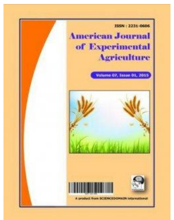

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A Fast Experimental Electrical Conductivity Survey for Agricultural Applications, Case of Small Crop Area of Otoes (*Xanthosoma* sp.) in Central Region of Panama

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Authors' contributions

This work was carried out in collaboration between all authors. Author AM designed the study, wrote the protocol and wrote the first draft of the manuscript. Authors AM, JS, NB and JO conducted measurements and reviewed the experimental design. Authors FV and BD managed the geochemical analyses of the study. Author CAH worked the protocol for data acquisition and reviewed all drafts of the manuscript. Author LP performed the statistical analysis. All authors read and approved the final manuscript.

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ABSTRACT

A quasi-continuous automatic recording system of apparent electrical conductivity data of soil (EC_a) was assembled to obtain at a reliable and fast rate, spatial distribution maps of this physical parameter. The device was moved manually throughout several profiles in a small zone of 3753 m^2

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used for the farming of otoes (*Xanthosoma* sp.) in Panama, Central America, obtaining 401 voltage values in approximately 20 minutes. These voltages were turned into EC_a values and mapped. This result was compared with total dissolved solids (TDS) and pH maps of 29 soil samples at 20 cm of depth; salinity was also measured. The EC_a map presented a zone of high electrical conductivity (130 - 500 µS/cm) on the Eastern part which is consistent with the zones in the TDS and pH maps whose value ranges fall within the optimal threshold for *Xanthosoma* sp. (45-95 mg/l and 5.5-5.8 respectively). Salinity levels were weak (<0.10%) and are consistent with the zone of high EC_a typical of non-saline soils. All these results show a significant potential in the use of this mobile system to achieve a fast assessment of agricultural exploitation zones. Finally, a highly moderate correlation is showed among the values of EC_a and TDS, and pH data.

Keywords: Apparent electrical conductivity (EC_a); square quadrupole array; pH; total dissolved solids (TDS); Xanthosoma sp.

1. INTRODUCTION

The study of soils constitutes a topic that has been highly addressed by the scientific community throughout the world, because the understanding of their physical properties has a significant impact in the positive exploitation of natural resources. Therefore, geophysical methods play an important role in the fast evaluation of a determined zone of interest. One of these techniques is the electrical method which has had a key role in solve various problems linked to the detection of archeological features, groundwater and zones of high agricultural productivity (just to mention a few examples). This electrical technique has its beginnings in the second decade of the last century and it was not until the last decades of the 20th century that electronic and computerized systems (with AC sources) capable to automate the recording of field data, and in addition to the election of special electrodic configurations with the feature of determining the magnitude and the course of the electrical anisotropy. In this sense, the square quadrupole array is adapted to a great number of demands that includes the issues caused by such effect until the coverage a large extension of land in a relatively short period of time. The use of such configuration started in the 60's of the last century, where it was used to solve geological problems [1,2], as well as archaeological problems [3-7] and in explorations of groundwater [6,8,9]. Currently, this technology is being used successfully in zones of agricultural cultivation [10].

The aim of this work is focused on the study of the effectiveness of the assembling of a mobile system that is made up of metallic wheels traction that supports a platform with an AC source, a data logger and a GPS. A case study related to a small crop area of otoes (*Xanthosoma* sp.) located in the central sector of the Isthmus of Panama, is presented. Such results include a mapping of apparent electrical conductivity (EC_a) and some geochemical parameters (Total Dissolved Solids - TDS and pH) obtained by the analysis of a set of samples collected in the site of interest. A Pearson correlation among these data is also presented in the study.

2. SOME ADVANTAGES OF THE SQUARE QUADRUPOLE ARRAY IN ELECTRICAL PROSPECTION AND TECHNICAL DESCRIPTION OF THE DEVICE

The knowledge of physical properties of the soils is of fundamental importance since according to soil mechanics it is possible to predict the future behavior of a soil under loads when it contains different moisture contents. On the other hand, in archaeology and agriculture, the accurate interpretation of these properties will involve the optimization of material and human resources. Today farms require a complete knowledge of the growing areas, which would lead to increase the data density and time reduction of laboratory sample analysis; this implies an additional problem related to the changes experienced by soil properties if the process of collection of samples is developed for several days. Because of this, the use of a mobile system for making faster and more detailed EC_a data acquisition can play an important role.

The electrical method is based on the measurement of the apparent electrical resistivity of the soil or its inverse value, the EC_a. The methodology is characterized by the use of an alternating or direct current passing through the ground between two electrodes (A and B); this electrical current generates a voltage which can be recorded by another two electrodes (M and N) inserted few centimeters into the soil; then, the knowledge of electrical current (i), the voltage (ΔV) and the geometry of this quadrupole (which is defined through a geometrical coefficient), allow the calculation of EC_a. Through a simple form and according to the physical laws, the equation obtained is:

$$EC_a = b\,R^{-1}$$

In this equation, $R = \Delta V / i$ and the proportionality constant between EC_a and R varies according to the quadrupole array, which depend on the research objectives. Of all the possible electrode arrays, the square quadrupole is the most symmetrical array since the electrodes are located in the vertices of a square and the effects of the apparent anisotropy are reduced significantly [5]. For such array, the previous equation is represented by:

$$EC_a = \left(\sqrt{2}-1\right)\left(\pi a\sqrt{2}\right)^{-1} R^{-1}$$

Where *a* represents the dimension of sides of the square and is part of the geometrical coefficient.

The device was assembled following three important concepts: (i) the mobile part, (ii) the quasi-continuous injection system of electrical current and data-logger, and (iii) GPS. For the first part, four metallic wheels of 0.15 m of diameter were built; 15 equi-spaced pins of metallic stainless steel of 5 cm long and 0.5 cm of diameter were inserted in each wheel, which also contribute to the traction in the soil for a continuous movement along a profile. Each set of wheels (front and rear) was linked to an aluminum platform of (1.20 x 0.60) m of surface through an insulating materials; such platform serves as support for the devices that will be described later. In the second part, a prototype of alternating current source was used; this device transforms a continuous signal of 12 V supply in a signal of 40 Hz and an output of 50 V. In the output, a square electrical pulse of 5 mA is generated; the outputs of the injection system are connected to the base of the front wheels represented by A and B of depicted in Fig. 1(a).

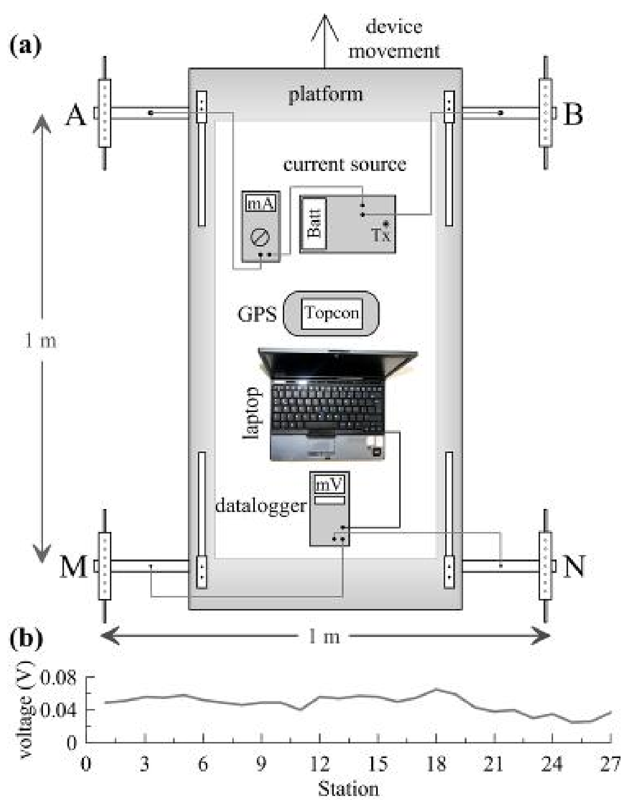

Fig. 1. (a) General scheme of mobile device (square quadrupole array) for automatic recording of voltage and (b) graph of voltage data recorded long a profile

On the other hand, the rear wheels, represented by M and N of the Fig. 1(a), are connected to a data logger through connection cables, which record in each time interval, the voltage generated in the soil when the electrical current is injected through the front wheels. The data logger is connected to a laptop for the automatic storage of voltages. The acquisition program can be configured in a range of a temporary period of time that is between 1 and 500 seconds according to the study. Eventually, GPS is incorporated to the mobile system for recording coordinates of the measurement points along a given profile. These coordinates, after undergoing a post-process using GPS data (from a fixed base) can be associated with voltage data recorded, which are then translated into EC_a values. Fig. 1(b) shows an example of a graph of voltage recorded along a given profile.

One way to check the effect of anisotropy is to measure the value of EC_a for different angles of the square quadrupole array and then represent this data in a polar graph. In this work, the tests were carried out for a value of *a* = 1.0 m which corresponds to the AB, MN, AM and BN distances (see Fig. 1(a)). In this result, the variations in EC_a for different angles with respect to North, are low (106.5 and 118.1 μS/cm); this reflects the low sensitivity of the system to the apparent anisotropy (see Fig. 2).

3. EC_a MEASUREMENTS IN QUATERNARY SEDIMENTS OF PANAMA CENTRAL ZONE - AGRICULTURAL APPLICATIONS

In general, the electrical methods have played an important role in agricultural issues [11-15]. The mobile device was used in a small test area located in the central sector of the Isthmus of Panama (Central America) which is characterized by the presence of quaternary alluvial sediments. Fig. 3(a) shows the geographical location of the site and Fig. 3(b) and (c) detailed satellite images of the interest area. This test zone has 3753 m^2 and is used today for growing otoes (*Xanthosoma* sp.).

A total of 21 profiles between crops lines separated a distance of 1.5 m were surveyed in a period of about 20 minutes. Then the data logger recorded a total of 401 voltage values while the system is in a continuous movement; this data was translated into EC_a values and associated with the corrected global positioning data. Fig. 4 shows the mobile system with accessories used in this test.

This information was finally processed geostatistically with Surfer 12 of Golden Software to generate a map of spatial variations of EC_a, see Fig. 5(a). Additionally, TDS, pH and salinity

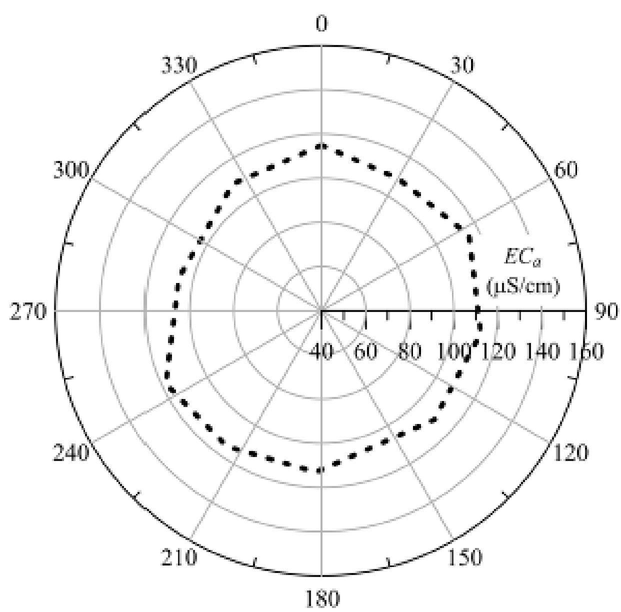

Fig. 2. Polar graph showing the EC_a values by the dotted line using the square quadrupole array

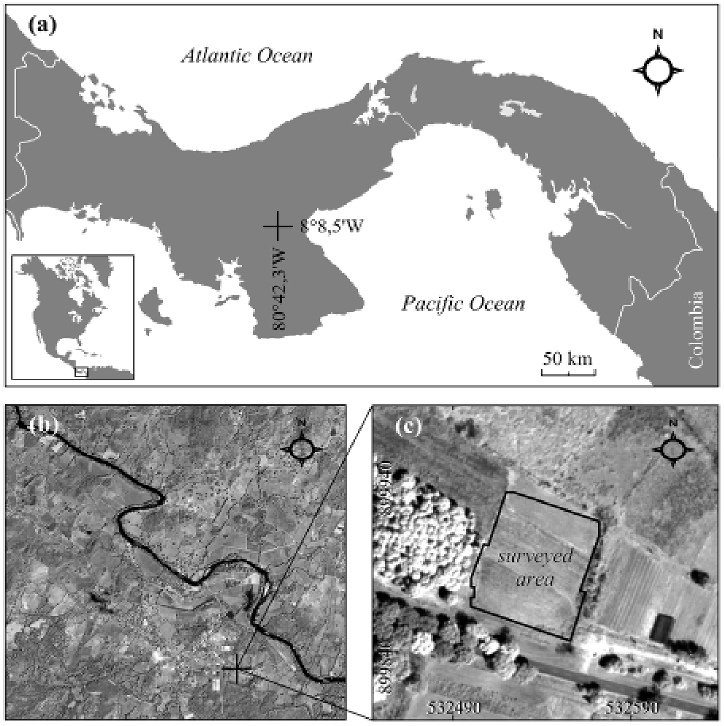

Fig. 3(a). Location of the test site, central sector of the Isthmus of Panama and (b), (c) satellite images of the prospected area

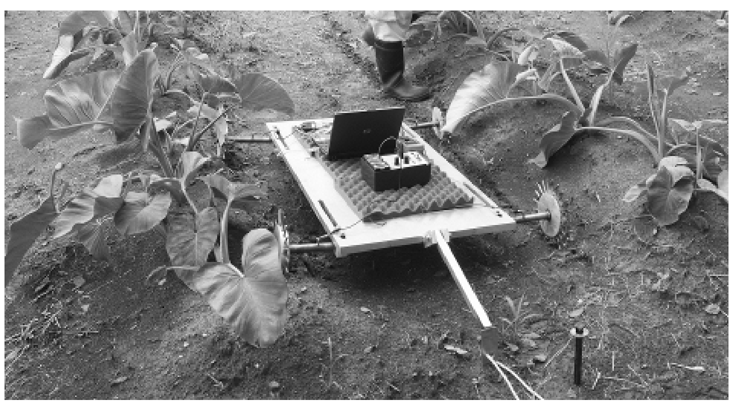

Fig. 4. Mobile quadrupole square system and accessories used for automatic recording of voltages in the 21 profiles established in the test area

percentages of 29 soil samples to a depth of 20 cm were measured. pH measurements were performed according to the AASHTO Designation T 289-91 (1996) using a Corning 320 pH electrode. TDS measurements and the percentage of salinity were conducted through the use of an Orion 145 + Thermo-Scientific device; the results were based on the method developed by [16].

Only TDS and pH were geostatistically processed because the salinity percentages presented a low variation in their values (< 0.10%). A Pearson correlation analysis between the geophysical and geochemical data was carried out by Matlab program. The results of the mapping process of TDS and pH values are presented in Fig. 5(b) and (c), respectively; the difference between the map of Fig. 5(a) and Fig. (b) and (c) is the density in the EC_a data (401) versus TDS and pH data (29).

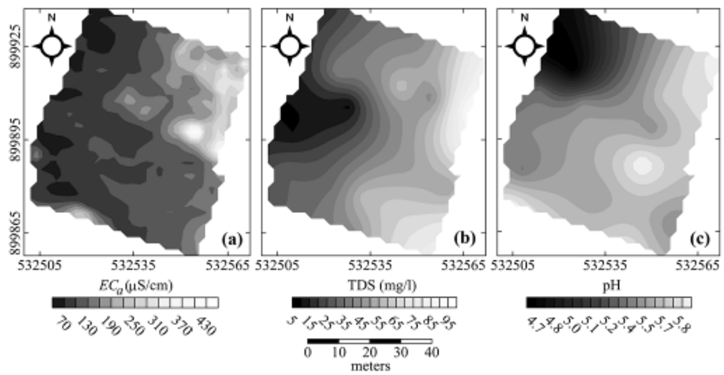

Fig. 5. Map of spatial variation of (a) EC_a, (b) TDS and (c) pH at the *Xanthosoma* sp. growing area

Table 1. Statistical and correlation coefficients for 29 measurements of EC_a, TDS and pH

Property	Min	Max	Mean	Median	Stan. Dev.	Correlation	
						TDS	pH
EC_a (µS/cm)	58.7	355.1	130.1	111.6	64.6	0.5857	0.5446
TDS (mg/l)	8	92	43	41	23		
pH	4.62	6.70	5.49	5.52	0.42		

The result of the electrical prospecting using the mobile system shows a high electrical conductivity zone in the Eastern sector of the map, with values between 130 and 500 µS/cm; this range is not more than 2000 µS/cm which represents the upper limit for non-saline soils. This fact is confirmed by the low salinity percentages of geochemical analysis obtained. The area represented by a light gray hue of Fig. 5(a) agrees well with shaded areas clear hue of Fig. 5(b) and 5(c), the characteristic ranges of these areas for the TDS and pH ranging between 45-95 mg/l and 5.5-5.8, respectively. The ranges of these parameters fall within boundaries which are characterized by high agricultural yield areas for *Xanthosoma* sp. (otoes), which is where most of the nutrients are concentrated.

About the statistical analysis and Pearson correlations, the mean value of EC_a data obtained by mobile system in the 29 positions (where the samples were obtained), was 130.1 µS/cm (see Table 1 above) with a positively skewed in the sample population distribution. Furthermore, the values of TDS have a mean of 43 mg/l, with a distribution positively skewed. The pH values have a mean of 5.49 and the distribution was also positively skewed. These results show a moderately high correlation between EC_a and TDS data (0.5857), and between EC_a and pH data (0.5446), see Table 1.

4. CONCLUSION

In order to generate spatial variation maps of EC_a in tropical areas like Panama, it has been common to measure this parameter by using different electrode arrangements manually displaced along several profiles (spatial maps). The main disadvantage of this methodology is the measuring time when we want a good density of data (high resolution maps) over relatively large areas. Thus, the use of a square quadrupole array adapted to a mobile system comprising: (i) an electrical current source, (ii) a quasi-continuous automatic voltage recording system, and (iii) a GPS, is an advantage to generate EC_a maps in a very short period of time (187.6 m^2/min for lines spaced 1.5 m), also with a low cost and low sensitivity to the effect of apparent anisotropy. The use of this system in a test area for growing otoes (*Xanthosoma* sp.) located in the central sector of the Isthmus of Panama could be accomplished in a relatively short time (about 20 minutes). The area of high EC_a values matches whose geochemical properties (TDS and pH) that are characteristic of soils that present high growing potential for *Xanthosoma* sp. This high degree of reliability offered by the geophysical survey has also been highlighted by the correlation results of geophysical and geochemical data obtained in the 29 positions of the test site.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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