Automation of the analysis of soil properties from an electrical conductivity sensor using the Arduino microcontroller

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Abstract: *Due to the environmental impacts that improper handling causes to the soil, the definition of production areas using tools such as soil electrical conductivity sensors helps to perform a faster analysis of the soil type and help in the decision to be taken for soil correction. The aiming of this research was to investigate the correlation between the conductivity of the soil and its properties, in order to perceive the viability of the application of the electrical conductivity sensors in making decisions for soil correction, seeking to automate the data collection process aimed at greater efficiency in the same chemical analysis. In other words, that automation of data collection tends to work with the needs of the precision agriculture, such as looking for ways to spend less in agricultural activities and setting up ideal terms for agricultural crops. The results are promising, because they show that the sensor used with the Arduino microcontroller to measure electrical resistance of the soil may be a useful tool for measurements of some properties of the soil.*

Keywords: Precision agriculture; Electric conductivity; Soil properties.

1. INTRODUCTION

In tropical regions, macronutrients N, P, K, Ca, Mg and S (also called main nutrients) are absorbed by the plant in a larger proportion than the micronutrients B, Zn, Cu, Fe, Mo and Cl. Both are constituents of the minerals and organic matter of the substrate where the plant grows and are also dissolved in the soil solution. One or more nutrients may be almost absent in soil or in a form that the roots can't absorb. To make them available, the soil should be well managed. However, when nutrients are absent, they need to be replenished.

Following the specifications of the Brazilian Agricultural Research Corporation (Embrapa), the use of the soil generates wear of the same nutrients and its liming would be the correction of these traits, so that new plantations are made or the acidity of the soil is corrected for the same type of plantation. For this, limestone is usually inserted into the soil. However, other elements, such as potassium, can be used [EMBRAPA 2000].

The measurement of physical parameters of the soil (and in particular of the subsoil) shows that there may be significant variations in the same pasture plot. The evaluation of soil and vegetation variability in a permanent pasture is the basis for differentiated management of fertilization, which is the main improvement tool used by farmers in permanent pasture in the Alentejo region of central-southern Portugal [SERRANO et al. al. 2009]. One of the limiting factors of crop development is soil acidity. Brazilian soils are, in general, acid soils and with low availability of nutrients necessary for a higher yield of the crops. Therefore, a practice that is necessary is the correction of this acidity, creating better conditions both in soil fertility and in plants [BRAGA, 2010]. Soil analysis is the instrument the technician uses to recommend lime and fertilizer needs, improving soil fertility conditions so that plants can find the nutrients they need to respond with high yields. It is important to know these concepts so that we have a broader understanding of soil fertility conditions and management [Braga 2011].

Because of this, numerous researches have been made in the last decades, with the aim of improving the use of pesticides and fertilizers in the most diverse plantations, and the incorrect use of these resources can cause problems to the environment and also a higher cost of production.

1.1 Precision Agriculture

Precision farming emerged from machines with Global Positioning System (GPS) receivers for the purpose of generating productivity maps. The use of it has grown greatly due to advances in referencing technology, positioning and remote sensing technologies. Using these procedures, many concepts were born in agriculture, such as the Geographic Information Systems (GIS) and the application of inputs at variable rates. That is, it is a concept of agricultural production system that involves the development and adoption of management techniques, based on knowledge as the main goal of optimizing profitability. This system allows management practices to be applied using a personal computer, which makes it possible to manage each field location appropriately and, if economically and technically advantageous, to manage it at this level [Guerra 2006].

The increasing intensification of agricultural production has led conventional agriculture to treat the field in a uniform manner, based on average values, ignoring the spatial and temporal variations of the various factors involved in the agricultural production process, such as: nutrient content, organic matter, moisture, soil variability and climate [Silva et al. 2013].

One of the pillars of precision agriculture is the treatment of agricultural areas according to local needs. However, a large number of samples would be required to establish a good characterization of the distribution and occurrence of some physical or chemical attributes of the soil, increasing costs excessively. This makes the process often unfeasible [Nunes et al. 2014].

The traditional process of sampling and evaluation of soil characteristics is very demanding in terms of time, reagents required in the analyzes and manual work. In addition, it is based on the use of destructive methods, which involve the physical collection of soil samples in georeferenced positions and their analysis in the laboratory. This is a very demanding process in terms of time, labor and reagents, and may compromise the viability of a precision agriculture project [Serrano et al. 2009].

Precision agriculture allows a more rational planning of nutrient management, pest control, soil moisture, weed control, and selection of cultivars due to their adaptability to the different conditions identified by the use of georeferenced coordinate delimitation in cultivated areas [Silva et. to 2013].

For the application of precision agriculture techniques, knowledge of the spatial variability of soil attributes is indispensable. Knowing the behavior of the variables spatially it is possible to efficiently plan the interventions to be performed in a field of production [Bottega et al. 2015].

1.2 Electrical Conductivity of Soil

In the midst of advances in electronics, the electrical conductivity of the soil stands out, which can be easily measured, transmitting a low electric current, in which electrons move through the soil. The soil is composed of solids, liquids and gases, the latter are insulation and do not conduct electricity. On the other hand, the solid phase (as clay particles) and the liquid phase (soil solution) play an important role in the movement of electrons [Reis et al. 2009].

In a detailed study using only one commercial system for its measurement, it was obtained the indication that the electrical conductivity of the soil responds to the variations in the texture of the soil and its moisture contents, which demonstrates the potential that it has as a tool for facilitate the process of obtaining data for the physical characterization of soils [Molín & Rabello 2011]. For Najm et. al (2014), there is some relationship between the apparent electrical conductivity of the soil and the chemical attributes of the soil, reflecting on the development of cane. Serrano et. al (2009) obtained values of interesting determination coefficients between pH and electrical conductivity and between electrical conductivity and pasture productivity.

It was evaluated the spatial distribution of the electrical conductivity of saturation extract, total organic carbon and organic matter and it was verified that the electric conductivity maps were inversely proportional to those of organic matter and organic carbon [Silva et al. 2013]. As a practical, quick and inexpensive alternative to map soil variability, one can use the apparent electrical conductivity, a measure of the ionic activity of the soil solution, the predominant form of nutrient occurrence in its liquid phase and its absorption plants. A research on the relations between soil attributes that interfere with cotton productivity found that soil electrical conductivity was an adequate tool for the identification of soil acidity and nutrient variability [Sana et al. 2014].

The aim of the sensors is to reduce the time of analysis of soil samples. Some sensors work as measuring instruments: analog and/or digital ohmmeter and digital capacitor, to obtain the potential difference, resistivity and electrical capacitance of the soil. The use of a microcontroller, such as Arduino, assists in the process of automating tasks, making the process agile and more effective by bringing almost immediate responses, as well as concentrating measurements on a single device. It can be observed that the Arduino microcontroller is able to obtain measures of electrical resistance with practicality and precision. The system automates the data collection process, doing it in a practical and fast way, besides presenting a low cost [Damiati et a.l 2014]. In the studies of Monteiro Junior et al. (2012) and Damiati et al. (2014), who worked with the Arduino microcontroller and sensors of electrical measurements, correlations with soil attributes were verified using the standard voltage of the microcontroller of 5 volts. The authors verified that the Arduino microcontroller presented capacity to measure the variations of the electrical resistance of the soil, correlating with the properties of the soil. These experiments demonstrated the possibility of their use to verify soil fertility.

The spatial and temporal variability of soil attributes, productivity, fertility, electrical conductivity and others can be measured and recorded. In this way, the knowledge of these data can be used to make planting decisions and chemical applications at each point of the cultivated area, and no longer by the simple average of the total area. Within each variant of soil attributes, being physical, chemical, and biological, there are many others. As a result, the use of these technologies as tools to support farmers makes it possible to determine the types, timing, quantity and exact location of inputs to maximize production and minimize the use of energy sources in agriculture, thus reducing environmental impacts (Celinski 2008).

1.3 Objectives

One of the objectives of the work was to design an electric circuit with the use of a soil moisture sensor adapted for readings of soil electrical conductivity, correlating the measured results by the sensor with the soil properties. Another objective was to automate the data collection process with the use of the Arduino microprocessor, developing a code for it to work agile, making readings of voltage and electrical resistance, to verify the feasibility of the application of fertilizers in the proportions suitable for correction of the nutrients.

2. MATERIALS AND METHODS

In order to carry out the experiment, 30 soil samples extracted from Fazenda Capão da Onça, belonging to the Ponta Grossa State University, located in the Campos Gerais region, in the municipality of Ponta Grossa, state of Paraná, were tested. The experiment was carried out in the electronics laboratory of the Department of Informatics of the same university.

In the development of the experiment, an electric circuit was designed according to Figure 1, where two digital multimeters were used in order to measure the voltage and electric current of the sensor, by means of the manual calculation of Ohm's Law, obtaining the resistance value electrical resistance, in order to be compared with the value of the electrical resistance obtained by the Arduino microcontroller. The multimeter incorporates several electrical measurement instruments into a single device such as voltmeter, ammeter and ohmmeter by default. The models ET1110 of the Minipa were used in order to compare the data values obtained by the Arduino microcontroller.

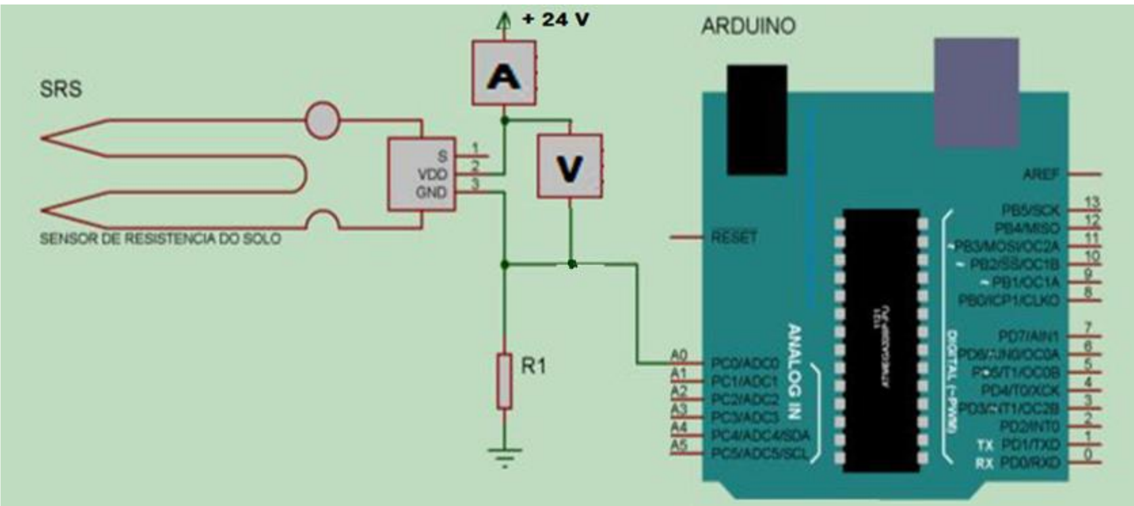

Figure 1. Circuit used in the experiment - Source: The autors, 2017.

The C language program was developed for the Arduino microcontroller to be able to measure and calculate the electrical resistance value of the samples tested. An LCD screen was used together with the Arduino microcontroller to serve as a user interface. Although using a 24-volt voltage, provided by an adjustable power supply from the laboratory to feed the soil electrical resistance sensor in the experiment, the design was able to identify any voltage that was worked on the sensor because it was set at the beginning, after connecting the sensor rods, making the resistance equal to zero, since the resistors of the voltage divider were predetermined. This adjustment made by the Arduino microcontroller allows the use of batteries for use in analyzes directly in the field, where the energy consumption by the battery causes it to not maintain a constant voltage, which affects the results. Thus, in the development of the experiment, the Arduino microcontroller identified the resistance of the sample through the electrical conductivity sensor, measuring the voltage variations of the voltage divider. As the Arduino microcontroller performed the readings, the values measured by the multimeters connected to the proposed circuit were recorded, in order to correlate the values obtained by the Arduino microcontroller with the values of the soil properties of the samples obtained in the laboratory. For the accomplishment of the experiment, all the soil samples were also humidified and the time of reading of the samples was standardized.

2.1 Electrical conductivity sensor

In order to use the Octupus Soil Humidity sensor in this work, it was necessary to modify it because it was originally created to measure soil moisture. With the modification, the rods that had their equal (negative and positive) polarities on the same face of the sensor now have the two polarities on the same face of the sensor plate. Thus, when introduced into a soil sample, it proved to be an excellent sensor for reading the soil electrical resistance.

2.2 Power supply

Using the sensor as a resistance, and based on previous studies, a 24 volt source was used in order to obtain greater precision in measurements. Then, because the voltage was beyond that supported by the Arduino inputs, it was necessary to design a voltage divider, in order to use up to the voltage limit specified for the Arduino. Thus, it could be stated that it was possible to use the sensor in the experiment, specifications of the Arduino microcontroller. In order to perform the experiment, an external power supply was used to feed the circuit with the aforementioned voltage of 24 volts. The source used was the FA-3003 DC model from Power Supply.

3. RESULTS AND DISCUSSION

For the values measured using the Arduino microcontroller, in comparison with the values measured with the digital multimeters, a correlation index of 99.57% was obtained for the electrical voltage readings and a correlation index of 99.30% for the readings of electrical resistance of the soil. The results presented in the tables below describe the correlation between values of soil properties, already obtained in previously performed laboratory analyzes, with the values of resistance and electrical voltage obtained in the experiment, through the Arduino microprocessor and multitests. Calculations were made using the Microsoft Office Excel 2013 program.

The chemical attributes of the soil discussed in the tables below are the potential of hydrogen (pH), organic matter (M.O), phosphorus extracted from resin (Presina), potassium (K), calcium (Ca) and magnesium (Mg); and the following indicators: sum of bases (SB), cation exchange capacity (CTC) and base saturation (V%). In Table 1, we can verify the Pearson correlation coefficients of the resistance and electrical voltage in relation to the soil attributes, using readings with the Arduino microcontroller.

Table 1. Pearson's correlation coefficients of resistance and electrical voltage in relation to soil attributes, using readings with the Arduino microcontroller

	pH	M.O	Presina	H+Al	K	Ca	Mg	SB	CTC	%V
Tensão(V)	0,07	0,15	0,02	0,00	0,11	0,12	0,01	0,10	0,1	0,09
Resistência(Ω)	0,11	0,23	0,02	0,01	0,14	0,17	0,10	0,16	0,2	0,13

In Table 2, we can verify the Pearson correlation coefficients of the resistance and electrical voltage in relation to the attributes of the soil, using readings with voltmeter and ohmmeter.

Table 2. Pearson's correlation coefficients of resistance and electrical voltage in relation to soil attributes, using voltmeter and ohmmeter readings

	pH	M.O	Presina	H+Al	K	Ca	Mg	SB	CTC	%V
Tensão(V)	0,06	0,15	0,01	0,00	0,13	0,13	0,00	0,10	0,10	0,09
Resistência(Ω)	0,11	0,20	0,00	0,00	0,15	0,17	0,10	0,16	0,18	0,13

In Table 3, we can verify the correlation coefficients of the Second Order Polynomial Trend Line of the resistance and electrical voltage in relation to the soil attributes, using readings with the Arduino microcontroller.

Table 3. Correlation coefficients of the 2nd Order Polynomial Trend Line of the electrical resistance and voltage in relation to the soil attributes, using readings with the Arduino microcontroller.

	pH	M.O	Presina	H+Al	K	Ca	Mg	SB	CTC	%V
Tensão (V)	0,217	0,411	0,547	0,148	0,318	0,226	0,084	0,214	0,075	0,148
Resistência(Ω)	0,310	0,335	0,438	0,063	0,474	0,255	0,164	0,27	0,197	0,184

In Table 4, we can visualize the correlation coefficients of the 6th Order Polynomial Trend Line of the electrical resistance and voltage in relation to the soil attributes, using readings with the Arduino microcontroller.

Table 4. Correlation coefficients of the 6th Order Polynomial Trend Line of the electrical resistance and voltage in relation to the soil attributes, using readings with the Arduino microcontroller.

	pH	M.O	Presina	H+Al	K	Ca	Mg	SB	CTC	%V
Tensão (V)	0,330	0,62	0,67	0,42	0,48	0,43	0,30	0,46	0,52	0,41
Resistência(Ω)	0,425	0,71	0,55	0,41	0,62	0,46	0,39	0,47	0,5	0,39

From the obtained results, it was observed that there is an average correlation with M.O, Presina, K and CTC, because according to Doria Filho (1999), the correlation coefficient is considered average above 0.5; strong above 0.75; perfect when equal to 1 and non-existent being equal to 0. Considering all other correlation indexes, it can be inferred that this proposed system with the modified humidity sensor, together with the Arduino microcontroller prepared to measure the electrical resistance of the soil, has a better performance for measurements of potassium (K) and organic matter (M.O), respectively, with correlations of 0.62 and 0.71; according to the 6^{th} order polynomial trend line.

Thus, Souza et al. (2012) verified in their study that increased doses of (K) acidified the soil solution and increased its electrical conductivity. It is also emphasized that Cruz et al. (2014) verified that soil electrical conductivity levels allow a correlation with other soil parameters, where their spatial variation can be attributed to variations in organic matter, among other soil properties.

4. FINAL CONSIDERATIONS

Under the conditions in which this research was carried out, the Arduino microcontroller was able to measure the variations of the electric resistance of the soil, correlating strongly with the measurements obtained by the digital multimeter. In this way, it was demonstrated the possibility of its use to verify soil fertility. It was also verified that the results are promising, since they demonstrate that the sensor used with the Arduino microcontroller to measure the electrical resistance of the soil can be a useful tool for measurements of organic matter and for measurements of soil potassium content, besides have demonstrated a very practical and rapid analysis to obtain the measurement of soil attributes through the use of the Arduino microcontroller.

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