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High-resolution mapping with on-the-go soil sensor and its relation with corn yield and soil acidity in a dystrophic Red Oxisol

G. M. Corassa[1], T. J. C. Amado[2], R. A. Schwalbert[1], G. B. Reimche[2], D. Dalla Nora[2], T. A. N. Horbe[2], F. M. Tabaldi[2]

[1] Department of Agricultural Engineering, Federal University of Santa Maria, Roraima Av., 1000, 97105-900, Santa Maria, Rio Grande do Sul, Brazil.

[2] Department of Soil Science, Federal University of Santa Maria, Roraima Av., 1000, 97105-900, Santa Maria, Rio Grande do Sul, Brazil.

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Abstract. *Spatial representations of soil attributes with low resolution can lead to gross errors of recommendation and compromise the efficiency of soil corrections and consequently the grain yield. However, obtaining the spatial variability of soil attributes with high resolution by soil sampling is not recommended because of its large time spent and high cost of laboratory analysis what makes difficult their large-scale application. This way, the on-the-go soil sensing has been used in precision agriculture (PA), but, studies are still incipient in Red Oxisols in Southern Brazil. The aims of this study were to examine relationships between soil electrical conductivity apparent (ECa), measured through the on-the-go sensor, with soil properties and corn yield, besides mapping with high resolution the main acidity attributes of Southern Brazil dystrophic Red Oxisol. The mobile soil sensing was performed in two fields with 42 and 39 ha located in northwest of Rio Grande do Sul State, Brazil using the sensor VERIS 3100. It has been calibrated to operate in depths of 0-30 cm and 0-90 cm. The soil sampling was performed using an auger at 0-15 cm depth. The yield grain was obtained by used of yield sensor installed on the combine. The ECa was related with corn yield, cation exchange capacity, sum of bases, and calcium and magnesium content, in both fields, having yet relationship with soil acidity properties at the low chemical quality field. The ECa was an efficient indirect method of getting high-resolution soil acidity mapping in a dystrophic Red Oxisol. Once, the*

ECa sensing on-the-go calibrated to the soil type and crop investigated, and being combined with site-specific soil sampling it becomes an effective strategy for the spatial high-resolution chemical attributes allowing adequate prescription variable rate correctives and soil conditioners.

Keywords. *Precision agriculture, electrical conductivity, soil attribute.*

Introduction

The spatial variability knowledge of physical-chemical attributes in agricultural soils is a pre requirement to adopt the specific site management of soil and plants (Adamchuk et al., 2007). This characterization is traditionally made through the direct soil sampling, which demands a high amount of field work, and associated to time and the analysis cost difficult your application in large scale (Machado et al., 2006). In this sense, it has been growing the interest for tools that supply an intensive amount of data by area in a short period of time (Adamchuk et al., 2007), with low costs, (Machado et al., 2006), and capable of indirectly characterize the spatial variability of soil attributes and the vegetal performance in agricultural areas (Corwin et al., 2006; Adamchuk et al., 2007).

In this way, the soil apparent electrical conductivity (ECa) has been used in precision agriculture (PA) as a predictive tool for physical-chemical attributes in the soil (Lund et al., 1999; Corwin et al., 2006; Machado et al., 2006; Peralta & Costa, 2013). The most recent systems for ECa on-the-go measurements are mobile equipments that are able to move quickly through the field enabling the sensing of a large agricultural area.

Based on the ECa, Corwin et al. (2006) efficiently spatialize the soil quality in agricultural areas on the California state. Peralta & Costa (2013) reported the efficient of ECa in definition of management zones in Argentina. Sana et al. (2014) observed a relationship between the ECa and the acidity components in a Dystrophic Red Oxissol in Goias state, Brazil. In the same way, Carmo (2014) working with EC measured in laboratory, found a high relationship with attributes of soil acidity in seven soils from Minas Gerais state, Brazil. The author has concluded after calibration studies that the ECa could be indirectly used to estimate a liming requirement. Since the EC presents a high relationship with ECa (Lund et al., 1999), the on-the-go system could reduce the time and expenses with soil sampling and it would support the adoption of site-specific management strategies.

The aims of this study were to examine relationships between the ECa, measured through an on-the-go sensor, with soil properties and corn yield. Moreover, mapping with a high resolution the main attributes of acidity in a dystrophic Red Oxisol in the Southern of Brazil.

Material and Methods

The study was conducted in two close fields located in the city of Carazinho in Rio Grande do Sul state, Brazil. The experimental field 1 has 41 ha and it is located in the 52°43'29,5"W and 28°19'02,47"S geographical coordinates, while the field 2 has 39 ha and it is located in the 52°43'56,84"W and 28°19'30,78"S geographical coordinates. The fields have been managed in a no-till system since 20 years ago. The system follows a crop rotation with wheat (*Triticum aestivum* L.) or black oats (*Avena strigosa* Schreb.) during the winter, and soybeans (*Glycine max* L.) or corn (*Zea mays* L) during the summer, having a predominance of the legume crop in the summer. In both areas the soil is classified as a dystrophic Red Oxissol with a clay texture.

The ECa readings were made before the crop planting using the Veris 3100 sensor (Lund et al., 1999). The sensor was calibrated following the company instructions and it was set to operate in the

0-30 and 0-90 cm depths. Transects spaced in 20 meters were used throughout the field to do the ECa readings (Lund et al., 1999). The soil samplings were made after the ECa readings and right before the corn planting, using a soil auger in a depth of 15 cm. In the field 1 were collected 23 soil samples delimited with a grid sample of 2 ha. In the second field, 11 points were allocated according to the ECa zones (Peralta & Costa, 2013). Each sample consisted of 8 cores collected randomly around the georeferenced point in a radius of 3 meters. It was used a portable differential global positioning system (DGPS) to locate the point samples in both experimental fields.

The physical-chemical soil attributes evaluated in the analysis were the clay content (g kg^{-1}), pH H_2O (1:1 relationship), Aluminum (Al^{3+}, $cmol_c$ dm^{-3}), Calcium (Ca^{2+}, mg dm^{-3}) and Magnesium (Mg^{2+}, mg dm^{-3}) exchangeable (extracted by KCl 1 mol L^{-1}), Phosphorus (P, mg dm^{-3}) and Potassium (K^{+}, mg dm^{-3}) (extracted by $Mehlich^{-1}$), besides the Sum of Basis (SB, $cmol_c$ dm^{-3}), Cation Exchangeable Capacity (CEC effective and CEC in pH 7.0, $cmol_c$ dm^{-3}), Bases Saturation (V, %) and Aluminum Saturation (m, %) (Tedesco et al., 1995).

The corn crop was planted in September 12, 2012 in the field 1 and September 17 in field 2, and the Pionner 30F53H® was the hybrid planted. The corn yield production was registered with a TC59 New Holland harvester equipped with a NH PLMS (AgLeader) flow and humidity sensor, and a Trimble® GPS with correction for internal algorithm. The ECa points, soil attributes and corn yield production should coincide, thus the data were filtered in function of the soil sampling points, calculating the mean value in function of the neighbors points in a radius of 15 meters. On this way, each yield production point was represented by an average of 55 to 60 readings and the ECa by 12 to 15 readings. Data were submitted to a descriptive statistical analysis and the Pearson linear correlation analysis ($p \leq 0.05$) through the R 3.1.3 (R Core Team, 2015) statistical analysis program. The attributes were spatialized using the cokriging as the interpolation method, and the relationship between the ECa and the corn yield production was obtained by a polynomial regression analysis ($p \leq 0.05$). After polynomial adjustments, it was established the ECa classes in function of relative corn yield.

Results and Discussion

For the field 1, the shallow ECa presented positive and significant coefficients ($p<0.01$) for Ca^{2+}, Mg^{2+}, pH H_2O, SB, V and CEC ($p<0.05$) (Table 1). The same attributes, except for the CEC, presented positive correlation ($p<0.01$) with the deeper ECa. For the field 2, positive ECa correlations ($p<0.01$) were found with Ca^{2+}, Mg^{2+}, CEC and SB, which directly affect the corn yield production (Dalla Nora & Amado, 2013). Furthermore, SOM and clay content had positive correlation ($p<0.01$) with ECa (Table 1). Same as observed in the field 2, many papers reported a high correlation between ECa and clay content (Machado at al., 2006; Molin & Castro, 2008). Negative correlations were obtained between the ECa and Al^{3+}, $H+Al^{3+}$ and m levels in the field 1, which presented a lower chemical quality in the soil acidity attributes. In both experimental fields, it was observed a high correlation ($r=0.98$; $p<0.01$) between the shallow and deeper ECa layers agreeing with reported data of Sana et al. (2014). Therefore, it was chosen to use for the following analysis only the deeper ECa layer, since it is more stable through the years in comparison to the shallow ECa (Peralta & Costa, 2013).

Table 1. Coefficient of correlation between soil physical-chemical attributes, apparent electrical conductivity (ECa) and corn grain yield for the experimental field 1 and 2.

Attribute[1]	Field 1			Field 2		
	ECa shallow	ECa deep	Grain yield	ECa shallow	ECa deep	Grain yield
ECa shallow (mS m^{-1})	-	0.98^{**}	0.70^{**}	-		0.89^{**}
CEa deep (mS m^{-1})	0.98^{**}	-	0.77^{**}	0.98^{**}	-	0.90^{**}
pH H_2O	0.84^{**}	0.83^{**}	0.60^{**}	ns	ns	ns
Al^{3+} ($cmol_c$ dm^{-3})	-0.80^{**}	-0.82^{**}	-0.66^{**}	ns	ns	ns
$H+Al^{3+}$ ($cmol_c$ dm^{-3})	-0.79^{**}	-0.78^{**}	-0.47^{*}	ns	ns	ns
Ca^{2+} ($cmol_c$ dm^{-3})	0.88^{**}	0.86^{**}	0.61^{**}	0.79^{**}	0.74^{**}	0.76^{**}
Mg^{2+} ($cmol_c$ dm^{-3})	0.89^{**}	0.88^{**}	0.72^{**}	0.83^{**}	0.76^{**}	0.76^{**}
K^{+} ($cmol_c$ dm^{-3})	ns	ns	ns	ns	ns	ns
CEC effective ($cmol_c$ dm^{-3})	0.87^{**}	0.84^{**}	0.59^{**}	0.77^{*}	0.72^{**}	0.75^{**}
$CEC_{7,0}$ ($cmol_c$ dm^{-3})	0.42^{*}	ns	0.44^{*}	0.79^{**}	0.76^{**}	0.83^{**}
SB ($cmol_c$ dm^{-3})	0.88^{**}	0.86^{**}	0.62^{**}	0.85^{**}	0.79^{**}	0.80^{**}
P (mg dm^{-3})	ns	ns	ns	ns	ns	ns
V (%)	0.88^{**}	0.87^{**}	0.58^{**}	ns	ns	ns
m (%)	-0.79^{**}	-0.82^{**}	-0.69^{**}	ns	ns	ns
Clay (g kg^{-1})	ns	ns	ns	0.85^{**}	0.79^{**}	0.79^{**}
SOM (%)	ns	ns	ns	0.86^{**}	0.85^{**}	0.74^{**}
Vigor index (VI)	0.81^{**}	0.83^{**}	0.90^{**}	-	-	-
Grain yield (Mg ha^{-1})	0.70^{**}	0.77^{**}	-	0.89^{**}	0.90^{**}	-

[1]Al^{3+}=Aluminum; Ca^{2+}=Calcium; Mg^{2+}=Magnesium; K^{+}=Potassium; CEC= Cation Exchange Capacity; SB= Sum of Basis; P=Phosphorus; V=Basis saturation; m= Aluminous saturation; SOM=Soil organic matter. (*) Significant at 5%; (**) Significant at 1%; (ns) = Not significant

The figure 1 presents the ECa spatialization for the dystrophic Red Oxissol investigated in this study, which has the aim of guiding a program of variable rate correction.

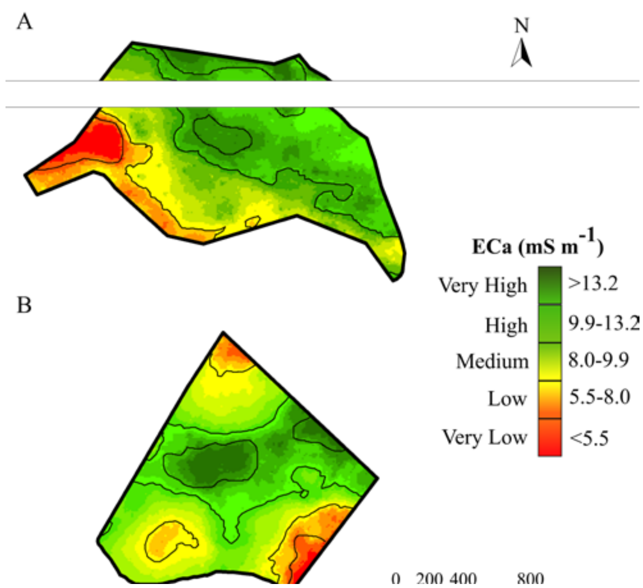

Fig 2. High-resolution spatialization of soil apparent electrical conductivity (ECa) measured by the 3100 Veris sensor for the field 1 (A) and 2 (B) enabling the variable rate of soil correctives and fertilizers. ECa zones delimited based on the corn relative yield production for both Red Oxissol studied.

The agronomical efficiency of these strategies should be evaluated in future experiments. Once the on-the-go ECa sensing is calibrated for a soil type and a desired crop, and combined with a soil sampling based on zones, it will be an efficient tool to spatialize the chemicals attributes of the soil with a high resolution aiming a variable rate application.

Conclusions

In a dystrophic Red Oxissol, the ECa presents a correlation with corn yield production. In the field with a lower chemical quality for acidity attributes (< pH H_2O, > Al^{3+} and > m), the ECa presents a positive correlation with Ca^{2+}, Mg^{2+}, pH H_2O, V, CS e CEC and negative with Al^{3+}, m and $H+Al^{3+}$. In the field with better chemical quality, the ECa presents correlation with Ca^{2+}, Mg^{2}, OM and clay content. The ECa sensing on-the-go calibrated to the soil type and crop investigated, and being combined with site-specific soil sampling it becomes an effective strategy for the spatial high-resolution chemical attributes allowing adequate prescription variable rate correctives and soil conditioners.

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