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The relationship between apparent soil electrical conductivity and soil properties[1]

Relação entre condutividade elétrica aparente e propriedades do solo

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ABSTRACT - Precision agriculture that is based on the physical and chemical properties of soil requires a dense sampling to evaluate spatial variability in the field. This dense sampling is often expensive and time consuming. One technique to reduce the number of samples is to define management zones based on information that is collected in the field. Some researchers have demonstrated the importance of the electrical properties of soil in defining management zones. Thus, the objective of this study was to evaluate the relationship between the apparent soil electrical conductivity and soil properties in mountainous areas of coffee production. The electrical conductivity of soil was evaluated at soil depths ranging from 0.00-0.20 m (EC20) and 0.00-0.40 m (EC40) using a portable meter. The mean values of EC20 and EC40 were 1.80 mS m^{-1} and 1.22 mS m^{-1}, respectively. Both EC20 and EC40 exhibited comparatively low correlations with the soil properties, whereas higher correlations were obtained for measurements of remaining phosphorus, wherein values of 0.427 and 0.465, respectively, were obtained.

Key words: Precision agriculture. Management zone. Sensors.

RESUMO - A agricultura de precisão baseada nas propriedades físicas e químicas do solo exige uma amostragem densa para se determinar a variabilidade espacial no campo. Essa amostragem densa, muitas vezes apresenta custo e tempo consumido elevado. Uma das técnicas para reduzir o número de amostras é definir zonas de manejo em função de informações coletadas no campo. Alguns pesquisadores têm demonstrado a importância desempenhada pelas variáveis elétricas do solo para definir zonas de manejo. Dessa forma, este trabalho teve como objetivo avaliar a relação entre a variabilidade espacial da condutividade elétrica aparente e propriedades do solo em regiões de produção de cafés de montanha. A condutividade elétrica foi medida no perfil de solo de 0,00-0,20 m (CE20) e 0,00-0,40 m (CE40) usando um sensor portátil. Os valores de CE20 e CE40 foram de 1,80 mS m^{-1} e 1,22 mS m^{-1}, respectivamente. Ambas CE20 e CE40 apresentaram baixa correlação com as propriedades químicas e a textura do solo, sendo que, a correlação mais elevada foi obtida para o fósforo remanescente com valores de 0,427 e 0,465, respectivamente.

Palavras-chave: Agricultura de precisão. Zonas de manejo. Sensores.

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INTRODUCTION

Coffee production in different countries has been transformed into a specialized field. Consumers demand a high quality product, and coffee producers are looking for ways to reduce costs and add value to their product through production systems that provide special attributes to their coffee. Precision agriculture is a technique that may be used to attain these goals. By practicing precision agriculture, it is possible to identify areas that will give higher yields and that have the potential to produce higher quality coffee. Precision agriculture can also be used to optimize the use of inputs in the production system and make business more profitable.

The use of precision agriculture that is based on the chemical and the physical properties of the soil requires a dense sampling to determine spatial variability in the field (SILVA et al., 2010). A decreased density of sampling can lead to errors in estimating the spatial variability of soil nutrients and, consequently, errors in recommendation.

One technique for reducing the number of samples is to define management zones (MORAL *et al*., 2010; XIN-ZHONG *et al*., 2009). The field information frequently used for defining management zones is based on a digital elevation model, maps of soil fertility that have been generated from systematic sampling in the field and yield maps that have been obtained for more than one season. Recently, some researchers (CORWIN; LESCH, 2003; CORWIN *et al*., 2003; CORWIN; LESCH, 2005a; CORWIN; LESCH, 2005b; CORWIN *et al*., 2006; LESCH *et al*., 2005; MORARI *et al*., 2009; SAEY *et al*., 2009; YAN *et al*., 2007a; YAN *et al*., 2007b; YAN *et al*., 2007c; YAN *et al*., 2008) have demonstrated that soil electrical parameters in the field can be used to explain variability in the physical and chemical properties of the soil. Additionally, these parameters are reliable and easy to measure. Thus, the objective of this research was to evaluate the relationship between the apparent soil electrical conductivity and soil properties in a coffee production system that is located in a mountainous area.

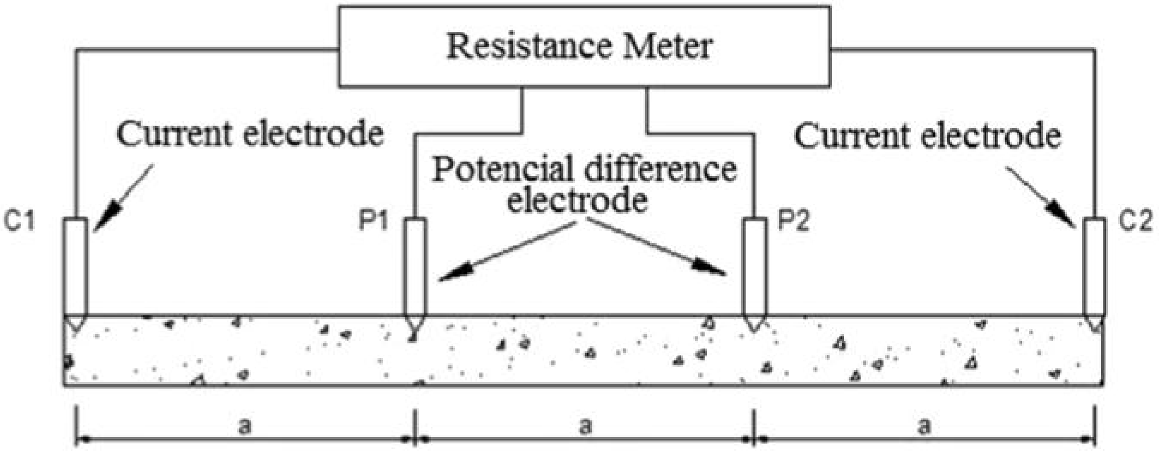
MATERIAL AND METHODS

The data for apparent soil electrical conductivity were measured on a farm located in Araponga (20°42’33” S, 42°34’17” W, average altitude of 913 m a.s.l.), Minas Gerais, Brazil . This farm has an area of 86 hectares and is planted with the *Coffea arabica* L. species. The average altitude is 904 m, the area is predominantly mountainous, and the soil is classified as Typic Hapludox (SOIL SURVEY STAFF, 2006). According to the Brazilian soil classification the soil is classified as *Latossolo Vermelho Amarelo*.

The resistivity method was used to measure the apparent soil electrical conductivity. In this method, four equally spaced electrodes are placed in contact with the soil surface. An electric current is applied between the two external electrodes and the electrical potential difference is measured in the inner electrodes, as shown in Figura 1. This configuration is commonly referred to as the Matrix Wenner configuration (CORWIN; HEDRICKX, 2002; CORWIN; LESCH, 2003).

A portable sensor, model ERM-02, manufactured by Landviser, was used to characterize the apparent soil electrical conductivity by the resistivity method. Two electrode spacing configurations were used: one with 0.20 m (EC20) spacing and another with 0.40 m (EC40) spacing.

Figura 1 - A diagram of the four-electrode resistance meter with two current electrodes (C1 and C2) and two potential electrodes (P1 and P2) that was used in this study (CORWIN; LESH, 2003)



The apparent soil electrical conductivity and the soil properties were determined in a 20.20-ha area. The EC20 and EC40 were measured at 141 points in the experimental area. The soil was sampled in the canopy projection of culture and depth of 0-0.20 meters in an irregular mesh with 141 points (SILVA *et al.*, 2010). Soil samples were collected at each point in order to determine the soil texture and chemical properties. At each sampling point, three single samples were collected in a radius of 1 m around the point where the EC20 and EC40 were measured. Soil samples were analyzed in order to obtain the soil texture composition (clay, silt, and sand), electrical conductivity in the extract of soil to water ratio (1:5), moisture, and soil fertility (pH; potential acidity; P, K, Ca^{2+}, Mg^{2+}, Al^{3+}, and H-Al levels; sum of basis; effective cation exchange capacity (CEC t); cation exchange capacity at pH 7 (CEC T); basis saturation; aluminum saturation; remaining phosphorous; and Zn, Fe, Mn, Cu, and organic matter). The relationship between the apparent electrical conductivity and the soil properties was determined by calculating the Pearson's correlation coefficient. In order to complement the characterization of the soil, a water retention curve was determined using the Extractor Richards method (RICHARDS, 1965). For this test, 15 out of 141 sampling points were randomly selected to perform the measurements.

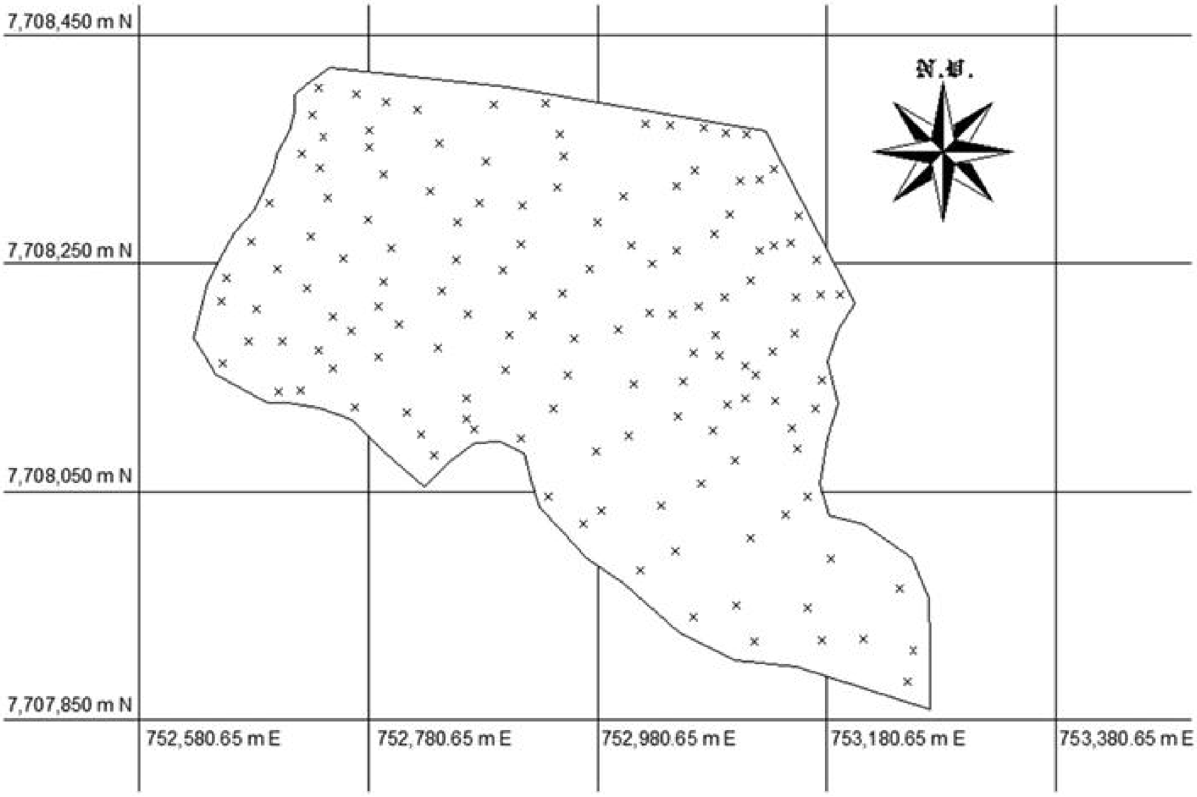
As can be observed in Figura 2, each sampling point was georeferenced using a DGPS Promark 3, which was manufactured by Magellan. For differential correction, data from the Brazilian Network for Continuous Monitoring (RBMC) were used. GNSS solution software (developed by Magellan) was used to process the data.

RESULTS AND DISCUSSION

The results of the descriptive statistics for EC20, EC40, and the some soil properties are shown in Table 1. Therein, it can be observed that the EC20 exhibited a coefficient of variation that was greater than that for EC40, which indicates a greater variability in EC20 values due to variations in soil properties near the surface.

The average values of EC20 and EC40 were 1.80 and 1.22 mS m^{-1}, respectively. These values are relatively low when compared to the apparent electrical conductivity

Figura 2 - Location of the apparent soil electrical conductivity sampling points in the Brauna Farm



Datum: SAD69 UTM Zone 23S

Table 1 - Summary statistics of the soil data

Variable	Average	Min	Max	M	SD	Ck	Cs	CV
EC20[1] (mS m^{-1})	1.80	0.40	5.24	1.62	0.87	1.93	1.16	48.16
EC40[2] (mS m^{-1})	1.22	0.40	3.45	1.08	0.53	3.07	1.47	43.28
MC[3] (kg kg^{-1})	0.31	0.21	0.42	0.31	0.04	0.35	0.24	12.40
pH[4]	5.76	4.83	7.74	5.69	0.50	1.52	0.88	8.63
P (mg dm^{-3})	4.36	1.10	22.10	3.80	2.53	17.20	3.16	57.90
K (mg dm^{-3})	89.21	17.00	165.00	81.00	32.06	-0.64	0.39	35.94
Ca^{2+} (cmol$_c$ dm^{-3})	2.70	0.43	9.22	2.63	1.20	6.06	1.57	44.66
Mg^{2+} (cmol$_c$ dm^{-3})	1.21	0.21	3.71	1.16	0.48	4.22	1.19	39.52
Al^{+3} (cmol$_c$ dm^{-3})	0.20	0.00	1.17	0.09	0.27	2.05	1.59	135.95
H + Al[5] (cmol$_c$ dm^{-3})	7.44	0.50	12.70	7.60	2.45	-0.04	0.31	32.92
SB[6] (cmol$_c$ dm-^{3})	4.13	0.74	11.51	3.98	1.61	2.73	1.00	38.89
CEC t[7] (cmol$_c$ dm^{-3})	4.33	1.71	11.51	4.20	1.44	4.23	1.38	33.30
CEC T[8] (cmol$_c$ dm^{-3})	11.57	5.62	16.27	11.63	1.91	0.52	0.31	16.50
V[9] (%)	36.75	6.50	94.50	34.00	15.59	1.61	0.97	42.41
m[10] (%)	6.43	0.00	59.10	2.40	9.96	7.15	2.40	155.02
OM[11] (dag kg^{-1})	5.42	2.50	7.96	5.35	1.03	0.04	0.08	18.93
P-rem[12] (mg L^{-1})	19.26	11.30	31.60	18.90	4.17	0.26	0.68	21.64
Zn (mg dm^{-3})	2.05	0.35	5.75	1.93	1.17	0.26	0.80	57.21
Fe (mg dm^{-3})	45.13	18.80	120.30	41.70	17.09	4.67	1.72	37.87
Mn (mg dm^{-3})	9.26	2.30	42.30	8.00	5.73	9.60	2.45	61.94
Cu (mg dm^{-3})	0.86	0.10	2.88	0.79	0.53	1.69	1.12	61.25
CEe1:5 [13] (mS m^{-1})	5.00	4.00	9.00	5.00	1.00	0.68	0.72	16.71
Coarse Sand (dag kg^{-1})	26.78	17.00	41.00	27.00	4.39	0.02	0.28	16.41
Fine Sand (dag kg^{-1})	12.16	7.00	20.00	12.00	1.90	1.36	0.48	15.59
Silt (dag kg^{-1})	7.49	4.00	15.00	7.00	2.04	0.91	0.89	27.30
Clay (dag kg^{-1})	53.57	39.00	66.00	54.00	4.90	-0.04	0.23	9.14

[1]/EC20, apparent soil electrical conductivity for the 0 to 0.20 m layer; [2]/ EC40, apparent soil electrical conductivity for the 0 to 0.40 m layer; [3]/MC, Moisture Content; [4]/ pH, active acidity in water; [5]/ H + AL, potential acidity; [6]/SB, sum of basis; [7]/ CEC t, effective cation exchangeable capacity; [8]/ CEC T, cation exchangeable capacity at pH 7; [9]/ V, basis saturation; [10]/ m, aluminum saturation; [11]/OM, Organic Matter; [12]/P-rem, remaining phosphorous; [13]/ CEe 1:5, electrical conductivity of soil extract at 1:5.; Min = Minimum; Max = Maximum; M = Median; SD = Standard Deviation; Ck = Coefficient of Kurtosis; Cs = Coefficient of Skewness; CV = Coefficient of Variation

of saline soils at 135.7 and 86.18 mS m^{-1}, as shown by Yan *et al.* (2007c) and Yan *et al.* (2008). In non-saline soils, Machado *et al.* (2006) and Aimrun *et al*. (2007) have obtained average apparent soil electrical conductivity values of 5.2 and 5.67 mS m^{-1}, respectively. These mean values of electrical conductivity are still higher than those found in this study. However, much lower than the values determined in saline soils.

Despite the low values of electrical conductivity, the average apparent soil electrical conductivity values were well within the range of the electrical conductivity of soil extract (1:5) that were determined in the laboratory, which confirm the results from other studies (CORWIN; LESCH, 2003; CORWIN; LESCH, 2005b; MORAL *et al*., 2010; YAN *et al*., 2007c). These observed low values may have resulted from a low cation exchange capacity of the soil, as reported by Corwin and Lesch (2005b). The cation exchange capacity of soil is related to the amount and type of clay and organic matter content in the soil. Although the soil has high clay content, probably, the clay itself has a low quality. Moreover, as shown in Table 1, the measured soil has a low organic matter content, which influences reflects a low cation exchange capacity and, consequently, low electrical conductivity.

The minimum and maximum values of conductivity were 0.40 and 5.24 mS m^{-1}, respectively. This amplitude is less than that obtained by Machado *et al*. (2006), who recorded minimum and maximum conductivities of 1.90 and 13.70 mS m^{-1}, respectively. Aimrun *et al*. (2007) obtained minimum and the maximum values of 0.90 and 64.10 mS m^{-1}, whereas Faulin and Molin (2006) obtained values of apparent soil electrical conductivity ranging from 0.60 to 16,6 mS m^{-1}. These differences in amplitude may not relate to soil moisture conditions. As shown in Table 2, for the 15 water retention curves that were obtained in this study, it was found that the soil during the electrical conductivity measurements was at or near field capacity. Thus, the amplitude of variation was low, probably due to the low cation exchange capacity, as shown in Table 1.

The ranking of the Pearson's correlation coefficients between EC20, EC40, and the soil properties are presented in Table 3. The results in Table 3 indicate that EC20 and EC40 strongly correlate to each other (0.896), which agree with result obtained by Vitharana *et al*. (2008) in a similar study. EC40 exhibited higher correlation coefficients with most soil properties in comparison to EC20. This may be due to major changes in the physical and the chemical characteristics that occur near the soil's surface, which increase the oscillation of EC20 and reduce the coefficient of correlation.

In general, EC20 and EC40 had low correlations with soil properties. The highest correlation coefficients for EC20 and EC40 were found for remaining phosphorus, which had values of 0.427 and 0.465, respectively. Moreover, EC20 and EC40 did not show significant correlations with the physical properties of soil, except for the silt content.

The recommended phosphorus dosage for crops can be obtained as a function of the remaining phosphorus and the clay content. In soils that have been classified as Typic Hapludox (SOIL SURVEY STAFF, 2006), higher clay and oxide contents correlate with lower remaining phosphorus contents due to a higher phosphorous adsorption capacity of the soil. If silt and sand were exclusively composed of primary minerals, soil with a high content of these two types of particles would be expected to have a low phosphorous adsorption capacity (DONOGEMMA *et al.*, 2008); however, Typic Hapludox soils have silt-sized microaggregates that are formed by the cementing action of Fe and Al^{3+} oxides. Thus, the apparent soil electrical conductivity becomes an alternative for the estimation of the available phosphorus.

Several authors (LESCH *et al.*, 2005; MACHADO *et al.*, 2006; MOLIN; CASTRO, 2008) have shown strong correlations between the soil electrical conductivity and the clay content, whereas

Table 2 - Soil retention curve

Soil Sample Number	Soil Moisture (kg kg^{-1})	Potential kPa				
		-10	-30	-100	-500	-1500
		---------------------------Soil Moisture (kg kg^{-1})------------------------				
1	0.344	0.367	0.331	0.306	0.278	0.241
2	0.337	0.312	0.293	0.268	0.24	0.229
3	0.357	0.327	0.301	0.276	0.248	0.226
4	0.285	0.267	0.245	0.22	0.192	0.176
5	0.358	0.355	0.332	0.307	0.279	0.235
6	0.314	0.323	0.304	0.279	0.251	0.229
7	0.327	0.318	0.296	0.271	0.243	0.225
8	0.362	0.332	0.316	0.291	0.263	0.242
9	0.329	0.32	0.294	0.269	0.241	0.228
10	0.417	0.376	0.334	0.309	0.281	0.257
11	0.294	0.306	0.279	0.254	0.226	0.201
12	0.281	0.273	0.255	0.23	0.202	0.175
13	0.315	0.354	0.311	0.286	0.258	0.228
14	0.313	0.305	0.27	0.245	0.217	0.189
15	0.258	0.275	0.244	0.219	0.191	0.173

Table 3 - Ranking of the Pearson's correlation coefficient between the soil properties and apparent soil electrical conductivities for 0 to 0.20-m and 0 to 0.40-m soil layers

Ranking	Soil Property	EC20(1)	Ranking	Soil Property	EC40(2)
1	EC40	0.896	1	EC20	0.896
2	P-rem(3)	0.427	2	P-rem	0.465
3	Mn	0.377	3	Mn	0.457
4	V(4)	0.375	4	V	0.402
5	CEC t(5)	0.352	5	CEC t	0.393
6	Ca^{2+}	0.346	6	Ca^{2+}	0.386
7	SB(6)	0.342	7	SB	0.374
8	H + Al(7)	-0.314	8	K	0.318
9	K	0.287	9	H + Al	-0.297
10	pH(8)	0.275	10	pH	0.286
11	Mg^{2+}	0.231	11	Zn	0.245
12	OM(9)	-0.205	12	Mg^{2+}	0.23
13	m(10)	-0.202	13	Silt	0.195
14	Silt	0.194	14	m	-0.179
15	Zn	0.174	15	OM	-0.178
16	Fe	-0.174	16	P	0.158
17	Al^{3+}	-0.161	17	CEe(1:5)	0.156
18	Soil Moisture	NS	18	Soil Moisture	NS
19	P	NS	19	Al^{3+}	NS
20	CEC T(11)	NS	20	CEC T	NS
21	Cu	NS	21	Fe	NS
22	CEe(1:5)(12)	NS	22	Cu	NS
23	Coarse Sand	NS	23	Coarse Sand	NS
24	Fine Sand	NS	24	Fine Sand	NS
25	Clay	NS	25	Clay	NS

[1]/ EC20, apparent soil electrical conductivity for the 0 to 0.20 m layer; [2]/ EC40, soil apparent electrical conductivity for the 0 to 0.40 m layer; [3]/P-rem, remaining phosphorous; [4]/ V, basis saturation; [5]/ CEC t, effective cation exchangeable capacity; [5]/SB, exchangeable sum of basis; [7]/ H + AL, potential acidity; [8]/ pH, active acidity in water; [9]/OM, organic matter; [10]/ m, aluminum saturation; [11]/ CEC T, cation exchangeable capacity at a pH of 7; [12]/ CEe 1:5, electrical conductivity in the extract of soil to water ratio (1:5); NS - Not Significant at the 5%

others (AIMRUN *et al.*, 2007; CARROLL; OLIVER, 2005; CORWIN; LESCH, 2005b; CAMBOURIS *et al.*, 2006; CORWIN *et al.*, 2006; MORARI *et al.*, 2009) have not found any such correlations. The results of this study indicate that the correlation between apparent soil electrical conductivity and clay content was either low or absent. The observed low correlation coefficient may be due to the low coefficient of variation of the clay content. Although electrical conductivity did not exhibit any correlation with the clay content, its correlation with the remaining phosphorus was related to variability in physical-chemical, mineralogical, and soil texture characteristics (EBERHARDT *et al.*, 2008; SILVA *et al.*, 2010; SOUZA *et al.*, 2006).

The soil moisture content was not correlated with the apparent soil electrical conductivity, which is probably due to the low coefficient of variation for soil moisture. While studying the influence of soil moisture on the apparent soil electrical conductivity, Faulin and Molin (2006) concluded that when the amplitudes of variation in clay and moisture content were high, higher correlation coefficients between electrical conductivity with soil moisture and clay content were found. The authors worked in two different areas for two consecutive years and obtained coefficients of variation for moisture content that ranged from 7.30 to 30.51% and for clay content that ranged from 15.86 to 42.47%, respectively. The coefficients of variation for the clay and soil moisture content that were obtained in the present study are also considered to be low, with values of 9.14 and 12.40%, respectively. These findings explain why there was no relationship between the moisture content and the soil electrical conductivity.

CONCLUSIONS

1. The average values of apparent soil electrical conductivity were low compared to values observed for saline soils and soils with high values of cation exchange capacity;
2. The apparent soil electrical conductivity using electrode distances of 0.00 to 0.20 m and 0.00 to 0.40 m exhibited strongly correlate to each other;
3. The highest correlation coefficient was found between the apparent soil electrical conductivity and the remaining phosphorus;
4. There was no significant correlation between the apparent soil electrical conductivity and the clay content;
5. The soil moisture content was not correlated with the apparent soil electrical conductivity.

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