IRRIGATION MANAGEMENT

CALIFORNIA ALMOND **SUSTAINABILITY PROGRAM**

california almonds
Almond Board of California

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INTRODUCTION – SUSTAINABILITY AND IRRIGATION MANAGEMENT

The first almond orchards in California were primarily planted as done for centuries in Europe—on hillsides without irrigation. Almonds originate in dry areas of central and southwest Asia and are highly drought tolerant. However, as the industry grew in the first half of the 20th century, a revolution in California Almond farming took place when growers discovered that planting orchards in fertile, well-drained soils with irrigation and fertilization could double or triple yields. This innovation and the subsequent expansion of almond growing in the Central Valley eventually established California as the leading source of almonds globally.

In the intervening years, a dramatic change has also taken place in irrigation technology. To early flood and furrow systems were added various sprinkler types and then drip tape and micro-sprinkler systems. Besides new systems for distributing the water in the orchard, new technologies have been developed to support decisions for optimizing the amount and timing of water applications—soil moisture sensors, tensiometers, evapotranspiration devices, and pressure chambers for measuring plant water stress. Some of these devices are now connected to the Internet and transmit data that can be checked via cell phone. Additional technologies are being researched; some will likely become commercially viable in the future.

The introduction of advanced irrigation technologies over the past three decades led to another significant increase in yields for California Almond orchards, and this contributed to another major expansion period for the almond growing community. In addition to yield increases, the efficient timing and delivery of water can enable more efficient application of crop nutrients, reduce weed and disease pressures, and improve harvest timing. Of course, these technologies can require significant money and time to install and maintain, but they enable growers to maximize their return on water applied.

Older technologies, such as flood or sprinkler systems, have some advantages for sustainability which should not be overlooked, however. For example, some older systems require less energy for pumping and therefore decrease adverse air quality impacts. Moreover, farmers who want to use vegetation or cover crops to build soil organic matter and/or keep dust down may need to deliver water to the entire orchard floor. It should also be pointed out that even older irrigation systems can be made more efficient by the use of best practices for scheduling and maintenance.

Over time, various factors have reduced access to and/or increased the price of irrigation water in much of California. Whether you need to reduce water use or simply want to maximize yields, irrigation efficiency is critical for maximizing your returns in farming California Almonds today.

Orchard Establishment

The orchard establishment interval is the best opportunity to address many soil and water issues through strategic soil amendments, rootstock selection, tree spacing, irrigation system design and other measures. It is also the time to take stock of the investment required to maximize the orchard's potential. Collecting information and thinking strategically prevent mistakes which might reduce yields or result in costly annual inputs.

A MAP IS WORTH A THOUSAND WORDS

Since the first aerial photos of fields became available, people have been struck by how a simple photograph can reveal soil variations as variations in crop growth. Of course, not everyone can jump in a plane and take a photo of a field, but today satellite photos are downloadable for free from the Internet. Often, you can download several photos going back years or even decades. When establishing a new orchard, photographic records provide an opportunity to look at whatever was growing on the property before and see if there are areas of poor growth which might reflect soil variations or problems. This simple bit of information can help to target sampling for soil compaction, soil type, nematodes, etc.

USDA soil maps are also freely available online and allow you to identify potential soil differences (e.g., sand streaks) which may impact the watering needs of trees in different parts of the orchard. These maps are not always highly accurate, so they should be used as a starting point for guiding soil testing.

Sensing technologies, such as soil electroconductivity (EC) mapping, provide additional information. EC mapping technology maps variation in the soil related to soil texture or salinity—either of which may require attention prior to orchard development. Use the maps to guide sampling and additional testing.

Few people have tried yield mapping in orchard crops, but yield maps are becoming more common in field crops. If the previous crop on this land was yield mapped, this information could be used to identify soil variations as well.

	For this orchard, the following practices and/or technologies for improving water use efficiency were used during establishment:	Not familiar with this	I didn't try it	Used this practice	Not applicable
1	Were you involved in this orchard's establishment? ☐ Yes (continue with the following questions) ☐ No (skip to question 16 on page 12)				
2	Soil maps (e.g., NRCS soil series or web soil survey) were used to identify potential variations in soil texture, salinity, water holding capacity, or other factors.	☐	☐	☐	
3	Aerial or satellite photos (e.g., Google Earth) were used to identify potential variations in soil texture, salinity, or other factors.	☐	☐	☐	
4	Yield maps from the previous crop (almonds or another crop) were used to identify potential variations in soil texture, salinity, or other factors.	☐	☐	☐	
5	A GPS map of soil characteristics using sensing technology (e.g., EC, Veris® or SIS) was made and used to identify potential variations in soil texture, salinity, or other factors.	☐	☐	☐	
6	Backhoe pits were dug or deep auger/core samples were taken (guided by the above and other observed factors) in strategic places to determine:	☐	☐	☐	
	a. texture (percent sand, clay, silt) or saturation percentage	☐	☐	☐	
	b. compaction layers or other soil stratification	☐	☐	☐	
	c. salinity	☐	☐	☐	
	d. pH	☐	☐	☐	
	e. soil organic matter	☐	☐	☐	
7	Deep ripping, slip plowing, or tree hole backhoe pits were dug to address drainage and/or compaction issues (preferably after first testing for these problems).	☐	☐	☐	☐
8	If suggested by soil sampling, soils were amended to adjust pH, sodicity, salinity, etc. during orchard development.	☐	☐	☐	☐
9	Soils were amended with organic matter during orchard development.	☐	☐	☐	
10	All water sources were sampled and lab-evaluated for water quality/irrigation suitability. ☑	☐	☐	☐	
11	Rootstocks were selected based on soil texture and drainage conditions as well as potential soil pest or disease problems.	☐	☐	☐	
12	The irrigation system was designed to meet or exceed a specific target distribution uniformity.	☐	☐	☐	
13	The irrigation system was designed for the site so that irrigation sets correspond to soil texture zones and/or topography.	☐	☐	☐	
14	An economic analysis utilizing the type of information in this section and expected returns was done prior to moving forward with the orchard development/redevelopment.	☐	☐	☐	☐
15	Other: ______________________________			☐	

Thinking outside the rectangle

Most property lines are rectangular, and most irrigation sets probably are as well. For orchards with uniform soil, a rectangular design may be best. However, soil conditions can vary across a block significantly. To ensure optimal yields, associated irrigation rates ideally vary by soil condition. So, rather than simply asking your irrigation system designer for the least expensive installation, analyze options for creative ways to improve your economic returns through more efficient water application—even if a more expensive system is needed.

One guide to getting the best irrigation system for your money is the Irrigation Consumer Bill of Rights™ from the Cal Poly Irrigation Training and Research Center. A copy is provided in this module.

☑ This practice may also have food safety implications. Consult ABC GAP recommendations for more information.

References and more information

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NRCS Web Soil Survey: http://websoilsurvey.nrcs.usda.gov

Sanden, Blake. 2006. Soil and Water Quality for Trees and Vines. *Proceedings California Plant and Soil Conference 2006.*

University of California, Davis Agricultural & Resource Economics Cost Studies: http://coststudies.ucdavis.edu/

General Irrigation Consumer Bill of Rights

Note: This supplements other Irrigation Consumer Bills™ written for specific irrigation methods. Discuss these items with your irrigation dealer before purchasing your irrigation system. The discussion will help you to make wiser selections of design options, and to appreciate the obligations of both yourself and the dealer in creating your irrigation system.

DESIGNER QUALIFICATIONS

- What are the dealer credentials (formal training, references, designer certification by The Irrigation Association, contractor's license, and/or professional agricultural engineer registration)?

DESIGN FEATURES (GENERAL)

- What is the life expectancy of system components?
- What safety features have been included?
- What are the options for future upgrades?
- What is the recommended list of spare parts?

SPECIFIC OPERATING/DESIGN PARAMETERS

- What will be the distribution uniformity on the whole field when brand new?
- Does the system provide climate control?

WATER REQUIREMENTS

- What are the peak daily needs (acre-inches) for a normal year?
- What is the system delivery capacity in 24 hours (acre-inches)?
- What is the anticipated amount of water to be used per year (acre-feet)?
- If the field has plants with different spacing, ages, or varieties, what is the recommended procedure to provide the appropriate amount of water per acre per week to each block?
- Energy consumption:
    - Is it possible to pump all water during off-peak hours?
    - What are the pump and motor/engine efficiencies?
    - Are you provided with a pump curve showing the GPM and pressure?
    - What is the sensitivity of pump flow rates to well water changes?
    - What is the energy cost per acre-foot?
- Filtration:
    - Is filtration necessary, and, if so, what type is provided?
- Chemical injection:
    - Are locally required backflow prevention and safety devices provided?
    - What is the capacity of the injector in gallons per hour?
    - Can the equipment inject both fertilizers and other chemicals?
- Flow meter:
    - Does it measure both flow rate (GMP) and volume (acre-feet) applied?
    - Does installation follow manufacturers' recommendations with regard to lengths of straight pipe, pipe diameter, and straightening vanes?

- Pressure, air, and flushing:
    - Are there adequate air vents, vacuum relief valves, and flush-outs?
    - What are the number, type, and size of pressure relief valves?
    - Is the pressure rating of all system components sufficiently high for the anticipated water temperature, surge pressures, and normal pressures?

WARRANTIES

- Who provides equipment installation, start-up, and adjustment?
- What are the warranties on individual component and system design performance?
- Who is providing warranties and what do the warranties cover and exclude?
- Are the providers financially capable of standing behind their warranties?
- What is the availability of replacement parts?
- Will you be provided with a packet containing manufacturers' literature, warranties, and operation instructions for the system?
- Is the irrigation dealer a full-service dealer?

The General Irrigation Consumer Bill of Rights™ and Irrigation Consumer Bill of Rights™ for Drip/Micro-irrigation were developed by the Irrigation Training and Research Center (ITRC) and reproduced here with ITRC permission.

ITRC
California Polytechnic State University (Cal Poly)
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Irrigation Consumer Bill of Rights for Drop/Micro Irrigation

Note: This supplements the General Irrigation Consumer Bill of Rights™. Discuss these items with your irrigation dealer before purchasing your irrigation system. The discussion will help you to make wiser selections of design options, and to appreciate the obligations of both yourself and the dealer in creating your irrigation system.

FILTRATION

- What is the equivalent mesh size?
- How frequently will filter flushing be necessary, and how much water will be used per flush? How will the flush water be disposed of?
- Does this filter require pre-filtration?
- What is the procedure for flushing (manual, automatic, take-apart)?
- How is this filter protected from corrosion on both the inside and outside?
- Does the pump provide enough water to flush the filter and operate the irrigation system simultaneously? Is a separate valve needed to sustain back flush pressure?
- What are the initial adjustments necessary for the filter, and who will make them?
- Through what variation in flow rate can the filter be effective?
- Is a backup filter required? How will it be flushed, what are its mesh requirements, and where will it be located?
- If a back flush flow adjustment is necessary, is it possible to view and sample the back flush water in order to make proper filter adjustments?
- What is the safe operating pressure of the filter?
- How much pressure loss is there through the filter when clean, and when dirty?

FLOW RATES AND PRESSURES

- What is the minimum pressure anticipated at any emitter?
- What is the average emitter flow rate and pressure?
- How are pressures regulated throughout the system?
- Do pressure regulators require any adjustments?

CHEMICAL INJECTION

- What type of chemical injection is needed to minimize emitter plugging?
- Has the water been tested for pH, iron, manganese, and sulfur bacteria problems?
- What equipment components can be damaged by injected chemicals?

GENERAL REDUCTION OF PLUGGING

- Is insect damage to emitters a problem in the area? How will the design alleviate that problem?
- Are adequate flush-outs provided throughout the whole system?
- If used, can in-field filters and hose screen washers be easily cleaned?

GENERAL AGRONOMIC

- What percentage of soil volume will be wet?
- Are any chemical additives needed to minimize water runoff from the soil surface?

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Irrigation Infrastructure and Maintenance

Irrigation efficiency is related to many factors. People often single out the type of irrigation system as the key factor. While important, any type of irrigation system can become less or more efficient depending on how it is used and maintained.

16	What is the type of irrigation system for this orchard (not counting systems for frost control)? It is recommended that you assess one irrigation set at a time. If you wish to assess an orchard with multiple types of irrigation systems, please select all appropriate types. ☐ Drip ☐ Micro-sprinkler ☐ Flood or furrow irrigation ☐ Sprinklers
17	Is this system also intended for use for frost protection? ☐ Yes ☐ No If yes, is the system capable of producing 30-45 gpm per acre? ☐ Yes ☐ No ☐ I don't know

MEASURING SYSTEM PERFORMANCE

How do you know if your irrigation system is optimally distributing water? Monitoring and recording the amount of water flowing through the system alerts you if problems are developing and gives you a record for charting performance day to day and year to year.

A distribution uniformity test assures that the system is not overwatering some trees and under-watering others (likely reducing yields in either case).

Pumps lose efficiency over time as impellers wear and conditions (such as water table level) change. The Center for Irrigation Technology at CSU Fresno recommends pumps be tested every 1 to 3 years. Correcting problems can not only improve delivery of irrigation water but also save energy costs. For this reason, utilities often provide free or reduced-cost tests. More information is available at pumpefficiency.org.

Micro-irrigation has many advantages for ensuring the efficient use of water to meet yield targets. However, if filters malfunction, filters or emitters can become clogged and reduce water output by more than 50%. Pressure gauges can help detect clogging filters but should be checked periodically for accuracy.

Even small amounts of water lost from a system can add up to significant losses over time. If your water demands frequent filter flushing, a system that re-captures the flush water can be worthwhile. Likewise, frequently checking for leaks can prevent costly losses of both water and yield (due to thirsty trees).

	For my orchard, I am using the following practices and/or technologies for maximizing my irrigation system efficiency:	Not familiar with this	I haven't tried it	I have tried it	My current practice	Not applicable
	ALL SYSTEMS					
18	I monitor the average depth of water penetration during the irrigation season (e.g., using auger, probe, tensiometers, or other soil moisture monitoring techniques).	☐	☐	☐	☐	
19	A distribution uniformity test has been done on the irrigation system at least once in the past year (or, if the orchard is flood or furrow irrigated, a distribution uniformity test has been done in the past 5 years).	☐	☐	☐	☐	
	PUMPS AND FILTERS: Most irrigation systems have pumps and filters. If you have a system that does not involve a pump (e.g., gravity fed) and/or filters, answer *Not applicable* where appropriate to the following questions:					
20	A pump efficiency test has been conducted by a qualified technician at least once in the past 3 years.	☐	☐	☐	☐	☐
21	Flow meters are installed on lines from pumps and are installed according to manufacturer instructions. (If no meters are installed, answer *Not applicable* to the following flow meter questions.)	☐	☐	☐	☐	☐
	a. Flow meters are monitored for each irrigation set each time it is run.	☐	☐	☐	☐	☐
	b. Flow meter readings are recorded for each irrigation set each time it is run.	☐	☐	☐	☐	☐
	c. All flow meters have been inspected and calibrated in the past 2 years.	☐	☐	☐	☐	☐
22	Pressure gauges are installed for measuring pressure drops through filters. (If no gauges are installed, answer *Not applicable* to the following pressure gauge questions.)	☐	☐	☐	☐	☐
	a. Pressure drop through filters is checked with every irrigation (manually or through electronic sensors), and filters are cleaned when significant pressure differences are found.	☐	☐	☐	☐	☐
	b. Pressure gauges are checked for accuracy at least annually.	☐	☐	☐	☐	☐
23	Pressure check points are installed on key lines from pumps.	☐	☐	☐	☐	☐
24	Are filters cleaned manually or by an automatic system? ☐ Manually ☐ Automatically					
25	A backup screen is in place in case of filter failure (for sand filters).	☐	☐	☐	☐	☐
26	A pressure-sustaining device is in place to keep the system pressure up during back flushing.	☐	☐	☐	☐	☐
27	Filter status (and flushing system) is manually checked at least twice a season and corrected if necessary.	☐	☐	☐	☐	☐
28	During filter flushing, flush water is captured for reuse.	☐	☐	☐	☐	☐

This section contains various best practices associated with different types of irrigation systems. Please first answer the questions that apply to all systems and then just the questions that apply to the system in the orchard you are assessing.

NOTE: Pages 14-15 contain sets of practices specific to different types of irrigation:

- Drip or micro-sprinklers, and Sprinklers—page 14
- Flood/furrow—page 15

For these pages, only answer questions for sections that apply to the irrigation system(s) in the orchard being assessed. Questions applying to all orchards resume on page 26.

This section applies to drip and micro-sprinkler systems *only*. Skip if not applicable to this orchard.

	For my orchard, I am using the following practices and/or technologies for maximizing my drip or micro-irrigation system efficiency:	Not familiar with this	I haven't tried it	I have tried it	My current practice	Not applicable
	DRIP AND MICRO-SPRINKLERS					
29	The system has pressure compensating emitters to help maintain system distribution uniformity.	☐	☐	☐	☐	
30	The pH of the irrigation water source(s) has been checked at least once in the past year.	☐	☐	☐	☐	
31	The EC (electroconductivity or salinity), bicarbonate, and/or iron levels of the irrigation water source(s) have been tested at least once in the past 2 years.	☐	☐	☐	☐	
32	Filtration and chemical treatment are used as needed to prevent clogging from biological causes.	☐	☐	☐	☐	
33	All irrigation lines and emitters are checked for leaks or clogs at least weekly (preferably with every irrigation for micro-sprinklers).	☐	☐	☐	☐	
34	Irrigation lines are flushed at least at the start of the season, at least once mid season, and more often as needed.	☐	☐	☐	☐	
35	System pressure at the emitters farthest from the pump is checked at least once per season. (Monthly is recommended.)	☐	☐	☐	☐	
36	Other: ________________________________				☐	

This section applies to sprinkler systems *only*. Skip if not applicable to this orchard.

	For my orchard, I am using the following practices and/or technologies for maximizing my sprinkler system efficiency:	Not familiar with this	I haven't tried it	I have tried it	My current practice	Not applicable
	SPRINKLERS					
37	All sprinklers are checked for leaks or geysers with each irrigation.	☐	☐	☐	☐	
38	In the past 5 years, sprinkler heads or nozzles have been checked for wear and replaced with the correct nozzle size to maintain distribution uniformity.	☐	☐	☐	☐	
39	Other: ________________________________				☐	

This section applies to flood or furrow systems *only*. Skip if not applicable to this orchard.

	For my orchard, I am using the following practices and/or technologies for maximizing my flood or furrow irrigation efficiency:	Not familiar with this	I haven't tried it	I have tried it	My current practice	Not applicable
	FLOOD/FURROW					
40	The orchard was laser leveled during orchard establishment.	☐	☐	☐	☐	
41	Levee locations in the orchard are based on observed infiltration rates (i.e., each check is appropriately sized for maximum water application uniformity).	☐	☐	☐	☐	
42	The orchard produces no tailwater, or a tailwater recovery and reuse system is in place.	☐	☐	☐	☐	☐
43	Flow meters are installed on lines from pumps or in supply pipelines or ditches (e.g., Weir notch or Parshall flume), or a record of metered flow volumes is provided to me by my district.	☐	☐	☐	☐	☐
	a. Flow meters are monitored at each irrigation.	☐	☐	☐	☐	☐
	b. Water volumes are recorded for each irrigation.	☐	☐	☐	☐	☐
	c. All flow meters have been inspected and calibrated in the past 2 years.	☐	☐	☐	☐	☐
44	Other: ____________________				☐	

Flood Irrigation Sustainability

Flood or furrow irrigation is not widely practiced in California orchards today. It generally uses more water than other forms of irrigation and tends to deliver lower yields than drip or micro-sprinklers. However, flood or furrow irrigation has advantages for controlling small burrowing mammals in the orchard, requires little or no energy for pumping when done with gravity-fed water, and has lower infrastructure costs. Moreover, farmers who want to use vegetation or cover crops to build soil organic matter and/or keep dust down may need to deliver water to the entire orchard floor.

For optimizing water applications, space levees/checks in the orchard according to soil type. That is, if water tends to infiltrate more rapidly in one area, encourage water to move more quickly to areas with slower infiltration rather than making uniform-sized checks.

References and more information

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Toro Ag Irrigation Resources: http://www.toroag.com

Irrigation Scheduling 101

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CALCULATING ORCHARD WATER USE

To optimize irrigation scheduling, the variables of weather, water availability, and plant stress must be taken into account. Each of these variables may change throughout the irrigation season, increasing the complexity in determining when an irrigation should occur and the amount of water to apply.

To determine how much water to apply, the irrigation needs of the plant must be calculated. This amount is weather driven and is influenced by the humidity, temperature, and time of day. The demand for water by the almond tree is called evapotranspiration (ET). ET accounts for the loss of water through soil surface evaporation and the loss of water through openings in the leaves, stomates, that allow the gas exchange required for photosynthesis.

To determine irrigation scheduling, the amount of water used by ET must be calculated. This is done by measuring water use by a reference crop (ETo) and multiplying it by a scientifically based crop coefficient (Kc). The Kc is a simplified way of representing the ratio of water use by the crop in question (ETc) to the ETo. Knowing this, the following equation can be constructed to calculate almond water use:

$$ETc = ETo \times Kc$$

The state of California operates the California Irrigation Management Information System (CIMIS), a network of over 120 automated weather stations across the state. Information from the stations is available for free online, and is updated hourly. The ETo used throughout California is calculated from grass pasture. When accessing CIMIS to view weather conditions and water use, the values are always presented for the ETo. Therefore, to determine the ETc, locate the weather station closest to the orchard, download the cumulative ETo for all of the days since the last irrigation (or any other time frame), and multiply that number by the Kc for almonds to calculate the amount of water your orchard lost due to ET.

Since almonds experience changes in physiological conditions and canopy coverage throughout the year, there are different Kc values for different periods of the year. Table 1 provides crop coefficients as provided by the United Nations Food and Agricultural Organization for almond orchards experiencing light to moderate winds with and without cover crops.

Table 1: Almond crop coefficients provided by the United Nations Food and Agricultural Organization								
Almond Orchard Kc by Month	Dec / Jan	Feb	Mar	Apr	May	June / July / Aug	Sept	Oct	Nov
With cover crop	0.85	0.85	0.85	0.95	1.05	1.15	1.10	0.90	0.85
Without cover crop	0.00	0.00	0.50	0.70	0.85	0.90	0.80	0.75	0.65

Remember that these coefficients are based upon research, and further research may refine the values listed above. There is currently ongoing research within California to revise these numbers. When the research is complete, any new numbers will be published in various California ag journals and posted to the reference section of the CIMIS website.

Now that the Kc and ETo have been identified, almond water use can be calculated. To illustrate the ease of ETc calculations, Table 2 provides an example in calculating the amount of water used by a mature almond orchard in May 2010.

Table 2: Example evapotranspiration calculations for a mature almond orchard in Merced County for May 2010. All units are in acre inches per acre.				
Week	ETo for the week (Grass water use) provided by CIMIS	Almond Kc for the month of May (from Table 1)	ETc for the week (water lost from the orchard)	Cumulative total of water use by the Almond Orchard w/cover crop
May 1st – 7th	1.65	1.05	1.74	1.74
8th – 14th	1.20	1.05	1.26	1.26 + 1.74 = 3
15th – 21st	1.39	1.05	1.46	3 + 1.46 = 4.46
22nd – 28th	1.19	1.05	1.25	4.46 + 1.25 = 5.71
29th – 31st	0.72	1.05	0.76	5.71 + 0.76 = 6.47

As Table 2 demonstrates, a mature almond orchard grown under the described conditions used nearly 6.5 acre inches of water per acre in May of 2010.

The crop coefficient for young orchards (generally less than 7th leaf) will be slightly lower than that of a mature orchard. To calculate how much lower, estimate the canopy coverage of the orchard at mid-day by estimating the area of the orchard floor that is shaded by the tree. Double this percentage and then multiply by the corresponding crop coefficient. For example, a 3rd leaf orchard covering 40% of the orchard floor will use 80% of the water that a mature orchard would use. Once the canopy shades 50% of the orchard floor, assume that it will use full ETc.

Tables of historical ETc values for each week of the year for almonds in California are also available. The historical values are based on several years of ET calculations for each week. They cannot account for variations in weather that occur every year (unseasonably hot or cool weather). Nevertheless, they are simple to use and are much better than attempting to guess the orchard's water demand.

DETERMINING WATER HOLDING CAPACITY

Understanding the needs of the tree is only one part of efficiently irrigating. The second component is understanding how much water can be held within the given soil of an orchard. Conceptually, soil is similar to a sponge, being filled with water upon irrigation and slowly being drained or 'squeezed out' over the course of the irrigation cycle. If too much water is applied to the soil, it either runs off the surface or drains out of the bottom of the soil column. If too little, there isn't enough water for the tree to make it to the next irrigation without undergoing stress. The maximum amount of water that can be held within the soil after it has had time to drain is the soil water holding capacity.

It is important to understand a few terms when dealing with and discussing soil water holding capacity. Soil saturation is when all of the soil pores in a given layer of soil are filled with water—this condition occurs immediately after irrigation and continues until gravity pulls the water through the pores of the soil. Once the soil has drained, usually 1-3 days after an irrigation/rain event, the soil is at field capacity. This water is held against gravity within small pores by the soil particles, and is the largest volume of water that a given amount of soil can hold between irrigations. In contrast, the permanent wilting point of a soil is the point at which all the water available to plant roots is gone. The difference in water volume between the field capacity and wilting point is the available soil water holding capacity—or the amount of water available to the plant.

It is important to note that at field capacity not all of the pore space is filled with water, and at permanent wilting point not all of the water is removed from the soil. The amount of water to refill the soil profile is related to the texture of the soil; coarser soils hold less water while fine, heavy soils hold more. This is due to the differing size of soil particles and pore space in these soils. In general, soils are about 50% solids, 50% pore space. The pore spaces hold varying proportions of water and air.

Table 3: Available water for various soil types		
Type of Soil	Range (in/ft)	Average (in/ft)
Coarse (S/LS)	0.6-1.00	0.75
Sandy (LS/SL/L)	1.00-1.50	1.25
Medium (L/SCL)	1.25-2.2	1.50
Fine (SiL/SiCL/CL/SIC)	1.7-2.4	2.00

Basically, when efficiently irrigating, water needs to be applied to refill the soil profile to field capacity but prevent the loss of water to deep percolation. Thus, determining how much water can be applied when irrigating depends on the soil within the orchard. The available soil water holding capacity can be looked up in Table 3. It is given in terms of inches per foot of soil depth. Table 3 gives a rough approximation of available water capacity by soil types, but more specific information about the soil type and texture within an orchard is available from the USDA Natural Resources Conservation Service (NRCS, formerly the Soil Conservation Service). A visit to the local county NRCS office or use of the free online Web Soil Survey (websoilsurvey.nrcs.usda.gov) will provide information regarding the soil profile and soil types and water holding capacity within the orchard. Keep in mind that these maps are not always accurate. Fact check the soil map by walking the orchard and reviewing the texture changes, digging backhoe pits, or using a soil auger. Table 4 is an example of a report generated from the Web Soil Survey showing a Hanford sandy loam with available water holding capacity of 0.11-0.13 in/in at a depth of 0-12 inches and 0.12-0.15 in/in at a depth of 12-60 inches:

Table 4: Example from Web Soil Survey:								
Map symbol & soil name	Depth	Sand	Silt	Clay	Moist bulk density	Available water capacity	Linear ex-tensibility	Organic matter
	In	Pct	Pct	Pct	g/cc	In/In	Pct	Pct
HdA: Hanford	0-12	---	---	7-18	1.50-1.60	0.11-0.13	0.0-2.9	0.5-1.0
	12-60	---	---	7-18	1.50-1.60	0.12-0.15	0.0-2.9	0.0-0.5

Also keep in mind that soil is 3-dimensional. Soil sampling at various depths can help determine if the soil texture throughout the root zone is uniform or made up of layers of textures. It is advisable to have soil maps on hand to help identify known texture changes. Root zone depth is usually determined by soil being excavated by an auger/probe, texturing the soil, and checking for roots. For most orchards, if the ground was prepared properly during establishment, there will be between 3-4 feet of root zone. The presence of a clay lens, hardpan, or gravel layer may reduce the root profile depth and water availability to the tree. Once a soil texture profile has been developed, the amount of water that the soil can hold can be easily calculated by using Table 3 on page 19. For example:

Table 5: Example calculation of Available Water Holding Capacity

Soil Surface (in)	Soil Texture	Depth in Feet	Available Water Holding Capacity (From Table 3)	Available water in each soil layer (in)
1-12	Sand	1	0.6	0.6
13-24	Loamy Sand	1	0.8	0.8
25-42	Sandy Loam	1.5	1.0	1.5
				Total: 2.9

In the example above, there are 2.9 inches of water available for the tree to use. When scheduling to irrigate, do not deplete the available water completely. Upon using 50% of the available water, irrigation should occur. Letting the profile go completely dry will deplete all deep soil moisture, stress the tree, and affect tree performance (yields). Irrigating at 50% depletion also provides a bit of a “fudge factor”, helping to avoid potential mistakes. So, using the example above, irrigation should be scheduled when 1.4-1.5 inches of water have been used by evapotranspiration.

Knowing the amount of water that can be held within the soil is also helpful in determining how much water is needed to refill the entire rooting profile. In the soil profile used in the example above, irrigating more than 3.0 inches may lead to deep percolation. Deep percolation may be of benefit if leaching of salts from the rooting profile is desired, but it may also leach nutrients out of the root zone. This not only wastes fertilizer but also may result in nitrate contamination of groundwater.

For more information and estimating soil moisture by the ‘feel’ method, please check the references and more information section of this module.

TAKING IRRIGATION EFFICIENCY INTO ACCOUNT

When water is applied to an orchard, loss of some amount of water should be expected, and must be considered when calculating the amount of water being applied. If not, an overestimation of the amount of water reaching the trees will occur. This amount of loss will vary on the irrigation system used, soil and climatic conditions, and water management conditions.

Water applied to a field can be lost by runoff, percolation below the root zone, sprinkler spray evaporation, and off-target drift. Efforts to minimize these inefficiencies should be employed, and could include longer irrigation sets at lower rates, the construction of tailwater return systems, and/or sub-surface installed systems.

Irrigation efficiency (Ea) is defined as the percentage of applied water that is held in the root zone. Mathematically, it is:

Ea = water stored/water applied

Irrigation methods commonly used within the almond orchard include surface irrigation systems, such as flood and furrow, and pressurized systems, including sprinkler, drip, and micro-sprinkler. Irrigation efficiency differs with each system (Table 6). With surface systems, fast movement of the water from the head end to the tail of the field end usually results in higher irrigation efficiency. Within pressurized systems, distribution depends on design parameters including spacing, nozzle type and size, riser height, and operating pressure. Keep in mind that maintenance and filtration affect pressurized systems more than surface based systems. Pressurized systems, however, are usually more efficient due to the reduction of run-off and water loss through deep percolation.

Table 6: Application efficiency typical of various irrigation systems

System	Ea (%)
Basin/Flood	65-80
Furrow	65-75
Solid Set Sprinkler	75-85
Micro-sprinkler	85-90
Drip	90-95

When calculating orchard water needs, irrigation efficiency must be taken into account or under-irrigation will occur. Table 7 includes some examples that show the different water application needs due to differences in irrigation efficiency.

Table 7: Example of differences among system efficiencies

Location: San Joaquin Valley
Soil: Loamy Sand
Rooting Depth: 5 feet
Available Water-Holding Capacity (AWC): 0.6 in/ft
Depletion of AWC before irrigation: 50%
Irrigate when AWC reaches 1.5 inches

Flood Irrigation	Micro-sprinkler	Drip Irrigation
Ea = .70	Ea = .85	Ea = .90
Weekly ET = 1.5 inches	Weekly ET = 1.5 inches	Weekly ET = 1.5 inches
Water required to recharge 1.5 inches: 2.14 inches	Water required to recharge 1.5 inches: 1.76 inches	Water required to recharge 1.5 inches: 1.67 inches
Difference from drip: + 0.47 inches	Difference from drip:+ 0.09 inches	

Over the course of the crop year, there may be 15 or more inches of water needed to fully irrigate a flood irrigated orchard in comparison to a drip irrigated orchard. If unaccounted for, this lack of water will lead to water stress and loss of potential yield.

APPLYING A LEACHING FRACTION IN SALINE CONDITIONS

Much of the Central Valley has access to high quality surface irrigation water through irrigation districts. Nevertheless, many almond orchards around the state have irrigation sources of variable quality. An example might be a well that pumps from an aquifer that contains high levels of sodium or chloride. Testing your water quality on a regular basis is recommended since aquifer quality can change over time.

Orchards with a water source that is saline need to take salts into account especially when using drip irrigation or micro-sprinklers. The salts that make the water saline will accumulate within the rooting zone of the tree unless extra water is applied. The amount of water needed to flush the salts beyond the root zone is called the leaching fraction or leaching factor. For more information about the effective use of leaching to move salts and under what conditions it is recommended, see the *Almond Production Manual* from the University of California.

Calculating the amount to apply as a leaching fraction is dependent upon the salinity of the soil and the salinity of the irrigation water source. An agriculture testing lab can generally run a test to determine water salinity or a kit can be purchased to be used around the farm. The salinity is measured through electroconductivity or EC and is expressed in units of deciSiemens per meter (dS/m).

Once you have the soil and water source salinity measured, the following equations can be used to determine the proper 'leaching fraction':

ECe = Salinity of the Soil (dS/m)

ECiw = Salinity of Irrigation Water (dS/m)

Ea = Irrigation System Application Efficiency

$$\text{Leaching Requirement (LR)} = \frac{\text{ECiw}}{(5 \times \text{ECe}) - \text{ECiw}}$$

$$\text{Gross Inches} = \frac{\text{Net Inches Required}}{(1 - \text{LR})\ (\text{Ea})}$$

Here is an example of calculating the leaching fraction for an orchard with the following parameters: 1.98 net inches of water needs to be applied, the efficiency of the irrigation system is 80%, the soil EC is 4.0 dS/m, and the EC of the irrigation water is 2.0 dS/m:

ECe = Salinity of the Soil (dS/m) = 4.0

ECiw = Salinity of Irrigation Water (dS/m) = 2

$$\text{Leaching Requirement (LR)} = \frac{\text{ECiw}}{(5 \times \text{ECe}) - \text{ECiw}} = \frac{2}{(5 \times 4.0) - 2} = 0.11$$

$$\text{Gross Inches} = \frac{\text{Net Inches Required}}{(1 - \text{LR})\ (\text{Ea})} = \frac{1.98}{(1 - 0.11)(0.8)} = 2.78$$

Using this example, 2.78 inches of water would need to be applied to supply the needed 1.98 inches and maintain the soil EC at 4.0. The extra 0.8 inches is used to compensate for the irrigation system inefficiency and the leaching fraction. Watering less than 2.78 inches will lead to a buildup of salts and eventually to a salinity problem.

BRINGING IT ALL TOGETHER

To help with the understanding of how to schedule an irrigation using ET, soil water holding capacity, irrigation system efficiency, and leaching fractions, an example calculation has been included. The following worksheet was put together by Ken Oster of USDA NRCS for a hypothetical almond orchard in Stanislaus County with an effective rooting depth of 30 inches and a salinity problem. He used soil data from the NRCS Web Soil Survey for the available water holding capacity at this sample site.

HOW MUCH IRRIGATION WATER TO APPLY BASED ON YOUR SOIL

Determine available water holding capacity (AWC) of your soil.

Soil Texture Depth	Texture (inches)	Layer Thickness (inches)	AWC (in. water/in. soil)	Total AWC (inches)
Silt Loam	*0-8*	*8*	*0.17*	*1.36*
		Total Rooting Depth =		Total =

Crop:
Potential Root Zone: ________inches
Effective rooting—upper 1/2 of maximum root zone (zone of 90% of the roots by weight, and supplying 70% of the water): ________inches
Available water holding capacity (AWC): ________inches
Management allowed depletion (MAD): ________% = 0.________
Inches required = 0. ________ x ________ AWC (inches) = ________.
Application efficiency (Ea): ________%
Gross inches $\dfrac{\text{Net inches required}}{\text{Ea}}$ = _________

NOTE: Generally, 50% is the MAD for orchards, unless experience guides you to adapt this.

See Table 6 for typical system efficiencies

When salt is an issue:

ECe = salinity of oil (dS/m) = ________
ECiw = salinity of irrigation water (dS/m) = ________
Leaching requirement (LR) = $\dfrac{\text{ECiw}}{(5 \times \text{ECe}) - \text{ECiw}}$ = _________
Gross Inches = $\dfrac{\text{Net inches required}}{(1 - \text{LR})\ (\text{Ea})}$ = _________

EXAMPLE: AWC of Hanford sandy loam

Soil Texture Depth	Texture (inches)	Layer Thickness (inches)	AWC (in. water/in. soil)	Total AWC (inches)
Sandy Loam	0-12	12	0.12	1.44
Sandy Loam	12-60	48	0.13	6.48
		Total Rooting Depth = 60		Total = 7.92

Crop: Trees
Potential Root Zone: 60 inches
Effective rooting—upper 1/2 of maximum root zone (zone of 90% of the roots by weight, and supplying 70% of the water): 30 inches
Available water holding capacity (AWC): 7.92/2 = 3.96 inches
Management allowed depletion (MAD): 50% = 0.5
Inches required = 0.5 x 3.96 AWC (inches) = 1.98
Application efficiency (Ea): 80% = 0.8
Gross inches $\frac{1.98}{0.8}$ = 2.48

ECe = salinity of oil (dS/m) = 4.0
ECiw = salinity of irrigation water (dS/m) = 2
Leaching requirement (LR) = $\frac{2}{(5 \times 4.0) - 2}$ = 0.11
Gross Inches = $\frac{1.98}{(1 - 0.11)(0.8)}$ = 2.78

Irrigation Volume and Timing

45	How many acre inches of water were applied (not rainfall) to this orchard for the season being assessed?	__________ acre inches/acre
46	Are you estimating this amount, or is this amount verified by measurement (e.g., flow meters)?	☐ meters ☐ estimate
47	What is the source of irrigation water for this orchard?	☐ ground (well) water ☐ surface/district water ☐ both

	For my orchard, I am using the following practices and/or technologies for determining *when* to irrigate:	Not familiar with this	I haven't tried it	I have tried it	My current practice	Not applicable
	IRRIGATION SCHEDULING					
48	I irrigate on a standard schedule/interval of my choice (i.e., by the calendar). ☐ Yes ☐ No					
49	I irrigate based on my water district's delivery schedule. ☐ Yes ☐ No					
	SCHEDULING BASED ON EVAPOTRANSPIRATION (ET)					
50	I make irrigation decisions by following historical ET.	☐	☐	☐	☐	
51	I make irrigation decisions by following real time evapotranspiration (ETc) data at least weekly and calculating the water volume leaving the plant and soil.	☐	☐	☐	☐	
	PLANT STRESS MONITORING					
52	I decide when to irrigate based on visual plant stress. ☐ Yes ☐ No					
53	I decide when to irrigate based on measured plant stress by: a. Monitoring plant water stress with a method that is not a pressure chamber (remote sensing, canopy temperature, etc).	☐	☐	☐	☐	
	b. Monitoring plant water stress (stem water potential) with a pressure chamber.	☐	☐	☐	☐	
	SOIL MOISTURE MONITORING					
54	I monitor soil moisture by sampling with a shovel or auger (i.e., feel and appearance method).	☐	☐	☐	☐	
55	I monitor soil moisture with devices such as neutron probes, dielectric device, tensiometers, etc.	☐	☐	☐	☐	
	a. Soil monitoring is done with real-time, continuous monitoring.	☐	☐	☐	☐	☐
	b. I have determined the available water holding capacity (AWC) of the soil for each irrigation set.	☐	☐	☐	☐	☐
	c. I have determined the Management Allowed Depletion amount I desire to apply during crop growth stages (including possible regulated deficit irrigation).	☐	☐	☐	☐	☐

	For my orchard, I am using the following practices and/or technologies for determining *when* to irrigate:	Not familiar with this	I haven't tried it	I have tried it	My current practice	Not applicable
	IRRIGATION SCHEDULING (continued)					
56	In addition to the above factors, my irrigation schedule is influenced by other limitations such as peak energy pricing. ☐ Yes ☐ No					
57	Other scheduling practices: ___________________________				☐	

	For my orchard, I am using the following practices and/or technologies for deciding *how much* water to apply:	Not familiar with this	I haven't tried it	I have tried it	My current practice	Not applicable
58	From the options below, choose the one which best describes how you plan irrigations: ☐ I generally irrigate on a standard interval (e.g., every 8 days) and a standard run time (e.g., 8 hours). ☐ I generally irrigate on a standard interval (e.g., every 8 days), but adjust the run time based on how much I want to apply. ☐ I generally irrigate using the same run time, but adjust the interval based on how much I want to apply.					
59	The amount I apply is based on what my water district delivers. ☐ Yes ☐ No					
60	I irrigate following a table of historical ET amounts.	☐	☐	☐	☐	
61	I irrigate following real-time evapotranspiration (ETc) data at least weekly and calculating the water volume leaving the plant and soil.	☐	☐	☐	☐	
62	I use Regulated Deficit Irrigation (RDI) where appropriate during the season.	☐	☐	☐	☐	
63	I apply a leaching fraction for salinity if indicated by soil or water quality testing. (A leaching fraction is an extra portion of irrigation water applied to flush salts from the root zone.)	☐	☐	☐	☐	☐
64	Other scheduling practices: ___________________________				☐	

	For my orchard, I keep the following information on hand for calculating how much water to apply:	Not familiar with this	I haven't tried it	I have tried it	My current practice	Not applicable
65	The actual application efficiency of the irrigation system, measured in the past 12 months.	☐	☐	☐	☐	
66	The actual hourly application rate of each irrigation set (inches per hour or gallons per acre per hour), measured in the past 12 months.	☐	☐	☐	☐	
67	The actual distribution uniformity of each irrigation set, measured in the past 12 months.	☐	☐	☐	☐	
68	Flow rate per hour of pumping or gravity flow (flood or sprinklers), or gallons per hour per tree (micro sprinklers) or per 100 feet of drip tape.	☐	☐	☐	☐	
69	Total amount of time required to apply an inch (or other measurement) of water.	☐	☐	☐	☐	
70	Other efficiency practices: ___________________________________				☐	

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Water Penetration and Salinity

	For my orchard, I am using the following practices and/or technologies for improving the penetration of my irrigation water:	Not familiar with this	I haven't tried it	I have tried it	My current practice	Not applicable
71	Select the description which best describes this orchard's infiltration status: ☐ My orchard does not have water penetration problems. Water does not pond on the soil surface for long periods, and soil aeration and root growth appear to be adequate. If true, the remaining items on this page may not apply. Choose "not applicable" for those which do not apply. ☐ My orchard has had some of the above symptoms of water penetration problems, and I have taken the following corrective steps:					
	a. I have adjusted my irrigation to shorter, more frequent run times to prevent ponding or runoff.	☐	☐	☐	☐	☐
	b. I alternate my water source (e.g., between well and district/ surface water) to take advantage of the effect of different salt levels (not applicable to all situations).	☐	☐	☐	☐	☐
	c. In the past 12 months, I have had my soils tested for salinity and the types of salts present (e.g., electroconductivity or EC plus Sodium Adsorption Ratio or SAR).	☐	☐	☐	☐	☐
	d. In the past 12 months, I have had my irrigation water source(s) tested for salinity and the types of salts present (e.g., electroconductivity or EC plus Sodium Adsorption Ratio or SAR).	☐	☐	☐	☐	☐
	e. I periodically apply organic matter to my soil.	☐	☐	☐	☐	☐
	f. I periodically plant a cover crop or maintain annual volunteer vegetation in the orchard.	☐	☐	☐	☐	☐
	g. I apply gypsum, sulfuric acid, or other chemical additives such as organic polyacrylamides (PAM) and polysaccharides or surfactants to the soil or irrigation water to improve water penetration.	☐	☐	☐	☐	☐
	h. My soil surface seals, and I use tillage to enhance water penetration.	☐	☐	☐	☐	☐
72	Other: ____				☐	

#	For my orchard, I am using the following practices and/or technologies for preventing salinity problems:		Not familiar with this	I haven't tried it	I have tried it	My current practice	Not applicable
73	If from a well, irrigation water is tested at least every other year for pH, salinity, total dissolved solids, boron, selenium, chloride, and sodium.		☐	☐	☐	☐	☐
74	If problems exist with the quality of the irrigation water:	a. The orchard's soil salinity (soil EC) is monitored and irrigations include a leaching fraction or other measures to address potential problems.	☐	☐	☐	☐	☐
		b. The water is treated (e.g., reverse osmosis [RO] or nanotech filter) to reduce salinity.	☐	☐	☐	☐	☐
		c. The water is amended to assist infiltration.	☐	☐	☐	☐	☐
75	Other: ____					☐	

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