. Cross-linked semivariograms of the variables of area A1, being (A) Soil moisture x CEa 0-0.3 m, (B) Soil moisture x CEa 0.3-0.6 m and (C) Soil moisture x CEa 0.6-0.9 m.



The cross-inference of soil moisture through CEa is affected for A1, due to the low dependence between them. Bottega et al. (2014) observed similar behavior for the estimation of soil parameters through CEa in soils altered by agriculture. This can occur due to the low variability of the soil moisture data of the first layer (Figure 3B), regardless of its use.

Thus, for A2, the data spatial dependence for the three initial layers was observed, but with lower dependence on the third layer. In this way, it is inferred that at deeper soil layers, the precision of the soil moisture estimation by CEa can be reduced from the electromagnetic induction reader (EM38®).

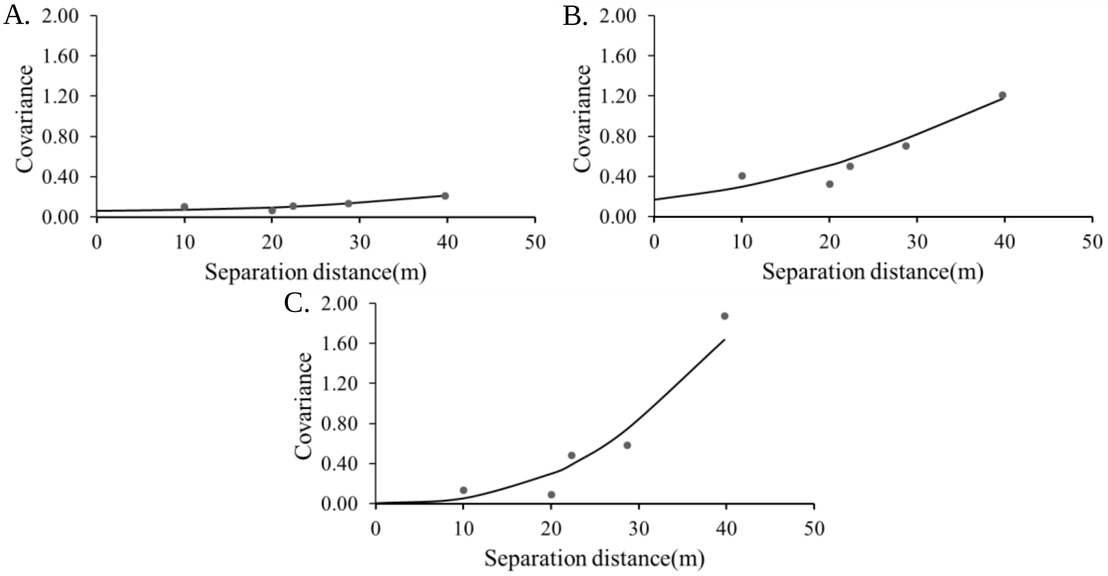
Figure 5. Cross-linked semivariograms of the variables of area A2, being (A) Soil moisture x CEa 0-0.3 m, (B) Soil moisture x CEa 0.3-0.6 m and (C) Soil moisture x CEa 0.6-0.9 m.



It can be observed that the Gaussian model was the one that best fitted the soil moisture covariance data set, with the CEa at all depths evaluated (Figure 5A and 5B). With this result of the Gaussian adjustment for the areas and depths, it can be inferred that the covariance between moisture and CEa is also Normal.

Observing the crossed semivariograms of the area A3 in Figure 6, it can be emphasized that for the three layers of soil, the sill for the semivariograms was not established.

Figure 6. Cross-linked semivariograms of the variables of area A3, being (A) Soil moisture x CEa 0-0.3 m, (B) Soil moisture x CEa 0.3-0.6 m and (C) Soil moisture x CEa 0.6-0.9 m.



The increase in covariance for the cross-semivariograms is more visible for the deepest layer, in the plowing area. The covariance values for 0-0.3 m were 0.1; For 0.3-0.6 m of 1 and for 0.6-0.9 m of 1.8, all values for the same separation distance. Thus, this result corroborates with the Box-Plots in which in A3 occurs higher variation of the data and thus the increase in dispersion for the soil moisture values and CEa.

Areas A2 and A3 presented high values and variations for CEa, but did not prevent mapping for soil moisture from the data obtained with the EM38®. For agricultural areas, Molin and Faulin (2013) and Lopes and Montenegro (2019) identified soil moisture variation as a function ECa, being a good alternative for soil monitoring, applicable to precision agriculture.

This is due to the existence of covariance, which was obtained computing the variation of the electromagnetic induction reading as a function of the variation of the soil moisture values. In this way, it is possible to subsidize precision agriculture, similar to Sousa et al. (2016), which verified the relevance of the soil attributes mapping to obtain higher accuracy in the interpretation and management recommendations, thus providing higher efficiency.

Future studies should be performed to verify the performance of the cross-variance between moisture and CEa for the rainy periods or with higher soil moisture.

6 CONCLUSION

The data obtained with EM38® present adequate resolutions for irrigated areas and precision agriculture in alluvial soils, especially in relation to the application of cross-geostatistics between moisture and CEa variables, for periods of strong water restriction, thus allowing a more precise mapping produce.

High covariance between soil moisture and CEa are identified in the fallow area (A2) and in the plowing area (A3) for the three depths, under conditions of extreme water scarcity. For alluvial areas, a covariance of soil moisture with CEa is detected as well as the occurrence of strong spatial dependence.

The method allows improvements for future sampling plans, particularly for analyzing soil moisture and salinity non-sampled locations, at distances no higher than the correlation lengths.

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