Better Growing

By Tim Spann
Research Program Director

Using Soil Moisture Sensors to Improve Irrigation Efficiency

As California's historic drought drags on, every grower is feeling the pinch and trying to make the most of every drop of water available. There are many tools available that growers can use to help improve their irrigation practices and ensure the water they are applying is used most efficiently. This article will describe some of these tools and how the information they provide can be used to help survive the drought and improve overall grove management.

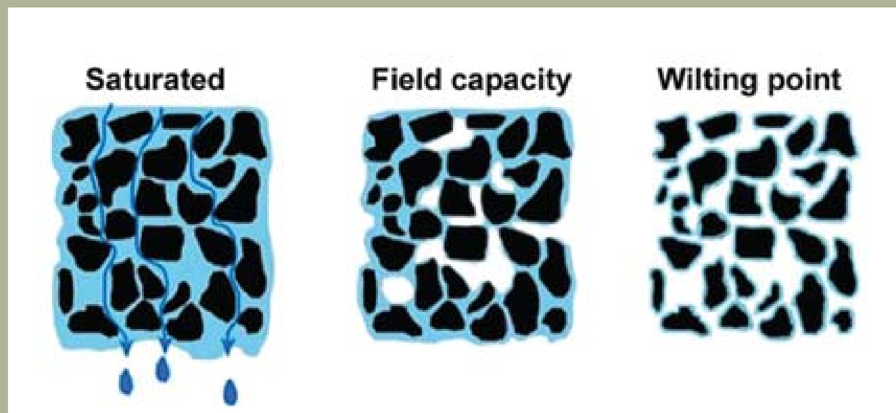

Figure 1. An illustration of the three phases of soil moisture — saturated, field capacity and the permanent wilting point. At saturation, all of the soil pores are filled with water, but the water is held weakly and the large pores will empty by gravity. At field capacity, the large pores have drained and filled with air, but the smaller pores remain water filled and no more drainage will occur by gravity. At permanent wilting point, the water remaining in the soil is held very tightly to the soil particles by adsorptive forces and the plant roots are unable to overcome these forces to extract more water.

Irrigation Distribution Uniformity

Before discussing the various systems available to improve water use efficiency it is important to mention irrigation system distribution uniformity (DU). DU is a measure of how evenly your irrigation system is applying water. If every sprinkler or emitter in your system (or a given irrigation zone) were putting out exactly the same amount of water over a given time, your system would have a DU of 1, or 100 percent.

Common things that negatively affect DU are poor system design, elevation changes, worn or improperly maintained emitters and leaks, among others. Many of the state's Resource Conservation Districts (RCD) offer free or low cost irrigation system DU checks for growers. The RCD will give you a comprehensive report on your system and offer advice on how to improve your system's DU. There are also programs available through the RCDs, water districts and the state to help offset the costs of upgrades you may make to improve your system's DU.

Improving your irrigation system's DU will ensure that you are applying water as uniformly as possible across your grove. But how do you make sure you are applying the right amount of water at the right time?

Understanding Soil Water

Soils are composed of two basic components — particles and pore space. The particles are the physical components that make up the soil structure — sand, silt, clay, gravel, organic matter, etc. The pore spaces are the voids between the particles that can be filled with water. A soil's water holding capacity is a result of the different ratio of the particles that make it up and their sizes. A soil composed of mostly small (clay) particles will have a high water holding capacity, whereas a soil composed of mostly large particles (sand) will have a low water holding capacity. A good soil has a mixture of large and small particles so that it has good water holding capacity, but also has enough air spaces for good root growth.

When you irrigate, you are filling the pore spaces within the soil with water. Immediately after irrigation the soil can be considered saturated. That is, the majority of the pores within the soil, large and small, are filled with water. The large pore spaces then drain, by gravity, leaving the small pores still filled. Once this free draining has been completed, the soil is at field capacity — the volume of water the soil is able to hold against gravity. As the soil continues to lose water by plant uptake and evaporation, the soil water content decreases. As the water content decreases, the remaining water is held more and more tightly by the soil particles through adsorptive forces. Eventually, the plant's roots cannot overcome these adsorptive forces and the soil is said to be at the permanent wilting point (PWP). These phases of soil moisture are illustrated in Figure 1 (see page 20). Water available when a soil is near field capacity is "easy" for the plant to take up, and as the soil gets closer to the PWP it becomes increasingly "difficult" for the plant to take up water.

Our goal in managing irrigation is to maintain soil moisture conditions as close to field capacity as possible so that water is easy for the tree to take up. However, if we stray too far the soil can become saturated, creating hypoxic (oxygen deficient) conditions that can lead to increased chloride uptake (see, Decision Support Tools for Avocado Fertilization and Salinity Management: Preview to the Final Project Report on page 25) and exacerbate Phytophthora. On the other hand, if we allow the soil to become too dry, the tree can struggle to take up water, which depending on the time of year can impact bloom, fruit set, fruit growth, flush development and fruit quality. So how do you achieve this apparent balancing act?

Monitoring Soil Moisture

The easiest way to monitor soil moisture conditions is through the use of soil moisture sensors. For a review of the different types of soil moisture sensors that are available, please see Soil Moisture Technology and Irrigation Management in the Fall 2014 issue of *From the Grove.* There are numerous suppliers of soil moisture sensors and grove monitoring systems on the market, a few of which are listed at the end of this article on page 24. Regardless of which system or type of sensor you use, the information they provide you and how you use that information is similar.

In June 2015, Crop Production Services (CPS) donated a weather station with soil moisture sensors to the Commission for use at Pine Tree Ranch. Since then, Decagon has also donated a soil moisture monitoring system to the ranch. The data shown and discussed in this article is from the CPS system, but again, it is how you use this data that is important, not which system you use.

The systems installed at Pine Tree Ranch both use capacitance type dielectric sensors placed at four depths — 4 inches, 8 inches, 12 inches and 16 inches — to cover the avocado root zone. These sensors use the capacity of the soil to conduct an electrical charge between two probes. The more moisture in the soil, the greater its capacity to conduct electricity and vice versa. Both systems at Pine Tree Ranch also have soil temperature and electrical conductivity (salinity) sensors built into them. The data from these sensors is reported as volumetric water content (VWC).

VWC is the volume of water in a given volume of soil and is expressed as a percentage. Thus, a VWC reading of 50 percent means that for every given volume of soil half of that volume is water (e.g., a 1 cup soil sample with 50 percent VWC would contain ½ cup of water). The range of VWC readings will vary based on your soil's composition. Typical sandy loam soils have plant available water at values between about 15 percent and 25 percent. The amount of plant available water (i.e., the span between PWP and field capacity) is dictated by your soil's texture. For example, a very sandy soil may only have plant available water between VWC values of 10 percent (field capacity) and 5 percent (PWP), whereas a very loamy soil with high organic matter content may have a range from 35 percent to 15 percent.

The Data

The VWC content data for July 2015 is shown in Figure 2. The upper graph shows the readings from all four sensors at the four different depths. The lower graph shows the average VWC over the four sensors. The green and red horizontal lines on the lower graph in Figure 2 represent the approximate upper and lower limits, respectively, of plant available water.

Looking at graphs like these tell us several things. First, irrigation (or rain) events are seen as sharp spikes. The very steep, rapid drop in VWC immediately following irrigation is free drainage of the large soil pores as the soil comes to field capacity. When the VWC reading goes above field capacity, leaching is occurring. Leaching is a necessary part of managing avocados for many growers in order to manage salinity levels. However, having data like these can help you to better manage your leaching and minimize excess leaching and water waste. The inverse of this is seen where the VWC dips below the red line. When VWC is below the red line, the trees may be struggling to take up water.

By looking at the graphs of the four different soil depths you can see that there is a lot of fluctuation in VWC at 4 inches. This is largely due to evaporative loss from the soil's surface. Applying a good mulch layer could reduce this fluctuation. You can also see that the soil moisture is depleted the quickest at 8-inch and 12-inch depths, whereas the 16-inch sensor consistently shows the highest VWC between irrigation cycles. This is likely because the trees where the sensors are located were planted in the summer of 2014 and they don't yet have a lot of roots at the 16-inch depth.

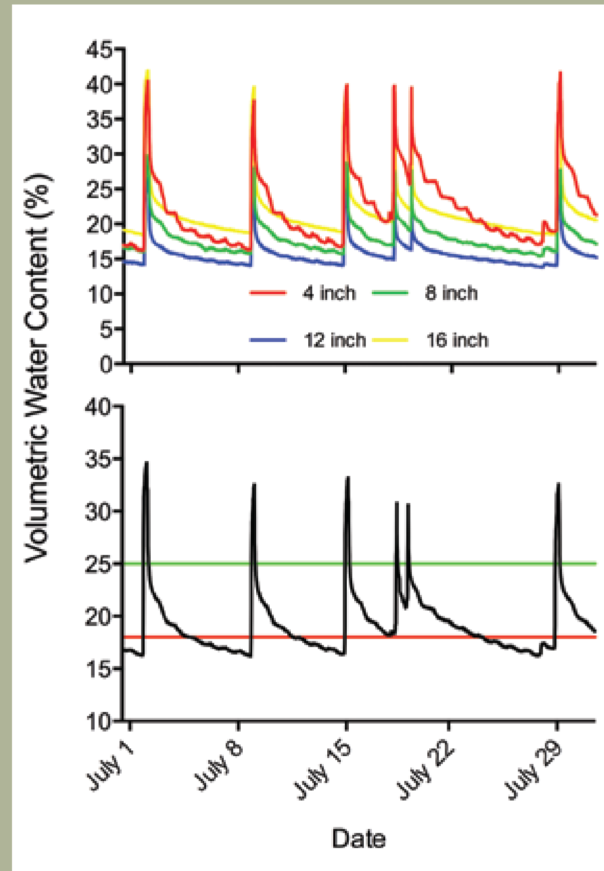

Figure 2. The soil volumetric water content at Pine Tree Ranch during July 2015. The top graph shows soil moisture readings from four different depths. The lower graph shows average soil volumetric water content and the field capacity (green line) and permanent wilting point (red line) levels.

Using the Data to Improve Management Practices

Installing a bunch of sensors in your grove is not going to do anything to improve the health and performance of your trees unless you use the data to change your management practices, but how?

The first, and given the current drought situation, most important thing soil moisture data can help you do is minimize water wastage. For example, the graphs in Figure 2 show that because of the very gravelly nature of the soil at Pine Tree Ranch, the water infiltrates very quickly and fills the soil profile. If we were to zoom in on these data we would see that none of the four sensors ever exceeds a value of about 40 percent VWC, which indicates soil saturation. Once we know this, we can use this information to guide our irrigation by watching our deepest soil moisture sensor — in this case 16 inches.

When our deepest sensor reaches 40 percent, any water we apply will simply push the water in the profile down below the root zone. In the case of Pine Tree Ranch, this typically occurs after two hours of irrigation. The effects of over-irrigation become even more critical if nutrients are being injected. Any nutrients leached below the root zone are literally money down the drain.

The second thing soil moisture data allows us to know is whether we are waiting too long between irrigations. This is indicated by the VWC dropping below the red line on the lower graph of Figure 2. The danger of waiting too long between irrigations is that the trees may actually be experiencing mild drought stress, even if they are not showing any signs of wilt. Drs. Ted Hsiao and Kent Bradford at UC Davis compiled the data from numerous drought stress studies and developed a generalized ranking of plant responses to moderate drought stress. They found that wilting was the fifth response after restriction of canopy development, increase in root growth relative to shoots, osmotic adjustment and stomatal closure. So what does this mean in the real world? It means that the tree is changing its allocation of resources from fruit growth to other processes (e.g., root growth) in order to deal with drought stress. And even though these periods of stress may be transient, their effects accumulate over time and can significantly affect yield.

In the case of Pine Tree Ranch, the data from these soil moisture sensors suggest that shorter duration irrigations more frequently may be better for optimal tree growth and water use.

Can You Really Grow Trees Successfully Based on Soil Moisture Data?

The short answer is yes. In Florida, Dr. Arnold Schumann conducted a study to test whether he could increase the growth and productivity of citrus trees by intensively managing the trees using soil moisture sensors to dictate when to irrigate. This experiment went as far as to have all of the irrigation valves and well pump controlled electronically to turn on and off automatically based on sensor data.

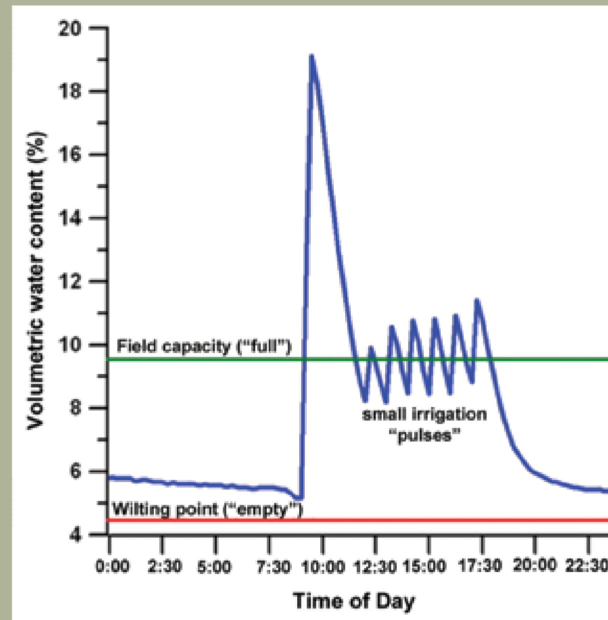

Figure 3. A typical daily soil volumetric water content graph for a citrus trial in a sandy soil in Florida. The graph illustrates how multiple small pulses of irrigation were used throughout the day to maintain the soil near field capacity and minimize tree stress.

In this case, only two soil moisture sensors were used, one at 4 inches and one at 18 inches. When the sensor at 4 inches indicated the soil was dry the irrigation would turn on. When the sensor at 18 inches detected the irrigation water the system would shut off. Bearing in mind that Florida's soils are extremely sandy, Figure 3 illustrates what a typical day's irrigation in summer looked like. The irrigation turned on and off multiple times per day for very short periods (about five minutes) in order to maintain the soil moisture level as close to field capacity as possible. (In heavier soils with better water holding capacity such frequent irrigations would not be necessary.) During the night, when the tree's stomates are closed and no water is being used by the tree there is no need to replenish the soil moisture. By keeping the soil as close to field capacity as possible, the tree always has access to "easy" water.

In the case of this Florida citrus study, the trees also were fertigated every day with very dilute fertilizer (about 150 ppm N). The entire system was based on the concept of "open hydroponics" put forth a number of years ago by a Spanish professor named Rafael Martinez. Essentially, by very intensively managing the water and nutrients supplied to the tree, the soil becomes little more than a physical support system for the tree. The goal of growing trees this intensively is that whatever is applied to the tree today is taken up today and incorporated into the structure of the tree.

The trial in Florida compared the intensively managed trees on drip irrigation with fertigation to conventional grower practices (microsprinklers and dry fertilizer application) and a hybrid system using microsprinklers with fertigation. The entire trial was 15 acres with replicated plots of ½ acre each.

The results of this trial after 2.5 years are shown in Table 1 on page 24. In absolute terms, the intensively managed trees did not save a lot of water. However, because the trees experienced virtually no drought stress, they grew much more quickly and have a 50 percent larger canopy after

Table 1.

Cumulative water and nitrogen fertilizer applied, and citrus tree canopy growth over 2.5 years.			
	Grower Standard	Microsprinkler	Drip
Irrigation water (gal/acre)	133,718	143,242	103,422
Fertilizer N (lb/acre)	253	64.3	47.5
Canopy volume (ft^3/acre)	27,523	36,705	41,464
Water efficiency (ft^3 of canopy/1000 gal water)	205.8 (1x)	256.2 (1.24x)	400.9 (1.95x)
N efficiency (ft^3 of canopy/lb N)	108.8 (1x)	570.8 (5.2x)	872.9 (8.0x)

2.5 years. This resulted in a water use efficiency (ft^3 of canopy per gallon of water) of almost twice the grower's standard practices. In addition, by "spoon" feeding the fertilizer to the trees every day and ensuring that a minimum of leaching occurred, the nitrogen use efficiency was eight times higher in the intensively managed trees. The hybrid system using microsprinklers with daily fertilizer injection improved water use efficiency by 25 percent and nitrogen use efficiency by 5 times.

Not every grower is going to be able to afford a myriad of sensors, electronic valves and computer control systems to manage their irrigation. However, the data from soil moisture sensors can be used to modify your irrigation practices to achieve modest water savings by minimizing excess irrigation (except as needed to manage salinity), and improve tree growth by minimizing the drought stress the trees experience between irrigations. When these changes are coupled with improved fertilization practices tree growth, yield and health can be improved immensely.

The following is a short list of some of the companies who manufacture soil moisture sensors and environmental monitoring systems. Some companies offer basic systems and others offer very complex systems that can monitor many different environmental conditions. All of them offer data loggers that connect to their sensors and can send data to your computer by Wi-Fi network, cellular connection or manual download. All of these companies can provide systems that will provide you with the basic soil moisture data described in this article. Which, if any, system you choose will depend on your budget, the size of your grove and what you are trying to accomplish. Each of these companies has a very competent technical support department that can help you design a system to best suit your needs..

Spectrum Technologies, Inc.
Aurora, IL
800-248-8873
http://www.specmeters.com/

Onset Hobo Data Loggers
Bourne, MA
800-564-4377
http://www.onsetcomp.com/

Decagon Devices
Pullman, WA
800-755-2751
http://www.decagon.com/

CPS Crop Connect
Madera, CA
559-479-2138
http://cropconnect.com/weather/

Anything Weather Communications
Palm Desert, CA
800-845-0383
http://www.anythingweather.com