Grower's Guide to Impacts and Strategies of Proper Irrigation Management

in California Almonds and Walnuts

By

Matthew A. Comrey

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Major: Agronomy

Program of Study Committee:
Adam Thoms, PhD Major Professor
Allen Knapp, PhD Major Professor
Gail Nonnecke, PhD Committee Member

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Introduction

In recent years, attention has focused on agricultural water consumption in California due to drought conditions experienced from 2012-2016. California agriculture accounts for roughly 34 million-acre feet of water use on an annual basis (Walters, 2019). Many regulatory agencies, such as the Regional Water Quality Control Board, now require growers and agriculture producers to account for water used to irrigate their crops. This regulatory pressure is causing growers and crop consultants to consider scientific approaches to irrigation scheduling and evaluate the various benefits. By adopting a scientific approach to irrigation scheduling, growers and agriculture producers have improved yield, quality, and orchard longevity.

Findings from a walnut (*Juglans spp. L.*) orchard case study in Sutter County, California, reported that implementing Evapotranspiration (ET) forecasting and weekly stem water potential measurements, increased edible yield of nuts by 4% (Comrey, 2018). The grower did not utilize ET forecasting in the prior year but instead relied heavily on a soil moisture probe to gauge soil moisture and estimate runtime. This grower participated in the case study because the telemetry equipment being used in the orchard may have been broken and/or installed incorrectly due to lack of wetting throughout deeper areas of the rootzone. After adopting ET, as a method to determine how long the irrigation system should run each week, water reached the three- and four-foot depths and a more complete wetting of the deeper areas of the root zone was accomplished. Because adequate moisture was supplied to the tree root zones, the orchard was able to set more nuts due to its increase in floral bud development and was able to carry all these nuts through to harvest as well as increased vegetative growth (Little, 2006).

Another key benefit experienced by this orchard was the improved quality of the harvested crop. Larger sized nuts, lack of staining, and lighter color are all essential factors when growers try to secure a quality premium from the processor. Deductions in payout occur when a crop is delivered that is poor quality or takes additional procedures and/or time to process into the final product. This grower received deductions from the processor in the previous year and suffered decreased profitability. Once the grower adopted the two previously mentioned irrigation scheduling tools (Et and stem water potential measurements), a much higher quality crop was harvested. The delivered crop suffered no serious staining nor undersized nuts, and more jumbo-sized nuts were obtained, which secured a premium price.

Section I: Background Information

Irrigation Systems and Design:

Irrigation system and design are important considerations when developing an orchard management plan and the orchard's establishment. Various orchard crops have different plant spacings, effective rooting zone diameters, and different water requirements based on crop type. Soil type plays a significant role in water requirements of various orchard crops. An almond (*Prunus dulcis* [Mill.] D.A. Webb) orchard planted in California's Sacramento Valley with heavier soil (higher in clay content) would be irrigated with a different strategy and irrigation system than an orchard located in the Central Valley of California. The Central Valley contains a sandier or lighter soil profile than soils of the Sacramento Valley making the Central Valley soils much less efficient at storing water (for greater detail see page 8, Soil Type and Impact on Irrigation Strategy). Low-pressure irrigation systems with lower water output are more efficient for orchards planted in sandier soils. Variation in soil type is just one example of the many considerations needed to determine an irrigation system design. The three irrigation designs most prevalent in orchard cropping systems include micro-irrigation, solid-set, and flood irrigation, each with varying efficiencies, cost implications, benefits and challenges.

Irrigation is not only useful in the summer months for plant growth but is an important tool for frost protection. The varying temperature differences between the Northern Sacramento Valley and the Central Valley, make frost protection a necessary consideration in parts of the state. Average springtime temperatures (February through May) varied greatly when analyzed for two cities: Chico, CA (Sacramento Valley) and Tulare, CA (Central Valley). The average springtime low is 45.5°F and the average high is 65.2°F for Chico, whereas the average springtime low is 48.6°F and the average high is 70.6°F for Tulare (NOAA, 2021). Average cooler springtime temperatures in the Northern part of California produce a serious risk to both Almond and Walnut orchards and must be accounted for when determining irrigation system and design. When temperatures are at or slightly below 32° F, growers can initiate irrigation and apply enough water to release heat in the orchards. This exothermic release of heat can sometimes be enough to prevent serious damage to both the trees and the crop.

Figure 1.1 Almond orchard with double lines of drip irrigation on soil on both sides of trees.

Table 1.1 Benefits (pros) and challenges (cons) of micro-drip irrigation system.

Pros	Cons
Low volume output (0.03"-0.06" per hr.)	Expensive installation
Highly efficient	Requires Maintenance- Acid injection/line flush
Precise water placement	Susceptible to vertebrate pest damage
Low canopy humidity contribution	Virtually no frost protection
Low contribution to pest pressure	Requires long runtime to meet Etc

Figure 1.2 Almond orchard with micro fan irrigation system on soil

Table 1.2 Benefits (pros) and challenges (cons) of micro-fan irrigation system.

Pros	Cons
Moderate volume output (0.05"-0.12" per hr.)	Expensive installation
Moderately efficient	Requires Maintenance- Acid injection/line flush
Lower energy cost than micro-drip	Susceptible to vertebrate pest damage
Moderate canopy humidity contribution	Low-moderate frost protection
Moderate contribution to pest pressure	Can wet center of row

Figure 1.3 Walnut orchard with a solid set irrigation system on the soil.

Table 1.3 Benefits (pros) and challenges (cons) of a solid-set irrigation system.

Pros	Cons
High volume output (0.1"-0.15" per hr.)	Expensive installation
Provides frost protection	Moderate to high contribution to pest pressure
Typically requires minimal maintenance	Low to moderate efficiency
Not susceptible to vertebrate pests	Wets a very large area of orchard floor

Figure 1.4 Walnut orchard with flood irrigation present on orchard floor.

Table 1.4 Benefits (pros) and challenges (cons) of a flood irrigation system.

Pros	Cons
High volume output (Rates will vary)	High contribution to pest pressure
Short runtime-low energy/labor cost	Lowest efficiency
No maintenance	Wets entire orchard floor
Not susceptible to vertebrate pests	Little frost protection (Walnuts)
Inexpensive installation	

Soil Type and Impact on Irrigation Strategy:

Soil type is a critical factor in producing agricultural products in the United States and the world. Soil type often dictates what crops can be produced within given regions and impacts the regional agricultural infrastructure. Soil type is characterized by a soil's composition of sand, silt, or clay and cannot be altered through management practices (Plaster, 2014). Soils contain three phases: solid, liquid and gas, each of these can vary in amounts based on soil type. The air phase (often called porosity) is typically classified into two groupings: macro- or micropores. Fertility management, and especially nitrogen management, is highly influenced by soil type which will require different strategies such as application amounts and timings. A soil with large amounts of macropores will need smaller nitrogen applications more frequently. The spatial layout as well as size of the various particles contribute to a soil's porosity which results in a dramatic impact on soil-water dynamics.

Water moves through soil through forces including gravitational, cohesion and adhesion (Taiz and Zeigler, 2006). Gravitational forces are the result of gravity pulling on the water particle. Cohesion is the force of attraction between water molecules while adhesion is the force of attraction between water molecules and a surface (Dane and Topp, 2002). Water is a dipolar molecule, consisting of a slightly negative charged pole at one end and a slightly positive charged pole at the other end (*Figure 1.5*). Cohesion occurs as a result of hydrogen bonding between the negative ends of one water molecule and the positive charge of another ("USGS", n.d.). When the positive end of the water molecule bonds with the net negative surface of soil colloids, adhesion occurs ("USGS", n.d.). Sandy soils have much larger pore spaces (macropores), allowing for greater gravitational influence on water movement between particles (Dane and Topp, 2002). This gravitational influence impacts both the infiltration rate and wetting pattern (*Figure 1.6*), particularly when water is applied to the soil surface by drip irrigation. Macropores result in much lower water holding capacity as water drains freely under the force of gravity, while micropores have a greater water holding capacity (Soil Quality Indicators, 2008).

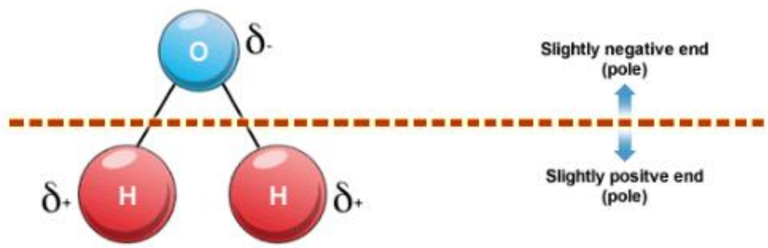

Figure 1.5 Water molecules exhibit a charge with a slightly negative and positive end

Heavier soils, or soils consisting of more clay content than sand, have overall greater total porosity (sum of various pore sizes and types) but much fewer macropores. This different consistency plays a large role on deep percolation as well as water holding capacity (WHC) because there is much lower gravitational influence on a clay soil with more capillary action (cohesion, adhesion). The previous figure (*Figure 1.6*)

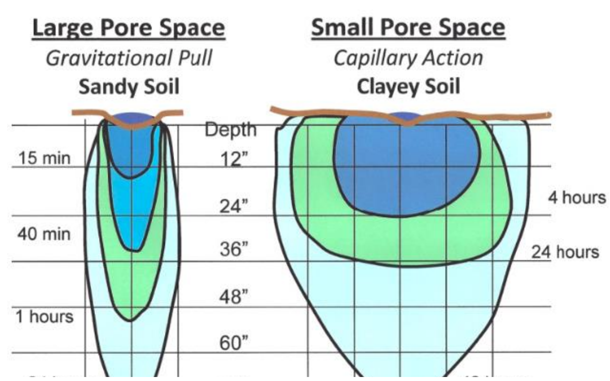

Figure 1.6 Soil-water movement differs over-time for sandy and clay soils

reflects the comparison between soil type and the different forces exhibited upon the soil water dynamic discussed above.

Different soil types along with the forces associated with both the movement of water as well as water holding capacity have a profound influence on irrigation strategy. These aspects along with other factors such as irrigation system design and crop type must be considered when making irrigation scheduling decisions. Clay dominated soils can hold more water than sand dominated soils but have much smaller pore size with a greater overall porosity. The consequence for this greater porosity is that much of the water stored is hygroscopic water and unavailable to plants due to strong adhesion forces. This results in the largest pool of available water being in the Silt loam and Clay loam textural classes (*Figure 1.7*).

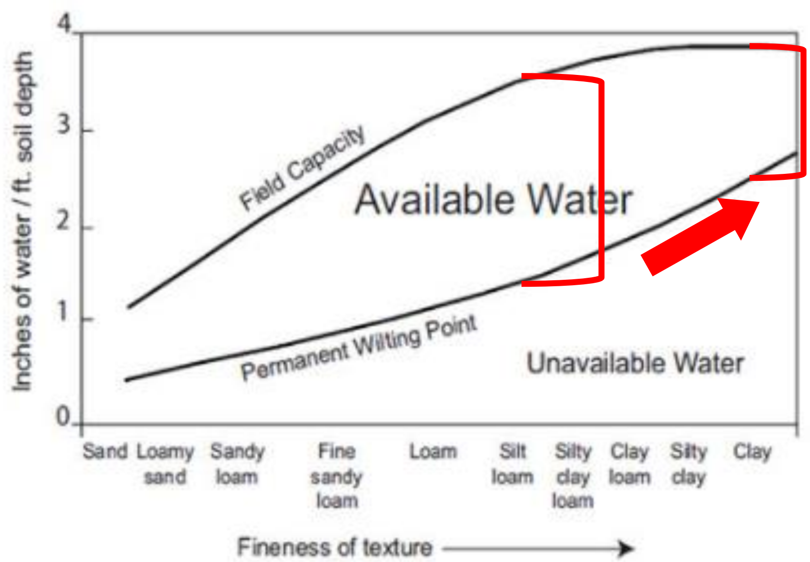

Figure 1.7 Soil moisture forms of various soil textures

Finer textured soils have a smaller pool of available water due to Hygroscopic water, or water that is held too strongly in micropores due to adhesion.

This small pool of available water at either end of the soil textural spectrum (*Figure 1.7*) requires irrigation practices to be similar. Irrigation water is applied with a more condensed interval for very light and very heavy soils for different reasons. Large irrigation volumes on sandy soils are highly inefficient due to deep percolation while large volumes on clay soils can result in excess puddling, low soil oxygen, and/or root rot problems. The key difference between these textural classes is in their physical makeup. The key differences between clay and sandy soils is not the mineral or organic matter content (although clay soils contain more organic matter, this is not the major difference), it is the relationship between air and water content (*Figure 1.8*). Mid-textured soils contain the ideal balance between water and air space and provide the adequate drainage needed for deep-rooted tree crops.

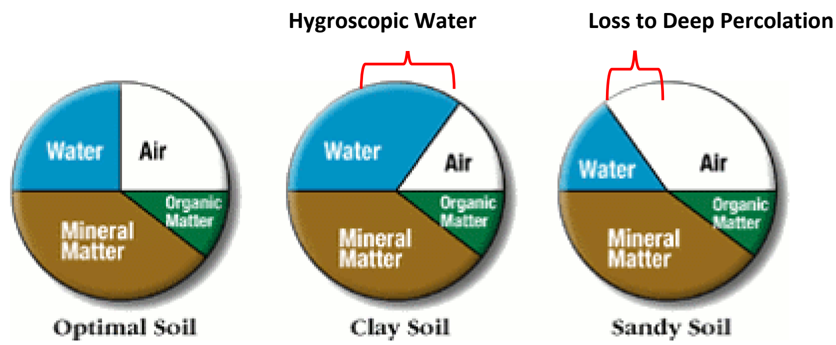

Figure 1.8: Distribution of the phases of various soil types

Due to the semi-permanent nature of most orchards, (re-planting of an orchard is typically done every 25-35 years in California) and the impact that both surface and sub-surface drainage can have on the longevity of the orchard, attention must be paid to both soil texture as well as soil-water dynamics. Site evaluations are critical in understanding the influence of soil type and winter rainfall on irrigation. It is important that early blooming orchard crops be planted in soil types that allow for adequate drainage of excessive spring rains; spring transpiration rates are not high enough to remove excess moisture. Plant roots also are not producing the necessary secondary metabolites needed to fight off infection from fungal pathogens like *Phytophthora* spp. Soil-water dynamics have a profound impact on ion movement and nutrient uptake as well, with severe consequences resulting from over- or under-irrigation on nutrient management.

Consequences of Over- or Under-irrigation on Tree Health and Nutrient Uptake

Consequences for both under- and over-irrigating nut orchard crops may occur when employing various irrigation scheduling techniques. Visual symptoms can sometimes be consistent with both under- and over-irrigating, such as general yellowing and wilting of foliage can be a symptom of decreased turgor from under-irrigation or from a lack of gas exchange in the roots due to over-irrigation. Irrigation management has a profound impact on other inputs and variables relating to the production of the orchard, particularly ion movement and integrated pest management (IPM).

Ion Movement

Ion movement (*Figure 1.9)* is characterized as the movement of both cations and anions within the soil and soil solution complex (Tiaz and Zeiger, 2006). Various ions move via different mechanisms within the soil and soil solution depending on numerous factors such as: valence charge, molecular shape, and solubility. Ions such as di-hydrogen phosphate and potassium ions move primarily via diffusion, which is movement from high concentration to low concentration through random thermal motion (Sharma, 2018). This movement takes place within the soil solution and requires adequate moisture levels for its occurrence. Ions such as nitrate move primarily via mass flow, or movement within the transpiration stream created by plants or trees (Sharma, 2018). Finally, cations such as calcium are taken up by plants through root interception or physical contact of the ion with roots where exchange can then take place (Tiaz and Zeiger, 2006). These mechanisms of ion movement and uptake are highly impacted by soil moisture, making irrigation management an important tool in maximizing nutrient use efficiency.

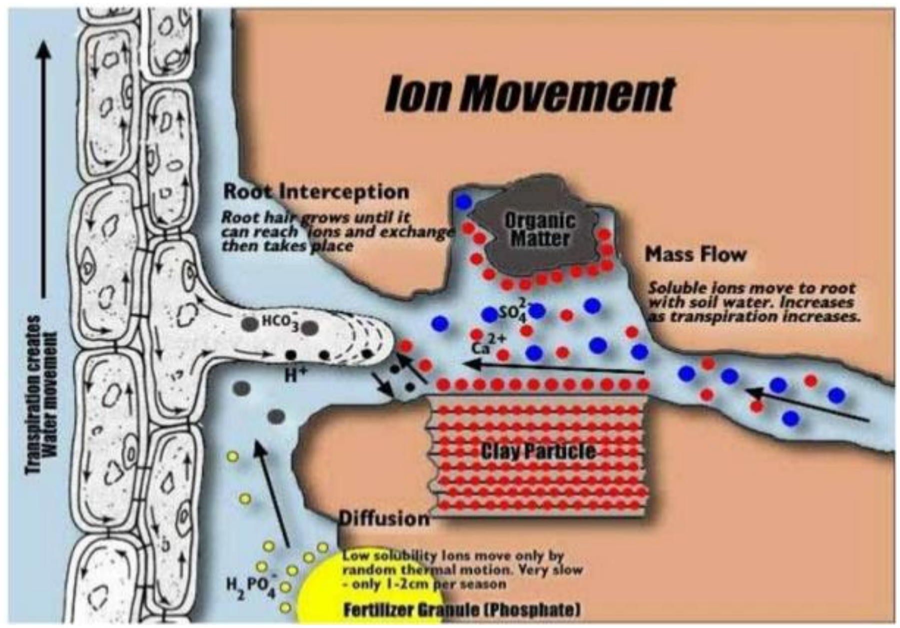

Figure 1.9 Ion movement in the soil occurs via root interception, mass flow, or diffusion

Irrigation not only plays a prominent role in the uptake of various ions; it can also impact the various 'loss mechanisms' inherent with nutrient management. Both cations as well as anions that rely on water as a vehicle of movement (i.e. diffusion and/or mass flow) can be lost from poor irrigation management. Nitrogen transformations in the soil can be sensitive to soil moisture status; for example, over-irrigation can result in either the leaching of nitrate or de-nitrification. Under irrigating can result in equally inefficient losses through ammonia volatilization under overly dry conditions. Cations such as Potassium (K^+) and Phosphates (PO_4^-) that move primarily via diffusion (the random thermal motion within the soil solution) are highly dependent on adequate soil moisture. This form of ion movement is highly limited when soil is dry and soil moisture is limited.

Integrated Pest Management

Irrigation scheduling can have a dramatic impact on a grower's IPM strategy. The microclimate of the orchard depends heavily on irrigation type, soil type, and planting density and can easily become conducive to various pest populations. For example, heavy soils are conducive to *Phytophthora* spp. infection and can be devastating in early season, over-irrigated conditions of a soil that is poorly drained. In this case, accounting for a heavy soil as well as improving drainage would be an important component to the irrigation strategy. Summer Two-Spotted Spider Mite (*Tetranychus urticae*) pressure can be reduced by ensuring that orchards are fully irrigated. When plants have adequate turgor pressure from fully irrigated conditions, these mites find it difficult to use their undersized mouthparts to feed on foliage.

In almond production, hull split is the initial stage of nut maturity where the outer protective hull (common term for pericarp) begins to develop a longitudinal suture that will eventually expose the shell (endocarp) of the nut (seed). Hull split is a very susceptible physiological stage because the nut/shell is exposed to insect pressure from Navel Orangeworm (*Amyelois transitella*) and fungal infection from hull rot (*Rhizopus stolinifer* or *Monilinia fructicola*). The almond hulls are ideal environments for the hull rot fungal pathogen to complete its life cycle because there is adequate water as well as nutrients (almond hulls represent a significant nutritional sink) available after colonization. Once colonized, harmful compounds and toxins are produced and can damage and/or kill tissues as infection spreads through spurs and into shoots. The best tool that growers have for combating hull rot in almonds is their understanding of irrigation principles and strategies for reducing hull rot incidence in their orchards.

Once the suture begins to develop in the orchard during late summer, growers should begin implementing a regulated deficit irrigation (RDI) approach. This RDI approach produces a less than ideal environment for hull rot infection by mitigating canopy humidity as well as reducing hull moisture. In the examples of hull rot and *Phytophthora spp*., irrigation scheduling plays a direct role in managing the disease triangle to create a poor environment for the pathogen to establish and reproduce. When irrigation management is a priority, it is not uncommon for growers to see a reduction in certain pest damage (i.e. mite or hull rot) as well as a potential reduction in plant protection inputs.

<u>Soil Salinity and its Impact on Irrigation Scheduling:</u>

Salinity can be problematic for crop production in a variety of ways including degraded soil structure, reduced water infiltration, and increased concentration of specific ions toxic to the crop. Sodic soils are typically the cause of many issues associated with soil structure and can be quite toxic to orchard crops at sufficient concentrations. Other common specific ion toxicities in California orchards are Boron and/or Chlorine. Bulk Salinity, or combined effect from all soluble salts in soil can dramatically alter the osmotic gradient that exists between the soil, plant or tree as a conduit, and the surrounding atmosphere. When the osmotic gradient is reduced, trees and plants must work much harder to extract water from the soil resulting in chlorosis, wilting, poor nut quality, and stunted growth.

Drought conditions in California's semi-arid climate are contributing to the salinization of regions of the state. Orchardists continue to apply salts, via either fertilizers or poor-quality well water, while winter rainfall is insufficient in many years to leach these salts from the root zone. When salts are allowed to accumulate in the root zones of salt sensitive crops, reclamation strategies need to be employed to ensure yield potential is met. Orchard managers can manipulate irrigation schedules and strategies to mitigate salinity's impact on yield production.

Figure 1.10 illustrates the matric potential curve of a loam soil, including field capacity and wilting point at various soil moisture potentials (Brady and Weil, 2008). Soil water availability classifications of gravitational water, available water, and hygroscopic water are included as they relate to soil water content (y-axis). As bulk salinity concentrations increase in the root zone, soil moisture potential can decrease dramatically, and end up shifting to the right along the x-axis on the matric potential curve (illustrated by bold red arrow). The more this curve shifts to the right, the more energy required for trees to extract soil water via transpiration. This concept of shrinking pools of available water due to salinity concentrations is known as the Physiological Drought Effect.

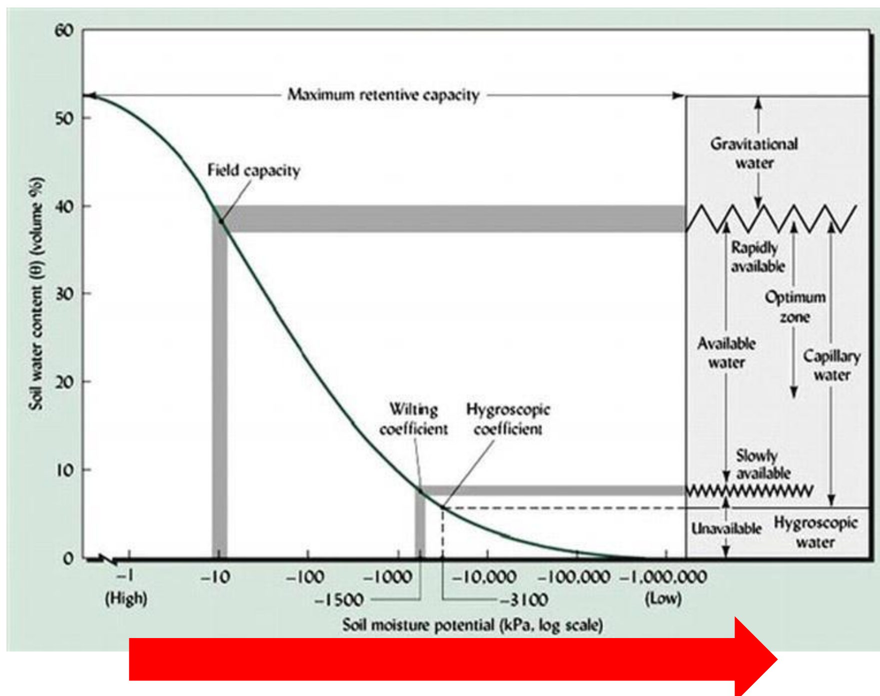

Figure 1.10 Matric potential curve for soil moisture of a loam soil

Salinity reclamation is driven by irrigation management, whereas managers can facilitate the movement of salts through the root zone by adopting one of two leaching strategies: in-season leaching or dormant leaching. Leaching is simply the "over-application" of irrigation water to ensure that dissolved ions are carried to deeper levels of the soil profile and out of the root zone. Leaching strategy depends on several variables: irrigation water quality, soil texture, and irrigation type. Improper leaching techniques have the potential to negatively impact nitrogen management, increase disease pressure due to increased canopy humidity, and inflated energy costs.

In-season leaching can be practiced in orchards that are planted in moderately well drained soils with moderately clean irrigation water without detrimental effects. A leaching fraction is expressed as a percentage and is the amount of additional water needed during an irrigation set to flush out salts. To calculate and adopt an in-season leaching fraction, bulk salinity of the soil (EC_e) as well as irrigation water salinity (EC_w) need to be known. An example of a leaching fraction calculation that assumes a soil EC of 0.9 dS/m, irrigation water EC of 1.5 dS/m, and Et_c of 1.5 inches is shown in Figure 1.11. The calculated leaching fraction is 0.14 or an additional 14% of irrigation above Et_c needed to prevent salt accumulation. In-season leaching strategies should take place in the summer months after nitrogen applications have concluded to maximize nitrogen use efficiently and prevent disease infection.

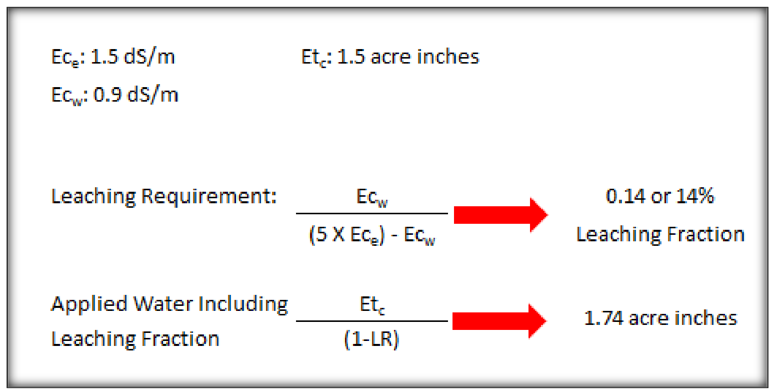

Figure 1.11 Example leaching fraction calculation used to figure additional irrigation to flush salts from the soil

Dormant leaching is used after harvest, when trees are entering the early stages of dormancy and transpiration is not occurring. Because there is little risk of negative effects from saturated soil conditions during the dormancy period, dormant leaching can be done in orchards with drainage problems from heavier soil texture and/or poor irrigation water quality. Dormant leaching consists of irrigating to field capacity prior to winter rains, allowing the clean rainwater to become the leaching fraction. Pre-irrigating is an important step to this strategy because salts will only leach below the rootzone if all soil pores are full going into the rain event. Dormant leaching can be an important tool for orchard managers to implement to hedge against salinization.

There are three specific tools that growers can employ to schedule irrigations more scientifically and efficiently (discussed in more detail in Section II). The tools consist of an Atmosphere-Based Approach, a Plant-Based Approach, and a Soil-Based Approach. Growers can ensure they are efficiently scheduling irrigations by adopting and leveraging two of these three tools in their orchard management.

Section II: The Three-Tool Approach to Irrigation Scheduling

This section will outline and describe the various tools, or approaches, to properly implement a more scientific method of scheduling irrigations. Each of these approaches uses different measurements and data to arm the irrigation manager with the information needed to answer two questions: "When do I turn the pump on?" and "How long should I run it?". These two questions are top of mind for any orchard manager who must filter through all of the environmental variables and come to some sort of irrigation schedule for their farm throughout the season. It is important for irrigators to utilize two of these three approaches to successfully schedule irrigations because data doesn't always reconcile perfectly in real-world conditions. Managers can adopt an Atmosphere-Based Approach, Soil-Based Approach, and/or Plant-Based Approach to better match irrigation applications with water exports from the orchard and decrease overall stress levels.

Atmosphere-Based Approach:

Four primary atmospheric conditions influence transpiration rates in plants. Three of these atmospheric conditions- air temperature, solar radiation, and wind increase transpiration rates while higher relative humidity depresses them. Estimating the amount that each of these conditions contributes to an orchard's Et rate is at the center of the atmosphere-based approach. Evapotranspiration is the sum of the orchard's transpiration as well as evaporation from soil surfaces of the orchard floor. Overall, evapotranspiration represents water use of the orchard. If we can accurately estimate the amount of evaporation experienced from the orchard floor as well as the transpiration rate of the crop, we can replace this water use with well-timed irrigations.

The first step in calculating crop evapotranspiration is to generate an Et_O or Reference Et value, which measures the Et rates of Kentucky bluegrass (*Poa pratensis L.*) for use as a baseline (CIMIS). Numerous weather stations comprise the California Irrigation Management Information System (CIMIS) and are located throughout the state and can generate regional Et_O values for irrigation schedules. The stations typically contain evaporative pans capable of measuring water loss through evaporation and instruments that measure environmental conditions that influence transpiration. The CIMIS then offers a platform for users to create an account and access up-to-date regional reference Et_O values and various reporting functions. Once users generate reference Et_O values, those values are converted to Crop Evapotranspiration (Et_C) in order to be reconciled with irrigation application rates (Allen et al., 1998).

The conversion of Et_O to Et_c accounts for the inherent differences in water use and water demand from crop- to- crop. Once the reference Et_O is known, a crop coefficient (K_C) is used to convert this reference value to actual crop evapotranspiration (Et_C). The K_C values can vary slightly depending on where and who publishes the values. There is some slight disagreement among research professionals as to the exact values (*Appendix slides*). This Et_C value then represents unadjusted total water use (as well as evaporative loss) by the orchard per acre (Allen et al., 1998). Once this value is known, irrigation managers can match the net export of water from the field with water application method and rate.

In order to effectively reconcile irrigation applications with estimated water removal (Et_C), the irrigation system outputs must be measured. It is important to take multiple measurements throughout the irrigation set at multiple locations to estimate the average application rate per acre. Information such as tree planting density, number of emitters per tree, and wetting radius are needed to calculate water application rates (*actual steps to completing these calculations found in Learning Module located in the Appendix*). Measuring application rates across the irrigation set assumes there is a relatively high distribution uniformity (DU) throughout the field (>80%).

DU is the relative consistency of the water application across an orchard from a given irrigation system and design. Figure 2.1 (West Coast Nut, 2019) illustrates several concepts relating to DU: A. Low

DU as well as Low efficiency, B. High DU and Low efficiency, and C. High DU and High efficiency. Low DU results in varying degrees of water application rates across an irrigation system, resulting in some trees becoming under-irrigated and some trees being over-irrigated. Low DU always results in inefficient use of water resources, and can result in low nutrient use efficiency, and lower yields. Efficiency, as it relates to irrigation management, refers to the appropriate distribution of moisture throughout the root zone. Efficient irrigation result in the proper amount of water being applied as well as the proper wetting depth throughout the root zone. Because both over-irrigating as well as under-irrigating are considered inefficient irrigation management, DU should be considered when determining irrigation application rates.

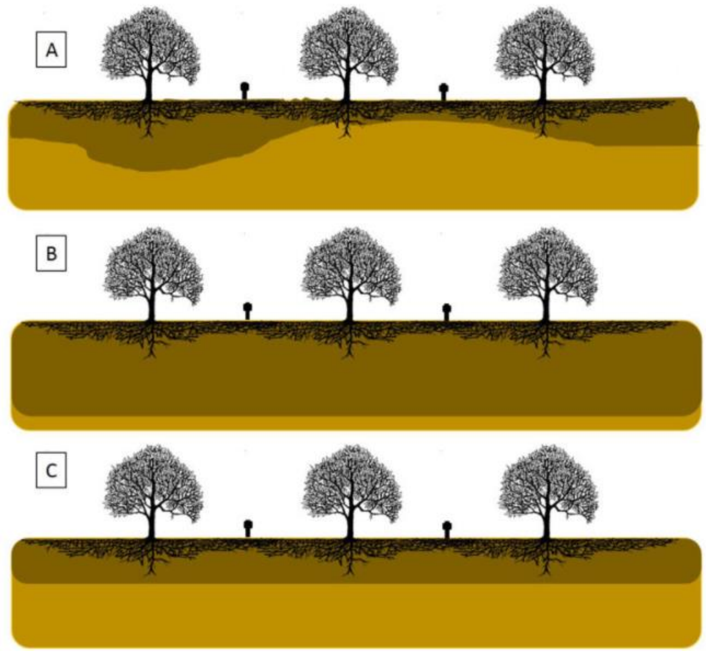

Figure 2.1 A. low distribution uniformity and low irrigation efficiency, B. High distribution uniformity and low irrigation efficiency, C. High distribution uniformity and high irrigation efficiency for an orchard irrigation system.

<u>Plant-Based Approach:</u>

The Plant-Based Approach utilizes any method or measurement that estimates the relative water stress experienced by a specific crop. This approach is most effective at answering the question regarding irrigation interval but can be quite ineffective at determining set length. Popular tools under this approach include NDVI imaging, pressure chambers, and/or sap flow monitors. These tools vary in their ability to provide useful information needed to make effective decisions as well as cost and ease of use. In my orchard irrigation management experience, using a pressure chamber to measure Midday

Stem Water Potential is a good balance between, providing useful/actionable measurements and cost/ease of use.

Stem Water Potential (SWP) is a measure of tension, which reflects the water status of the plant at a given point in time and is expressed as “bars”. This allows the user to measure and understand the levels of stress that the target plant is experiencing. Midday stem water potential measurements are taken between the hours of 10:30am through 2:30pm when transpiration and photosynthetic rates are at their peaks. Ambient air temperature as well as relative humidity can have a profound impact on transpiration rates and need to be accounted for when taking SWP measurements. These readings are then compared to stress ranges outlined by U.C. Davis, Department of Agriculture and Natural Resources (2007).

Procedures for taking SWP measurements vary slightly but are generally accepted and published in various online sources (*available in the Appendix*). Identifying an easily accessible side of the field that represents the field as a whole can reduce the pressure bomb technician’s time spent on site. Mylar bags are placed over leaves for at least ten minutes to allow equilibrium between leaves and the vascular system throughout the entire tree. Leaves are then removed with a razor and immediately placed in a specialized pressure chamber and sealed. Di-nitrogen gas is then slowly metered into the chamber, effectively increasing pressure within the sealed chamber. The end of the petiole is inserted through a grommet whereas the individual metering the gas can inspect the xylem from the severed end. Once water is seen ‘wetting/bubbling’ from the petiole, gas is shut off and measurement is recorded from the gauge. This measurement then represents the amount of force needed to “squeeze” water out of the leaf. The concept is not unlike a wet sponge, as a sponge becomes wetter it takes less and less force to wring the water from the pores.

Soil-Based Approach:

Understanding the amount of water a soil can hold versus the amount of water currently being held is an important component of irrigation scheduling. Because most plants receive 100% of their water needs through the soil via transpiration through the leaf, soil moisture evaluation is an important part of the irrigation puzzle. There are two popular strategies for employing the Soil-Based Approach in orchard production that can be both simple to implement and effective.

The first strategy is the Allowed Depletion Strategy, which quantifies the amount of water that the effective root zone can hold (*Figure 2.*2) while deducting estimated water loss (Et_c). Typically, a pre-determined depletion percentage is used (ex. 50%) to "trigger" an irrigation event. For example, an almond orchard planted on silty clay loam soil with an estimated effective rooting zone of four feet can hold approximately eight-acre inches of water (4 feet X 2 acre in. water held in one foot of clay loam soil). If 50% were the irrigation trigger, then irrigation would be initiated once accumulated Et_c reaches four-acre inches since the last irrigation event. This strategy requires a certain degree of record keeping as well as a good understanding of the texture of the soil profile.

Textural class	*Water holding capacity, inches/foot of soil*
Coarse sand	0.25 - 0.75
Fine sand	0.75 - 1.00
Loamy sand	1.10 - 1.20
Sandy loam	1.25 - 1.40
Fine sandy loam	1.50 - 2.00
Silt loam	2.00 - 2.50
Silty clay loam	1.80 - 2.00
Silty clay	1.50- 1.70
Clay	1.20 - 1.50

Figure 2.2 Soil texture class and water holding capacity in inches per foot of soil

The second strategy mentioned above has become widely used in California orchards in the past 15 years as cellular technology has improved exponentially. Telemetry equipment, equipped with sensors that can quantify the amount of soil moisture, can be installed in orchards and monitored remotely via cell phone or computer

Figure 2.3 Telemetry equipment installed and used for irrigation decisions in an almond orchard

(*Figure 2.3)*. These tools give the user instant decision-making data that is both stored and accessible for years. This equipment can be expensive to install and typically requires an annual data plan to remain connected and transmitting data. Hardware options for these telemetry stations include weather stations, pressure switches, flow meters, etc. that can provide enhanced capabilities or even add some level of automation to the system as well. These various strategies are outlined in further detail in the Appendix.

Conclusion:

Orchard producers are constantly searching for new ways to increase profitability by increasing yields and reducing costs. Scientific irrigation scheduling leverages widely available data into actionable strategies that can both reduce operating costs while improving yield and quality. The goal of this this creative component (with Appendix) is to provide orchard producers with an overview of various approaches to irrigation scheduling while outlining the numerous impacts irrigation has on their operation. Irrigation will continue to be a hot topic among UCANR as well as regulating bodies for years to come, providing farmers with little choice but to implement tools to properly evaluate irrigation needs. The aim of this creative component is to bridge the gap between the technical academic world with producers and irrigation managers who have to answer two simple questions; "When do I turn the irrigation pump on and How long do I run it for?"

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Figure 1.4 United States Geological Survey. (n.d.) Retrieved 28 May 2020. Retrieved from: https://www.usgs.gov/media/images/flood-irrigation-pecan-orchards-rio-grande-project-area-new-mex

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Figure 1.8 Orange Master Gardener. Retrieved 11 June 2020. Retrieved from: https://theorangegardener.org/topics/soil/tilth/tilth#header

Figure 1.9 M. Shravan Kumar. 2018. Mechanisms of nutrient uptake of plant root cells from soil. Retrieved from: https://www.slideshare.net/SRNRDY/mechanisms-of-nutrient-uptake-from-soil Accessed 11 June 2021.

Figure 1.10 Brady, N.C., & Weil, R.R. 2008. The Nature and Properties of Soils. 14th Edition. Upper Saddle River, N.J.: Prentice Hall

Figure 2.1 Lightle, D. 2019. Distribution Uniformity: Why it Matters, What Influences it, and Improving Yours. West Coast Nut. Retrieved 28 May 2020. Retrieved from: http://www.wcngg.com/2019/05/06/distribution-uniformity-why-it-matters-what-influences-it-and-improving-yours/

Figure 2.2 Plant and Soil Sciences eLibrary 2021. Soils-Part 2: Physical Properties of soil and soil water. ATI Soils. Retrieved from: https://passel-old.unl.edu/communities/index.php?idinformationmodule=1130447039&topicorder=10&maxto=10&minto=1&idcollectionmodule=1130274298

Figure 2.3 Chesini, M. 2020. Photo used by permission.

Permissions for Photos and Figures:

From: Matthew Comrey <MComrey@wilburellis.com>
Sent: Friday, July 17, 2020 2:06 PM
To: Paul P. Rusnak <PPRusnak@meistermedia.com>
Subject: Permission to use Photo

Paul,

My name is Matt Comrey and I am hoping to use the above photo that I pulled from one of your online publications. I am currently in a Graduate Program at Iowa State University and I am hoping to receive permission to use the above photo in a project regarding irrigation. The photo will be used as an example of microfan irrigation system layout. Please let me know if I have permission to use it or please put me in contact with the appropriate person for permission. Thanks.

Hi Matthew.

Thank you for reaching out regarding use of this photo.

You can use, but please credit the image to Bowsmith (https://www.bowsmith.com/)

Have a great day.

Paul Rusnak | Senior Managing Online Editor

Florida Grower | American Vegetable Grower | American Fruit Grower

GrowingProduce.com | GreenhouseGrower.com

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2431 Aloma Ave., Suite 124 | Winter Park, FL 32792

O: 407-539-6552

NSGS:

Subject: Permission to Use an image

Message: My name is Matt Comrey and I am a graduate student with Iowa State University. I'm hoping to use an image (url is copied below) in a project that I am completing on Irrigation Scheduling in Orchard Crops. I intend to use the image as an example of a flood irrigation layout in the section of my paper that discusses various methods of irrigation system layout. This image will be used strictly for educational purposes and will be cited appropriately.https://www.usgs.gov/media/images/flood-irrigation-pecan-orchards-rio-grande-project-area-new-mex

Good morning Matt,

Information from a USGS website/report/publication etc., are considered public domain. We just ask that you add a credit the USGS.

Please visit these websites for all the guideline details on how to credit the USGS: https://www.usgs.gov/faqs/are-usgs-reportspublications-copyrighted?qt-news_science_products=0#qt-news_science_products

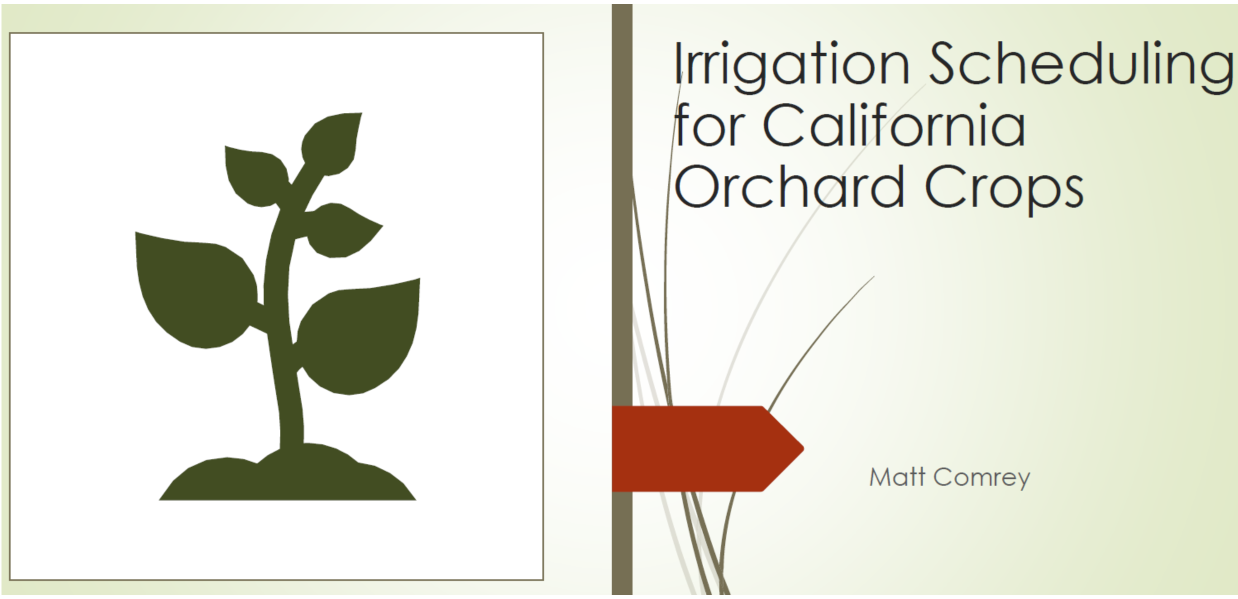
and https://www.usgs.gov/information-policies-and-instructions/copyrights-and-credits

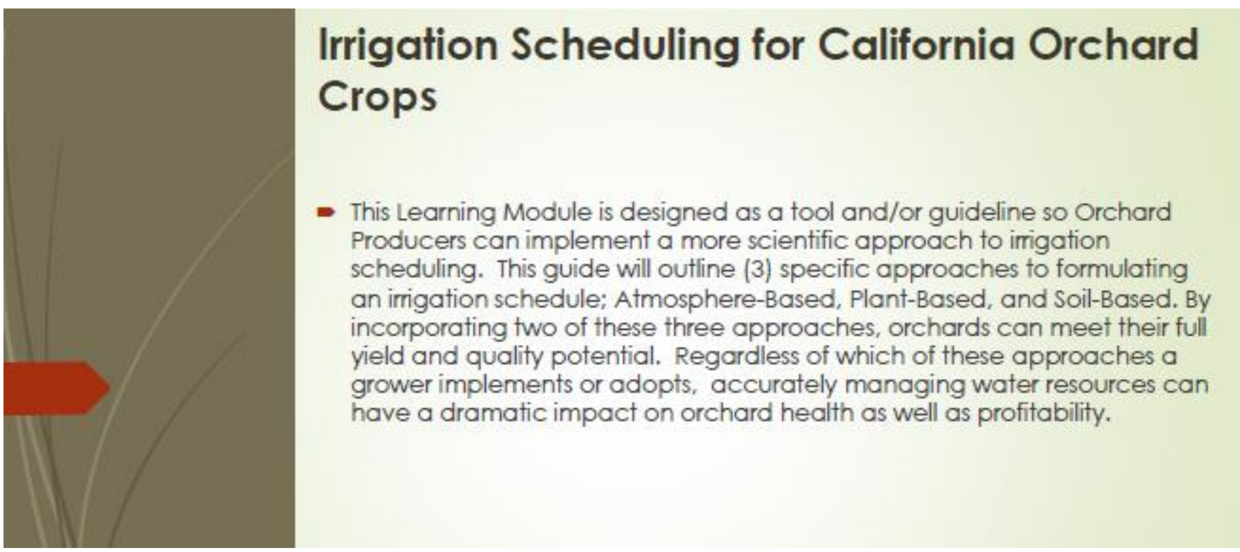
Thank you for contacting the USGS!

Sincerely,

Amelia Redhill
USGS - Menlo Park

Appendix i:


Irrigation Scheduling for California Orchard Crops
Matt Comrey


Irrigation Scheduling for California Orchard Crops
This Learning Module is designed as a tool and/or guideline so Orchard Producers can implement a more scientific approach to irrigation scheduling. This guide will outline (3) specific approaches to formulating an irrigation schedule; Atmosphere-Based, Plant-Based, and Soil-Based. By incorporating two of these three approaches, orchards can meet their full yield and quality potential. Regardless of which of these approaches a grower implements or adopts, accurately managing water resources can have a dramatic impact on orchard health as well as profitability.

Approaches to Scheduling Irrigations

- Atmosphere-Based Approach
- Plant-Based Approach
- Soil-Based Approach

Atmosphere-Based Approach

First step: Calculate Application Rates

Information needed to calculate:

- Tree Spacing
- Planting Density
- Irrigation Type
- Emitter Spacing/Density
- Application Rate per Emitter
- Wetting Radius (if applicable)

Equipment needed to Calculate

- Medium-Large "catch" container
- 100 ft tape measure
- 25 ft tape measure
- Calculator
- 1-1.5" rubber hose
- Shovel
- (2) Graduated Cylinders- (1) 0-100 ml scale & (1) 0-500ml scale

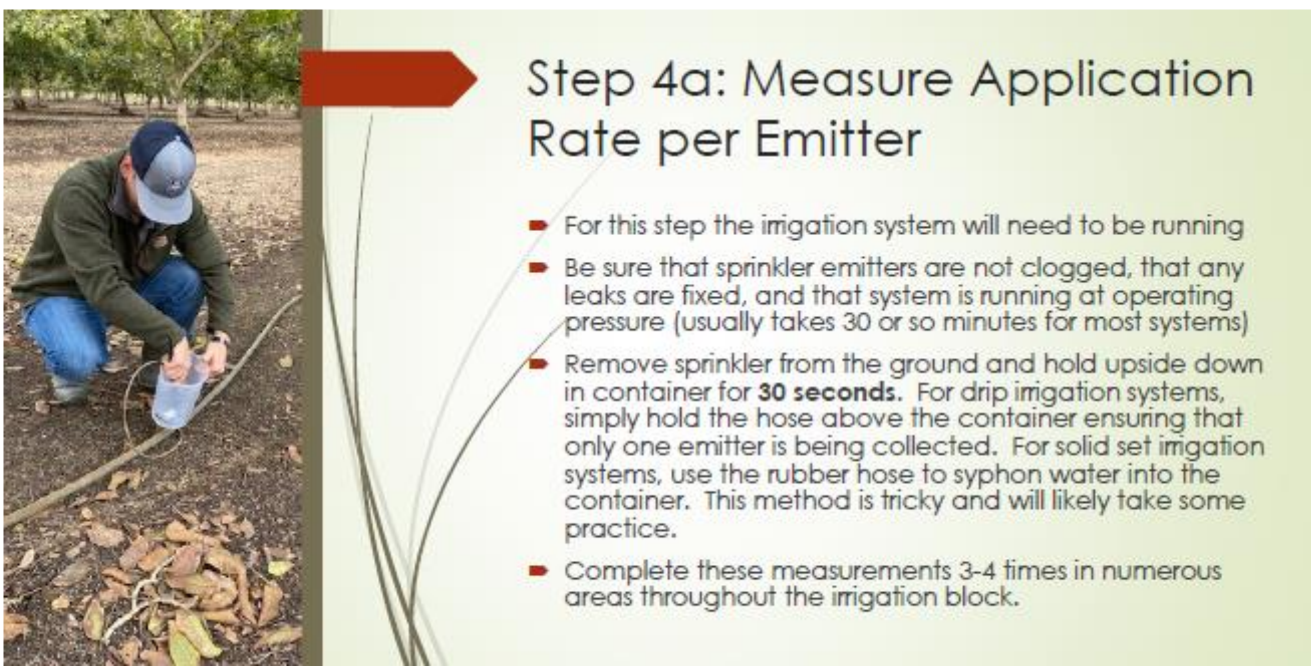
Step 1: Measure Tree Spacing & Calculate Planting Density

- Use 100 ft tape to measure Row Width (ft) and measure space between trees (ft)
- Once these two measurements are known, multiply two values together to get planting density in square feet. **Ex: Row Width- 20' Tree Spacing- 14' Trees per Square Foot= 1 tree per 280 ft^2**
- In order to calculate Planting Density- 43,560 (ft^2/acre) divided by # of Trees per Acre **Ex: 43,560 ft^2 per acre/280 ft^2 = 155 trees per Acre**

Step 2: Measure Emitter Spacing

- Method for measuring emitter density depends on irrigation type:
  - Drip Irrigation: Measure distance between emitters, then divide space between trees by distance between emitters which gives # of emitters per tree per hose. Then multiply # of emitters per tree per hose times # of hoses to get total # of emitters per tree. **Ex: Double line drip system with drip emitters spaced every 2 ft with 14 ft between trees- 14 feet/2 feet= 7 emitters per tree per hose. 2 hoses times 7 emitters per tree per hose= 14 total emitters per tree.**
  - Microjet/Microfan/Solid Set Irrigation: Much simpler! Simply count # of sprinklers per tree to understand Emitter Spacing. **Ex: If orchard has 1 sprinkler in between each tree this would be 1 Sprinkler per tree.**


Step 3: Calculate Emitter Density
Calculate Emitter density by multiplying # of trees per acre times # of emitters per tree. This gives you # of emitters per acre. Ex: 155 trees per acre times 1 sprinkler per tree= 155 sprinklers/emitters per acre.


Step 4a: Measure Application Rate per Emitter
For this step the irrigation system will need to be running
Be sure that sprinkler emitters are not clogged, that any leaks are fixed, and that system is running at operating pressure (usually takes 30 or so minutes for most systems)
Remove sprinkler from the ground and hold upside down in container for 30 seconds. For drip irrigation systems, simply hold the hose above the container ensuring that only one emitter is being collected. For solid set irrigation systems, use the rubber hose to syphon water into the container. This method is tricky and will likely take some practice.
Complete these measurements 3-4 times in numerous areas throughout the irrigation block.

Step 4b: Calculate Application Rates (Gallons per Hour per Emitter)

- Emitter application rates are typically collected in either ml/30 seconds for drip/micro systems and oz/30 seconds for solid set systems.
- These values will need to be converted to gallons per hour per emitter

To convert from ml/30 seconds to gph:

(Emitter output/29.5735 ml/oz)X(2)= # of oz/minute

(# of oz/minute)/128 oz/gallon= # of gallons per minute

(# of gallons per minute)X (60 minutes per hour)= **gallons per hour per emitter**

To convert from oz/30 seconds to gph:

(Emitter output)X(2)= # of oz/minute

(# of oz/minute)/128 oz per gallon= # of gallons per minute

(# of gallons per minute)X (60 minutes per hour)= **gallons per hour per emitter**

Example Calculations

Assuming a Walnut Orchard planted to a 30X30 spacing: Irrigation System is Microjet (1 sprinkler per tree) with a measured emitter output of **529.3 ml per 30 seconds**

- # of Oz/minute= (529.3/29.5735)X(2)= **35.8**
- # of Gallons per Minute= 35.8/128 oz per gallon= **0.28**
- Gallons per Hour per emitter= 0.28X60 minutes= **16.8**
- Total Gallons per hour per acre= 16.8X48.4 (emitters per acre)= **812**
- Acre Inches per hour= 812/27154 (gallons per acre inch)= **0.03**
- If wetting radius is 15 feet, wetting pattern is ~707 square feet (πr^2). This means irrigation water is only being applied to ~80% of orchard floor which effectively increases application rate
- Calculate *Actual Application Rate:* 0.03"/80%= **0.038 acre/inches per hour**

Grower	MK Neubert
Field and Crop	Hutchinson
Tree Spacing	30x30
Sprinkler Spacing	30x30
Emitters per acre	48.4
Catch from nozzle (gal per hour)	16.78022554
total gal per acre/ hr	812.1629161

avg ml/30 sec	529.3

Evapotranspiration

- Evapotranspiration is the combined water loss through transpiration of the tree as well as evaporation from the soil surface (assumes no ground cover).
- CIMIS (California Irrigation Management Information System) is a reliable resource for cumulative Et values (Et is measured in acre inches.
- Evapotranspiration Equation is: $Et_c = Et_O \times K_c$

Et_O= Reference Et: *Evapotranspiration as measured from Kentucky Bluegrass + Evaporative Pan (CIMIS).*

K_c= Crop Coefficient: *Value that quantifies the efficiency of the individual crop being measured (typically a tabular value-See Left)*

Et_c= Crop Evapotranspiration: *Actual Evapotranspiration of specific crop*

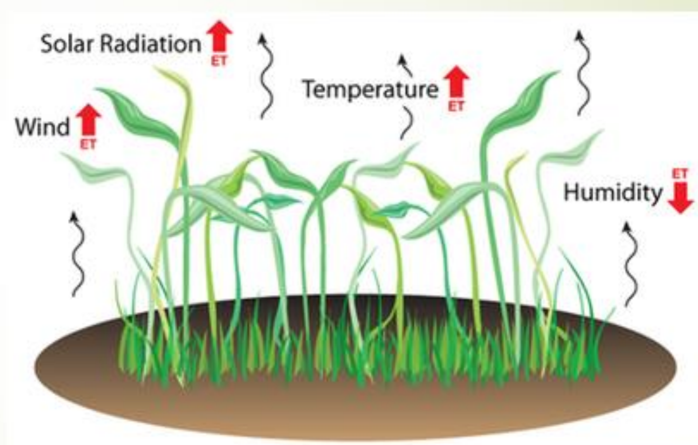
Values taken from UC ANR *Almond Production Manual*

Date	K_c
Mar 16-31	0.54
Apr 1-15	0.6
Apr 16-30	0.66
May 1-15	0.73
May 16-31	0.79
June 1-15	0.82
June 16-30	0.86
Jul 1-15	0.90
Jul 16-31	0.94
Aug 1-15	0.94
Aug 16-31	0.94
Sep 1-15	0.94
Sep 16-30	0.91
Oct 1-15	0.85
Oct 16-31	0.79
Nov 1-15	0.7

Values are from UC ANR *Walnut Production Manual*

Date	K_c
Mar 16-31	0.12
Apr 1-15	0.53
Apr 16-30	0.68
May 1-15	0.79
May 16-31	0.88
June 1-15	0.95
June 16-30	0.98
Jul 1-15	1
Jul 16-31	1
Aug 1-15	1
Aug 16-31	1
Sep 1-15	1
Sep 16-30	0.97
Oct 1-15	0.88
Oct 16-31	0.31
Nov 1-15	0.28

Environmental Factors that Drive Evapotranspiration



Back to the Calculations…

We are calculating Et_c as well as pump runtime for the 7-day period June 15th to 21st (Use previously calculated application rates)

- We see from the CIMIS Daily Report below that Et_o for the 7-day period is 1.91"
- To calculate Et_c we will need the K_c value from the table (0.95) note: this value is simply stating that during this period of the growing season, Walnuts are 95% efficient in utilizing water
- Now plug information into Et equation- 1.91 X 0.95= 1.81 acre inches
- In order to apply 1.81 acre inches of water, the pump needs to run for **47 hours** (1.81"/0.038" per hour)

California Irrigation Management Information System (CIMIS)

CIMIS Daily Report

Rendered in ENGLISH Units.
Monday, June 15, 2020 - Sunday, June 21, 2020
Printed on Tuesday, November 10, 2020

Verona - Sacramento Valley - Station 235

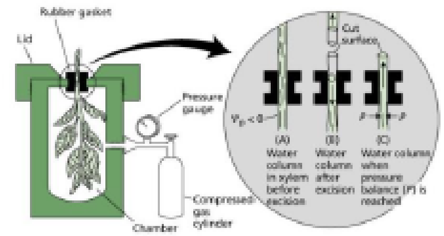
Date	ETo (in)	Precip (in)	Sol Rad (Ly/day)	Avg Vap Pres (mBars)	Max Air Temp (°F)	Min Air Temp (°F)	Avg Air Temp (°F)	Max Rel Hum (%)	Min Rel Hum (%)	Avg Rel Hum (%)	Dew Point (°F)	Avg Wind Speed (mph)	Wind Run (miles)	Avg Soil Temp (°F)
6/15/2020	0.32	0.00	581	14.8	87.3	58.5	71.5	87	28	55	54.1	4.5	108.5	74.1
6/16/2020	0.29	0.00	742	13.2	83.8	48.5	67.0	85	25	54	48.8	3.3	72.1	74.4
6/17/2020	0.33	0.00	734 R	11.0	87.3	39.7	72.0	83	25	41	47.2	8.3 Y	227.3 Y	73.8
6/18/2020	0.28	0.00	737	12.8	85.3	48.5	74.5	81	23	44	51.0	3.7	88.7	74.4
6/19/2020	0.28	0.00	718	14.4	87.3	54.5	77.1	79	23	45	54.3	4.5	107.8	73.8
6/20/2020	0.27	0.00	690	15.5	82.3	58.0	73.8	84	25	37	56.4	3.7	101.0	73.2
6/21/2020	0.27	0.00	728	15.8	87.2	57.1	70.7	85	28	33	58.3	3.8	93.3	77.1
Tots/Avgs	1.91	0.00	724	13.8	91.3	53.2	73.1	84	27	30	53.1	5.1	122.8	75.2

Plant-Based Approach

Using a Pressure Chamber

What is Stem Water Potential?

- A Pressure Chamber is a tool that uses Nitrogen gas to ‘squeeze’ water out of the petiole of an excised leaf
- The amount of force/pressure needed is *Stem Water Potential* (measured in bars)
- Therefore Stem Water Potential (SWP) is a method of quantifying the relative water stress level of the measured plant
- SWP is useful in answering the question: “When should I initiate an irrigation event?”, but does not answer the question: “How long should I run my pump for?”
- Therefore SWP measurements are particularly useful when coupled with Et forecasting *(See Atmosphere-Based Approach)*



Steps to Taking a Stem Water Potential Measurement

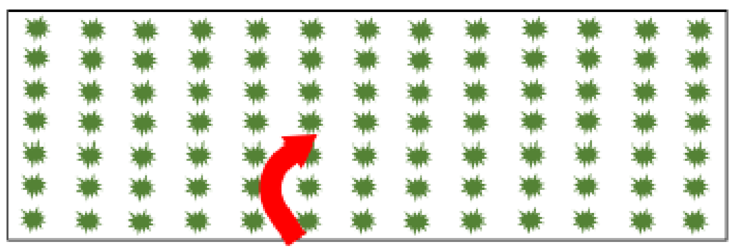
Site Selection → Leaf Selection → Operating the Pressure Chamber → Interpretation of the SWP Measurement → Reconciling SWP with Irrigation Status

Equipment Needed….

- Razor Blade or Sharp Knife
- Mylar Bags
- Colored wire irrigation flags
- Magnifying glass
- Notebook and Pen

Site Selection

- Leaf samples should be taken in each irrigation set
- Samples should be taken from the same area of a block and the same route or swath should be taken through the sampling zone
- Only healthy areas that represent the relative health of the entire block should be sampled

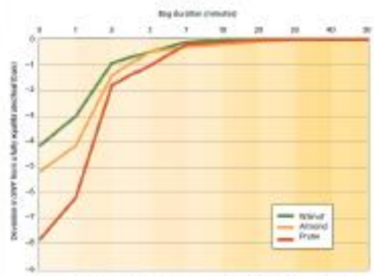


The above graphic illustrates an aerial view of an orchard setting with the red arrow illustrating a possible route for sampling

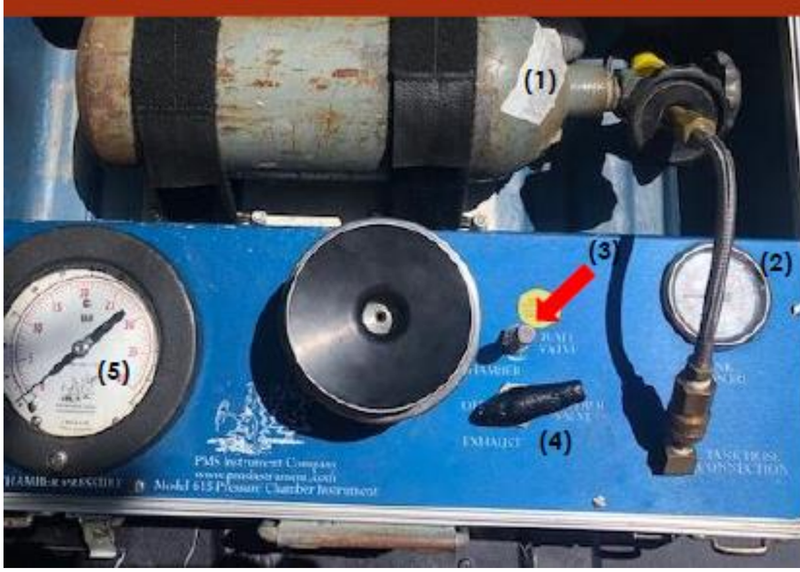
Leaf Selection

- Leaf Selection is as important as Site Selection
- Mylar bags should be placed on 6-8 different leaves from different trees throughout the 'sampling swath' for 7-10 minutes (Table at Right)
- Mylar bags are used to simulate nighttime and cause stomata to close, creating moisture equilibrium between leaf and other vascular tissue of tree (See Figure 8)
- Only leaves from healthy trees and shoots free from disease or insect pressure

Figure 8. Lower interior leaves are selected on almond (A and B), prune (C and D), and walnut (E and F) to measure SWP. Various methods—paper clip (A), Velcro (B), or ziplock (F)—may be used to hold bag on leaf. Photos: A. Fulton.



Operating a Pressure Chamber



- At left is Model 615 Pressure Chamber Instrument from PMS Instrument Company
- The tank of Nitrogen is at top and must be open prior to operation **(1)**
- Dial at Top Right indicates gas pressure **(2)**
- 'Rate Valve' controls how quickly gas fills the chamber **(3)**
- Control Valve operates the Chamber: 'Chamber' initiates pressurization, while 'Exhaust' bleeds pressure from the Chamber **(4)**
- Chamber Pressure (Gauge at Left) illustrates chamber pressure in Bars. **(5)**

Interpretation of the SWP Measurement

- Once leaf is inserted into the chamber with the petiole inserted through the grommet, the chamber can be pressurized
- Once the film of water begins to cause a "darkening" of the exposed tip of the petiole, stop pressurizing the chamber
- Stop pressurizing chamber prior to bubbles being seen
- Record the measurement from the pressure gauge prior to de-pressurizing chamber

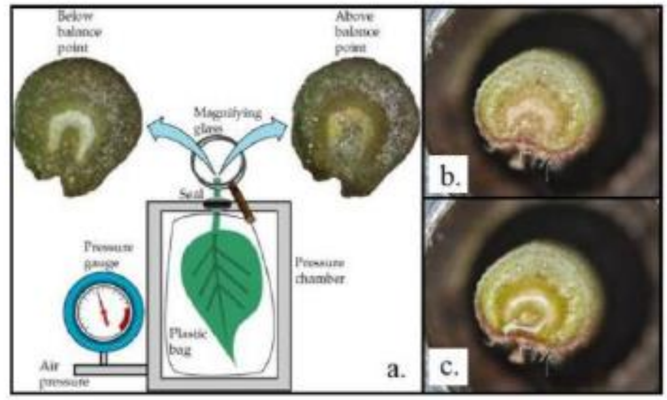


Figure 2. Cartoon depicting a pressure chamber used to measure the water tension force in a stem or leaf (water potential). A pressure chamber measures the force needed to push water out of a hydrated leaf (a). The reading on the pressure chamber when the dry petiole (b) moistens as a film of water is pushed out (c) provides an estimate of plant water potential.

Reconciling SWP with Irrigation Status

TENTATIVE GUIDELINES FOR INTERPRETING PRESSURE CHAMBER READINGS (MIDDAY STEM WATER POTENTIAL-SWP) IN WALNUT, ALMOND, AND DRIED PLUM. UPDATED MAY 2007.

Allan Fulton and Richard Buchner, UCCE Farm Advisors, Tehama County, Joe Grant, Farm Advisor, San Joaquin County, Terry Prichard, Bruce Lampinen, Larry Schwankl, Extension Specialists, UC Davis, and Ken Shackel, Professor UC Davis.

Pressure Chamber Reading (- bars)	WALNUT	ALMOND	PRUNES
0 to -2.0	Not commonly observed	Not commonly observed	Not commonly observed
-2.0 to -4.0	Fully irrigated, low stress, commonly observed when orchards are irrigated according to estimates of real-time evapotranspiration (ETc), long term root and tree health may be a concern, especially on California Black rootstock.	↓	↓
-4.0 to -6.0	Low to mild stress, high rate of shoot growth visible, suggested level from leaf-out until mid June when nut sizing is completed.	↓	↓
-6.0 to -8.0	Mild to moderate stress, shoot growth in non-bearing and bearing trees has been observed to decline. These levels do not appear to affect kernel development.	Low stress, indicator of fully irrigated conditions, ideal conditions for shoot growth. Suggest maintaining these levels from leaf-out through mid June.	Low stress, common from March to mid April under fully irrigated conditions. Ideal for maximum shoot growth.
-8.0 to -10.0	Moderate to high stress, shoot growth in non-bearing trees may stop, nut sizing may be reduced in bearing trees and bud development for next season may be negatively affected.	↓	Suggested levels in late April through mid June. Low stress levels enabling shoot growth and fruit sizing.
-10.0 to -12.0	High stress, temporary wilting of leaves has been observed. New shoot growth may be sparse or absent and some defoliation may be evident. Nut size likely to be reduced.	Mild to moderate stress, these levels of stress may be appropriate during the phase of growth just before the onset of hull split (late June).	Suggested mild levels of stress during late June and July. Shoot growth slowed but fruit sizing unaffected.
-12.0 to -14.0	Relative high levels of stress, moderate to severe defoliation, should be avoided.	↓	Mild to moderate stress suggested for August to achieve desirable sugar content in fruit and to reduce "dry-away" (drying costs).
-14.0 to -18.0	Severe defoliation, trees are likely dying.	Moderate stress in almond. Suggested stress level during hull split. Help control diseases such as hull rot and alternaria, if diseases are present. Hull split occurs more rapidly.	Moderate stress acceptable in September.
-18.0 to -20.0	Crop stress levels in English walnut not observed at these levels.	Transitioning from moderate to higher crop stress levels	Moderate to high stress levels. Most commonly observed after harvest. Generally undesirable during any stage of tree or fruit growth. Most appropriately managed with post-harvest irrigation.
-20 to -30	↓	High stress, wilting observed, some defoliation	
Less than – 30		Extensive defoliation has been observed	High stress, extensive defoliation

Soil-Based Approach

Interpreting Soil Moisture

Interpreting Soil Moisture Data

- Capacitance style sensors that can measure Volumetric Water Content are a popular choice for growers
- Sensors measure soil moisture on a volume basis and transmit this information to the cloud so it can be accessed by either cell phone or computer
- Provides a user with a snapshot of soil moisture trends and measurements

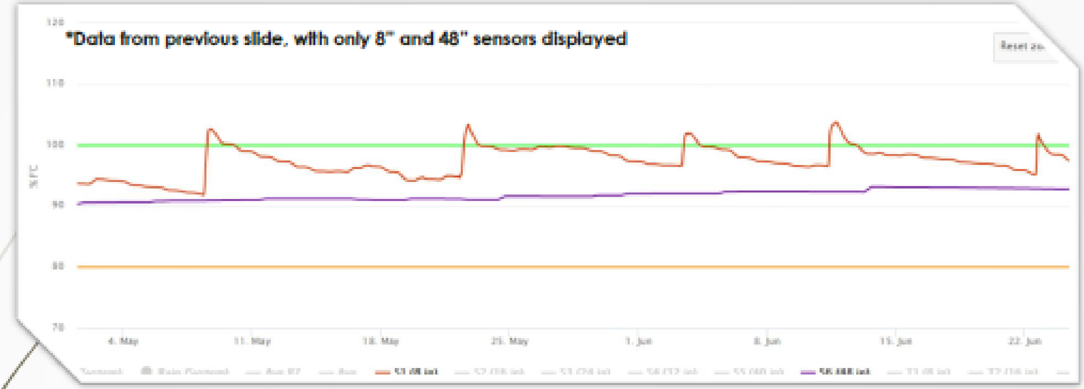
Identify Field Capacity or Upper Range

The graphic at left is a screenshot of actual data following rain events (red arrows). We see that the sensors at various depths reacted accordingly. Field Capacity is based on the 8" and 16" sensors- 24 hours after the event (marked with a red star)

- **Field Capacity is best identified while trees are dormant and not transpiring**
- **Field Capacity is the amount of soil moisture retained after a significant wetting event (rain/irrigation) against the force of Gravity**
- **Once 24 hours has past since the wetting event and gravitational water has percolated, the soil moisture reading is then identified as Field Capacity**
- **100% Field Capacity should be our target moisture level and is the backbone of soil moisture interpretations**

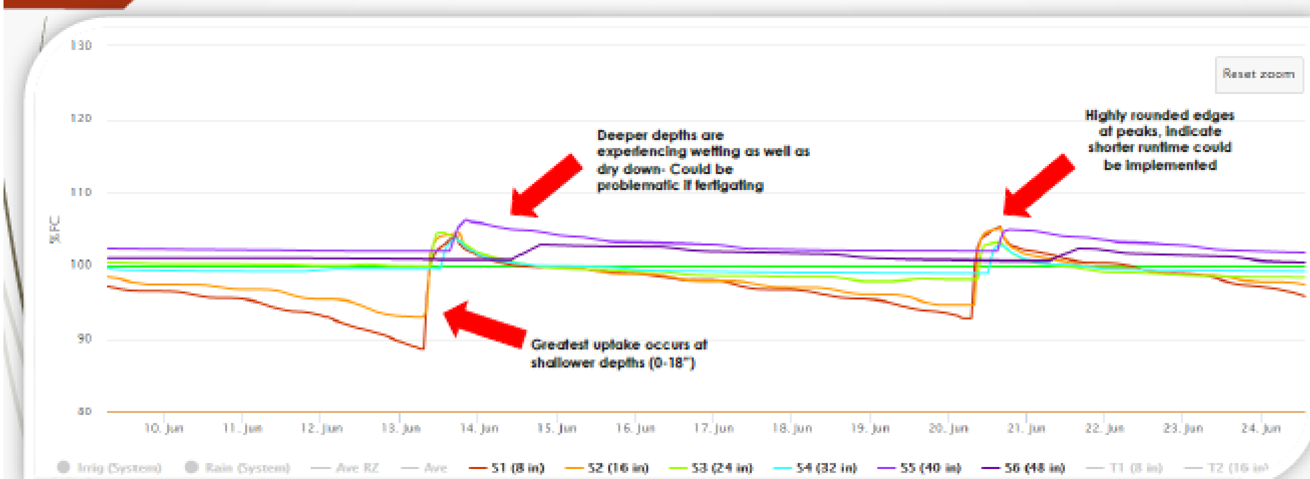
Soil Moisture Data- Young Almond Orchard

- The above graphic shows the irrigation history of a third leaf almond orchard with an effective rooting depth of 18-24"
- Irrigation water is applied until both the 8" and 16" sensors reach Field Capacity, while small registers are seen at deeper depths (24"-40")
- We see from the data that the shallower depths are kept moist, while the deeper depth don't experience much wetting and drying

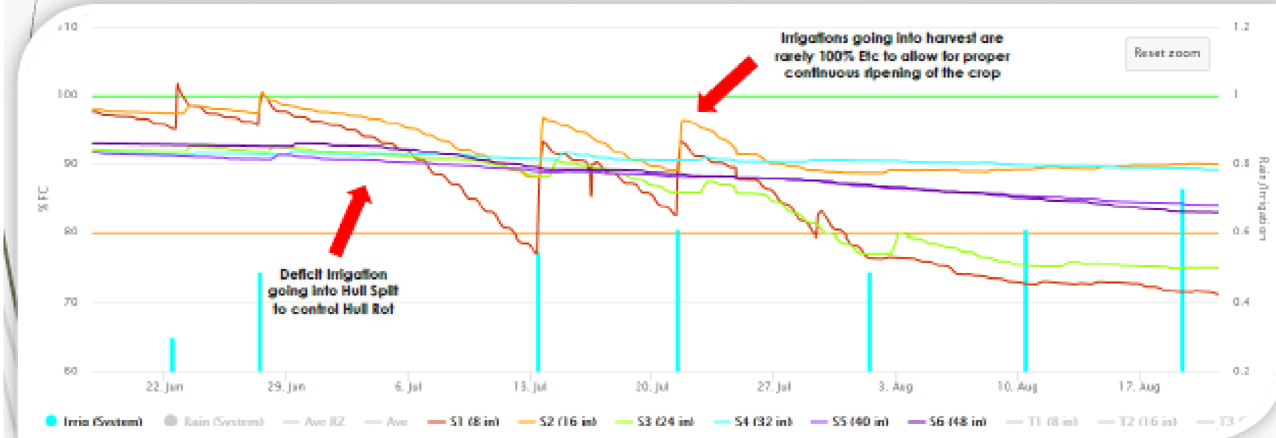


- Graphic from previous slide illustrating that irrigation isn't over applied because there are no dramatic spikes at the 48" depth
- This is an ideal condition when fertigating, water remains in the upper soil profile- We see that we're not leaching Nitrogen.
- There is some gradual rising of deep moisture, I believe this indicates that watering interval should be 7-9 days while slightly reducing runtime until we see deep moisture stabilize

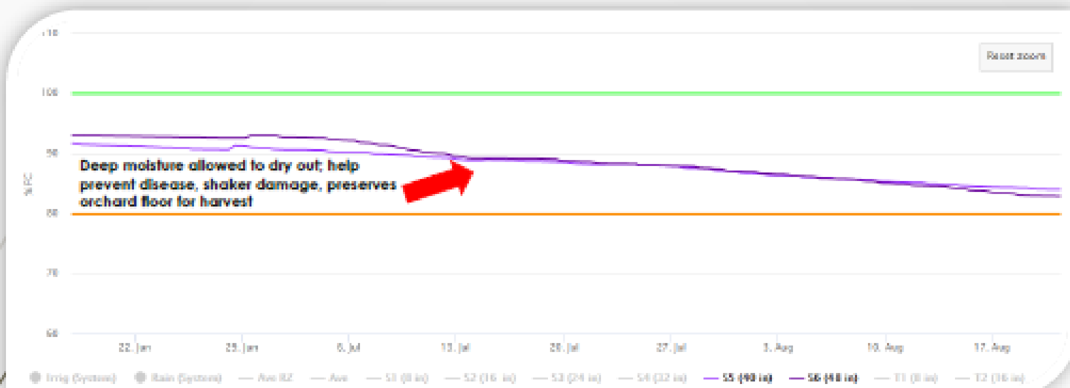
Soil Moisture Data- Mature Almond Orchard



Manipulating Soil Moisture through Maturity



Manipulating Soil Moisture through Maturity continued…



- Above graphic is a duplicate of the data presented in the previous slide with only the deep sensors highlighted (40" & 48" sensors)
- Irrigations (runtime & interval) are manipulated to allow for proper drying at deeper depths to help facilitate harvest