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Relationship between electrical resistivity and soil moisture.

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Abstract Summary.

Soil moisture monitoring is essential in irrigated agriculture for effective water management, reducing excessive water use while ensuring crops receive adequate moisture. The temperature dependence of soil electrical conductivity/resistivity has often been argued to compromise a straightforward correlation between electrical properties and directly measured soil moisture. This study reports a field experiment in which conductivity and soil moisture sensors were installed at two depth levels; meanwhile, surface resistivity measurements were taken with conventional dipole-dipole arrays. Since it was conducted during a period with minor soil moisture variation, the variation with soil temperature could be precisely accounted for. Our results show that temperature variation only affected conductivity/resistivity values at the most superficial level of the soil (15 cm), with minor variations below this level. For most of the dipole-dipole readings, the apparent resistivity fell within the error margin of the measurements.

Introduction

Soil electrical resistivity monitoring using geophysical methods (electrical resistivity tomography - ERT) has been used to assess soil moisture in environmental studies and irrigated agriculture. The main motivation for using remotely based geophysical data is to better assess the dynamics of vadose zone water, aiming for sustainable use of water in food production. Since measurements are made at the ground surface and water variation occurs at very shallow surface levels (less than 1 meter), temperature variations in potential can distort resistivity measurements, compromising the interpretation of results. This may hinder the recognition of soil moisture trends that describe the water dynamics in the concurrent processes of infiltration (downward movement) and evapotranspiration (upward movement). This study presents a field experiment monitoring electrical resistivity in an experimental agricultural area (Fazenda Santa Elisa, Campinas-SP) of the IAC (Instituto Agronômico de Campinas) over a period of eight days, during which only a minor irrigation episode was carried out by a central pivot, applying 10 mm of irrigation. As recorded by sensors installed at different soil levels, the soil moisture was low, allowing the present study to evaluate resistivity changes associated with soil temperature. We further explore how the measured values can be corrected and used and, more importantly, whether such variations can be detected considering the experimental error margin in the apparent electrical resistivity measurements.

Theory

Electrical resistivity (ER) is a physical property that indicates how difficult it is for charged carriers to pass through a material under an electrical potential difference. In the International System of Units (SI), resistivity ϱ is measured in ohm-meters (Ωm). Electrical conductivity, denoted as σ (S/m), is the reciprocal of resistivity, such that $\varrho = 1/\sigma$. In agriculture, soil conductivity is used to remotely assess water content across large land parcels, aiding food producers in accurately determining the amounts of water to be applied. A well-established model for soil conductivity was proposed by Rhoades [1] as

$$\sigma = \sigma_w \theta t + \sigma_s$$

where σ_w is the pore water specific conductivity (S/m), θ is the water volumetric content (WVC) (m^3/m^3), t is a transmission factor and σ_s the conductivity of the soil matrix. This equation schematically represents a circuit with two current paths: one along the pores filled with water and another along the solid-liquid interface of minerals present in the soil. Since the change in mobility of electrical carriers at the water-mineral interface is affected by temperature, it therefore affects the conductivity of the soil according to

$$\sigma_T = \sigma_{25}\,[1 + \ 0.02\,(T - 25°C)]$$

where σ_T is the conductivity at the temperature T, and σ_{25} is the conductivity at the reference temperature of 25°C. Common temperature correction in resistivity surveys reduces the apparent resistivity data measured at variable air temperatures to a reference temperature (usually 25 °C).

Materials and Method

The ER method involves injecting a direct current (DC) into the soil and measuring the resulting electrical potential distribution. Using different electrode arrays and spacing, it is possible to map the variation in resistivity laterally and at different depths. We applied a computerized acquisition system where 12 electrodes were distributed 0.5 m apart along a straight line to achieve 6 m. Apparent resistivity readings were obtained with dipole-dipole arrays at multiple investigation levels (1, 2, 3, 4) between the current and potential dipoles. Apparent resistivity databases were achieved using the same electrode setup (permanently installed in the soil surface). Resistivity sections, L1, L2, and L3,o n 06/24, 06/28 and 07/01, respectively. Each apparent resistivity reading was repeated multiple times until a pre-established reference error threshold (usually 2%-4%) was achieved. There were points with a margin of error greater than 2%-4%, but they were few. The electrical resistivity data were measured using a single-channel AGIUSA-SuperSting R1/IP resistivimeter, with a commuting box for up to 54 electrodes.

At positions of 6 and 9 m along the line under investigation, Campbell Scientific-CS616-L (VWC, soil conductivity, and temperature) were installed at depths of 15 and 30 cm, with records taken every 5 minutes. Soil properties monitoring was carried out from June 24th to July 1st (8 days), with one episode of water irrigation on June 30th.

Results

Figure 1 shows the results of soil monitoring during the experiment and the days on which ER surveys were conducted. Soil moisture remained largely stable over time, with only a slight increase following a minor water application of 10 mm by a central pivot irrigation system on June 30. Daily temperature variations with amplitudes of up to 9.8 °C were observed at the sensor 15 cm deep, but with a minor variation of 8 °C for the sensor 30 cm deep. It is worth noting the minor variations recorded by the soil conductivity sensors (values converted to resistivity) at the two locations monitored by the sensors. Despite showing different resistivity values at 6 m and 9 m, the values 30 cm below ground surface were practically the same over time. The temperature variation at sensor Z1-15 cm was 6.2 °C, Z2-15 cm was 7.4 °C, Z1-30 cm was 4.3 °C, and Z2-30 cm was 5.7 °C.

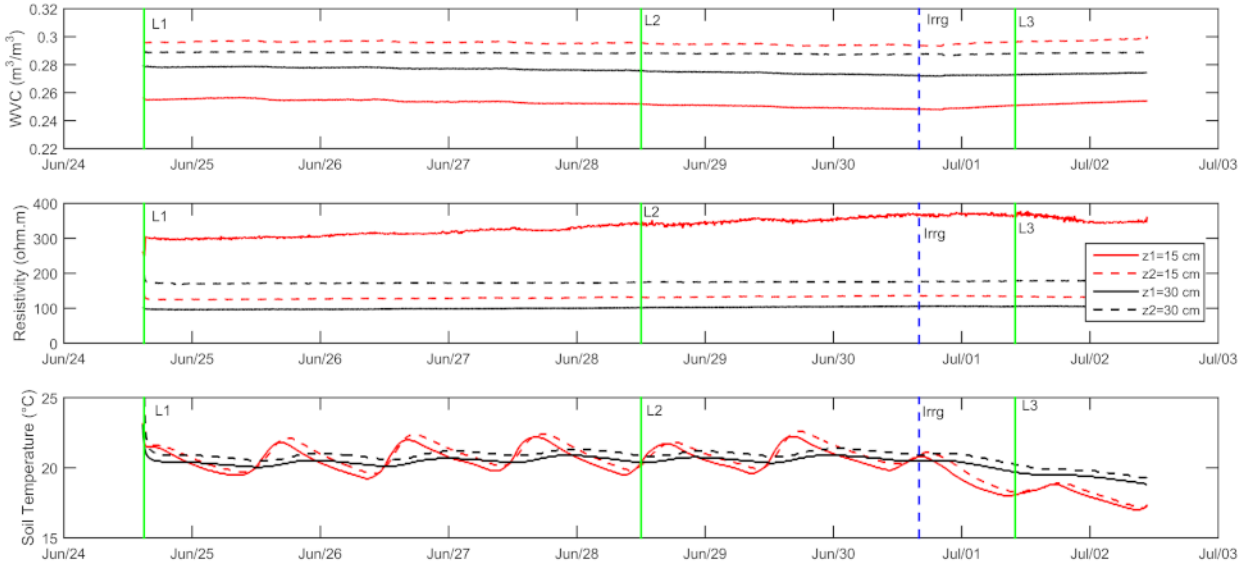

Figure 1: Water volumetric content (m³/m³), soil resistivity (ohm-m) and temperature (ºC) for sensors at depths of 30 cm (black lines) and 15 cm (red lines) along the profile. Positions z1 and z2 are 6 and 9 m, respectively, along the profile. The green lines are resistivity sections L1, L2 and L3 and the blue striped line is the start of irrigation.

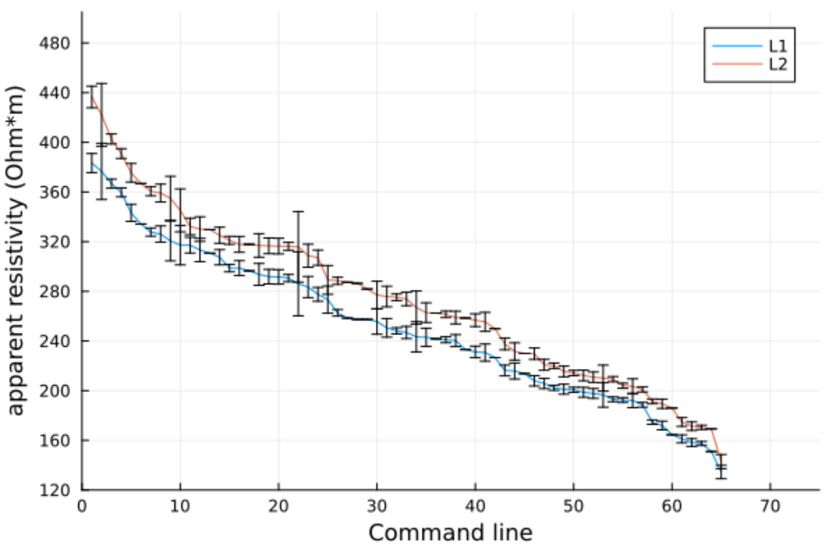

Figure 2: Comparison of lines 1 and 2, with resistivity data in decreasing order and synchronized.

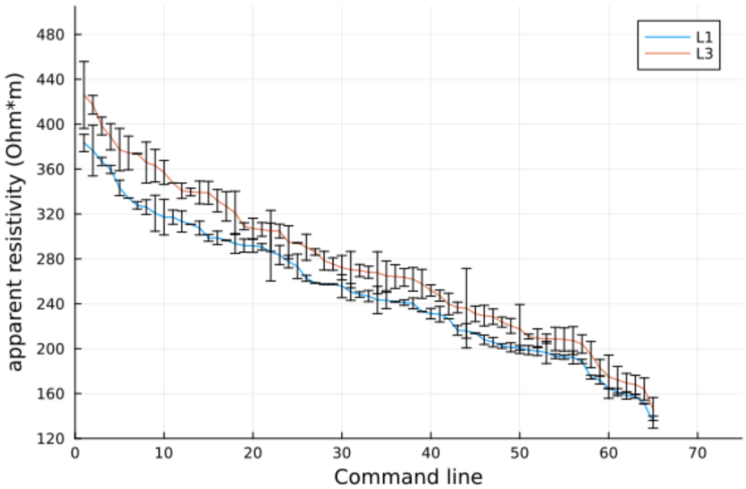

Figure 3: Comparison of lines 1 and 3, with resistivity data in decreasing order and synchronized.

Conclusions

The lines were chosen to verify how the resistivity changed over time in the study: one at the beginning, one in the middle, and one at the end. Two were pre-irrigation (L1 and L2), and one was post-irrigation (L3). Figures 2 and 3 present the L1 resistivity data in decreasing form, while L2 and L3 are synchronized with the data position in line 1. From Figures 2 and 3, it is clear that there was some variation in electrical resistivity; however, it was not substantial enough to create a significant contrast in electrical resistivities. Observing the points in the two figures and their margin of error, part of the differences in the point values may be influenced by changes in the region around the electrode. For this, more in-depth evaluations are necessary. Nevertheless, the variation in soil moisture was insufficient to produce noticeable changes in the upper sections. We only observed slight changes, which could be attributed to other factors such as temperature, albeit to a lesser extent, as illustrated in [2]. In agriculture, the effects of temperature on soil conductivity are most pronounced near the surface, as shown in the last graph of Figure 1. Therefore, in this case, temperature effects do not significantly influence the results in deeper regions of the soil and are primarily concentrated in the top layer of the soil.

References

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