A Review on Soil Moisture Sensing Techniques

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***Abstract*— At the farm level, irrigation is generally scheduled based on the grower's experience. An alternative approach entails the measurement of soil water status. Water stress in plants is related to available soil moisture. The lower the moisture contents of the soil , the higher the potential for water stress. This review provides a detailed synthesis of various approaches to estimate soil moisture.**

***Index Terms*—Soil moisture, tensiometer, dielectric sensors, gypsum blocks.**

I. INTRODUCTION

Water content measurements are commonly divided in two categories: gravimetric and volumetric measurements. Gravimetric measurements refer to the relationship between water mass content divided by total mass of the soil sample, dried at 105 degree celcius until the sample attains a constant weight. Volumetric water content measurements refer to the volume of water contained in a given volume of soil sample, and are useful for water resources management. There are three basic water content measurement methods: gravimetric, nucleonic and electromagnetic techniques [1].

II. A TENSIOMETER

A tensiometer is a kind of artificial root that measures soil moisture tension (Ψm) in the growing medium. The tensiometer consists of a shaft filled with (distilled) degassed water with a porous ceramic cup at the end and a dial vacuum gauge or a pressure transducer at the top. The shaft is generally made of plastic due to its low heat conduction and high resistance to corrosion. The ceramic cup has small air entry potentials in order to prevent de-saturation when subjected to negative potentials. The transducer can be connected to a data-logger for long-term monitoring, to a hand-held meter for spot measurements or to an irrigation controller. The tensiometer is buried at the desired depth in the rooting zone with the ceramic tip in close contact with the soil particles. The water in the tensiometer reaches equilibrium with the surrounding soil through the ceramic tip. When water is pulled out through the ceramic tip by drying soil, a tension is originated in the tube; when the soil is re-watered, the decrease in water potential gradient causes a reverse flow of water. As the soil goes through drying and wetting cycles as a result of ETC and watering (by irrigation or rainfall), tension readings can be taken. The porosity of the ceramic tip influences the velocity of water flow from and into the instrument. When used in very dry conditions, the ceramic must be very fine and this slows down the tensiometer reaction to the changes in soil Ψm. Tensiometers have many advantages that make them a competitive instrument for measuring soil moisture conditions [5]. They are accurate, low cost and not influenced by temperature and soil osmotic potential, since the salts move freely through the ceramic cup. Generally, tensiometers operate between 0 and 80°C. However, tensiometers have also some disadvantages. They are quite fragile and must be operated carefully in order to avoid the formation of air bubbles in the shaft, which may result in temperature dependent errors in reading. Moreover, they need regular maintenance, for instance to refill the water in the tube and to avoid the contamination by algae. The typical operating range of water-filled tensiometers is between 0 and -85 kPa, with an accuracy of 0.1 – 1.0 kPa [1]. Meron *et al.* (1995) used a control system for apple tree irrigation management using tensiometers [6]. Shock *et al.* (1999) used a similar approach but transmitted data from the data loggers to a central data logging site via radio[12].

III. DIELECTRIC SENSORS

Electro-magnetic (EM) moisture measurement methods are so-called indirect methods that determine an electrical property which is closely related to the water content of the material, such as the electrical conductivity (EC) or the dielectric permittivity. Since EC is also considerably affected by the salinity of the water, the dielectric methods promise accurate measurements. In dielectric sensors an alternating electric field is induced into the surrounding media. By measuring voltages and currents induced by this field in the measuring rods, the total complex electrical impedance is obtained for the media. This impedance relates to the complex permittivity, which can be converted into soil θ and bulk electrical conductivity EC, on the premises of known media calibration. The size and shape of the electric field depends largely upon the shape and size of the used electrodes for sensors. Furthermore, the penetration depth of the electric field is limited and decays rapidly the further away you get from the electrodes, as a reciprocal of the distance. There are different types of dielectric sensors depending on the output signal used for estimating θ viz. Time Domain Reflectometry (TDR) and Frequency Domain Reflectometry (FDR) .

TDR estimates the bulk dielectric permittivity, ε_b , of the soil mixture (soil, soil water and air) by measuring the propagation time of an EM pulse, generated by a pulse generator and containing a broad range of different measurement frequencies. The pulse propagates along a coaxial cable and enters the TDR probe, which is traditionally a pair of parallel metallic rods inserted into the soil. Part of the incident EM waves of the pulse is reflected at the top of the probe because of the difference in impedance between cable and probe. The remainder of the wave propagates through the probe until it reaches the end, where the wave is reflected back to its source. The transit time of the pulse for one round-trip, from the beginning to the end of the probe is measured.

For many years TDR has been the only principle used to measure soil θ . Advantages of the TDR sensor are it's ability to be left in place to continuously measure soil moisture content; it's ability to make easy and rapid measurements; use of universal calibration equation . Disadvantages include the relatively small zone of influence; it's sensitivity to air gaps between waveguide and soil; and signal attenuation caused by soil salinity . Cost of TDR sensor may range from $500 to thousands of dollars (e.g. Grow Point sensor from Environmental Sensors, Canada). Therefore, TDR technology is considered less suitable for irrigation control in commercial crops, although very recently some authors [1][2] reported on the application of TDR sensor for irrigation scheduling in nursery and greenhouse industry.

FD or capacitive techniques use capacitance to measure the dielectric permittivity of a surrounding medium and operate at one single measurement frequency. When the amount of water changes in the soil, a probe will measure a change in capacitance due to the change in dielectric permittivity that can be directly correlated with a change in soil water content[1] [2]. FD-sensors for soil moisture (e.g., Theta-probe, Delta-T Devices Ltd.) came onto the market more recently. The main advantage of FD sensors are less expensive electronics compared to TD methods and the immediate and accurate reading. Cost of Theta-probe, Delta-T Devices Ltd is @ $200 and EC-5 , 10HS from Stevens Water is @ $110 each. However, there are some drawbacks. For instance, they are affected by soil salinity, which attenuates the signal. There is also general consensus that FD sensors must be calibrated more frequently than TDR sensors. Thus, they are quite expensive for automated irrigation control system.

IV. Low Cost Electrical Resistance Soil Moisture Sensors (RZS)

The gypsum block (Plaster of Paris, $CaSO_4$) has been around since the 1940's, making it one of the oldest methods of soil moisture measurements. It is also one of the cheapest methods of soil moisture measurement. Un-calibrated gypsum block soil moisture sensors are available for as low as Rs. 200.0 per block. It can be used to measure soil moisture and assist in making irrigation decisions. The measurement range of gypsum blocks is between about 30 kPa and 1000 kPa. They are useful in crops where the irrigation schedule includes imposed periods of relatively dry soil moisture conditions such as regulated deficit irrigation (RDI) of grapes [1][3]. A moderate water stress imposed a few weeks after fruit set and maintained midway through berry formation may enhance the maturity of berries and improve the quality of grapes. For best results, it is reported that the average soil Ψ_m should be kept at -150 to -200 kPa in sandy soil, around -250 kPa in loamy soil and at -300 to -400 kPa in clay soil [4]. Therefore, a successful application of deficit irrigation needs the determination of soil water status and, in consideration of the range of Ψm previously reported, tensiometer are of little use and dielectric or gypsum block sensor must be used.

Gypsum blocks consist of two parallel electrodes embedded in blocks of gypsum. Their shape varies from rectangular to cylindrical and they are about matchbox size. Gypsum blocks are one type of resistance block which are buried in the soil to achieve good contact with the soil. Water is a good conductor of electricity and the more water present in the soil, the lower the resistance to electricity passing through it.

Use of the gypsum block fell out of favor for many years, as other high-tech soil moisture sensors made their appearance. Another problem with gypsum block is , if the DC current is applied to measure the resistance for more than a second, gasses form at the electrodes, and the apparent resistance changes if the reading is repeated. Hence an AC current should be used or the blocks should be read rapidly by a modern logger (in milli-seconds) provided readings are not taken too frequently [1][3].

Watermark soil moisture sensors are to be buried in intimate contact with soil at root depth, where they will reach equilibrium with the local soil moisture. The measurement correlates well with soil water potential. This is fine for agriculture, because water potential (in units of kilo-Pascal or centibar) best quantifies the work plant roots do to extract moisture from the soil. Of course, plants and soils have their individual characteristics. The bottom line is that the readings are related to plant stress and well being.

The signal is electrical resistance, which decreases with increasing soil moisture. The sensor construction is ingenious, a perforated stainless steel cylinder supports a permeable membrane, inside which there is a tightly packed sand aggregate, the "granular matrix", and at one end there is a wafer of gypsum, and concentric electrodes, which are attached to wires that emerge to the soil surface. The gypsum wafer serves as a buffer against differences in soil acidity and salinity, so that the electrical resistance between the electrodes depends on moisture and temperature only.

A special circuit is needed to measure the electrical resistance of the Watermark sensor. DC currents must not be allowed to flow through the wet part of the circuit, or else irreversible reactions will occur and spoil the readings. AC excitation avoids these problems, by reversing the polarity of the current many times per second, so that no net reaction takes place at either electrode. The circuit must also isolate the sensor electrodes from galvanic currents in the soil.

V. SUMMARY AND DISCUSSION

The standard method of soil water content measurement involves taking a physical sample of the soil, weighing it before any water is lost, and drying it in an oven before weighing it again. The mass of water lost on drying is a direct measure of the soil water content. This measure is normalized either by dividing by the oven-dry mass of the soil sample, in which case the units are gm/gm, or by converting the mass of water to a volume (by dividing the mass of water by the density of water) and dividing this volume of water by the volume of the sample, This method is standard and reliable [1]. Electromagnetic sensing methods are the TDR (Time Domain Reflectometry), FDR (Frequency Domain Reflectometry or capacitance) methods. [1]. TDR estimates the bulk dielectric permittivity of the soil mixture (soil, soil water and air) by measuring the propagation time of an EM pulse, generated by a pulse generator and containing a broad range of different measurement frequencies. FD or capacitive techniques use capacitance to measure the dielectric permittivity of a surrounding medium and operate at one single measurement frequency.

VI. CONCLUSIONS

Recent and current advances in electronics instrumentation have contributed to the widespread use of electromagnetic soil water measurement methods. The gravimetric method is probably the most accurate method for soil water content measurement since the soil sample is taken to the laboratory and can then be carefully and extensively analyzed. However, amongst the preferred electromagnetic sensing methods are the TDR (Time Domain reflectometry) and Capacitance methods because they permit obtaining measurements in situ [1].

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