Understanding soil-moisture sensor data

By Arnold Schumann and Laura Waldo

Florida citrus trees may require irrigation throughout the year due to the extremely sandy soils with low water-holding capacities and the warm subtropical climate with distinct drought periods in spring. Citrus trees are evergreen and may be actively growing at any time, with no true dormant phase. HLB-affected trees are particularly prone to multiple leaf flushes during the year and require a constant supply of water and nutrients. Accurate assessment of the daily water requirements for citrus trees and the effective application of irrigation to maintain growth and yields are therefore essential.

IRRIGATION SCHEDULING METHODS

Weather-based irrigation scheduling with daily evapotranspiration (ET) calculated from nearby weather stations or weather networks, like the Florida Automated Weather Network (FAWN), allows near real-time adjustment of irrigation requirements based on the previous day's estimated water use by the crop. A disadvantage of the ET method is that the data used to determine the current irrigation requirement is already a day old. In rapidly changing weather conditions, such as winter cold fronts or summer thunderstorms, the estimates of irrigation requirement may lag behind. There is also no feedback of irrigation events from a system based only on ET.

A soil-water-sensor system can provide instant feedback of soil-water conditions before, during and after irrigation or rain events and effectively has no time lag. More advanced irrigation scheduling systems integrate daily ET with in-field rain gauges and soil-water-sensing methods.

University of Florida/Institute of Food and Agricultural Sciences (UF/IFAS) research with soil-water sensors and their utilization by citrus growers showed that an accurate, properly installed soil-water-sensing system with data logging and graphing capability is the simplest tool for effectively scheduling citrus irrigation. The measured soil-water content automatically integrates the ET demand, rainfall, previous irrigation and the changing water requirements by the tree due to growth or dieback.

Interpretation of the graphical data trends from soil-water sensors may be challenging at first, since they resemble the line traces of electrocardiograms. In this article, the data trends from a pair of sensors installed in a citrus grove were analyzed in order to meaningfully explain the utilization of soil water by trees and its replenishment by irrigation or rainfall. The correct interpretation of sensor data can help develop irrigation best management practices and maximize tree growth and yields.

SENSOR PLACEMENT

The main goal of citrus irrigation is to maintain the soil-water content in the soil-depth interval occupied by the tree roots at optimal levels. A useful analogy is to imagine that for every tree, the roots and soil that will be irrigated occupy a well-defined, three-dimensional region of the soil profile, like a pot. To illustrate, Figure 1 shows the use of two time-domain reflectometry (TDR) soil-water sensors in plastic pots for growing citrus. The three steel prongs on the sensor are about 6 inches long and represent the sensing part of the device. When oriented vertically in the soil within the root system of a tree, the prongs measure the soil's water content at a depth of about 6 inches. This vertical orientation is useful for measuring the water content of the media and root system in the top 6 inches of the pot media, or the topsoil in the grove.

Figure 1. Acclima time-domain reflectometry (TDR) soil-water sensors are installed in pots used in hydroponically grown citrus under protective screen. The upper arrow shows the vertically installed sensor, and the lower arrow shows the horizontally installed sensor. The inset figure shows details of the three-pronged TDR sensor.

The second sensor (Figure 1) is installed into the base of the pot in a horizontal position to measure the water content of the media at the lowest drainage holes of the pot. In a field soil scenario, the lower sensor is also installed horizontally at a preset soil depth below the tree's main root mass to represent the bottom of the imaginary pot.

The soil depth at which the lower sensor should be installed will depend mainly on the soil type and the age/size of the trees, since these factors determine the root proliferation in the soil, both vertically and horizontally. For example, the root system of a healthy, mature citrus tree growing on a deep Ridge soil extends to a depth of about 5 feet (Figure 2). Even in deep soils, the majority of the root system exists in the upper 20 inches of the soil profile. In a Flatwoods soil and with young trees, the root systems are typically

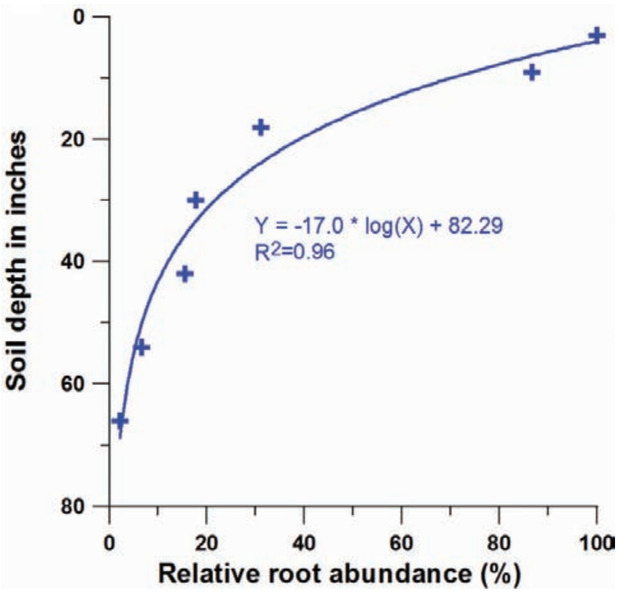

Figure 2. Relative citrus tree root abundance measured in 2002 from excavated soil cores at different depths of a Candler sand soil profile under more than 20-year-old Hamlin on Cleopatra mandarin trees (Schumann, 2002).

much shallower and mainly restricted to the depth of the topsoil profile only.

In the following case study, a pair of TDR sensors were installed vertically beside and horizontally under a recently planted young tree in order to schedule irrigation for a new 10-acre Tango block near Lake Wales on the Ridge. Acclima TDR sensors were chosen due to their high immunity to soil temperature and salinity variations, auto-calibration features and reliable performance on very sandy soils. Microjet sprinklers were installed on the northwest side of each tree for irrigation, fertigation and freeze protection. The microjet sprinklers were inverted in this grove in order to reduce the wetted ground area from a 12-foot-diameter circle to a 6-foot-diameter circle, thus improving irrigation efficiency for the young 3-foot-tall trees.

The upper sensor was installed vertically with its rods spanning the 0- to 6-inch soil-depth interval, at about 18 inches from the trunk of the tree, within the wetted zone of the microjet sprinkler and in the root zone of the tree. In general, the horizontal spread of citrus root systems in topsoil is radially out from the trunks, up to at least the canopy drip line. The soil midway between the trunk and the canopy drip line is a suitable position for a soil-water sensor because it is in the sprinkler-wetted zone, but out of reach from grove traffic and herbicide booms.

The lower sensor was installed horizontally in the soil at a depth of 18 inches. Typically, the lower sensor is installed directly below the upper sensor, in the same horizontal location between the tree trunk and the canopy drip line. *It is useful to think of the two sensors installed in the ground as representing the two sensors installed in a plastic pot (Figure 1, page 6), since their purpose is similar.*

The upper sensor is used to schedule the irrigation start times according to the amount of water detected in the topsoil, while the lower sensor provides information about whether the imaginary "pot" is not full yet, adequately filled or excessively filled ("overflowing"). These interpretations can all be obtained from the data graphs of the soil sensors (Figure 3, page 10). The data trends shown are real-time, soil-water measurements in the Tango grove during the week of April 22–29, 2017. They were displayed on a live internet website from a comprehensive weather station installed in the grove by the UF/IFAS Citrus Research and Education Center (CREC) in collaborative citrus undercover production research with growers (Figure 4, page 10).

MAKING SENSE OF SENSOR DATA

In Figure 3 (page 10), the sensor data is shown as a time series, where time is on the horizontal axis and volumetric soil water is on the vertical axis. The annotations shown in black explain some of the important features of the sensor data. Four horizontal lines indicate soil volumetric water reference points routinely used for irrigation scheduling (field capacity, navy blue; 25 percent depletion, light blue; 50 percent depletion, purple; permanent wilting point, orange).

During rainfall or irrigation, the soil pores progressively fill with water until they are all full and the soil is considered "saturated." Most soil-water sensors should read around 40 to 50 percent when a sandy grove soil is saturated, because all the water-filled space not occupied by solid soil particles constitutes about that percentage by volume.

A soil can only retain a specific smaller amount of water in its pores against the force of gravity. The excess water in a saturated soil will rapidly drain (in a few hours for sandy soils) until a steady state called field capacity (FC) is reached. This is where free drainage stops, and the remaining water in the pores is held by surface tension forces in the pores. The FC of a soil represents the upper-level, water-storage capacity that is useful to plants. The water at FC is readily utilized by plant roots, which will steadily deplete the soil water. This occurs mainly during the day, when transpiration is most active, until a low soil-water status is reached at which plants can no longer extract the water. At this soil-water content, called permanent wilting point (PWP), the soil is not completely dry. However, the water is so tightly held to the soil pore surfaces that the work (energy) required for its extraction cannot be met by the tree. At that time, the tree would typically show permanent wilting symptoms and decline or die if

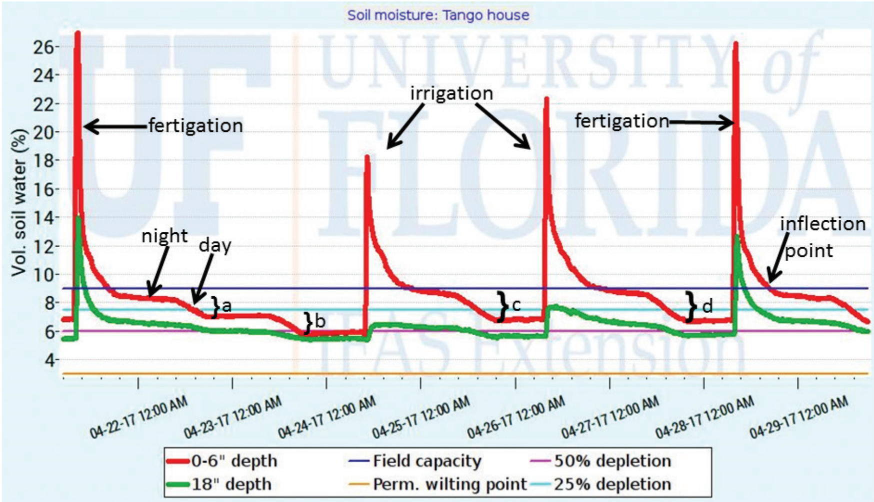

Figure 3. Time series plot of volumetric soil-water content measured with TDR sensors at two depths in the root zone of a young, 3-foot-tall Tango tree in Lake Wales, Florida, during the period of April 21–29, 2017. Labels a to d indicate the daily soil-water utilization by evapotranspiration.

Figure 4. Main web page of the comprehensive weather and soil moisture station installed by UF/IFAS CREC in the Tango citrus block in Lake Wales, Florida.

additional water is not provided.

The water content interval between FC and PWP is called the plant available water (PAW). For practical purposes and to optimize tree growth, soil-water content is not allowed to deplete down to PWP before applying irrigation. Higher thresholds have been determined through research —namely 25 percent depletion and 50 percent depletion of PAW. The 25 percent depletion line is used as an irrigation trigger during sensitive periods of growth, such as for very young trees, or in spring, when mature citrus trees are in bloom and leaf flush phases (February to June). The 50 percent depletion line is used to trigger irrigation for the remainder of the year.

In Figure 3, the shape of the topsoil moisture line (red) indicates the various activities during the week of data displayed. The rapid rise or spiking peak of the red line is due to the flooding of soil pores with irrigation water (irrigation in progress). The rapid decline of the line after reaching a peak indicates the cessation of irrigation and the rapid drainage of excess water. Where the slope of the declining red line changes abruptly ("inflection point" in Figure 3), the soil-water content at that point is approximately the FC of the topsoil.

Notice that after free drainage of irrigation or rain water has ceased, the red line shows a series of declining steps. The level part of each step occurs at night, and the steeply sloping declining part occurs during the day, due to water uptake by the tree during transpiration and evaporation from the surface of the soil. Steps labeled "a" and "b" were smaller and occurred during days that were cooler than days with larger steps "c" and "d," due to the effect of hot weather increasing evapotranspiration. If no irrigation or rain were to occur for additional days, such that the red line declined to approach the PWP, then the daily stepwise decrements would become progressively smaller. This would indicate the decreasing ability of the tree roots to extract water from the soil.

The soil-water content at the PWP is not arbitrary. It is defined as the water content at a soil-water potential of -1.5 megapascals (-217.6 pounds force per square inch). Like the FC, the PWP is characteristic for a particular soil. But unlike the FC, it is best measured in the laboratory.

The role of the green line (soil sensor at 18-inch depth) is illustrated in Figure 3. In a well-timed and quantified irrigation event, there should only be a minor peak. This indicates that the water reached the 18-inch depth, but not in excessive amounts. In other words, the imaginary pot is just full. If no peak occurs on the green line, then there is a danger that not enough irrigation or rain water was added to supply the root zone of the tree down to the 18-inch depth.

In contrast, a large peak on the green line indicates possible excessive irrigation. Most likely, the irrigation run time was too long. Notice the difference in green peaks occurring for irrigation of 20 minutes versus fertigation of 30 minutes, as indicated on the graph. Longer irrigation run times are unavoidable for fertigation in order to expel the injected fertilizer completely from the under-canopy irrigation lines.

In this case study, the grower was irrigating on about a two- to three-day interval, using the 50 percent depletion line as a trigger point for non-bearing, 8-month-old Tango trees. On record-breaking hot days when the risk of water stress in trees is higher, it is best to use the 25 percent depletion line to trigger irrigation. It is not necessary to use the green line for triggering irrigation events. Due to the lower organic matter content of the subsoil at 18 inches compared to the topsoil at 0 to 6 inches, they have different soil-water characteristics (FC, PWP), as indicated by the lower inflection points on the green versus the red curves.

CONCLUSION

In conclusion, citrus irrigation with soil-water sensors is very effective. It incorporates instant feedback information to the user, which is not readily available from other irrigation scheduling tools using daily ET or historical ET records. Not all soil-water sensors are equally effective, and the TDR model and brand shown in this case study was deliberately chosen for its proven accuracy and reliability. Proper installation of the sensors is also critically important, but beyond the scope of this article.

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