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Optimizing Irrigation Management Through Soil Water Monitoring

Optimizing irrigation scheduling is one of the most critical management decisions — it determines profitability and is one of the best ways to improve tree health, avoid root diseases, improve yields and reduce water bills. But irrigation scheduling requires site-specific knowledge of the soil's characteristics in order to determine when and how much water to apply. It also requires use of soil water monitoring devices to determine when to apply water, when to leach excess salts and how to avoid overwatering that wastes money and causes a whole set of separate problems that can reduce yields or even kill your trees by waterlogging. Good irrigation management becomes even more critical when using lower quality water that contains high levels of total dissolved salts and chloride.

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. The survey of more than 100 growers indicates that approximately half of all growers do not ever 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 may even be accomplished using soil water sensors that directly control the irrigation valves. Let's take a look at the basics of soil-water relations and how growers can design an irrigation water-monitoring system to get the most out of this valuable resource.

Dangers of Waterlogging

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. The roots also have energy-requiring ion pumps that drive uptake of nutrients into the cells and that partition chloride into the membrane-bound compartment called vacuoles that are inside the root cells. In soils with high clay content, overfilling the soil pores results in depletion of oxygen that 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 vessels that transport water to the leaves. Hypoxia can thus very rapidly lead to chloride toxicity in the leaf tissue. Ironically, overwatering is most likely to occur during soil leaching that is used to remove chloride from the root zone. Even short periods of low oxygen can lead to three-fold increases in leaf chloride concentrations. Leaching in poorly drained clay soils irrigated with low quality water may actually be one of the underlying reasons for chloride toxicity. 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 percent of the soil volume.

This phenomenon was very well demonstrated in classic experiments that were conducted by Hass in the 1940s. 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, Hass 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 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 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.

Soil Water Holding Capacity and Water Availability

To avoid waterlogging and optimize irrigation scheduling, it is important to understand the nature of soil. While soils appear to be solid under our feet, a good soil for plant growth typically has about 50 percent air space. Soil is thus somewhat analogous to a sponge. Air space between the soil particles and aggregates provides pores and channels for diffusion of oxygen to the roots and also serves as a reservoir for plant available water (PAW) — the small portion of water that can be easily accessed by plants. The sizes of the soil pore spaces span from a millimeter to microscopic pores that are a few millionths of a meter in size that altogether comprise the soil pore volume. The pore size distribution varies with the soil texture (percent 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 until the soil reaches "field capacity" — the point at which the soil pore space should ideally contain 50 percent air and 50 percent water. The fraction that is considered as PAW 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 percent or more in a clay soil.

The key to determining when and how much to water depends on the soil's 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. (See "Soil Moisture Technology and Irrigation Management" on page 17 for a review of soil monitoring equipment.).

PAW measurements indicate the soil *water potential* and are commonly measured in bars and centibars (cb). 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. 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.

Know Your Soils

One of the first steps in assessing the water holding capacity of your soil is to go to the USDA website, the Web Soil Survey (websoilsurvey.sc.egov.usda.gov), where you can enter the address of your orchard and obtain detailed information on your soils' physical and chemical characteristics as measured in the 1950s. 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 you can obtain information on the soil texture (sand, silt, clay), soil water holding capacity, and drainage class. This will identify soils and areas of your orchard that may be particularly problematic and can help growers design soil water monitoring and irrigation blocks that require different irrigation management.

Tensiometers

The most basic instrument for measuring plant available water is the tensiometer, which consists of a water-filled tube that has a 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 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.

Soil water potential and the total amount of plant available water vary for different soils. Heavier texture, clay soils can have 40 percent water after irrigation, of which only a small fraction (about 10 percent) 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 percent that is not available to the tree. Conversely, sandy soils drain rapidly after irrigation to retain 10-20 percent water, almost all of which is available to the tree during soil dry-down. Water

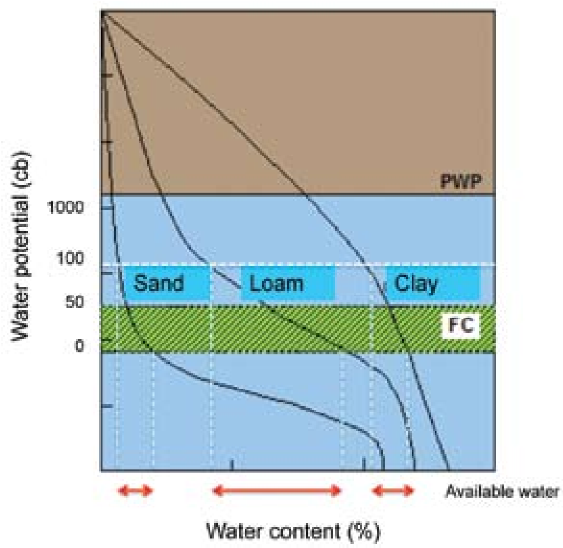


Figure 1. Soil water retention curve showing water potential versus water content for sandy, loam, and clay soils.

(FC = field capacity, PWP = permanent wilting point)

should be applied when the soil water potential reaches -25 to -50 cb, depending on the soil texture.

Because soil water content varies greatly across microsite locations in a grove, the placement of tensiometers is critical. The first step is to map the topography and soils in your grove and then divide the grove into irrigation blocks that will have the same irrigation 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 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 the tree trunk, and in the middle of the irrigation throw zone from the emitters, and at a depth of eight inches.

Ideally, another tensiometer should be installed at 18 inches, which provides an indicator of when water has moved past the root zone. This second tensiometer 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 percent in order 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.

Putting It All Together

Water management is one of the most important factors affecting avocado tree growth, yields, and tree health. Combining knowledge of your soil's characteristics with the water requirement as determined by the California Irrigation Management System (CIMIS), or a local weather station, is the best way to devise a strategy for your irrigation scheduling. Remember it is important to consider the water holding capacity of the particular soils in your grove so that you avoid overwatering. For example, CIMIS may recommend three inches of water to replenish water loss after one week — but 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 in one application and the water may be wasted by rapidly draining from the root zone into the lower soil profile.

Detailed scheduling related to the length of the irrigation set can also be accomplished by use of irrigation calculators that determine how much water to apply based on your tree size, the gallons-per-hour (gph) of your emitters, and the uniformity of your irrigation system. 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 in providing adequate water. Altogether these tools can save thousands of gallons of water, improve tree yields, and put more money in your pocket.

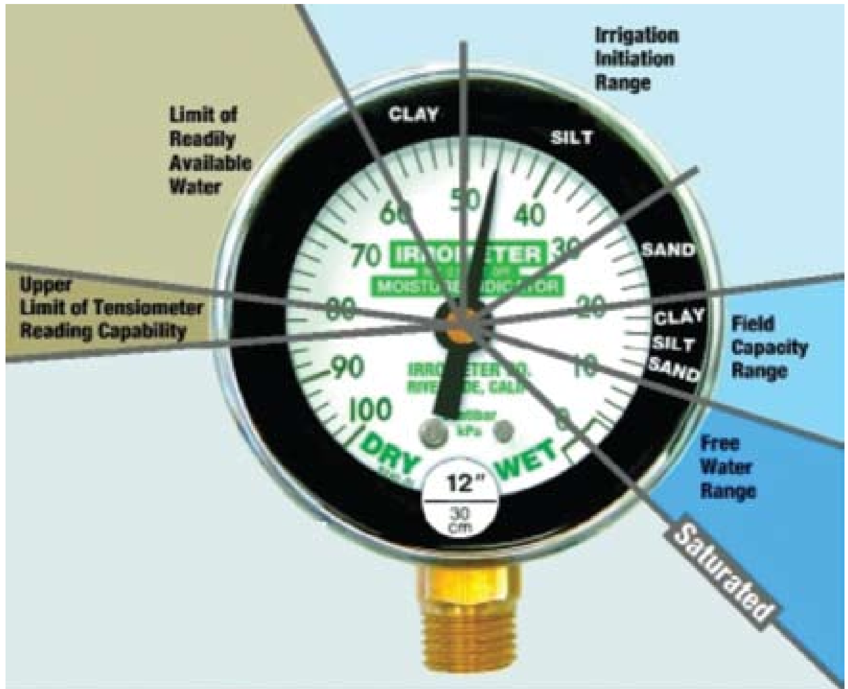
Specific recommendations:

- Avocado has shallow roots. Use mini-sprinklers. If drip irrigation is used, use many drippers to ensure water coverage across the entire diameter 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 percent or better.
- Check your water infiltration rates and use appropriate gph emitters to avoid runoff. Use pressure compensated emitters on hillsides.
- Map your grove soils to determine the physical characteristics that will in turn determine 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 root growth and reduce exposure to salts.

• Use CIMIS (www.cimis.water.ca.gov) and irrigation scheduling calculators to determine the duration and frequency of irrigation (www.avocadosource.com).



Soil Moisture Terms

Volumetric water content — a measure of the volume of water found in a volume of soil, expressed as cm3 of water/cm3 of soil.

Gravimetric water content — a measure of the mass of water found in a mass of soil, expressed as grams of water/grams of soil.

Soil water potential — how tightly the water is held in the soil against gravity, the forces between water molecules and solid particles, expressed as MPa, kPa or Bars.

Soil tension or matrix potential — terms used to describe soil water potential. It is an indicator of how hard a plant's root system must work to extract water from the soil. The drier the soil, the more negative the water potential value and the harder the plant has to work to uptake water. As the matrix potential approaches a value of zero then all soil pores, large and small, are completely filled with water, i.e. fully saturated.

Standard Water Content Terms

Saturated water content — the point at which all of the pores, macro and micro pores, in the soil temporarily fill up with water due to irrigation or precipitation.

Field capacity — occurs after macro soil pores have drained due to gravity, it is the amount of water held in the soil by its matrix potential against the forces of gravity. The point at which the soil pore space should ideally contain 50 percent air and 50 percent water.

Permanent wilting point — the point at which water is exponentially more difficult for the plant to draw up and in which the plant leaf stomata will close and shut down photosynthesis.

Plant available water — the small amount of water that a soil holds that is easily available to plants, calculated as the difference between permanent wilting point and field capacity.