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Advances in Water Management Using Capacitance Water Sensors

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Résumé
Il y a plusieurs détecteurs utilisés pour mesurer la teneur en eau dans le sol basé sur la constante diélectrique du sol mouillé qui est un mélange l'air, de sol et d'eau . Les sondes capactivites ont simplifié la détermination de la variation des teneurs en eau dans le temps et dans l'espace espace. À cause de leur prix relativement bas et leur facilité d'opération, les sondes capacitives sont acceptées par beaucoup de chercheurs et producteurs. Dans cette étude, nous donnons un aperçu du principe d'opération des sondes capacitives, de leur étalonnage et d'installation. L'utilisation des systèmes est diverse. Ils ont été utilisés comme une partie essentielle de beaucoup de programmes d'irrigation pour différentes cultures. Ces systèmes donnent des renseignements sur la transpiration de la végétation. Ils sont aussi utilisés pour déterminer la pluie efficace et des propriétés physiques du sol.

Introduction

Demands on water resources worldwide are increasing as the world population keeps growing and quality of living keeps improving in many countries. As the major water user, irrigated agriculture is expected to make substantial changes to optimize its water use. Water is critical for optimal growth and production. Several water management techniques have been developed, tested and used with different levels of success. Recent advances in microelectronics and emergence of high quality, low-cost high frequency oscillators have made capacitance sensors popular in-situ soil water content monitoring devices and consequently made automated capacitance soil water sensors more affordable (Fares and Alva, 2000). Capacitance sensors have been used to measure soil water content in a wide range of soil types by researchers and growers, for various applications such as irrigation scheduling and waste water treatment (Fares *et al.*, 2004; Fares and Alva, 2000).

The main objective of this manuscript is to synthesis the research work that the author conducted in using capacitance soil water monitoring sensors as an essential part in an integrated approach of water resources and solute management. Thus, the following topics will be discussed: theory of capacitance sensors, their calibration, different applications of this technology, and obstacles facing capacitance soil water content sensors.

Principle of Operation and Equipment design of Capacitance Soil Water Content Measuring Systems

Water molecule is dipole due to the presence of two partial positive charges on the hydrogen sides and a negative charge on the oxygen atom of the same molecule consequently has large dielectric constants, known also as dielectric permittivity. The dipolar nature of the water molecule provides to bulk water unique electrical properties that have long been the target of measurement of water in substances such as soil. When an external electric field is applied to any media containing water molecules, the charged molecules align themselves with the electric field where the positive charges of each molecule are in the direction of the applied field and the negative charges oppose the field. An internal electric field, which is opposite in

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direction of the external electric field, will result. Consequently, a reduction of the overall electric field and the overall potential occurs. Capacitance has been used to determine dielectric permittivity of different homogeneous and mixed medium.

Assuming that the dielectric properties of soil water are the same as that for bulk water, several dielectric mixing models have been developed to estimate the dielectric properties of wet soils. Capacitance soil water sensors operate at a narrow band frequency and use dielectric constant (K) of soil-water-air mixture to estimate soil water content. The K of water (78.54 at 22 ^oC) is large compared to those of soil matrix (K<10) and air (K=1), and thus dominates the dielectric permittivity of the air-soil-water mixture. A change in soil water content will strongly influence the K of soil. However, great variability of the K of soil minerals ($4 \leq K \leq 9$) and dry plant tissue ($1 \leq K \leq 4$) makes it necessary to calibrate these sensors for a particular soil and, if practical, for each soil horizon. In most cases, the relationship between the Multi sensor Capacitance Probes (MCP) output and volumetric soil water content (θ_v) is a 3-parameter power function (Fares et al., 2004). There are a number of capacitance designs, which differ from each other because of electrode configuration and geometry, range of operating frequencies, ease of use, and accuracy. Conceptually, capacitance sensor systems can be subdivided into two groups as single and multi-sensor systems. They also have different electrode designs: rod, flat, or cylindrical (Fig.1).

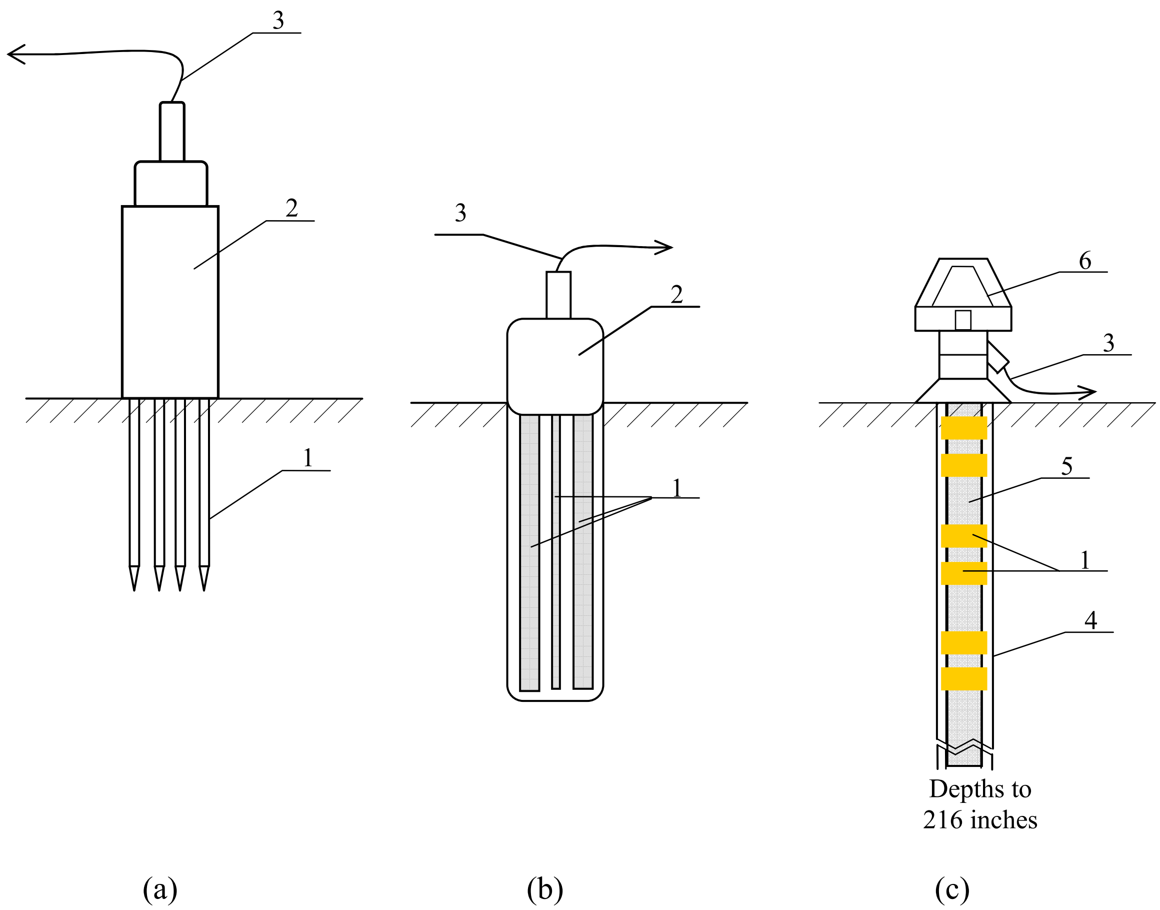

Figure 1. Schematic design of three types of capacitance systems: (a) Rod type electrodes with direct soil contact, (b) flat electrodes sealed in plastic, (c) ring electrodes in tube housing. 1-electrode, 2- electronic circuitry, 3-cable, 4-access tube, 5-circuit board, 6-top cap

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Installation and site selection

Installation of capacitance sensors should begin with careful selection of the site of interest which could be conceptually subdivided in two stages: macro and micro zone selections. Soil type and soil hydrological characteristics are spatially variable properties, and may differ significantly within short distances. The aim of soil water monitoring, however, is to provide the data, which can be used for management decisions applicable for the whole field using limited number of sensors.

Capacitance sensors installation procedure differs depending on the type of the sensor used. However, the general guideline is that soil disturbance should be minimized and good contact between probes or their access tubes and soil should be satisfied. When installing access tubes, it is a good practice to cover the soil surface where the installation will be conducted with boards or plywood to prevent compaction (Fig.1).

Rod sensors are carefully pushed into the ground in one steady motion, avoiding any sideway pressure (Fig.1a). The installation of sensors with flat electrodes, such as ECH2O (Decagon Devices, Pullman, WA) (Fig. 1b), is similar to that of rod type sensors. If the soil allows, the electrode is pushed into soil surface or side of the soil pit with precautions as previously described. Capacitance sensors with ring type electrodes are installed on the field using an access tube (Fig. 1c). The electrodes do not come in direct contact with the soil. The procedure may vary slightly depending on the accessories provided by the manufacturer and the probe type. When the installation of the access tube is complete, its lower end is sealed with a rubber plug.

Use of MCP to calculate different field water cycle components

Capacitance probes were used by Fares & Alva (2000) to optimize irrigation scheduling for citrus groves on a sandy soil by monitoring the water content every 30 minutes at 10, 20, 40, 70, and 110 cm below the soil surface at different locations. These data was further used to determine the components of citrus water budget (evapotranspiration, excess water losses) based on the water balance method. They reported cumulative annual evapotranspiration and drainage of 920 and 890 mm, respectively. In addition, 82% of the annual drainage occurred during the summer as a result of excess rainfall.

Fares et al (2000) used the Instantaneous Profile method in combination with capacitance probes, tensiometers, the Guelph permeameter, and the van Genuchten (1980) hydraulic functions to determine the hydraulic conductivity-water content-pressure head relationships of a Candler fine sand soil in Florida. The capacitance probe and tensiometer readings were taken simultaneously at 5 different depths. The analytical RETC (RETension Curve) model was used to extend soil water release curves beyond the limited range of tensiometer suction measurements. Results of this study demonstrate that capacitance probe is a practical tool that can be used in combination with the Guelph permeameter.

Temperature and salinity effects on capacitance sensors

Despite their success, capacitance system showed some temperature and salinity effects for different soil types. We studied the effect of salinity and temperature on a single sensor capacitance system in the laboratory. Our results showed an exponential increase in reading of the capacitance sensors due to the salt concentration increase. On average, there was a

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10% increase in sensor readings at high salinity levels. Seventy to 80% of this increase occurred over the first 25% of the tested salinity range. Sensor readings increased with increase in soil temperature and salinity. Further efforts are needed to eliminate or at least minimize these negative effects of soil salinity and temperature on the performance of capacitance sensors.

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