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Low cost aparatus for aparent soil electrical conductivity measurment based on direct currente

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ABSTRACT: Soil Electrical Conductivity (ECa) has been used as one of the tools to aid decision-making process in the realm of Precision Agriculture. Due to the lack of research regarding ECa in the Northen part of Mato Grosso, the difficulty to access the commercial available ECa tools given the high acquisition cost and the large demand of studies in the region which is the major grain producing state in the country, the objective of this study was to develop a low cost system for ECa measurement based on DC current. The apparatus was based on the classic measurement method known as "four electrode method", and the data acquisition setup was built based on a low microcontroled board utilizing modules for data storage and visualization. The tests for evaluating the setup capacity to measure the necessary parameters for ECa calculations, was accomplished utilizing digital multimeters as references for measuring the voltages differences across the reference resistor and output probes. Simple regression analyses was accomplished to evaluate the dada showing promising results and indicating that the developed setup was able to measure the necessary parameters for soil ECa calculation.

Keywords: precision agriculture, management zone, soil attributes.

Aparato de baixo custo para determinação da condutividade elétrica aparente do solo com base em corrente contínua

RESUMO: O mapeamento da condutividade elétrica aparente (CEa) do solo tem sido utilizado como uma das ferramentas de auxílio à tomadas de decisão no âmbito da Agricultura de Precisão. Devido à escassez de pesquisas na região Norte de Mato Grosso e a dificuldade de acesso às ferramentas de mapeamento de CEa devido ao alto valor de aquisição, objetivou-se desenvolver um sistema de baixo custo para determinação da CEa com base em corrente contínua. O aparato foi confeccionado com base no método clássico de mensuração direta da CEa conhecido como "método de quatro pontas" e o sistema de aquisição e armazenamentos de dados foi desenvolvido em placa microprocessada, utilizando módulos adaptadores para armazenamento e visualização de dados. Os testes para determinação dos parâmetros necessários para obtenção da CEa foram conduzidos em modo pontual, utilizando-se multímetros digitais como referência para mensuração das diferenças de tensão no resistor de referência e nos eletrodos de leitura. Análise de regressão foi utilizada para avaliação dos dados, que se mostraram promissores e indicam que o sistema desenvolvido foi satisfatório na mensuração dos parâmetros necessários para determinar da CEa do solo.

Palavras-chave: agricultura de precisão, zonas de manejo, mapeamento de atributos do solo.

1. INTRODUCTION

Precision Agriculture is based on agronomic practices, such as fertilization, weed control, pest and disease control, which should be accomplished taking in consideration the spatial variability (ORTEGA; SANTIBÁÑEZ, 2007). One of the greatest difficulties encountered in Precision Agriculture is determining the amount of inputs to be placed in the field considering the spatial and temporal variabiliy (ANSELIN et al., 2004; BOOLTINK et al., 2001). Since soil is the base for agriculture, the search for a good interpretation of its physical and chemical phenomena lead researchers to investigate ways of measuring its reactions using advanced technological instruments (CASTRO, 2004).

One of the soil attributes that has been intensely investigated is the soil apparent electrical conductivity (ECa), which is defined as the ability of the soil to transmit electric current (KITCHEN et al., 1996). Soil ECa has a fundamental characteristic that is to provide information on water content, clay and organic matter content, and the concentration of ions in the soil solution (CASTRO; MOLIN, 2004).

Among the several methods available to measure soil ECa, the methods by electromagnetic induction and by direct contact to the soil stand out. Some precision agriculture equipment was developed with the purpose of measuring soil ECa, thus providing the possibility of creating ECa spatial distribution maps (McNEILL, 1992; FREELAND et al., 2002).

There are several commercial equipment used for soil ECa mapping based on direct contact method such as Veris 3100 (Veris® Technologies), LandMapper ERM-02 (Landviser, LLC) and 5TE (Decagon Devices). There are also commercial systems based on the indirect method such as EM 38 (Geonics Limited), GEM-300 (Geophysical Sruvey Sistems, Inc.) and the LandMapper ERM-01 (Landviser, LLC).

According to Molin; Castro (2006), one of the commercial equipment most used in the field of precision agriculture is the VERIS 3100. The authors emphasized that due to its high cost, difficulty of importation and non-availability of specialized maintenance, there are few systems available in Brazil.

Veris 3100 is based on the direct "four-electrode" method for determination of soil ECa. This method allows the ECa to be determined in non-uniform samples of undefined dimensions by using four conducting rods (electrodes) positioned at defined spacings, applying a known voltage and current (SMITS,1958; CORWIN; HEDRICKX, 2002; CORWIN; LESH, 2003).

Considering the necessity of conducting studies with soil ECa focused precision agriculture in the northern region of Mato Grosso and the difficulty of access to high cost equipment, the objective of this work was to develop and evaluate the potential of a low cost device based in direct current for the determination of the necessary parameters (voltage and current) for soil ECa calculation.

2. MATERIAL AND METHODS

In the traditional direct method of ECa determination, based on the "four-electrode" model, the electric current (*I*) is induced to the ground through the lateral electrodes and the electric potential difference (*V*) is obtained in the internal electrodes (Figure 1).

The distance between the electrodes (*Si*) defines the depth whose reading of the soil ECa will be determined. By modifying *Si*, it is possible to obtain readings at different depths along the vertical profile of the soil.

Knowing the values of *V*, *I* and *Si*, it is possible to calculate the ECa (Equation 1), in which the Resistivity (ρ) is calculated by Equation 2. Assuming the symmetry between the electrodes, the ECa calculation can be simplified according to Equation 3.

$$ECa = \frac{1}{\rho} \quad (1)$$

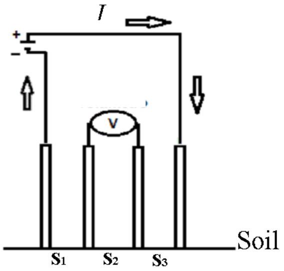


Figure 1. Four-electrode system for soil ECa determination.
Figura 1. Sistema de quatro pontas para determinação da CEa do solo.

where:

ECa - apparent electrical conductivity of the soil, in Siemens.metro (S.m).

$$\rho = \frac{2\pi\left(\frac{V}{I}\right)}{\frac{1}{S_1} + \frac{1}{S_2} - \frac{1}{(S_1+S_2)} - \frac{1}{(S_2+S_3)}} \quad (2)$$

where:

ρ - electrical resistivity, in Ω.m;
S_i - spacing between electrodes, in m;
V - electrical potential difference in volts;
I - electric current in amperes.

$$ECa = 2\pi S\left(\frac{V}{I}\right) \quad (3)$$

Based on the four-electrode model, the instrumentation of the device was developed so that it could (i) provide regulated direct current voltage to the emitter electrodes; (ii) determine the current (I) induced in the soil; and (iii) measure the electrical potential difference (V) between the receiving electrodes.

As the intention was to use the device powered by a vehicle battery (12 ± 2 Volts), it was necessary to make a regulator circuit to stabilize the voltage at 5 volts (compatible with the microprocessor board used) based on an adjustable regulator type LM317.

The measurement of the parameter *V* was accomplished using two analog ports (10 bits resolution analog to digital converter) of the microprocessed board Arduino MEGA 2560 embedded with microcontroller ATmel MEGA 2560. The determination of *I* was accomplished indirectly, using the voltage drop across the reference resistor (Rref), which allowed calculating *I* according to the Ohm's Law (Equation 4). For this purpose, two more analog ports of the microprocessed board were used.

$$V = R \times I \quad (4)$$

where:

R - resistance, in Ω.

Collected data was georeferenced using, a Garmin® LVC 18x LVC Global Navigation Satellite System (GNSS) module integrated to the data acquisition system. Communication with the GNSS module was implemented through one of the four hardware serial ports available on the Arduino Mega 2560 board using the RS232 serial communication protocol. In order to enable the communication between GNSS and board, it was necessary to use a signal converter (MAX 232) to modify the GNSS output voltage standard RS232 to the TTL (Transistor Transistor Logic) voltage level of the microcontroller. The module was configured to provide output information in the NMEA 0183 format and the information of location, time, and date was extracted from the $ GPRMC string.

Data storage was performed by using a Secure Digital (SD) card module coupled to the MEGA 2560 microprocessor board using the I2C communication protocol.

In order to visualize the data and monitor the operation of the system, an LCD (Liquid Crystal Display) module was installed.

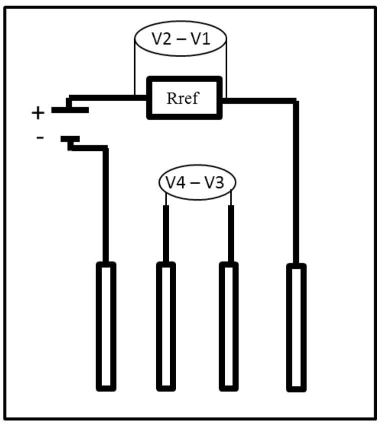
The data acquisition algorithm was developed to operate in two modes (continuous and static reading). The continuous mode enables the data aquisition system to collect data while moving the equipament. In the static mode, the the data would be collected with the equipament halted. In this mode, the user defines de number of data readings should be taken before the average value is calculated and stored. In both modes, the data regarding measured voltages, as well as the calculated electric current and soil ECa, are stored along with geographic coordinate, date and time provided by the GNSS module.

All the components, except the GNSS, were installed inside of a plastic housing in such way that the control buttons (for control mode) and the LCD (data visualization) were accessible.

In order to evaluate the developed system, two multimeters (fluke 117) were used. One was to measure voltage between the reading electrodes (V4-V3). The second multimeter was used to verify the voltage drop (V2-V1) across the reference resistor used to calculate the current applied to the ground. The multimeters were installed in the constructed device (*quadridente*) (Figure 2) to enable the tests using the static reading method. The readings were conducted in soil conditions with different moisture content to force the variability in the soild ECa.

Measurements were taken at 10 different points of soil conditions, consequently providing different levels of ECa. For each measured situation, 10 repetitions of the voltage difference V2-V1 and V4-V3 were performed. The acquired data were stored in SD card according to the collection algorithm in static mode. The data obtained with the multimeters were annotated in spreadsheet for later analysis using the simple linear regression between the data obtained with the microcontroller and with the multimeters.

A.



B.

Figure 2. Schematic representation of the developed system representing the reading points to obtain the necessary parameters for ECa calculation (A); and instrumented apparatus (*quadridente)* used to obtain data in the static mode (B).
Figura 2. Representação esquemática do sistema desenvolvido representando as pontos de leitura para obtenção de parâmetros necessários para cálculo da CEa (A); e aparato (quadridente) instrumentado utilizado para obtenção de dados em modo pontual (B).

3. RESULTS AND DISCUSSION

The instrumentation of the prototype developed to measure ECa based on direct current was accomplished using common components available in the market, which provided a low construction cost. The metal frame of the appartus was constructed with materials easily found in the market as well, mainly rigth angle profile in carbon steel. The approximate cost with material used in the construction of the developed system is presented in Table 1.

It should be noted that the approximate cost without the GNSS module would be R$ 355.00, whereas systems available in the Brazilian market for static reading can cost around R$ 5000.00 (LandMapper ERM-02 and 5TE Decagon Devices) without including the GNSS/GPS module. Systems capable large scale ECa mapping (reading in continuous mode) have considerably higher values (above R$ 60.000,00). Obviously, the developed apparatus, built for static reading is not for commercial purposes and needs to be thoroughly tested in terms of durability.

The data of the voltage difference through the reference resistor (V2-V1) is presented in the scatter plot (Figure 3) and the results of the regression analysis are presented in Table 2.

According to the t-test, the hypothesis ho: $\beta i = 0$ (slope and intersection) is rejected, indicating that there is a linear relationship between the variables obtained with the multimeter and microcontroller, as expected. The slope constant equal to one is in the 95% confidence interval and indicates that the microcontroller is responding according to the reference (multimeter), not requiring calibration for

Table 1. Material used for construction of the apparatus used to measure soil ECa (August 2014).
Tabela 1. Material utilizado para construção do aparato utilizado para mensuração da CEa do solo (Agosto de 2014).

Description	Value (R$)
Arduino Mega 2560 microprocessor board	180.00
Liquid Crystal Module (LCD) and Control Keypad	25.00
Data storage module on SD card	60.00
GNSS module	300.00
Electronic components	10.00
Material for mounting the circuits and housing of the instrumentation system	50.00
Material for construction of the device (*quadridente*)	30.00
Total	655.00

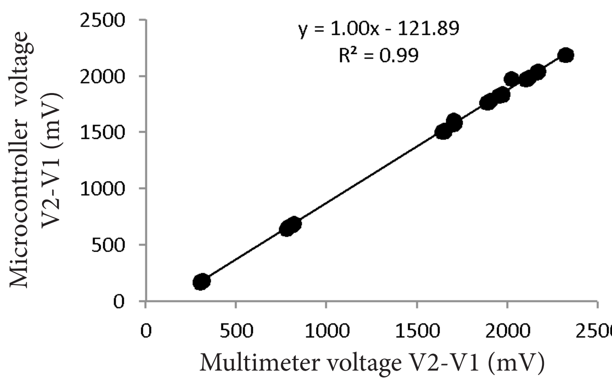


Figure 3. Scatter plot and trend line adjustment for the voltage difference data (V2-V1) through the reference resistor.
Figura 3. Gráfico de dispersão e ajuste de linha de tendência para os dados referentes à diferença de tensão (V2-V1) através do resistor de referência.

Table 2. Results of the regression analysis for the voltage difference (V2-V1) through the reference resistor.
Tabela 2. Resultados da análise de regressão para as leituras de diferença de tensão (V2-V1) através do resistor de referência.

	gl	SQ	MQ	F	P > F
Regression	1	39844278.38	39844278.38	363341.98	0.000
Residue	98	10746.73	109.66		
Total	99	39855025.12			

Coefficients		Standar error	t	P > |t|	[Confidence interval 95%]	
Intersection	-121.89	2.98	-40.85	0.00	-127.816	-115.974
Inclination	1.00	0.00	602.78	0.00	0.998	1.005

this constant. On the other hand, for intersection, the fact of being non-zero requires calibration. However, it is a simple procedure with only one calibration point to adjust the intersection of the equation.

The data of the voltage difference determined through the reading electrodes are presented in the scatter plot of Figure 4 and the results of the regression analysis are shown in Table 3.

According to the t-test, the hypothesis ho: $\beta i = 0$ is rejected for the slope and is not rejected for the intersection. The slope value equal to one within the 95% confidence interval and intersection value equal to zero, also within the 95% confidence interval, indicates that the microcontroller is responding accordingly and that no calibration of these parameters is necessary.

With the proposed system, it is possible to obtain the necessary parameters (*V* and *I*) to calculate the ECa, according

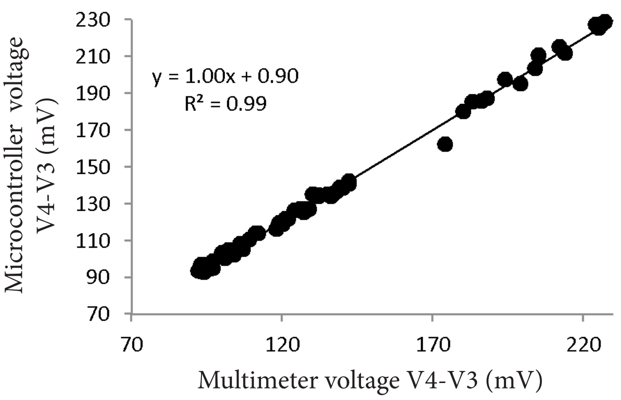


Figure 4. Scatter plot and trend line adjustment for the data related to the voltage difference (V4-V3) measured through the reading electrodes.
Figura 4. Gráfico de dispersão e ajuste de linha de tendência para os dados referentes à diferença de tensão (V4-V3) medido através dos eletrodos de leitura.

Table 3. Results of the regression analysis for the voltage difference (V4-V3) measured through the reading electrodes.
Tabela 3. Resultados da análise de regressão para as leituras de diferença de tensão (V4-V3) medido através dos eletrodos de leitura.

	gl	SQ	MQ	F	P > F
Regression	1	619556.91	619556.91	75840.22	0.000
Residue	98	800.59	8.17		
Total	99	620357.49			

Coefficients		Standar error	t	P > |t|	[Confidence interval 95%]	
Intersection	0.90	0.64	1.41	0.16	-0.369	2.176
Inclination	1.00	0.00	275.39	0.00	0.990	1.004

to Equation 3. The value of *V* was determined directly by reading of V4-V3 and the value of *I* was calculated by using the reading of V2-V1 and applying Equation 4.

4. CONCLUSIONS

The low cost developed apparatus based on direct current was effective in determining the parameters *V* and *I* (voltage and current) required to estimate the soil ECa.

Validation test using commercial systems to determine ECa of the soil was not possible to be performed and needs to be conducted to better evaluate the proposed device.

The proposed system presents great potential for use in educational research institutions, mainly due to the low cost of construction, allowing access to a widely used tool in the field of Precision Agriculture.

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