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Evaluation of an experimental system of soil moisture registration for irrigation management in potted vineyard (*Vitis vinifera* L. CV Bobal) of multi-depth temperature compensation based in resistivity measurements

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ABSTRACT

Measurement of soil moisture is a fundamental parameter for irrigation scheduling. In order to determine this parameter, many types of sensors are employed. Some of these sensors for soil moisture measurements are based on electric resistivity. Measurements are affected by many factors including soil temperature, length of probes, amongst others, that can cause incorrect determination of soil moisture levels. Consequently, this can lead to inappropriate or unnecessary irrigation. The main objective of this paper is the presentation of results of several experiments focused on determining adequate temperature compensation for a simple soil moisture measurement and registration system based on resistivity measurements (Wenner compensation). Moreover, a comparison between the data obtained by this device and a reference sensor is included. The device was calibrated in a plot with potted vineyards (*Vitis vinifera* L. cv Bobal on 110R) under drip irrigation and additional conditions. Results are adequate and include a method of compensation of measured values based in a rolling average model of soil temperature with a good agreement. A simple weighed combination of box temperature of the device and 14 cm deeper temperatures can provide a useful level of Wenner compensation. Additionally, this device has a competitive price and is adequate for water management in crops.

1. Introduction

Basically, in agriculture sciences, the determination of water requirements of a crop over time is based on soil water balance measurements, plant measurements and the evaporative demand. All of these parameters are used for estimating the irrigation water scheduling for a specific crop. Irrigation water scheduling for a crop has to determine the quantity of water and the time when this quantity has to be applied. Moreover, in order to optimize water supply and to rationalize the management of water demand of crops, an adequate irrigation scheduling has to be established. This periodic irrigation scheduling is based on physical-mathematical models. Moreover, in order to determine the soil water balance, soil moisture measurements have to be taken into account. The use of soil-based water status measurements have been adopted as an adequate strategy for water balance estimation and many methodologies to measure water fluxes from crops have been traditionally developed (Albaugh et al., 2014; Barlet et al., 2014; Wang et al., 2014; Rallo et al., 2014; Everwand et al., 2014; Holland, 2012). The ultimate objective of these techniques is to provide farmers with information about the most appropriate volumes of irrigation to apply in each phenological period of the crop, depending on the desired yield levels and other parameters. For determining soil moisture, a great range of sensors are used (Vienken et al., 2013).

There is a wide range of electrically based soil moisture measurement techniques well established in the fields of geophysical surveying (Linck and Fassbinder, 2014; Lehmann et al., 2014) and agronomy (Fatas et al., 2014; Baghdadi et al., 2014), among others. In these measurement techniques are included resistivity based methods such as the Wenner (Jiao-Jun et al., 2014), Schlumberger

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Arrays (Mosuro et al., 2012), capacitive based methods such as frequency domain reflectometry (FDR) (Al-Asadi and Mouazen, 2014; Jaria and Madramootoo, 2013) and time domain reflectometry (TDR) (Janik et al., 2014) as well as Radiation based techniques such as the Neutron Probe (Kodikara et al., 2014).

By far the simplest of these are the resistivity based techniques (Igboama and Ugwu, 2011; Environmental Geophysics, 2011), which whilst suffering from a susceptibility to a variety of differing soil conditions such as composition (Kibria and Hossain, 2014; Hanson and Peters, 2000), texture (Hadzick et al., 2011; Nadler, 1991), varying pH (Islami et al., 2012; Ishada and Makino, 1999), salinity (Velstra et al., 2011; Austin and Rhoades, 1979; Read and Cameron, 1979) and temperature (Newill et al., 2014; Afa and Anaele, 2010) can still be highly effective in detecting relative changes in soil moisture level. In particular, the temperature of the soil is significant as this can affect the electrochemical properties of the soil being sampled.

To complicate matters further, the temperature of the soil can vary significantly within only a few centimetres of depth in areas where there are significant changes in surface temperature between day and night (Brocca et al., 2014). This often shows as a time 'lag' with increasing depth (Huang et al., 2013). The majority of the devices for soil moisture measurements based on resistivity include metal rods as probes. These rods may typically be 10 to 25 cm in length and are therefore exposed to differing soil conditions along their length, thus seeing a composite picture of the conditions below the surface.

This paper presents results from studies into these effects on a simple Wenner array in a range of mulch enriched substrate and a hi-silica, clay based soils of several experimental plots. The experiments were set out for obtaining data of soil moisture with a prototype based in the Wenner array technique during the irrigation of a potted vineyard (*Vitis vinifera* L cv Bobal in 110R) under drip irrigation recording data every 3, 10 or 30 min. The reference data were collected every minute and the vineyard was subject to variable irrigation. This prototype device is shown to be adequate for commercial and researching uses in agronomy because its low cost and versatility (Newill et al., 2014; Austin and Rhoades, 1979).

2. Material and methods

For the development of the experiments, a Wenner array prototype was designed. Moreover, this device has been calibrated in an experimental plot with potted vineyards under drip irrigation and several varied conditions of soil and irrigation.

2.1. Wenner array prototype

The prototype for this experiment is based on the Wenner array technique. Additionally, several devices are integrated into this prototype in order to measure, collect and upload data. This prototype was implemented using a peripheral interface controller (PIC) and additional elements (Fig. 1). Specifically, the prototype consists of a PIC18F26K22 (Microchip, 2000) microcontroller with built in multi-channel, 10 bit analogue to digital convertor, a vertical column of temperature sensors placed 4 cm apart in the soil, and four metal rods (culinary grade steel) of 23 cm length and 2 mm diameter held 6 cm apart each inserted 20 cm into the ground. Five PIC pins were required for the implementation of each array, the first to act as a current source, the second as a current measurement point and current insertion point into the soil, the third and fourth as voltage measurement points in the soil and the fifth as a current extraction point from the soil. A reference resistor of known value was used between the first and second pins, and by measuring the voltage difference across this resistor, the current flowing through the soil was determined. The third and fourth pins provide a high input impedance voltage measurement and given the known current, the resistance of the soil between these two points can be determined (see Fig. 2). As the voltage measurements require extremely small currents, this measurement technique is relatively immune to irregularities in probe to soil impedance.

To minimize ground field, capacitive and electrochemical effects, the system used a square wave oscillating voltage, first passing the current in one direction, then reversing polarity to pass the current in the opposite direction. A frequency of 20 Hz was used, as suggested by US Geophysical Surveys (Environmental Geophysics, 2011), with a processor voltage of 3.3 V (regulated).

Given the range of observed soil resistance values seen in earlier trials (Oates et al., 2014), the reference resistor value of 330 Ω was chosen to maximize measurement resolution. This gave an absolute current limit of 10 mA, well within the PIC limit of 25 mA, but in effect, typical observed currents were of the order of 2 to 3 mA.

The system used 4 cycles, each of 50 ms, taking voltage and current readings 24 ms into each half cycle, and averaging the results. Readings taken earlier in the cycle demonstrated differing capacitive effects within different types of soil, but in earlier, more detailed experiments, these were typically found to be minimized towards the end of the 25 ms half cycles.

The temperature readings were made using probe heads consisting of two, 1N4148 diodes in series, forward biased by a known, small constant current (nominally 8 μA provided by the PIC CTMU CC source). The forward voltage developed by the diodes under these circumstances is linearly proportional to the temperature (Yedamale, 2009) but with a negative slope coefficient. Five temperature probes were inserted into the soil in a vertical column, spaced 4 cm apart, with the first approximately 2 cm above the surface, the second 2 cm below the surface and the last 14 cm below the surface. Readings were taken every 3, 10 or 30 min (depending on the experiment) and to reduce random noise, each stated reading is the average of 64 readings taken approximately 20 μS apart. A 1 KΩ resistor was used in series at the PIC end to limit the current in the event of a short circuit in the probe or its wiring. Two diodes in series were used to give an effective resolution of 1/6 degree centigrade at minimum cost. Two point temperature calibration was performed under known conditions of 5 and 27 degrees centigrade.

The system was powered from three 1.5 V alkaline AA cells. Whilst the PIC is in sleep mode, current consumption (including regulator leakage) is less than 100 μA. Current consumption peaks at around 4 mA for around 1 s every 10 or 30 min, thus, based on a nominal capacity of 1200 mAH, the power source can be sustained in excess of a year provided the unit is not subjected to wide extremes of temperature which would reduce battery life.

All the electronics and batteries were housed in a small IP56 rated ABS box, with a light emitting diode (LED) protruding from the top, connected to the PIC via a 1 K resistor. This allowed both status indication (when configured as a digital output) and monitoring of the external brightness level (when configured as an analogue input), providing a convenient day/night reference channel. A future development will allow data extraction via this LED acting as a bi-directional optical link, however at present, data is extracted using PICKIT3. All resistors were of 1% tolerance, 1/4 W rating and metal film construction to aid repeatability. As the device was unlikely to be subject to significant electromagnetic interference, for cost reasons, no special consideration was given to PCB layout or cabling arrangements. The total cost of materials in the prototype, including box and batteries, was less than 10 €.

The PIC18F26K22 has 64 kB of flash memory, with the assembler programme code taking less than 2 K, this leaves more than adequate storage space for almost 8000 readings (of 8 B in length) to be logged. At 3 min intervals, this allows readings to be logged