Low cost apparatus for apparent soil electrical conductivity measurement based on direct current

Fabiano Silva BARBOSA¹, Rodrigo Sinaidi ZANDONADI*¹

¹ Instituto de Ciências Agrárias e Ambientais, Universidade Federal de Mato Grosso, Sinop, Mato Grosso, Brasil.
* E-mail: zandonadi.rodrigo@gmail.com

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 microcontrolled 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.

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 variability (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
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 Survey Systems, 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; LEISH, 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.

\[
\text{EC}_\text{a} = \frac{1}{\rho} \quad (1)
\]

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

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

where:
- ρ - electrical resistivity, in Ω.m;
- S₁ - spacing between electrodes, in m;
- V - electrical potential difference in volts;
- I - electric current in amperes.

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 acquisition system to collect data while moving the equipment. In the static mode, the data would be collected with the equipment halted. In this mode, the user defines the 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 soil 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 results of the regression analysis are presented in Table 2.

The data of the voltage difference through the reference resistor (V2-V1) is presented in the scatter plot (Figure 3) and indicates that there is a linear relationship between the variables obtained with the microcontroller and with the multimeters.

![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).](image)

### 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 apparatus was constructed with materials easily found in the market as well, mainly right 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.

![Figure 3. Scatter plot and trend line adjustment for the voltage difference data (V2-V1) through the reference resistor.](image)
Table 2. Results of the regression analysis for the voltage difference (V2-V1) through the reference resistor.

<table>
<thead>
<tr>
<th></th>
<th>g1</th>
<th>SQ</th>
<th>MQ</th>
<th>F</th>
<th>P &gt; F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regression</td>
<td>1</td>
<td>39844278.38</td>
<td>39844278.38</td>
<td>363341.98</td>
<td>0.000</td>
</tr>
<tr>
<td>Residue</td>
<td>98</td>
<td>10746.73</td>
<td>109.66</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>99</td>
<td>39855025.12</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 2. Resultados da análise de regressão para as leituras de diferença de tensão (V2-V1) através do resistor de referência.

<table>
<thead>
<tr>
<th>Coefficients</th>
<th>Standard error</th>
<th>t</th>
<th>P &gt;</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Intersection</td>
<td>-121.89</td>
<td>2.98</td>
<td>-40.85</td>
<td>0.00</td>
<td>-127.816 -115.974</td>
</tr>
<tr>
<td>Inclination</td>
<td>1.00</td>
<td>0.00</td>
<td>602.78</td>
<td>0.00</td>
<td>0.998  1.005</td>
</tr>
</tbody>
</table>

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 $\beta_i = 0$ 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 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.

5. ACKNOWLEDGEMENTS

Acknowledge to the CNPq/PIBIC program for the granting of the Scientific Initiation Scholarship, year 2013/2014.

6. REFERENCES


