A Capacitive-Based Soil Moisture Sensor

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Abstract - A capacitive soil sensor under development uses changes in the RC time constant to determine the soil conductivity and wetness. The soil/water/sensor combination is modelled to provide a theoretical basis and is verified experimentally.

I. INTRODUCTION
The amount of moisture available to a plant can vary within a local area and may depend on soil types, runoff, salinity, water table variability, and evaporation. It can be useful to determine the available moisture for small areas, even down to the immediate area around each plant in the case of orchards and viticulture. This allows the irrigation requirements for these small areas to be suitably adjusted to provide only sufficient water for the plants requirements. A further advantage is the reduction of rising salinity levels due to over-watering. To do this a very economical sensor needs to be developed with suitable methods of sampling each sensor.

II. SOIL MOISTURE
Soil moisture content can be expressed in terms of:
- Soil Moisture Potential in units of pressure (kPa);
- Volumetric Soil Moisture Content as a ratio or percentage, or as Weight Ratio.

Soil Moisture Potential (Soil Tension) is a measurement of how difficult it is for a plant to obtain water from the soil[1]. For different soils containing a given amount of water the work required by the plant to obtain water may vary significantly. This may depend on the adsorption onto soil particles (Matric Potential) and solutes in the soil water for instance (Osmotic or Solute Potential).

Matric Potential: water molecules form hydrogen bonds with soil particle surfaces as well as with other water molecules (cohesion). Since any attempt to remove water from the soil (plant transpiration or direct evaporation) is opposed by these forces the water is said to be under tension[2].

Osmotic or Solute Potential: Inorganic salts and some large organic molecules are osmotically active and also decrease the potential energy of the soil water[2].

Gravitational Potential: The water level (height) in the soil profile also affects the water potential, the deeper the water the lower the potential energy.

Volumetric Soil Moisture Content and Weight Ratio methods suffer from several problems making measurements of these types less useful. This is due to several reasons. Soils swell with uptake of water, different soils will pack better than others and the amount of water contained does not give any indication of how difficult it is for the plant to extract water (clay vs. sandy soils).

III. THEORY
The soil moisture sensor presently being developed measures the change in capacitance across the probe as a function of water content in the surrounding soil. The dielectric constant of water is an order of magnitude greater than that of common soil components. In a soil/water matrix the amount of water present greatly influences the capacitance between two conductive plates placed in the matrix.

If the sensor plates are insulated then the resulting capacitor becomes effectively 3 series capacitors with the middle capacitor (C3) bridged by a resistance (R2) dependant of matrix conductivity (see fig 1). The resulting charge/discharge characteristic of this network is dependent on both water content and conductivity. Since resistance is inversely proportional to both conductivity and the amount of water in the matrix and capacitance is proportional to the amount of water in the matrix then the time constant of the RC combination can be used to determine the conductivity directly.

Errors will result if the charge/discharge times are used to determine the water content for soils and water of different conductivities, but this can be corrected by knowing the conductivity.

Fig1. Soil and Sensor equivalent circuit
IV. EXPERIMENTAL RESULTS
Initial measurements were made of the discharge time of the capacitor formed by the insulated probes placed in the soil water matrix. The sensor probe was formed from two insulated areas of copper on the front and rear faces of a double-sided printed wiring board and connected directly to the electronics on the same board. A measurement is made by first charging the capacitive probe and then measuring the discharge time. The discharge time (see fig 2) measured by gating a counter fed with a 4.7MHz clock, increased with increased water content as expected and a small increase in conductivity caused by the addition of NaCl initially increases the discharge time but ceases to have any appreciable effect (see fig 3) beyond conductivities of .015 Scm (around the value for tap-water). This occurs since the capacitor C3 (see fig 1) formed by the water as a dielectric is effectively shorted out by the water conductivity (R2). C2a and C2b, which are formed between the probes and the conductive water with the probe insulation as the dielectric, are now the only components which vary with the water content. C1 is fixed and is the dry probe capacitance.

V. DISCUSSION
It is apparent that C3 only plays a part in the measurement of water content in very low conductivity soil/water matrices and in normal conditions water content can now be related to the value of C2 only. Measurements so far suggest this is the case. Non-linearity in the measurements made so far may be a result of water absorption into the insulating coating over the probe and needs further investigation.

An additional benefit in using insulated probes prevents problems due to electrolysis and allows a wider use of probe material.

Some initial simulations of the circuit in Figure 1 suggest that it will be possible to separate water content and conductivity values from the charge discharge characteristics.