The influence of soil moisture on the spatial and temporal variability of soil electrical conductivity

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Abstract

Soil electrical conductivity (EC) is a soil quality indicator that is associated to attributes of interest for site-specific soil management such as soil moisture and texture. The present study performed spatial monitoring of soil moisture in two experimental fields of Brazilian soils for two consecutive years and modeled its influence on soil EC. Soil EC, moisture and clay content were evaluated by statistical, geostatistical and regression analyses. Semivariogram models, adjusted for soil moisture, had strong spatial dependence, but the relationship between soil moisture and soil EC was obtained only in one of the experimental fields, where soil moisture and clay content range was higher. In this same field, the correlation coefficients between soil moisture and clay content were above 90%. In the second field, the low soil moisture and clay content range explain the absence of a relationship between soil electrical conductivity and soil moisture.

Keywords: precision agriculture, soil physics, geostatistics, soil sensors

Introduction

Soil electrical conductivity (EC) has been shown to be an effective and rapid indicator of soil variability and production potential (Corwin et al., 2003; Corwin & Lesch, 2005). This is associated to soil attributes of interest in precision agriculture. An EC model developed by Rhoades & Corwin (1990) describes three conduction pathways: (i) between alternate layers of soil particles and soil solution, (ii) through continuum soil solutions, and (iii) through or between soil particle surfaces directly in contact with each other. Therefore, in addition to soil moisture content, EC is associated to soil salinity, clay content and cation exchange capacity, clay minerals, pore size and distribution, organic matter and temperature (Sudduth et al., 2001). EC was also shown to indicate soil texture variability, i.e., EC is higher in soils with high clay content and lower in soils with high sand content (Molin & Castro, 2008).

Commercial devices for rapid EC determination provide useful information for decision-making in crop management (Siri-Prieto et al., 2006). However, the quality of EC information on Brazilian soils is poor. This information is important for tropical agricultural soils, especially because they usually have low levels of dissolved salt. Since EC, texture and moisture are expected to be correlated, the present study performed spatial monitoring of soil moisture in two experimental fields with different texture over two consecutive years and evaluated the influence of moisture on soil EC. The results provide new insight on the interpretation of EC information for tropical soils and on its relationship with soil moisture.

Material and methods

This study was carried out in two fields with different soil texture. Field 1 (24º 32'S 50º 21'W), covers 18.9 ha, with a mean altitude of 826 m and dystrophic red latosol (oxisol) with moderate A horizon and medium texture. Field 2 (22º 41'S 49º 59'W) covers 22.2 ha, with a mean altitude of 533 m, and predominance of alic red latosol (oxisol) with moderate A horizon and medium texture. Soil EC was measured with a Veris 3100® direct-contact sensor (Veris Technologies, Inc., Salina, KS, USA) passing along parallel lines through the fields. The sensor concentrates the readings at down to 0.3 m or 0.9 m. In the present study, only the shallowest soil layer (0.3 m) was evaluated. Field 1 was studied in October 2003 and June 2004 and Field 2 in October 2003 an October 2004. While the sensor was pulled over the fields, soil samples were collected and georeferenced to determine moisture content in the 0.3 m layer. The samples were taken to the laboratory, weighed, oven dried at 105ºC until mass stabilization and weighed again to determine gravimetric soil moisture content. To determine soil texture by Bouyoucos's method, 5 sub-samples were collected at each sampling site. After an exploratory and discrepant data analyses the spatial dependence analyses were conducted and data were interpolated by ordinary block kriging using Vesper 1.6 software, which generates raster maps with 10 m x 10 m pixels. Regression analysis was used to evaluate the interdependence of the attributes studied. EC, moisture and clay content values were interpolated to obtain coefficients of determination (r^2).

Results and discussion

The attributes studied had similar mean and median values, although medians were in general lower and some asymmetrical distributions were observed (
Table 1). According to Cambardella et al. (1994), this indicates that atypically distributed data does not affect the measures of central tendency.

Table 1. Exploratory statistics for soil EC (mS m^{-1}), moisture (%) and clay (%) content.

Year	Variable	Number of Points[1]		Mean	Median	Min.	Max.	SD[2]	CV[3]	Asym.[4]	Kurt.[5]
		Initial	Final						(%)		
				Field 1							
	EC	5004	5003	4.1	3.6	1.0	12.9	1.8	43.5	0.86	0.28
03	Moisture	83	83	16.2	14.8	10.3	27.6	4.6	28.6	0.78	-0.37
	EC	8472	8472	3.0	2.4	0.6	13.1	1.7	57.4	1.08	0.92
04	Moisture	84	84	15.6	14.2	9.2	26.6	4.8	30.5	0.68	-0.60
	Clay	42	42	21.5	18.9	11.5	42.3	9.1	42.5	0.90	-0.45
				Field 2							
	EC	10402	10388	6.2	6.1	2.9	16.6	1.3	21.5	0.70	1.70
03	Moisture	63	63	12.4	12.3	9.5	14.5	1.3	10.8	-0.46	-0,65
	EC	8734	8529	8.3	8.2	3.9	12.7	1.7	20.2	0.16	-0,12
04	Moisture	33	32	12.2	12.1	10.1	13.6	0.9	7.3	-0.27	-0,32
	Clay	92	92	23.1	23.0	16.1	36.2	3.7	15.9	0.80	1.48

[1]Before and after removing the outlier data identified by exploratory analyses, [2]Standard deviation; [3]Coefficient of variation; [4]Asymmetry; [5]Kurtosis

Field 2 had lower attribute variation than Field 1. According to the classification proposed by Warrick & Nielsen (1980), CVs in Field 1 can be considered moderate, whereas in Field 2 they were low for moisture content and moderate for soil EC and clay content. Corwin et al. (2003) and Corwin & Lesch (2005) found similar CV values in North American soils.

Table 2 shows semivariogram models and parameters. The attributes were fitted to the spherical model over a two-year period, except for soil EC in Field 2, which was fitted to the exponential model.

Table 2. Semivariogram models and parameters fitted to the soil attributes studied.

Year	Attribute	Model	C_0	Sill (C_1)	R (m)[3]	DR (%)[4]	SDD[5]	RSS[6]
				Field 1				
03	EC	Sph.[1]	0.1352	2.9402	135.9	4.60	Strong	8.69E-03
	Moisture	Sph.[1]	0.0001	0.0633	168.7	0.16	Strong	6.71E-05
04	EC	Sph.[1]	0.1358	2.6778	140.8	5.07	Strong	3.00E-02
	Moisture	Sph.[1]	0.0090	19.3800	148.9	0.05	Strong	30.76
	Clay	Sph.[1]	0.0002	0.1509	153.0	0.13	Strong	1.17E-03
				Field 2				
03	EC	Exp[2]	0.8284	1.3195	24.5	62.79	Mod.[7]	6.83E-04
	Moisture	Sph.[1]	0.0001	0.0122	185.4	0.83	Strong	9.16E-05
04	EC	Exp.[2]	0.6555	1.4109	21.2	46.47	Mod.[7]	6.79E-03
	Moisture	Sph.[1]	0.0003	0.0062	361.1	4.76	Strong	2.20E-06
	Clay	Sph.[1]	0.0122	0.0240	307.3	50.41	Mod.[7]	3.19E-05

[1] Spherical; [2] Exponential; [3] Range (m); [4] Dependence ratio; [5] Spatial dependence degree; [6] Residual sum of squares; [7] moderate.

According to the $C_0/(C_0+C_1)$ ratio, the attributes studied had moderate to strong spatial dependence, showing that their spatial distribution was not randomized (Cambardella et al.,1994). This finding corroborates earlier studies that found strong spatial dependence of soil moisture at 0 to 0.25 m depth (Grego & Vieira, 2005). In Field 1, spatial dependence explains 95.4% of total EC variation in 2003 and 94.9% in 2004, with random error caused by a nugget effect of 4.6% and 5.1%, respectively. In Field 2, random errors in EC were 62.8% in 2003 and 46.5% in 2004. These errors are associated to lower spatial dependence of EC variation in Field 2 compared to Field 1.Table 3 shows the coefficients of determination (r^2) from regression analyses between EC and soil moisture and clay levels. These correlations were significant (F test, $P<0.01$) except for clay content in Field 2 in 2004 (F test, $p<0.1$).

Table 2. Regression analyses between EC and soil moisture and clay levels.

			Moisture level		Clay level	
	Field	Year	r^2	F	r^2	F
EC	1	2003	0.77	*	0.73	*
		2004	0.74	*	0.72	*
	2	2003	0.04	*	0.00	*
		2004	0.09	*	0.00	ns

* F test, significant at $p<0.01$; ns = F test, non-significant ($p>0.01$)

The coefficient of determination (r^2) between soil EC and clay content in Field 1 was similar to those reported in earlier studies, where r^2 values ranged from 0.50 (Johnson et al., 2001) to 0.76 (Corwin et al., 2003). Regression analyzes between soil EC and moisture level in Field 1 was 0.73 in 2003 and 0.74 in 2004. An important result was reading repetition over the two years. The fact that EC reading varied as a function of soil moisture at reading time suggests that it is a good soil quality indicator that is magnified by moisture level, which in turn depends on soil texture. In Field 2, r^2 was close to zero between EC and soil moisture and null between EC and clay content, indicating the weak or even absent correlation between EC and these variables. The expected attribute relationships were not obtained in Field 2, likely because it had lower clay and moisture ranges than Field 1, i.e., lower spatial variability of the attributes, illustrated by lower spatial dependence. The relationships between the attributes were well evidenced in Field 1. In this case, soil EC can be used to delineate management zones as a function of soil clay content. This was indeed highly correlated with moisture levels in 2003 (r^2=0.93, p<0.0001) and 2004 (r^2=0.92, p<0.0001). Soil EC reading depends on soil texture and moisture availability, which are spatially variable attributes that may further affect productivity.

Conclusions

Soil moisture content exhibits a high degree of spatial dependence. A correlation between moisture and EC was found only in experimental Field 1, which had a higher soil moisture range. An important result is data repetition over the years, suggesting that EC is a qualitative indicator in areas with high spatial variability in soil texture. In Field 2, where soil moisture range was lower, EC was not associated to moisture level.

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References

Cambardella, C.A., Moorman, T.B., Novark, J.M., Parkin, T.B., Karlen, D.L., Turco, R.F., Konopka, A.E. 1994. Field-scale variability of soil properties in central Iowa soils. Soil Sci. Soc. Am. J., Madison, v.58, n.5, p.1501-1511.

Corwin, D.L., Lesch, S.M., Shouse, P.J., Soppe, R., Ayars, J. E. 2003. Identifying soil properties that influence cotton yield using soil sampling directed by apparent soil electrical conductivity. Agron. J., Madison, v.95, n.2, p.352-364.

Corwin, D.L., Lesch, S.M. 2005. Characterizing soil spatial variability with apparent soil electrical conductivity Part II. Case study. Comput. Electron. Agric., Oxford, v.46, n.1-3, p.135-152.

Grego, C.R., Vieira, S.R. 2005. Variabilidade espacial de propriedades físicas do solo em uma parcela experimental. Rev. Bras. Ciênc. Solo, Viçosa, v.29, n.2, p.169-177.

Johnson, C.K., Doran, J., Duke, H.R., Wienhold, B.J., Eskridge, K., Shanahan, J.F. 2001. Field-scale electrical conductivity mapping for delineating soil condition. Soil Sci. Soc. Am. J., Madison, v.65, n.6, p.1829-1837.

Molin, J.P., Castro, C.N.D. 2008. Establishing management zones using soil electrical conductivity and other soil properties by the fuzzy clustering technique. Scientia Agricola, Piracicaba, v.65, n.6, p.567-573.

Rhoades, J.D., Corwin, D.L. 1990. Soil electrical conductivity: effects of soil properties and application to soil salinity appraisal. Comm. Soil Sci. Plant Anal., Philadelphia, v.21, n.11/12, p.837-860.

Siri-Prieto, G., Reeves, D.W., Shaw, J.N., Mitchell, C.C. World's oldest cotton experiment: Relationships between soil chemical and physical properties and apparent electrical conductivity. Comm. Soil Sci. Plant Anal., Philadelphia, v.37, n.5-6, p.767-786, 2006.

Sudduth, K.A., Drummond, S.T., Kitchen, N.R. 2001. Accuracy issues in electromagnetic induction sensing of soil electrical conductivity for precision agriculture. Comput. Electron. Agric., Oxford, v.31, n.3, p.239-264.

Warrick, A.W., Nielsen, D.R. 1980. Spatial variability of soil physical properties in the field. In: D. Hillel (Ed.). Applications of soil physics. New York: Academic Press, 385 p.