Ali Fares · Ashok K. Alva

Evaluation of capacitance probes for optimal irrigation of citrus through soil moisture monitoring in an entisol profile

Received: 11 August 1998

Abstract Continuous monitoring of soil moisture content within and below the rooting zone can facilitate optimal irrigation scheduling aimed at minimizing both the effects of water stress on the plants, and also the leaching of water below the root zone, which can have adverse environmental effects. The use of Sentek capacitance probes (EnviroSCAN RT5) in scheduling citrus irrigation was evaluated using 3-year-old Hamlin orange trees \textit{[Citrus sinensis (L.) Osb.]} on Swingle citrumelo rootstock \textit{[Citrus paradisi Macf. × Poncirus trifoliata (L.) Raf.]} grown in a Candler fine sand (hyperthermic, uncoated, Typic Quartzipsamments). Available soil moisture calculated according to capacitance probe readings of soil moisture agreed well with that calculated using soil water release curves determined in the laboratory. A utility program was developed to process the data collected by the capacitance probe into a spreadsheet format. Processed data were used to calculate soil water storage within and below the citrus root zone at desired time intervals. Irrigation set points (i.e., full point equivalent to maximum desirable water storage and refill points I and II) were defined based on field capacity determined both in the field and in the laboratory and permanent wilting point. It was possible to maintain the water content in the root zone between the full and refill points I and II during most of the growing season. Although soil water content in the root zone exceeded the full point during periods of high irrigation, it drained rapidly within 24–48 h after the end of such irrigation events. Using soil moisture depletion in the root zone during periods of low water application to estimate citrus evapotranspiration (ET), the calculated daily average ET during 10-day period in November was 1.33 mm day$^{-1}$.

Introduction

As water resources become scarce, even in humid areas such as Florida, efforts are being made to protect these resources by optimizing water use and minimizing nonpoint source pollution of groundwater. Deep sandy soils in the central Florida ridge area have low water-holding capacities. Although the annual rainfall in Florida is about 1300 mm, the nonuniformity of rainfall distribution is the main reason for using supplemental irrigation to achieve high economic returns from citrus production (Koo 1969; Smajstrla et al. 1988). A common problem with any irrigation system is determining the timing and duration of irrigation events. Growers generally assess crop response visually to decide when to irrigate. Such visual observations frequently correspond to levels of water stress that may affect tree growth and/or production adversely. Furthermore, soil moisture status may change so rapidly that watering may be required before growers have noticed visual stress symptoms. The impact of soil moisture deficit on tree growth and production can vary substantially depending on crop growth stage. For citrus, the flowering and fruit-set stages during the early part of spring are the most sensitive to moisture stress. Thus, soil moisture should be maintained not to fall below 33% depletion of available soil moisture (Koo 1969; Tucker 1986; Parsons 1989). During the rest of the year, the available soil moisture can be depleted by up to 50–67% prior to irrigation (Koo 1969; Smajstrla et al. 1987). Available soil moisture is determined as the difference between the water content at field capacity and permanent wilting point (Sodek et al. 1990).

Field capacity is defined as the amount of water held in the soil after excess water has been drained and the rate of downward movement has materially decreased,
which usually takes place within 2–3 days after rainfall or irrigation in permeable soils of uniform structure and texture (Veihmeyer and Hendrickson 1949). The concept of field capacity is useful in field management for estimating soil water storage (Kutilek and Nielsen 1994), particularly in coarse-textured soils, where internal drainage is initially rapid but soon slows down significantly, as opposed to medium or fine-textured soils where redistribution can persist at appreciable rates for many days (Hillel 1982). Determination of water content at field capacity is usually based on laboratory measurements of water content in soil samples subject to –0.1 and –0.33 bar pressure for coarse and medium or fine-textured soils, respectively. Since no laboratory system is capable of duplicating soil–water dynamics in the field, it is highly desirable to measure field capacity in the field wherever possible.

The aim of an efficient irrigation scheduling program is to replenish the water deficit within the root zone while minimizing leaching below this depth. Excess water leaching below the rooting depth may result in nutrient losses which increase production costs and may adversely impact on the environment. To determine the optimal irrigation management during the growing season, the soil water content in the root zone should be monitored continuously. Thus, a system that continuously monitors changes in soil moisture status during and after irrigation, and controls the amount of water applied, is necessary in order to optimize irrigation and fertilizer management.

Sensors such as time domain reflectometry tensiometers, and capacitance probes may be used to measure soil moisture content before making irrigation decisions. Recent advances in microelectronics have improved the technique of measuring the dielectric constant of the soil–water–air medium as an alternative means of continuously measuring in situ soil water content. The dielectric constant of a medium depends upon the polarization of its molecules in an electric field. Because the dielectric constant of water (80) is large compared with that of the soil matrix (< 10) or air (1), a change in water content (θ) will strongly influence the dielectric constant of the growing medium (soil–water–air mixture). The relationship between the change in water content and the dielectric constant of the medium depends upon soil type and the frequency range of the measuring apparatus. A probe surrounded by soil constitutes the capacitor. When a capacitor contains soil as the insulator between the two electrodes, measurement of the dielectric constant for soil can be used for estimating θ.

The capacitor usually takes the form of a cylinder housing the electronic circuitry, with two metal bands placed on the outside at a vertical distance of 5–8 cm apart. The electrical field that is formed is approximately 50% greater than the distance between the electrodes (Kutilek and Nielsen 1994). The sensors measure at an operating frequency in excess of 100 MHz to overcome interfacial polarization effects including salinity, which affect most of the capacitive-based measuring devices that have been described in the literature (Dean et al. 1987). Sensors are either permanently buried at the desired soil depths or are inserted into a PVC access tube. A calibration curve of the measured electrical value against volumetric water content is generally linear for the majority of soils (Mead et al. 1995). The accuracy of the data will depend on the quality of calibration carried out between the signal output of the sensor and the actual volumetric soil water content.

Several researchers (e.g., Thomas 1966; Hoekstra and Delaney 1974) found that the capacitance probe method was independent of soil type within wide ranges of soil moisture levels. Conversely, Bell et al. (1987) showed that capacitance probe results were influenced by soil type. Bulk density can also influence the measurement of soil water content using the capacitance probe method (Kuraz and Matousek 1977).

Mead et al. (1995) reported that the Sentek EnviroSCAN RT5 capacitance probe is sensitive to soil salinity and would therefore require individual calibrations for each soil under moderate soil salinity conditions. These Sentek capacitance sensors have been tested both in the laboratory (Paltineanu and Starr 1997) and under field condition (Starr and Paltineanu 1998) to measure the dynamics of soil water content. More aspects of the Sentek EnviroSCAN RT5 capacitance probe have been discussed by Paltineanu and Starr (1997), Starr and Paltineau (1998), Mead et al. (1995) and Buss (1993).

The objectives of this study were: (1) to use capacitance probes to determine irrigation set points under cropped field conditions and (2) to evaluate the performance of capacitance probes for citrus irrigation scheduling in deep sandy soils.

**Materials and methods**

The evaluation of EnviroSCAN capacitance probes began in 1995 in an ongoing field experiment using nonbearing citrus trees in a Candler fine sand (hyperthermic, uncoated, Typic Quartzipsammets) at the Citrus Research and Education Center of the University of Florida, Lake Alfred, Fla. A typical soil profile of a Candler fine sand consists of Ap (0–20 cm), E1 (20–50 cm), E2 (50–100 cm), E3 (100–130 cm) and E/Bt (130–200 cm) horizons, with average bulk densities of 1.59, 1.52, 1.51, 1.61, and 1.55 g cm$^{-3}$, and saturated hydraulic conductivities of 5.21, 9.48, 8.52, 7.27, and 6.96 m day$^{-1}$, respectively (Sodex et al. 1990). The soil moisture characteristic curves for the above-soil horizons are shown in Fig. 1. The mean (from 1961 to 1990) annual rainfall for this location is 1219 mm. The June through September rainfall accounts for up to 60% of the annual rainfall and during this period rainfall exceeds evapotranspiration. Nonuniform seasonal distribution of the rain as well as year-to-year variations in rainfall have serious effects on agricultural production and supplemental irrigation is necessary of optimum crop production.

**Description of the field experiment**

Hamlin orange trees [Citrus sinensis (L.) Osb.] on Swingle citrumelo rootstock [Citrus paradisi Macf. × Poncirus trifoliata (L.) Raf.] were planted in September 1993. The trees were irrigated using a micro-sprinkler system with one emitter per tree delivering 0.05 m$^3$ h$^{-1}$. Each emitter covered a wetting area of 7.3 m$^2$, which