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Optimizing Avocado Irrigation Practices Through Soil Water Monitoring

Irrigation scheduling is one the most critical management decisions that affects avocado fruit yields and profitability. While most successful avocado growers have developed their irrigation practices to a level that enables good production, the continuing increase in water costs and implementations of water restrictions due to drought have placed increasing pressure on growers to further improve their water use efficiency. Many growers are also increasingly relying on groundwater or are considering the use of reclaimed water resources, which are usually more saline than potable water, and thus increase the need for careful soil water monitoring in order to prevent soil salinization. However, knowing when and how long to water requires a basic understanding of a soil's physical properties, as well as the use of soil water monitoring devices to determine when to apply water, when to leach excess salts, and how to avoid overwatering, which wastes money and causes problems that can reduce yields or even kill avocado trees by waterlogging. This article takes a look at the basics of soil water relations and irrigation water-monitoring technology that can help growers obtain improved water use efficiency.

Based on the preliminary results from a recent survey on water management practices, soon to be published, there is considerable room for improvement in soil water monitoring. A recent survey of over 100 avocado growers indicates that approximately half of all growers never measure their soil water status, and among those who do, the vast majority rely on the "feel" method in which a soil core is taken and felt by hand to gauge its relative moisture level. Although this method serves as a rough indicator of when to water, soil water monitoring equipment can provide much greater precision in determining when and how much water to apply. As California farmers move toward practices that provide the best water use efficiency, irrigation scheduling is better accomplished using soil water sensors that directly control the irrigation valves. The process begins by first determining the water holding characteristics of your orchard soil to obtain a value for the amount of plant available water that can be stored between irrigation sets, and the depth of the root zone that needs to be maintained to provide adequate water and air.

Other important tools for deriving an irrigation plan include use of soil maps to determine the soil water holding capacity and the fraction of the soil water that is available for plant uptake. Combined with the use of online tools provided by the California Irrigation Management System (CIMIS), it is possible to determine both the water needs of an orchard and the amount of plant available water (PAW) that is in the soil at any particular time. This information can be used to determine the water balance and how much needs to be applied to maintain soil moisture in the root zone, while also allowing the soil to retain sufficient air to support root growth. Irrigation calculators are also available to determine how much water to apply based on tree size, the gallons-per-hour (gph) of the irrigation emitters, and the uniformity of the irrigation system. Altogether these tools can save thousands of gallons of water, improve tree yields, and increase profitability.

Soil water holding capacity and water availability

While soils appear to be solid under our feet, a good soil for plant growth typically has about 50% air space. Soil is thus somewhat analogous to a sponge. Air space between the soil particles and aggregates provide pores and channels for diffusion of oxygen to the roots and also serves as a reservoir for plant available water. The size of the soil pore spaces range from a millimeter to microscopic pores that are a few millionths of a meter in size. Altogether, this void comprises the soil pore volume or air space in which water or air resides. Only a small portion of this water can be easily accessed by plants, which is referred to as the plant available water (PAW). The pore size distribution varies with the soil texture (% sand, silt, clay). When a soil is irrigated to saturation, all of the pores will temporarily fill up, after which the large pores drain freely, from gravity, until the soil reaches "field capacity" at which point the soil pore space should ideally contain 50% air and 50% water. The fraction that is considered as plant available water is held mainly in the medium size pores where water adheres by capillary forces (think of a wet sponge after it has been allowed to freely drain). After PAW is depleted, the remaining water is the fraction that is held in very small pores and in very thin water films on the soil particle surfaces (equivalent to a moist sponge from which water can no longer be squeezed). This is called hygroscopic water and is measured only by weighing the soil after it has been completely dried in an oven. Depending on the soil type, the hygroscopic water can comprise anywhere from a few percent of the total soil volume in a sandy soil, and up to 30% or more in a clay soil.

The key to determining when and how much to water depends on the soils total water holding capacity, and how far it can be drawn down before it becomes unavailable to plants. There are a variety of instruments for measuring both PAW and soil volumetric water content. The most basic devices for measuring PAW include tensiometers, gypsum blocks, and similar devices, whereas the volumetric water content is measured using probes that determine the water content of the soil using radio waves, or by weighing the mass of water in the soil before and after drying in an oven. Measurements of PAW measure the soil water potential and are commonly measured in bars and centibars (1/100th of a bar = 1 centibar, cb = 1 kilopascal , kPa). Water enters the plant roots by osmosis, which allows the plant to draw water from the soil when the water potential is between 0 and 1500 cb, after which most plants reach the "permanent wilting point". Immediately after watering a soil to saturation, the water potential measures 0, after which the soil will drain to achieve field capacity (-5 to -10 cb). As the soil dries out, the force by which water is held in the soil increases exponentially, such that you would never want to approach the wilting point as the plant leaf stomata will close and shut down photosynthesis well before this water potential is reached in the leaf tissues. In order to provide adequate water, irrigation is normally started when the soil dries to -25 cb for sandy soils, or to -50 cb for clay soils. This provides optimal water availability that does not restrict plant growth.

One of the greatest dangers in mismanaging irrigation is over watering to the point of waterlogging. Avocado roots require oxygen in order to function and maintain the osmotic potential in the roots that drives water uptake across the cell walls. Roots also require oxygen to produce energy to drive the cellular ion pumps that transport nutrients into the cells and that partition chloride into membrane bound compartment called vacuoles that are inside the root cells. In soils with high clay content, overfilling the soil pores with irrigation water results in depletion of oxygen, which causes the roots to stop taking up nutrients and water, and can quickly kill the roots. Lack of oxygen also causes the ion pumps that function to keep chloride in the roots to release chloride into the xylem vessels that transport water to the leaves. Hypoxia can thus very rapidly lead to chloride toxicity in the leaf tissue when trees have previously been accumulated chloride in the roots following irrigation with saline water. It is especially important to avoid waterlogging the soil during leaching, as salts that have accumulated in the root system move to the canopy during these events. Even short periods of low oxygen can lead to 3 fold increases in leaf chloride concentrations. The key in this situation is therefore to apply water in a manner that avoids saturating the soil and reducing the air space to less than 20% of the soil volume for any extended period of time.

In avocado, symptoms of overwatering can mimic symptoms of under watering — both conditions result in droopy leaves and decreased growth thus making it difficult to determine the source of the problem simply by looking at the tree. The exact degree to which avocado can withstand low oxygen is not yet known and is further complicated by the differing levels of tolerance to low oxygen for different rootstocks. Nonetheless, the overall effects of waterlogging on avocado were very well demonstrated in classic experiments that were conducted by Haas in the 1940s. (Haas, 1949) At that time, it was already well recognized that avocado trees performed very poorly in heavy poorly drained soils or in shallow soils where even well drained soils can be waterlogged by water that perches over a rock or a hardpan layer. To illustrate the effects of drainage and aeration, Haas set up an experiment in which he placed avocado trees in containers into secondary pots that had different size drainage holes that increased the time it took for the pots to drain. These experiments clearly showed that even a few hours of waterlogging could greatly reduce tree growth and root function. It turns out that avocado is not only one of the most sensitive plants to salinity and chloride, but also is one of the most sensitive of all plants to waterlogging. Careful water management and use of methods that promote soil aeration (site selection, soil berming, mulches) are thus essential to obtain good yields.

Know your soils

One of the first steps in assessing the water holding capacity of your soil is to visit to the USDA website, the Web Soil Survey (http://websoilsurvey.sc.egov.usda.gov), where one can enter the address of their orchard and obtain detailed information on yours soil's physical and chemical characteristics, as measured in the extensive 1950s soil surveys. Once the address is entered, the user marks an area of interest using a pointer tool, and then proceeds to the soil properties tab where they can obtain information on the soil texture (sand, silt, clay), soil water holding capacity, and drainage class. This will identify soils and areas of an orchard that may be particularly problematic, and will help in identifying irrigation blocks that require different irrigation management.

Managing soil water

The most basic and commonly used instruments for measuring plant available water are tensiometers and gypsum blocks, both of which measure the "soil water potential". A tensiometer consists of a water-filled tube that has a water-porous ceramic cup attached to the bottom. Once inserted into the soil, water is pulled out through the ceramic cup by the suction forces of the soil. The water column in the main tube pulls on a vacuum gage that measures the suction in units of centibars. The tensiometers are installed to place the ceramic cup portion at a depth that matches with the root zone. PAW is the water fraction that over the range from field capacity (typically 12-18 cb) up to 100 cb, where all plant available water has been depleted. Because the water potential increases exponentially as the soil dries, an upper limit of 25 cb is used in sandy soils. Clay soils can be drawn down to 50 cb, at which time irrigation should be started.

Another commonly used method for determining soil water potential is the use of gypsum blocks. These devices determine soil moisture by measuring the electrical resistance to current flow between electrodes that are embedded within a block of gypsum, or a similar material. The gypsum block allows moisture to move in and out as the soil becomes more saturated or dries out. When more moisture is absorbed by the block it lowers the resistance reading indicating a more saturated soil. The blocks are inexpensive and are easy to replace but require a data logger in order to get the readings. In addition, the blocks eventually dissolve and need to be replaced. As with tensiometers, gypsum blocks are somewhat slow to respond to rapid changes in soil moisture. They are the most useful for measuring the slow dry-down of soil over time, and thus are used to guide when irrigation should begin. On the other hand, the slow response time limits their utility for determining when to turn off the water, which can lead to overwatering when irrigation valves are directly controlled by these types of sensors.

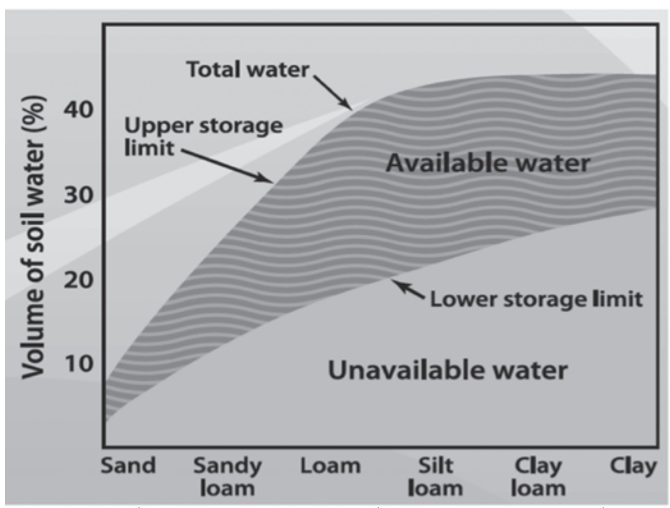

Figure 1. Soil water retention curve showing water potential versus water content for sandy, loam, and clay soils.

Soil water potential and the total amount of plant available water vary for different soils. Heavier texture, clay soils can have 40% water after irrigation, of which only a small fraction (~10%) may be available to the tree. These soils can thus become "dry" with no plant available water, but still have soil moisture levels of 30% that is not available to the tree. Conversely, sandy soils drain rapidly after irrigation to retain 10-20% water, almost all of which is available to the tree during soil dry-down. Water should be applied when the soil water potential reaches -25 to -50 cb, depending on the soil texture. (Fig. 1)

As soil water content varies greatly across microsite locations, placement of a tensiometer or gypsum block is critical for determining irrigation scheduling. (Fig. 2). The first step in setting up an irrigation program is to map the topography and soils in your orchard. The orchard can then be divided up into irrigation blocks that will all have the same schedule. Each block should have a minimum of one tensiometer that is installed next to a typical tree that represents the entire irrigation block. The best placement position at this location is in the middle of the irrigated portion of the soil where the roots are actively growing and taking up water, with a view on measuring the "average" water availability in the soil under the canopy. This is typically 1-2 meters out from

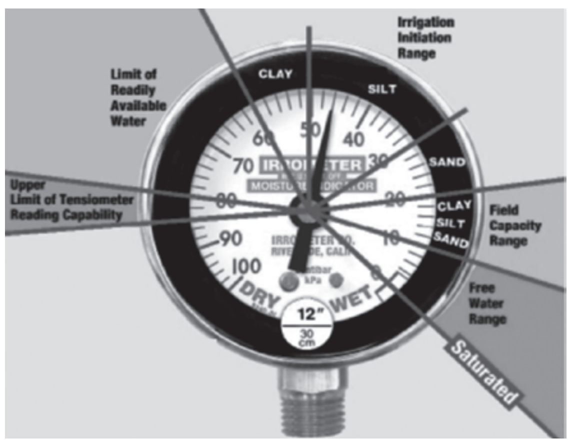

Figure 2. Sample Tensiometer Gauge with interpretation of dial readings

the tree trunk, and in the middle of the irrigation throw zone from the emitters, and at a depth of 6-8 inches. Ideally, another water monitoring device should be installed at 18 inches, which provides an indicator of when water has moved past the root zone. This second unit provides information on how long to water. By measuring the time it takes for the second tensiometer to detect the irrigation event, you can anticipate how long you need to water. Depending on your irrigation water salinity, you will want to adjust the leaching fraction (excess water) to around 10% to prevent salt accumulation. On the other hand, excess water over this amount is largely wasted, and can result in water logging as well as high water bills.

While many growers use combinations of tensiometers installed at different depths, another strategy is to use a tensiometer to determine when to water the trees, in combination with a dielectric-type soil probe that measures the volumetric water content in order to determine when to turn off the water. There are two types of dielectric sensors: TDR and capacitance. Both measure the dielectric constant of the soil. A dielectric is a material that does not readily conduct electricity — in this case the surrounding soil is the dielectric.

TDR sensors use time-domain-reflectometry. TDR measures the time a small electric pulse will travel from one electrode to another. As the moisture increases, the time the electric pulse takes to travel slows down. The reading can be influenced by soil texture, gravel content, incidental metal pieces, chemistry and salt. This method is highly accurate, though expensive, and usually reserved for research.

Capacitance sensors are two electrodes that are separated by a dielectric (soil). An oscillating frequency is applied between the sensors, which are influenced by the moisture in the surrounding soil. The resulting feedback frequency can be used to determine soil moisture content. These sensors are very responsive and sense the soil moisture in a volume of soil surrounding the unit. Still another method for measuring soil volumetric water content are neutron probes. Neutron probes work by emitting neutrons from a probe inserted in the soil. The instrument takes a reading of how the neutrons move through the soil, which can then be related to soil moisture content. Calibration is required to get accurate results. This method uses radioactive material that requires specialized training and certification, and are the most expensive option.

Table 1. Summary of Soil Moisture Measuring Technologies

Type	Advantages	Disadvantages	Cost range
Gravimetric	-Accurate -Low costs	-Labor intensive -Destructive sampling -Time consuming	-None
Tensiometer	-Continuous readings -Low costs -No calibration needed	-Maintenance required -Correct placement is difficult -Not reliable under very dry soil conditions	-$65+
Gypsum Block	-Continuous readings -Can take reading on the drier range	-Accuracy reduced in sandy soils -Data logger required -Requires calibration	-Probes $35+ -Data logger $300+
Dielectric Sensors (TDR)	- Continuous readings -No maintenance needed -Accurate measurement over a large range	-Expensive - Requires calibration -Computer software required	-Software $100+ -Data logger $300 -$800+ -Sensors $100 - $300+
Dielectric (Capacitance)	- Continuous readings -No maintenance needed -Accurate measurement over a large range	-Expensive - Requires calibration -Computer software required	-Software $100+ -Data logger $300 -$800+ -Sensors $100 - $300+
Neutron probe	-Most accurate	-Most expensive option -Computer software needed -Special training and permit for radioactive material	-System $4000+

Putting it all together

Water management is one of the most important factors affecting avocado tree growth, yields, and tree health. To determine an orchard's water requirements, CIMIS can be used to determine how much water needs to be applied in order to replenish what has been depleted by evapotranspiration. However, it is important to also consider the water holding capacity of your soil so that you avoid overwatering. For example, CIMIS may recommend 3 inches of water to replenish water loss after one week. However, if your soil will become completely saturated by this amount of water when applied at one time, then you risk waterlogging. Conversely, a well-drained sandy soil may not retain this much water when applied all at one application and the water may be wasted by rapidly draining from the root zone into the lower soil profile. Combining knowledge of your soil's characteristics with the water requirement as determined by CIMIS or a local weather station is best way to devise a strategy for your irrigation scheduling. Detailed scheduling related to the length of the irrigation set can also be accomplished by use of irrigation calculators. Lastly, soil water monitoring equipment should be used both to guide and refine the development of your irrigation schedule, and to provide oversight on how well your plan is working for providing adequate water and making the best use of this precious resource.

Specific recommendations:

- Avocado has shallow roots. Use mini-sprinklers. If drip irrigation is used, use many drippers to assure water coverage across the entire area of the soil covered by the tree canopy.

- Install tensiometers in multiple locations and at different depths in the same location to monitor soil water availability.

- Obtain a free water audit from your local water management district. Irrigation uniformity is critical and should be 90% or better.

- Check your water infiltration rates and use appropriate mph emitters to avoid runoff. Use pressure compensated emitters on hillsides.

- Map your soils on the orchard to determine their characteristics that will in turn determine your irrigation management. Be aware of shallow soils, or soils containing hard pans that can perch the water and prevent good drainage. http://websoilsurvey.sc.egov.usda.gov

- Overwatering of avocado can be a major hazard, causing root death. Waterlogging leads to rapid movement of chloride from the roots to the leaves, causing toxicity, leaf burn, and reduced yields.

- Salinity must be monitored to determine when to leach. Use a salinity pen to routinely monitor the level and location of salts in your soil profile.

- When using saline water supplies, keep the roots as oxygenated as possible by encouraging root growth near the surface, use berms, composts, and mulches to improve soil aeration and encourage root growth near the soil surface to reduce exposure to low oxygen and accumulated salts.

- Use CIMIS http://www.cimis.water.ca.gov, and irrigation scheduling calculators to determine the duration and frequency of irrigation http://www.avocadosource.com

Reference

Haas, A.R.C. 1949. Growth of avocado seedlings as affected by rate of soil drainage, California Avocado Society Yearbook 34: 139-143