ALMOND IRRIGATION IMPROVEMENT CONTINUUM

californa almonds

Almond Board of California

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INTRODUCTION AND OVERVIEW

The California almond industry began investing in research in 1982 to determine if a new irrigation method — microirrigation — could work in almond orchards. The results were positive and, by targeting water applications directly to the trees' roots instead of uniformly across the field, growers have conserved water and created other operational efficiencies.

Today nearly 80% of California almond orchards are using microirrigation and, as older orchards are replaced, we expect that number to grow.

Almond growers have made strides in irrigation efficiency, and there's more everyone can do, which is why the Almond Board of California (ABC) and almond irrigation experts developed the *Almond Irrigation Improvement Continuum* in 2017.

The *Almond Irrigation Improvement Continuum* is a comprehensive manual of irrigation management and scheduling practices. Recognizing that growers may be operating at different stages of irrigation efficiency, the *Continuum* provides information at three management levels, each covering the following concepts and how to execute and effectively integrate them:

- Measuring irrigation system performance and efficiency
- Estimating orchard water requirements based on evapotranspiration
- Determining the water applied
- Evaluating soil moisture
- Evaluating plant water status

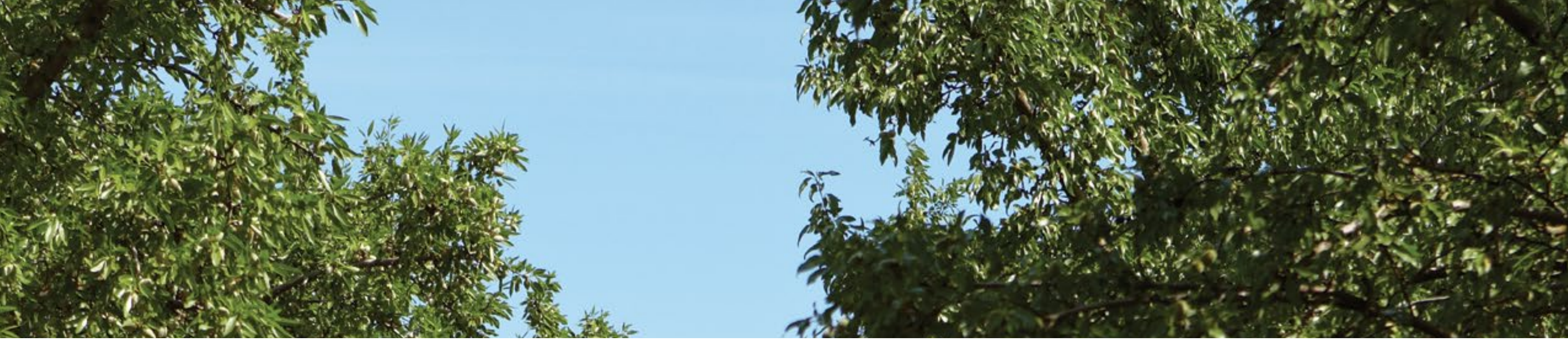
The *Continuum Level 1.0* (fundamental management) outlines irrigation management practices that are within reach for all California almond growers. The *Continuum Level 2.0* (intermediate management) and *Level 3.0* (advanced management) address practices at more sophisticated levels to attain even more "crop per drop."

ABC's first objective with the *Continuum* is to assist all almond growers in meeting *Level 1.0*. Beyond this, the Almond Board will work with growers to progress along the *Continuum* to *Levels 2.0* and *3.0*. This effort will be done in partnership with the many trusted and respected technical experts and resources available, such as University of California Division of Agriculture and Natural Resources Cooperative Extension.

ALMOND IRRIGATION IMPROVEMENT CONTINUUM

Use the management levels and guidance below to adopt good irrigation water management practices for almonds. Each level of the *Almond Irrigation Improvement Continuum* will provide the tools necessary to obtain measurements needed to best schedule and manage almond irrigation.

Measurement	**1.0 Fundamental**	**2.0 Intermediate**	**3.0 Advanced**
Orchard Water Requirements	Estimate orchard water requirements using "normal year" regional ETc to estimate irrigation demand on a monthly basis.	Estimate orchard water requirements using "normal year" regional ETc – adjusting for current weather and cover crop use on a biweekly basis.	Estimate orchard water requirements using "normal year" regional ETc to plan irrigations, then use real-time ETc data to correct the schedule on a biweekly basis.
Irrigation System Performance	Evaluate irrigation system for pressure variation and average application rate at least once every three years. Correct any diagnosed system performance problems.	Assess distribution uniformity and average application rate by measuring water volume at least every three years. Correct any diagnosed system performance problems.	Assess distribution uniformity and average application rate by measuring water volume at least every two years. Correct any diagnosed system performance problems.
Applied Water	Use application rate and duration of irrigation to determine water applied.	Use water meters to determine flow rate and water applied.	Use water meters to determine applied water and compare to crop water use (ETc, evapotranspiration) to determine irrigation efficiency.
Soil Moisture	Evaluate soil moisture based upon feel and appearance by augering to at least 3-5 feet. Monitor on a monthly time step.	Use manually operated soil moisture sensors to at least 3-5 feet and monitor on a biweekly time step. Use information to ensure calculated water is not over/under irrigating trees.	Use automated moisture sensors that store data over time. Review weekly to ensure calculated water is not over-/under-irrigating trees.
Plant Water Status	Evaluate orchard water status using visual plant cues just prior to irrigation or on a biweekly basis.	Use pressure chamber to measure midday stem water potential just prior to irrigation or on a monthly basis. Ensure calculated water applications are not over/under irrigating trees.	Use pressure chamber to measure midday stem water potential prior to irrigation or on a weekly basis, comparing readings to baseline values. Ensure calculated water applications are not over/under irrigating trees. Use it to assess when to start irrigating.
Management	**1.0 Fundamental**	**2.0 Intermediate**	**3.0 Advanced**
Integrating Irrigation Water Management Practices	Combine irrigation system performance data with "normal year" regional ETc to determine orchard-specific water requirements and schedule irrigations. Check soil moisture with an auger and/or monitor plant water status to verify scheduling.	Use irrigation system performance data with regional estimates of "normal year" ETc to schedule irrigations and adjust based on feedback from monitoring soil moisture or crop water status.	Use irrigation system performance data with regional estimates of "normal year" ETc to schedule irrigations. Monitor status using soil and plant based methods. Adjust irrigation schedule with real-time ETc as the season progresses.



Determining and Meeting Orchard Water Requirements

DETERMINING AND MEETING ORCHARD WATER REQUIREMENTS

1.0 Practice:

Estimate orchard water requirements using "normal year" regional crop evapotranspiration and other site-specific factors to determine irrigation applications on a monthly time basis.

An orchard's water requirement is a combination of the crop water use and other beneficial water uses, such as salt leaching (if necessary) and water added to account for irrigation nonuniformity. Crop water use is considered to include losses from the orchard's soil (evaporation) and tree's leaves (transpiration). These losses are combined into the term *evapotranspiration* (ETc), or, for our purposes, "almond water use." Almond water use can vary with climate, canopy size, existence of a planted cover crop or weeds, or reduced plant-available soil moisture.

The orchard water requirement is met by plant-available soil moisture stored in the root zone (including frost protection water applications if stored in the root zone), in-season rainfall stored in the soil, and applied irrigation water. In-season rainfall that enters the root zone for orchard use tends to occur in the first few months of the season. Likewise, stored soil moisture is at a maximum at the beginning of the season. It is not uncommon for these two water sources to supply the entire crop water use in the first month and up to 15 to 35% on a seasonal basis.

The amount of water available to the orchard from these sources can vary widely, since the rainfall stored in the root zone and in-season effective rainfall (rain that is ultimately used by the orchard) varies with rainfall duration and frequency, as well as with root zone water-holding capacity. As an example of the variability, rainfall in Bakersfield (ET Zone 15) averages 6.45 inches, while northern almond regions such as Red Bluff (ET Zone 14) average 24.5 inches. To determine the irrigation application target in northern almond regions, you must account for the orchard's use of moisture stored in the soil and in-season effective rainfall. The result will be a reduction of applied irrigation water or a delay in irrigation in the spring months, or both. In southern almond regions, effective in-season rainfall is small and soil storage is largely a function of applied irrigation water wetting the root zone.

ESTIMATING MATURE ALMOND ORCHARD WATER REQUIREMENTS

Orchard water use, or evapotranspiration (ETc), is the sum of the orchard water use through transpiration and water lost through evaporation from the soil surface. Climate factors affecting evapotranspiration include direct solar radiation (sunlight), temperature, wind and humidity. Tree and soil factors affecting evapotranspiration include canopy size, health of the tree, how tree row middles are managed (i.e., cover crop/weeds), and available soil moisture. Added to the orchard water use are other beneficial water uses that determine the orchard's water requirement, such as water used for salt leaching and to account for irrigation nonuniformity.

This section reviews calculations to determine the orchard water requirement for mature orchards without cover crops or vegetation in row middles (Fig. 1). The best way to determine a mature orchard's water requirement is by using climatic data and the orchard's specific characteristics.[1] An almond orchard is considered to be mature when about 70% or more of the orchard floor is shaded at midday during the middle of the growing season. More than 70% canopy coverage may result in increased water use; however, that level of coverage is considered to be the practical limit based on necessary cultural activities. If the shaded area of your orchard is less than 70%, refer to the section "Adjusting for Small-Canopy or Young Orchards."

Figure 1. Mature almond orchard with no cover crop. An almond orchard is considered mature when about 70% or more of the orchard floor is shaded at midday during the middle of the growing season. (Photo by T. Prichard)

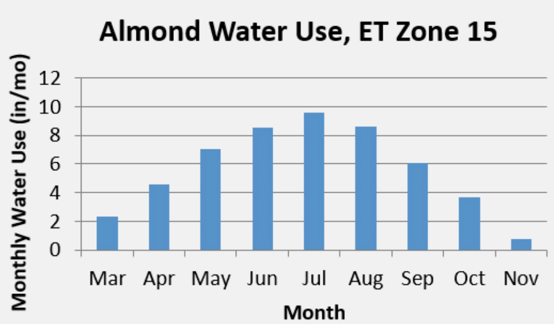


Figure 2. Monthly almond water use by a mature orchard with no cover crop and no significant water stress in climate zone 15 (Bakersfield to Los Banos), one of the four major climatic zones where California almonds are grown.

DETERMINING THE ORCHARD FLOOR SHADED AREA

The orchard floor shaded area is the percentage of tree spacing that is shaded when measured at midday. The percentage of ground shading can be estimated by visually examining the extent of the orchard floor shaded at midday or with the use of iPAR, an iPhone app created by Bruce Lampinen. For example, a tree spacing of 17 x 24 feet equals 408 square feet per tree. If the shaded area is 285 square feet, 70% of the tree spacing would be shaded.

MATURE ALMOND ORCHARD WATER USE

Each year, almond trees begin using water as the leaves develop and shoot growth begins. As the growing season progresses, and concurrent with canopy development, the water needed due to the warming climate increases, driven by longer days, higher temperatures and lower humidity. Together, these factors cause seasonal orchard water use to start at a low level, peak in midseason, and decrease as the growing season comes to an end (Fig. 2).

Once an orchard's mature water use has been determined, that amount may need to be modified to account for orchard-specific factors, such as soil or water salinity levels and irrigation system nonuniformity.

[1] Allen, R.G., Pereira, L.S., Raes, D. & Smith, M. 1998. Crop Water Requirements. FAO Irrigation and Drainage. Paper No. 56, Rome, FAO. http://www.kimberly.uidaho.edu/water/fao56/fao56.pdf.

CALCULATING ORCHARD WATER USE

Calculate almond orchard evapotranspiration (ETc) by multiplying the weather-based reference crop (ETo) by a canopy-based crop coefficient (Kc):

Crop water use (ETc) = Reference evaporation (ETo) × Crop coefficient (Kc).

- ETc (almond water use) in inches of water can be based on the day, week, month or season in order to assess the orchard's water requirements for irrigation scheduling purposes.
- ETo (reference ET) information is available from a variety of sources. The most well-known is the California Department of Water Resources CIMIS network of nearly 100 California weather stations that provide daily reference evapotranspiration values (www.cimis.water.ca.gov). CIMIS provides real-time current-season values and ETo in inches of water and can be based on the day, week, month or season (Table 1). Another source for this ETo data is the UC Statewide Integrated Pest Management website. Additionally, some newspapers and irrigation districts regularly publish CIMIS ETo data. While some in-orchard weather stations have the necessary inputs to calculate ETo, their accuracy depends on instrument siting. Use caution when using these ETo values. Best practices suggest verifying the values obtained in an orchard with the closest CIMIS station or to those obtained using spatial CIMIS.
- Kc (crop coefficient) for almonds has been experimentally determined for various times throughout the growing season. A crop coefficient is necessary to convert ETo, or reference ET, to an almond-specific number, as ETo represents the reference crop (grass pasture) used at CIMIS stations. Kc is the ratio at which the almond crop uses water compared with the ETo of the grass pasture. The Kc is developed under conditions where soil moisture is not limited and the crop is not under any water stress.

Historical "normal year," or long-term average ETo, can be more convenient than real-time ETo information because it is easier to access. It can also be used to prepare an irrigation plan for an entire irrigation season. The California climate zones from which regional ETo information is derived and from where almonds are grown are shown in Table 1. If more accuracy is desired, click here bit.ly/EToZones to download a Google Earth file that includes CIMIS ETo Zones for the California almond growing region.

		Zone 12[4]		Zone 14[5]		Zone 15[6]		Zone 16[7]	
	Kc[3]	ETo	ETc	ETo	ETc	ETo	ETc	ETo	ETc
Jan	0.40	1.24	0.50	1.55	0.62	1.24	0.50	1.55	0.62
Feb	0.41	1.96	0.81	2.24	0.92	2.24	0.92	2.52	1.04
Mar	0.62	3.41	2.11	3.72	2.30	3.72	2.30	4.03	2.49
Apr	0.80	5.10	4.09	5.10	4.09	5.70	4.57	5.70	4.57
May	0.94	6.82	6.44	6.82	6.44	7.44	7.02	7.75	7.31
Jun	1.05	7.80	8.20	7.80	8.20	8.10	8.51	8.70	9.14
Jul	1.11	8.06	8.93	8.68	9.61	8.68	9.61	9.30	10.3
Aug	1.11	7.13	7.90	7.75	8.59	7.75	8.59	8.37	9.28
Sep	1.06	5.40	5.73	5.70	6.05	5.70	6.05	6.30	6.68
Oct	0.92	3.72	3.41	4.03	3.69	4.03	3.69	4.34	3.97
Nov	0.69	1.80	1.23	2.10	1.44	2.10	1.44	2.40	1.64
Dec	0.43	0.93	0.40	1.55	0.66	1.24	0.53	1.55	0.66
Totals (in.)									
Yearly			49.75		52.61		53.73		57.70
Crop season[8]			47.43		49.69		51.06		54.56
Non-crop season[9]			2.32		2.92		2.67		3.14

Table 1. Thirty-year average evapotranspiration reference rates (ETo)[1] and almond (ETc)[2] for selected CIMIS zones in almond-producing areas of California.

Notes:

[1] Normal year evapotranspiration of unstressed grass (reference crop, ET0) 30-year CIMIS average for the respective zone.

[2] Evapotranspiration rates for almonds were calculated by multiplying ETo by the crop coefficient.

[3] Almond crop coefficient.

[4] Zone 12 ETo rates from Chico, Fresno, Madera, Merced, Modesto, and Visalia.

[5] Zone 14 ETo rates from Newman, Red Bluff, and Woodland.

[6] Zone 15 ETo rates from Bakersfield, Los Banos, and westside San Joaquin Valley.

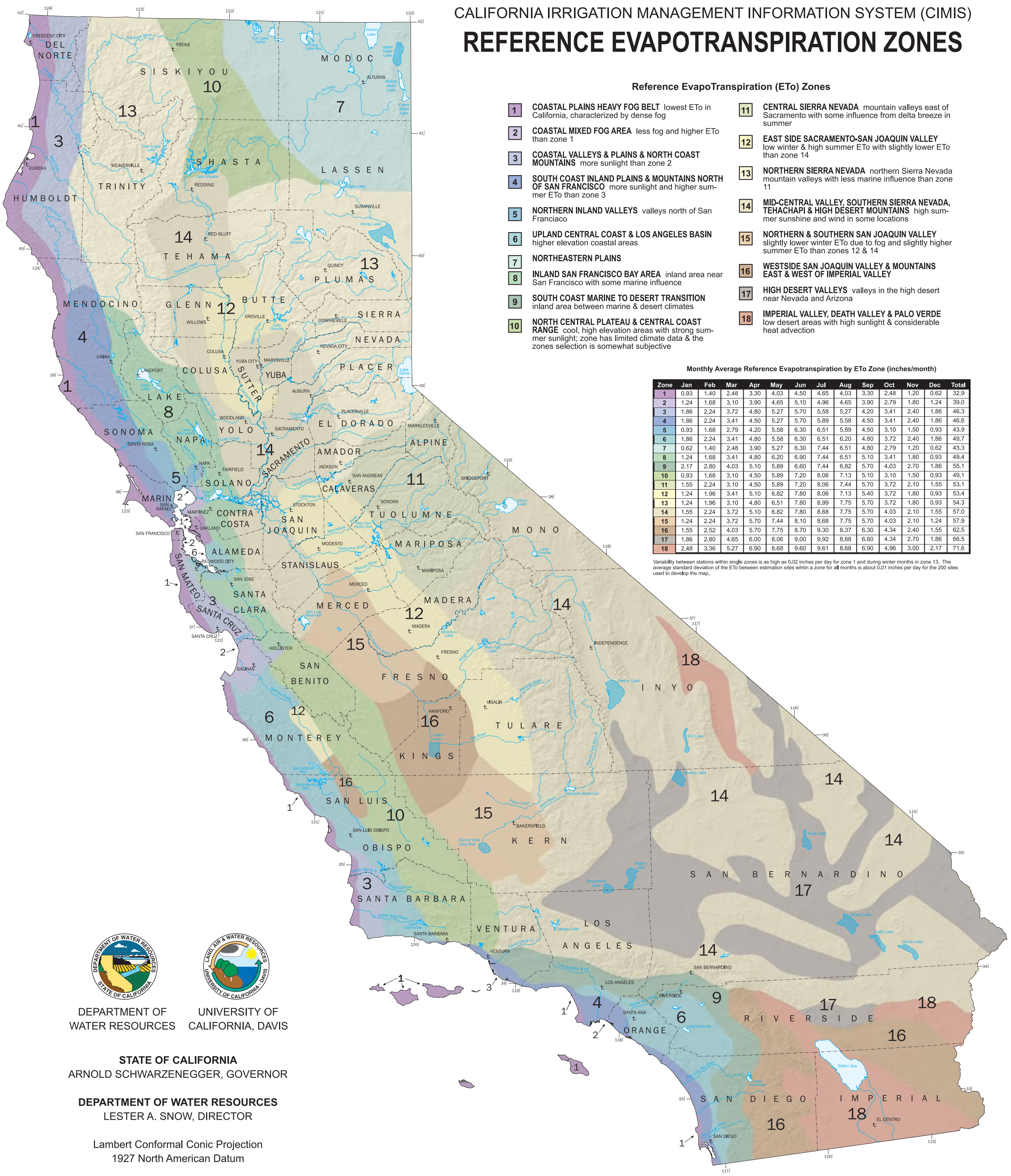
[7] Zone 16 ETo rates from Coalinga and Hanford.

[8] Crop season ETc rates for March to Nov 15.

[9] Non-crop season ETc rates for Jan, Feb, Nov 16–30, and Dec.

(Source: Adapted from Doll and Shackel 2015)

Table 1 lists historical monthly ETo values and ETc almond crop water use derived from Kc values for the four climatic zones where almonds are grown in California (Fig. 3). These monthly almond crop water use values are applicable to a mature almond orchard that has 70% or more of the orchard floor shaded at midday during the middle of the growing season, no middle cover, and no water stress.



Monthly Average Reference Evapotranspiration by ETo Zone (inches/month)

Zone	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1	0.93	1.40	2.48	3.30	4.03	4.50	4.65	4.03	3.30	2.48	1.20	0.62	32.9
2	1.24	1.68	3.10	3.90	4.65	5.10	4.96	4.65	3.90	2.79	1.80	1.24	39.0
3	1.86	2.24	3.72	4.80	5.27	5.70	5.58	5.27	4.20	3.41	2.40	1.86	46.3
4	1.86	2.24	3.41	4.50	5.27	5.70	5.89	5.58	4.50	3.41	2.40	1.86	46.6
5	0.93	1.68	2.79	4.20	5.58	6.30	6.51	5.89	4.50	3.10	1.50	0.93	43.9
6	1.86	2.24	3.41	4.80	5.58	6.30	6.51	6.20	4.80	3.72	2.40	1.86	49.7
7	0.62	1.40	2.48	3.90	5.27	6.30	7.44	6.51	4.80	2.79	1.20	0.62	43.3
8	1.24	1.68	3.41	4.80	6.20	6.90	7.44	6.51	5.10	3.41	1.80	0.93	49.4
9	2.17	2.80	4.03	5.10	5.89	6.60	7.44	6.82	5.70	4.03	2.70	1.86	55.1
10	0.93	1.68	3.10	4.50	5.89	7.20	8.06	7.13	5.10	3.10	1.50	0.93	49.1
11	1.55	2.24	3.10	4.50	5.89	7.20	8.06	7.44	5.70	3.72	2.10	1.55	53.1
12	1.24	1.96	3.41	5.10	6.82	7.80	8.06	7.13	5.40	3.72	1.80	0.93	53.4
13	1.24	1.96	3.10	4.80	6.51	7.80	8.99	7.75	5.70	3.72	1.80	0.93	54.3
14	1.55	2.24	3.72	5.10	6.82	7.80	8.68	7.75	5.70	4.03	2.10	1.55	57.0
15	1.24	2.24	3.72	5.70	7.44	8.10	8.68	7.75	5.70	4.03	2.10	1.24	57.9
16	1.55	2.52	4.03	5.70	7.75	8.70	9.30	8.37	6.30	4.34	2.40	1.55	62.5
17	1.86	2.80	4.65	6.00	8.06	9.00	9.92	8.68	6.60	4.34	2.70	1.86	66.5
18	2.48	3.36	5.27	6.90	8.68	9.60	9.61	8.68	6.90	4.96	3.00	2.17	71.6

Variability between stations within single zones is as high as 0.02 inches per day for zone 1 and during winter months in zone 13. The average standard deviation of the ETo between estimation sites wihtin a zone for all months is about 0.01 inches per day for the 200 sites used to develop the map.

Figure 3. Reference evapotranspiration (ETo) zones in California. Most almonds are grown commercially in zones 12, 14, 15 and 16. (Source: http://wwwcimis.water.ca.gov/Content/pdf/CimisRefEvapZones.pdf)

ACCOUNTING FOR COVER CROP WATER USE

A cover crop is a noneconomic crop that is grown in the tree row middles. Cover crops are classified based on the season of growth or species. Resident vegetation, or weeds, that are simply allowed to grow in the tree row middles can be managed like a cover crop. The water used by cover crops must be accounted for in determining the orchard water use. Orchards with cover crops in the row middles have higher evapotranspiration rates than orchards without them.[2]

Orchard middles are managed periodically by mowing, cultivation or herbicide application. Orchard managers may allow cover to grow in row middles at the beginning of the growing season, then remove it as harvest approaches. The orchard water requirement at the beginning of the irrigation season could be calculated using the following approach, but once the cover crops are removed, orchard managers should disregard this calculation.

The water use rate of cover crops in orchards is difficult to measure and has not been thoroughly investigated. Water use by cover crops depends on the mowing or cultivation frequency, plant density, degree of shading by the tree canopies, and whether the cover crop has sufficient water available (whether it is fully wetted by irrigation applications). Estimates of increased water use due to the presence of cover crops are site specific.

Figure 4. Almond orchard with fairly dense cover crop (top); almond orchard with fairly sparse cover crop (bottom). (Photos by T. Prichard)

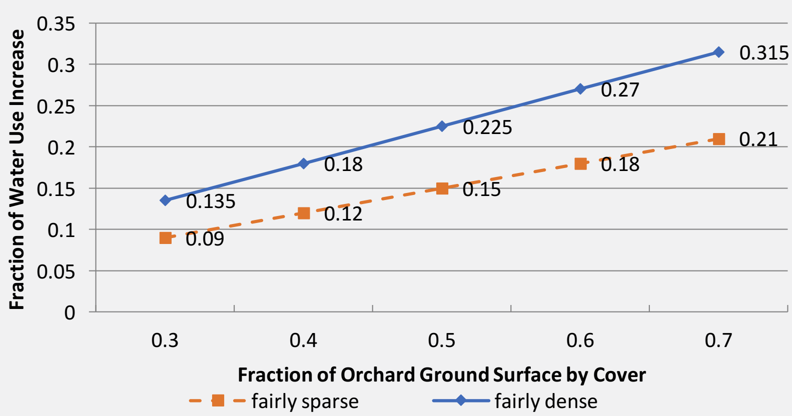


Figure 5. Fraction of orchard row covered by vegetation and the percentage of water use increase. Growers can use this chart to determine the additional water use of their orchard attributed to cover crops. (Source: Fereres et al 2012)

[2] Prichard, T., W Sills, W. Asai, L. Hendreicks, and C. Elmore. 1989. Orchard Water Use and Soil Characteristics. California Agriculture 43(4): 23–25.

Approximating the orchard water use increase due to cover crops depends mostly on the fraction of orchard ground surface occupied by the cover crop and the density of the cover crop (Figs. 4 and 5). When a cover crop has water available and is green and growing, the increased water use varies from 10 to 30%. The approach to account for this increase during the time the cover exists is as follows:[3]

Almond water use with middles cover = Monthly water use ETc ÷ (1 – % water use increase)

EXAMPLE

Zone 12: May ETc = 6.44 inches
Full-coverage irrigation system
Cover crop density is fairly sparse
Tree row spacing = 22 feet
Cover crop in middles = 15 feet wide
Fraction of orchard ground surface with middles cover = 15 feet ÷ 22 feet = 0.68 or 68%
Water use increase (from Fig. 5) = 0.20 or 20%

It would be necessary to provide 6.44 ÷ (1 – .2) = 8.05 inches of water for that month to adequately provide water for the trees and the cover crop.

For irrigation systems that are not full coverage, use only the green growing area to determine the fraction of the orchard that has cover.

For young orchards or orchards with less than 30% canopy shaded area and cover crops in the middles, the best approach is frequent soil moisture monitoring in the root zone to ensure adequate moisture.

ADJUSTING FOR SMALL-CANOPY OR YOUNG ORCHARDS

The smaller canopy of a young orchard (Fig. 6) uses less water than an orchard with mature trees (canopy at or near 70% shaded ground surface at midday). Additionally, the small root zone may not access the entire area where the water is applied, making the use of ET estimation less accurate than for mature trees.

Figure 6. Because young orchards do not have a full canopy, they use less water than mature orchards, and the irrigation amount must be adjusted to account for this. (Photo by T. Prichard)

[3] Fereres, E., D. Goldhamer, and V. Sadras. 2012. Yield Response to Water of Fruit Trees and Vines: Guidlines. In P. Steduto, T. Hsiao, E. Fereres, and D. Raes, eds., Crop Yield Response to Water. FAO Irrigation and Drainage Paper 66:246-295. FAO website, www.fao.org/nr/water/docs/irrigationdrainage66.pdf.

ET ESTIMATION

The evapotranspiration of young trees can be estimated by making in-orchard measurements of the shaded area at midday to determine the crop coefficient (Kc) then multiplying that Kc by the ETo just as in the method described for mature orchards. The percentage of ground shading can be estimated by visually examining the extent of the orchard floor shaded at midday or with the use of iPAR, an iPhone app created by Bruce Lampinen. Since the shaded area in young orchards increases over the season, the shaded area should be evaluated monthly. The shaded area is the percentage of the tree spacing that is shaded when measured at midday. For example, a tree spacing of 17 x 24 feet yields 408 square feet of growing area per tree. If the shaded area is measured at 163 square feet, the shaded floor area would be 40% of the tree spacing.

Studies relating the shaded area to tree ET have been conducted over the past 30 years using soil-based measurements of water use, and more recently using a more accurate measurement using a weighing lysimeter. The combined results of these studies are shown in Figure 7.[4,5,6,7,8] Evapotranspiration increases at a rate approximately 1.26 times the percent of ground shading. Current research is underway in almonds to measure shaded area and water use in a weighing lysimeter, which is much more accurate than the previously used soil-based water-use measuring methods. When results are available this relationship — if different — will be updated.

For convenience the relationship presented in Figure 7 is shown in tabular form in Table 2 for each 10% increase in shaded area.

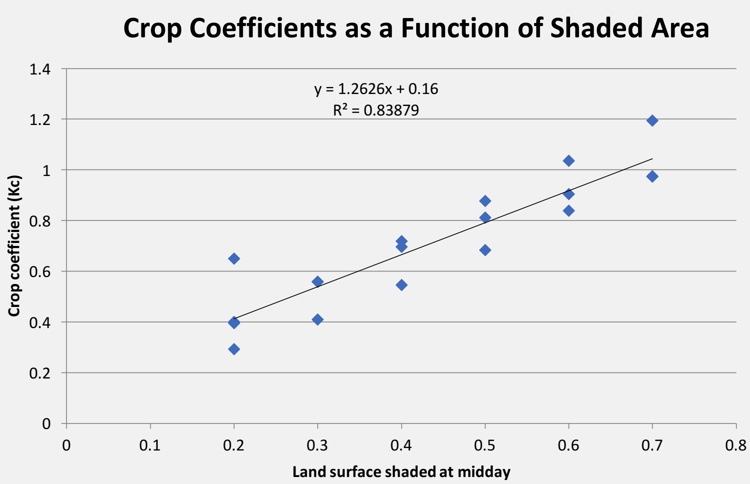


Figure 7. Relationship between the percentage of ground shading and crop coefficient (Kc).

% Shaded area	Crop Coefficient
20	41
30	54
40	67
55	79
60	92
70	100

Table 2. Growers can use this table to determine from the percent of midday ground shading in their orchard to estimate the crop coefficient of less than full canopy orchards.

[4] E. Fereres, D. Martinich, T. Aldrich, J. Castel, E. Holzapfel, and H. Schulbach.1982. Drip Irrigation Saves Money in Young Almond Orchards. California Agriculture 36:12–13.

[5] E. Fereres, D. Goldhamer, and V. Sadras. 2012. Yield Response to Water of Fruit Trees and Vines: Guidelines. In P. Steduto, T. Hsiao, E. Fereres, and D. Raes, eds., Crop Yield Response to Water. FAO Irrigation and Drainage Paper 66:246-295. FAO website, www. Rome: FAO. fao.org/nr/water/docs/irrigationdrainage66.pdf.

[6] Ayars, J.E., Johnson, R.S., Phene, C.J. et al. Irrig Sci (2003) 22: 187. https://doi.org/10.1007/s00271-003-0084-4.

[7] Lampinen, B., personal communication 2017.

[8] Shackel, K., personal communication 2017.

Use the following formula to adjust mature crop water use to that of a young orchard:

Young orchard water use (ETc) =
Biweekly (ETo) x crop coefficient (based on shaded area) = ETc (Fig. 7 or Table 2)

EXAMPLE A

Irrigation systems such as drip, which directs all the irrigation water to the root zone, can work well for the orchards with lower amounts of shaded area.

If water is applied to the entire orchard surface (e.g., by solid-set sprinklers) and the tree roots occupy only a small portion of the area, most of the applied water will not be accessible by the orchard, and the orchard will be under-irrigated. Frequent soil moisture monitoring will be required in the young trees' root zone to ensure adequate irrigation.

Use the following formula to adjust mature crop water use to that of a young orchard:

Young orchard water use (ETc) =
Monthly mature orchard water use (ETc) x percent of mature orchard ETc (Fig. 7)

EXAMPLE B

Zone 12 May ETc = 6.44 inches without middles cover

Young orchard ground surface shading at midday = 0.40 or 40%

Percentage ETc of a mature orchard = 0.67 or 67% (Fig. 7)

6.44 inches x 0.67 = 4.3 inches for the 40% coverage orchard

This method of using the percent of shading to determine the crop coefficient and ultimately water use is not recommended until the canopy reaches at least 30% shaded area when the roots will have expanded to most of the area where the irrigation water is applied.

Under-irrigation can occur if the calculated water is applied, but the root zone is not large enough to access the applied water. This is especially true when using irrigation systems which apply to the entire orchard surface (e.g., by solid-set sprinklers or surface irrigation) and the tree roots occupy only a small portion of the area, most of the applied water will not be accessible by the orchard, and the orchard may be under-irrigated. Irrigation systems which target the irrigation application to the root zone of the young tree are more likely to be successful in using this method. An additional consideration when using this method for estimating the water required for young trees is that as the root system expands into areas of the soil containing winter stored water, water required by irrigation will be reduced and should be accounted for when using this method. Frequent soil moisture or plant-based monitoring are more reliable methods to ensure adequate irrigation in an orchard with less than 30% shaded area.

ADJUSTING WATER USE FOR OTHER ORCHARD WATER REQUIREMENTS

In addition to the orchard water covered in the previous sections, a variety of factors can impact the actual water requirement of an orchard. These include the additional water needed to address factors such as salinity and irrigation system nonuniformity, or reductions in water use due to factors such as disease management and inadequate water supplies.

IRRIGATION SYSTEM NONUNIFORMITY

In addition to orchard water use described and calculated in the previous sections, other factors can impact the actual water requirement of an orchard. One of these is increasing the orchard irrigation amount to overcome irrigation system nonuniformity. System uniformity is determined by measuring the distribution uniformity (DU) of the orchard irrigation system. This discussion focuses on three issues:

- How the distribution of water throughout the orchard is related through the measurement of DU;
- Whether the measured distribution should be used as a modifier to increase the average irrigation application to ensure that less of the orchard is under-irrigated while over-irrigating a greater portion of the orchard; and
- The effect of over- or under-irrigation on orchard production and longevity.

Distribution Uniformity

The amount of over- or under-irrigation in an orchard depends on the distribution uniformity of the irrigation application, which is affected by pressure variations in the system, emitter clogging, slope and other factors. As described in the section “Irrigation System Performance” in *Continuum Level 2.0*, it is essential to evaluate your irrigation system for pressure or discharge differential and then estimate the distribution uniformity. If your system has low distribution uniformity, determine the causes and solutions to prevent over- and under-irrigation.

- **High DU Example:** High DU Example: Using the example of an average irrigation application of 1.0 inch and a measured DU of 90% (Fig. 8), the average area of the orchard (the 1/2 point on the graph) receives 1.0 inch (100%) of the target application. At the 1/8 points of the graph, the area of the orchard receiving the least water gets about 12% less water than the average, and the area receiving the most water gets about 12% more than the average.

- **Low DU Example:** Using the example of an average irrigation application of 1.0 inch and a measured DU of 75% (Fig. 8), the average area of the orchard receives 1.0 inch (100%) of the target application. At the 1/8 points on the graph, the orchard receiving the least water gets 30% less than the average (0.7 inch), and the area receiving the most water gets about 30% (1.3 inches) more than the average, which is almost double the drier 1/8 area.

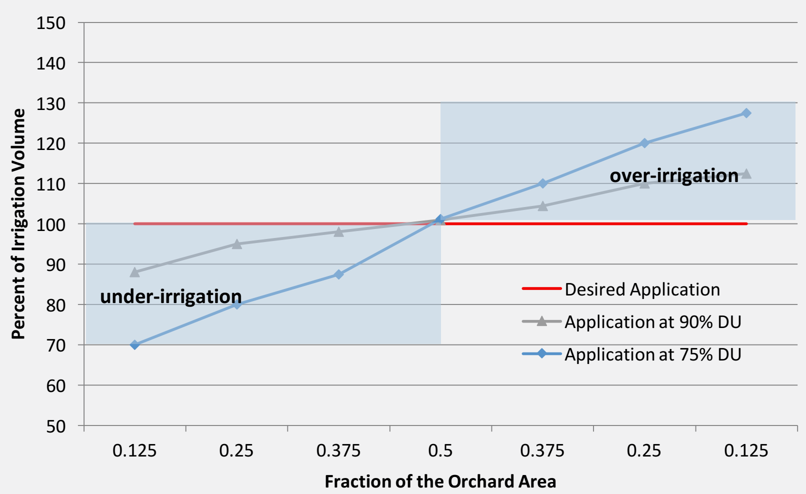


Figure 8. Irrigation distribution across an orchard measured 90 and 75% DU.

Using Distribution Uniformity to Adjust Water Application

It is possible to use distribution uniformity to adjust the water application by applying more water to ensure that most of the orchard receives the planned amount of water. The procedure is as follows:

$$\frac{\text{Orchard Irrigation Water Application}}{\text{Distribution Uniformity (DU)}} = \text{Applied Water Application considering DU}$$

- **High DU Example:** An average irrigation application of 1.0 inch at a distribution uniformity of 90% requires 1.11 inches of applied water. This is an 11% increase over the 1.0 inch of water applied if the DU were not a factor and assures that only 12.5% of the orchard will have less than the target application. However, that 11% is an increase in the average applied, since the distribution of the water is not changed. The 1/8 area of the orchard receiving the least water gets about 3% less than the 1.0 inch target. On the other end of the spectrum, the 1/8 area receiving the most water gets about 24% more than the 1.0 inch target (Fig. 9).
- **Low DU Example:** A 1.0 inch average irrigation application at a DU of 75% requires 1.33 inches of water. This is a 33% increase over the 1.0 inch if DU were not a factor (Fig. 10). However, that 33% is an increase in the average since the distribution of the water is not changed. The 1/8 area of the orchard receiving the least water gets about 7% less than the 1.0 inch target. On the other end of the spectrum, the 1/8 area receiving the most water gets about 69% more than the 1.0 inch target.

It is a simple fact that increasing the amount of water applied to overcome poor distribution uniformity to assure that less of the orchard is under-irrigated comes at the expense of overwatering the bulk of the orchard, which can lead to fertilizer leaching, disease, tree loss and inefficient use of water.

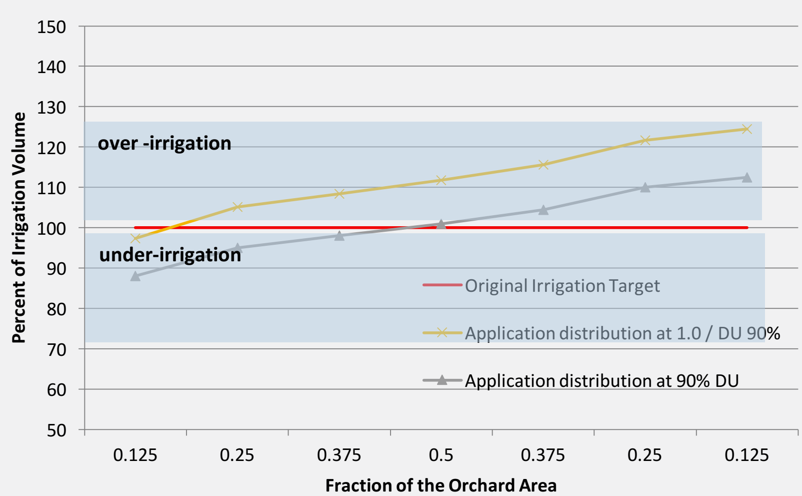


Figure 9. Irrigation distribution across the orchard measured at 90% DU and DU at 1.0 inch application divided by 90% DU.

Effect on Orchard Production and Longevity

When using the DU as a modifier, the amount of water going to the lowest-application areas of the orchard approaches the target average application, but the water applied in over-irrigated areas increases — in the case of 75% DU, up to 69% more water than desired (Fig. 10).

This over-irrigation can cause production losses and reduce orchard longevity. In contrast, if more water is not added to compensate for poor DU, some of the orchard will be under-irrigated. The solution lies in improving DU to a point where there is minimal difference in the over- and under-irrigation levels in the orchard. A DU of about 90% is probably optimal, as research has shown that trees are able to produce optimally with about 90% of full irrigation.[9] Orchards with lower DU should be analyzed to determine the problem and solutions implemented to improve DU.

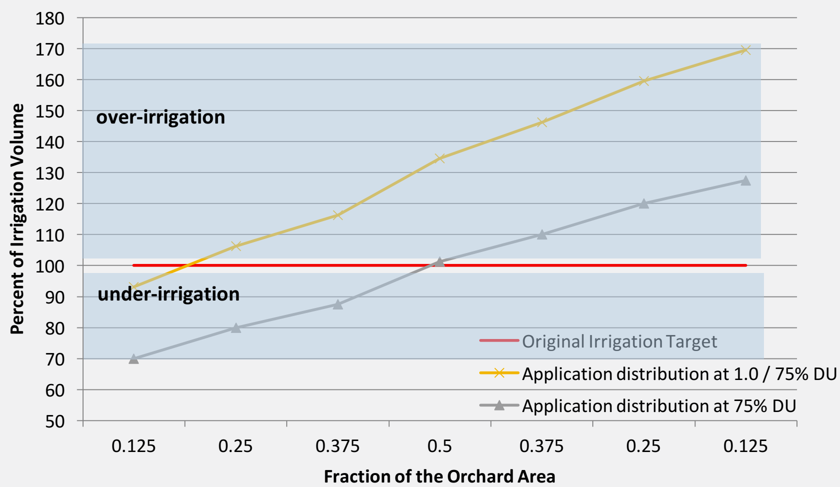


Figure 10. Irrigation distribution across the orchard measured at 75% DU and DU at 1.0 inch application divided by 75% DU.

IRRIGATION WATER AND SOIL SALINITY

This section describes the effects of irrigating almonds with waters that contain salts, how they build up in the root zone, and how the irrigation schedule may be altered to reduce soil salinity caused by irrigation waters. It is not meant to be a discussion on salt leaching or soil reclamation methodology.

All irrigation water contains dissolved mineral salts, but the concentration and composition of the salts depend on the specific water source. Over time, salts can build up in the root zone and can reduce orchard production if not removed by leaching. Salt buildup poses two distinct hazards to almond orchards in the root zone: the total salt content and the toxic effect of specific salts such as sodium, chloride and boron.

Excess total salinity from concentrating salts in the crop root zone creates an osmotic stress, which reduces crop growth. The most common positively charged ions, or cations, are calcium, magnesium and sodium, while the most common negatively charged ions or anions, are chloride, sulfate and bicarbonate. To overcome increased osmotic stress, plants must expend more energy to absorb water from the saline soil, leaving less energy for plant growth. The more saline the irrigation water, the faster salts build up in the soil, potentially reaching a level that reduces production.

Higher irrigation water salinity requires applying more water than required by normal orchard water use or using rainfall to leach salts below the root zone and maintain production. In areas where irrigation water salinity levels are low or rainfall is high, rainfall may be all that is needed to maintain an acceptable level of salts in the root zone. When salts in irrigation water are higher and coupled with lower rainfall, the irrigation amounts may need to be increased to ensure adequate salt leaching. Additionally, in orchards with poor irrigation distribution uniformity, some areas of the orchard may receive enough water to leach salts, while 50% of the orchard gets less than the average amount of water, causing less or no leaching.

The salinity of the water used for irrigation and the salinity of the saturated soil extract is reported as electrical conductivity (EC) in units of decisiemens per meter (dS/m) (which is the same as the older unit, millimho per centimeter, or mmho/cm). The maximum soil salinity that does not reduce yield below that obtained under nonsaline conditions is

[9] Shackel, K. et.al. 2017 ABC Water Production Function Report.

known as the salinity threshold. For almonds, this is an average root zone salinity 1.5 dS/m. Irrigation water salinity concentrates over time by a factor of 1.5 in the soil when about 15% of the applied water passes through the root zone as deep percolation. Therefore under these conditions, a water salinity of 1.0 dS/m concentrates to 1.5 dS/m as the average root zone salinity.

Figure 11 illustrates the yield response of almonds to increasing salinity of the irrigation water using this 1.5 concentration factor.[10] Note that yield is not reduced until the threshold salinity is reached.

To maintain a favorable salt balance, deep percolation of water is needed to transport the salt introduced by the irrigation water out of the root zone. The amount of deep percolation required is referred to as the leaching requirement (LR), and it depends on irrigation water quality, as well as the crop sensitivity to salinity, which can vary by rootstock and variety. LR is expressed as a percentage of the applied irrigation water.[10] The leaching requirement is the minimum leaching to prevent yield loss; another common term, “leaching fraction,” is the fraction or percentage of water applied to the orchard that actually drains below the root zone.

As the concentration of the salts in the water increases, more salinity is transported into the orchard, and more leaching is required to leach salts below the root zone.

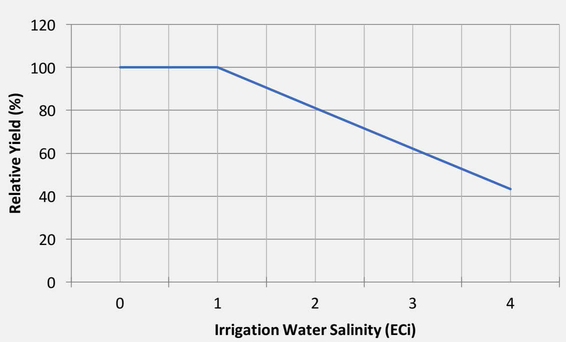


Figure 11. Relative almond yield (percent) as a function of ***irrigation water salinity*** *(dS/m) assuming a 15% leaching fraction, as defined in Maas and Hoffman 1977.*[11]

Irrigation water electrical conductivity (dS/m)	Leaching requirement % to maintain root zone salinity at 1.5dS/m
0.25	3
0.50	7
0.75	11
1.00	15
1.20	19
1.50	30

Table 3. Leaching fraction required to maintain average root zone salinity at the threshold with increasing salinity in the irrigation water.

Table 3 gives the leaching requirement expressed as the percentage of crop water use necessary to maintain the average salt concentration in the root zone at the salinity threshold at various irrigation water salinities. The purpose of these leaching requirements is to understand the long-term effect of the salinity buildup in the soil, and the amount of water required to maintain a favorable salt content in the soil to prevent crop loss. In soils of high permeability, employing these leaching fractions can effectively reduce average root zone salinity, especially if beginning the season at or near the soil salinity threshold. Experience has shown in-season leaching practices on heavier or poor water infiltration soils to be difficult to achieve — especially when combined with hullsplit deficit irrigation. Often times, more damage is done to the trees due to soil water-logging and subsequent root death with minimal reduction in root zone salts. In this case off-season leaching is recommended.

In addition to the effect of salinity on the orchard, elements such as sodium (Na), chloride (Cl) and boron (B) can build up in the root zone and be taken up by the tree to a toxic level, burning the leaves and reducing photosynthesis. Because there are differences in tolerance to these elements among rootstocks and varieties, tissue analysis is the best indicator of the toxic element hazard. Boron and sodium can be leached — just as with total salts — but are more difficult to remove than the other salts.

[10] R. S. Ayers and D. W. Westcot. 1985. Water Quality for Agriculture. FAO Irrigation and Drainage Paper no. 29. Rev 1. Rome: FAO. http://www.calwater.ca.gov/Admin_Record/C-110101.pdf.

[11] Maas, E. V., and G. J. Hoffman. 1977. Crop Salt Tolerance: Current Assessment. Journal of the Irrigation and Drainage Division, ASCE 103 (IR2): 115–134.

LEACHING MANAGEMENT CONSIDERATIONS

- Leaching may not be needed every season.
  - Soil testing will help determine when leaching is necessary or how much is needed.
- Rainfall may adequately reduce salts when it fills the root zone to field capacity and then provides the leaching water requirement.
  - In areas of lower rainfall, early-fall dormant irrigation can recharge the root zone and reduce the rainfall amount required to meet the leaching requirement.
- To the extent possible, time irrigations to leach salinity during fallow or dormant periods. This will avoid critical periods of crop growth and development when nitrogen uptake and fertilization should not be occurring.
- If the root zone starts the season at the salinity threshold, in-season leaching will be necessary to prevent yield loss.
- Poor irrigation distribution uniformity, if used to increase the average application of irrigation water, may achieve the leaching requirement in some parts of the orchard.
  - If a DU of 75% is used, 63% of the orchard would meet or exceed the leaching requirement, while 37% of the orchard would not.
  - If a DU of 90% is used, about half of the orchard would meet or exceed the leaching requirement, while the other half would not.
- The use of partial-coverage irrigation systems — drip and microirrigation — results in different salt buildup patterns than with full-coverage systems like surface irrigation and full-coverage sprinklers. Typically, the salts build up on the edge of the wetted zone. Leaching with the irrigation system is not as effective as with traditional surface-applied full-coverage systems. Irrigate to fill the root zone near the end of the season to leverage effective rainfall. This practice tends to keep accumulated salts moving away from rather than into the root zone.

Determine the applied water required to leach salts from orchards without adequate rainfall using the formula and required information below:

$$\text{Applied Water} = \frac{\text{ETc}}{1 - \text{LR}}$$

1. Determine the crop water use (ETc) for the orchard with information in the section “Calculating Orchard Water Use.”
2. Select the leaching fraction (LR) from Table 3 based on the irrigation water salinity.
3. Using the following example or your own data, calculate the amount of water required to adequately irrigate the orchard and leach salts.

EXAMPLE

Example: ETc = 47.5 in

EC irrigation water = 1.0 dS/m

LR = 0.15 or 15% (from Table 3)

Applied water = 47.5÷(1–0.15) = 55.9 in

IRRIGATION WITH INADEQUATE WATER SUPPLIES

Deficit irrigation is the practice of supplying less water to the orchard than what is required to meet full crop (ETc) water use. Recently, this practice has been employed by growers during the drought, when not enough water was available to meet the needs of the orchard.

Water deficits occur when a tree's water demand exceeds the amount of water available in the soil. These deficits increase water tension within the plant; when this stress is high enough, it negatively affects many plant processes. Unless severe water supply issues are present, deficit irrigation should not be practiced on young orchards because it delays orchards from coming into production.

Deficit irrigation can be done in developed orchards at a proportional deficit at some percentage of full water across the entire season or at specific growth or nut development stages.[12] The method and/or timing are usually directed at solving a water supply problem or a specific disease issue, as described in the section "Irrigation and Hull Rot Disease Management," below.

Since deficit irrigation programs are designed to provide a percentage of full water use, accounting for the deficit is straightforward. For example, if conditions dictate that a grower will receive 30% less water than they normally receive (70% of full irrigation), the following formula would apply:

ETc under deficit irrigation =
ETc under full irrigation x 0.7

For specific deficit irrigation strategies and their impact on almond growth and yield, see UC ANR Publication 8515, Drought Management for California Almonds.[13]

IRRIGATION AND HULL ROT DISEASE MANAGEMENT

Hull rot is an infection of almond hulls caused by *Rhizopus stolinifer* or *Monilinia fructicola*. Upon infection, pathogens release toxins that are translocated into the fruiting wood, which kills the wood and causes crop loss. Research conducted between 1990–2000 has shown that incidence of this disease can be reduced with balanced nitrogen applications and hullsplit deficit irrigation from post-kernel fill through 90% hullsplit.[14] This phase of nut development corresponds to the first sign of hullsplit and extends about three weeks into hullsplit depending on the season. The actual calendar dates are dependent on the almond variety and the weather patterns for the specific season. Properly timed and applied irrigation deficit can reduce hull rot by 80 to 90%. Throughout the duration of the study, the application of this practice did not affect yield or kernel size.

Typically, a 10 to 20% reduction in applied water will be needed, but because this depends on the orchard's soil and irrigation system, it must be determined on an orchard-by-orchard basis.[13]

More information on implementing hullsplit deficit irrigation can be found in the UC ANR publication 8515, Drought Management for California Almonds,[13] which discusses implementation, considerations and trade-offs associated with deficit irrigation in almonds.

[12] Goldhamer, D., and J. Girona. 2012. Almond. In P. Steduto, T. Hsiao, E. Fereres, and D. Raes, eds., Crop Yield Response to Water. FAO Irrigation and Drainage Paper 66:358–373. FAO website, www.fao.org/nr/water/docs/irrigationdrainage66.pdf.

[13] Doll, D. and K. Shackel. 2015. Drought Tips, Drought Management for California Almonds UCANR Publication 8515. http://anrcatalog.ucanr.edu/Details.aspx?itemNo=8515.

[14] Teviotdale, B. D., Goldhamer, and M. Viveros. 2001. The Effects of Deficit Irrigation on Hull Rot of Almond Trees Caused by *Monilinia fructicola* and *Rhizopus stolonifer*. Plant Disease 85(4): 399-403. ASP Journals website, http://apsjournals.apsnet.org/doi/abs/10.1094/PDIS.2001.85.4.399.

MEETING THE ORCHARD WATER REQUIREMENT

The orchard water requirement is met by the available soil moisture stored in the root zone at the beginning of the season plus in-season rainfall stored in the soil (including frost protection water applications if stored in the root zone), and applied irrigation water.

In-season rainfall that enters the root zone for orchard use tends to occur in the first few months of the season, and stored soil moisture is at a maximum at the beginning of the season. It is not uncommon for in-season effective rainfall and stored soil moisture to meet the entire crop water use in the first month and from 15 to 35% on a seasonal basis. The remainder of the orchard water requirement must come from irrigation.

ESTIMATING IN-SEASON EFFECTIVE RAINFALL

For areas likely to experience significant rainfall during the season, the following method is suggested to estimate the effective rainfall in a given rainfall event. A rainfall event can be a single day or multiple sequential days of rainfall. It utilizes your rainfall data and the daily ETo from a nearby CIMIS station. CIMIS data can be obtained from the California Irrigation Management Information System (CIMIS) website, http://www.cimis.water.ca.gov/.

Effective Rainfall (inches) =
(Rainfall (inches) from event – 3 days of ETo (inches) after the event) x 0.75

Example 1

Merced CIMIS Station 148, April 8–10, 2016: 2.65 inches of rain. ETo April 11-13, 0.5 inches

Effective Rainfall (inches) = (2.65 – 0.5) x 0.75 = 1.7 inches

Example 2

Shafter CIMIS Station 5, April 7–10, 2016: 1.01 inches of rain. ETo April 11-13, 0.41 inches

Effective Rainfall (inches) = (1.01 – 0.41) x 0.75 = 0.7 inches

ESTIMATING SOIL-STORED WINTER RAINFALL

Winter rain can help meet part of the water use of orchards because rainwater can infiltrate the soil and remains as stored soil-water until the following growing season. The estimation of soil-stored winter rainfall is a two-step process. First, the amount of rainfall is reduced by some evaporative losses; this final quantity is known as effective rainfall. Secondly, the soil must have the capacity to store the effective rainfall within the root zone of the crop. Effective rainfall in excess of the root zone capacity is lost to deep percolation and is not available to the orchard.

EFFECTIVE RAINFALL

Relatively involved techniques have been developed to account for winter rains stored in the soil when determining crop evapotranspiration (ETc).[15] However, a simple but practical method exists that works well for California almond-growing areas. It relies on the use of monthly total rainfall and ETc during the crop nongrowing season (Table 1). For almond the non-growing season is from Nov. 15 (approximate leaf-drop date) through the month of February. Effective rainfall was calculated based on these relationships using average year monthly rainfall totals for six valley locations (Table 4).

This table provides a good starting point for planning an irrigation schedule; however, actual winter rainfall data will provide a better estimate.

ET Zone	12			15			12			14			12			12		
	Arbuckle			**Bakersfield**			**Chico**			**Dixon**			**Fresno**			**Merced**		
	Rain	ETc	Effective Rainfall	Rain	ETc	Effective Rainfall	Rain	ETc	Effective Rainfall	Rain	ETc	Effective Rainfall	Rain	ETc	Effective Rainfall	Rain	ETc	Effective Rainfall
	Inches																	
Nov 16-30	1.07	0.51	0.56	0.32	0.60	0.00	1.64	0.51	1.13	1.47	0.63	0.84	0.59	0.51	0.08	0.67	0.51	0.16
Dec	2.99	0.43	2.56	1.02	0.50	0.53	4.61	0.43	4.18	4.75	0.61	4.11	2.01	0.43	1.58	2.09	0.43	1.66
Jan	3.91	0.52	3.39	1.14	0.60	0.52	4.84	0.52	4.32	4.82	0.64	4.18	2.28	0.52	1.76	2.60	0.52	2.08
Feb	3.00	0.74	2.26	1.22	0.90	0.37	4.41	0.74	3.67	4.76	0.86	3.90	2.01	0.74	1.27	2.36	0.74	1.62
Total			8.77			1.42			13.30			13.03			4.69			5.52

Table 4. Average rainfall and effective rainfall for seven Central Valley locations. (Source: usclimatedata.com)

Determining the soil moisture stored in the tree's root zone is important information for good irrigation water management. Stored soil moisture serves as a bank account of water available for the orchard. As the trees "withdraw" water from the stored soil moisture bank account, irrigation "deposits" must be made throughout the growing season to maintain available water in the account. Maintaining available water in the root zone provides the orchard with a cushion in case of under-irrigation due to management miscalculations, equipment failure or other factors that affect the availability of water.

Growers should evaluate soil moisture by monitoring on a frequent basis to inform irrigation management decisions. Stored soil moisture is accessed by the tree's roots and is withdrawn to satisfy the tree water needs; this should be accounted for in irrigation decision making. Refer to the section "Soil Moisture."

[15] R. G. Allen, J. L. Wright, W. O. Pruitt, L. S. Pereira, and M. E. Jensen. 2007. Water Requirements. Chapter 8 in G. J. Hoffman,, R. G. Evans, M. E. Jensen, D. L. Martin, and R. L. Elliott, eds., Design and Operation of Farm Irrigation Systems. 2nd ed. St. Joseph, MI: American Society of Biological and Agricultural Engineering.

ROOT ZONE WATER-HOLDING CAPACITY

Controlling factors of root zone water-holding capacity include soil texture and structure, depth of root zone, and root extensiveness.

Use the information presented in the section "Soil Moisture" to determine the extent of the root zone and its estimated water-holding capacity. Then compare the effective rainfall with the root zone capacity. The amount of stored moisture cannot exceed the maximum root zone capacity, regardless of the amount of effective rainfall.

Table 5 shows the plant-available water held by soils of different texture when fully wet or field capacity. Plant-available water is the amount of water stored in the soil that plants can take up. It is the difference in soil water content between field capacity and the permanent wilting point. Since some water is held so tightly by the soil that plants cannot take it up, available water content is less than the total amount of water held in soil.

Soil texture	Plant-available water-holding capacity (in. of water per ft. of soil)
Very coarse sand	0.40 – 0.75
Coarse sand, fine sand, loamy sand	0.75 – 1.25
Sandy loam, fine sandy loam	1.25 – 1.75
Very fine sandy loam, loam, silt loam	1.50 – 2.30
Clay loam, silty clay loam, sandy clay loam	1.75 – 2.50
Sandy clay, silty clay, clay	1.60 – 2.50

Table 5. Plant-available water-holding capacities of various textured soil.[16] (Source: Adapted from Schwankl and Prichard. 2009)

ESTIMATING SOIL-STORED WINTER RAINFALL EXAMPLE

Location and Conditions

Merced, California: Mature trees; loam soil; solid-set sprinkler irrigation; root zone depth 4 feet

Plant-available water-holding capacity = 2.0 inches of water per foot (from Table 5)

Root zone plant-available water-holding capacity:

Root zone depth = 4 feet x 2.0 inches water = 8.0 inches plant-available water

Effective nongrowing season rainfall: Merced, average year 5.5 inches (from Table 4)

Estimating Root Zone Water-Holding Amount

Since the average effective rainfall does not exceed the estimated root zone water-holding capacity of 5.5 inches, use 5.5 inches as the estimated root zone water-holding amount.

If a postharvest irrigation was applied, the unused portion can be added to the effective rainfall. Additionally, irrigation water applied in the off-season and water applied for frost protection can also be a source of stored soil moisture and can be added to the root zone water amount if the root zone's capacity is not exceeded.

[16] Schwankl, L. J., and T. L. Prichard. 2009. University of California Drought Management website. http://UCManageDrought.ucdavis.edu.

USING IN-SEASON EFFECTIVE RAINFALL AND SOIL STORAGE IN AN IRRIGATION SCHEDULE

Effective in-season rainfall and stored soil moisture can be a significant source of water that should be accounted for in an irrigation schedule. In almond-growing regions of the northern San Joaquin Valley and the Sacramento Valley, where rainfall is higher, effective rainfall can commonly contribute from 10 to 35% of the seasonal crop water use, depending on orchard soil and root characteristics. Simple steps to account for the effectiveness of rainfall and soil storage to partially supply the crop water use are outlined below.

The procedure begins with calculating the orchard water use as modified by the factors such as any necessary leaching fraction, as discussed in the above sections.

Once the orchard water requirement is determined, account for the contribution from in-season effective rainfall and stored moisture, both of which reduce the irrigation amount.

In-Season Effective Rainfall

In the Merced example above, a single rainfall event was used to illustrate the method of calculation. For the year 2016 three significant rainfall events occurred from March through April. Using the same calculation method described above then adding them together, this period supplied 4.3 inches in-season effective rainfall.

Stored Soil Moisture from Winter Rainfall

Continuing with the Merced example, the nongrowing season of Nov. 15 through Feb. 29, 2016, had 6.7 inches of effective rainfall (Table 6), which does not exceed the root zone capacity of 8.0 inches. So we will use the 6.7 inches for our stored moisture content.

About 50% of the plant-available water stored in the root zone can be used before tree stress begins. It is good practice to maintain the soil moisture no lower than that level to avoid plant water stress, especially early and in midseason, during tree growth and nut sizing. If water stress is desired for hullsplit and disease management later during the season, the soil moisture level must be kept below this level and best determined using the pressure chamber. In our example, 6.7 inches of effective rainfall would be reduced by half, to 3.3 inches. If used over a three-month period, the amount would be about 1.1 inches per month.

Table 7 shows the accounting for effective rainfall and soil-stored moisture based on our example conditions above in determining the irrigation schedule.

	Rain	ETc	Effective Rainfall
	Inches		
Nov 15-31	0.45	0.45	0.00
Dec	2.39	0.48	1.91
Jan	5.26	0.49	4.77
Feb	0.44	1.54	0.00
Total			6.68

Table 6. Effective rainfall Merced CIMIS Station 148, 2015-16 nongrowing season.

	Zone 12 Merced 2016			
	ETc	Effective rainfall	Stored moisture	Irrigation application
	(in)	(in)	(in)	(in)
March	2.1	2.7	0.0	
April	4.1	1.6	1.1	1.4
May	6.4	0.0	1.1	5.3
June	8.2	0.0	1.1	7.1
July	8.9	0.0		8.9
August	7.9	0.0		7.9
September	5.7	0.0		5.7
October	3.4	0.0		3.4
Nov 1–15	0.6	0.0		0.6
Season	**47.4**	**4.3**	**3.3**	**40.4**
Mar-June	*20.8*			*13.8*

Table 7. Accounting for in-season rainfall and stored moisture using 2016 Merced conditions and Zone 12 monthly orchard water requirements.

In our Merced example, the irrigation water application was reduced by 36% from March through June, or by 16% on a seasonal basis. Rainfall varies between different almond-growing regions of the Central Valley, and the amount of the rainfall contribution can be more or less than this example.

Determine the difference between the estimated crop water use and the effective rainfall and available soil storage:

Estimated orchard water requirement – Effective rainfall – Available moisture = Irrigation application

This is the estimated amount of water that will need to be allocated throughout the growing season using timely, efficient irrigation.

NEXT STEPS

Once the estimated orchard water requirements of a specific orchard have been determined, use the irrigation system application rate to determine the appropriate irrigation system operation time. The “Irrigation System Performance” section in *Continuum Level 1.0* provides guidance to measure the system application rate and distribution performance.

MOVING UP THE CONTINUUM

“Orchard Water Requirements” practices in *Continuum Level 1.0* rely on monthly estimates of orchard water use to develop an irrigation schedule. To improve upon that, *Level 2.0* practices use a biweekly time that allows for anticipation of lower ET in the first two weeks of the month of water use in contrast to the last two weeks (from leaf-out to midseason). The opposite is found from midseason to leaf drop. “Orchard Water Requirements” in *Continuum Level 3.0* accounts for over- and under-estimation of ET and irrigation applications, as well as for any application errors in subsequent irrigations.

DETERMINING AND MEETING ORCHARD WATER REQUIREMENTS

INTRODUCTION

An orchard's water requirement is a combination of the crop water use and other beneficial water uses, such as salt leaching (if necessary) and water added to account for irrigation nonuniformity. Crop water use is considered to include losses from the orchard's soil (evaporation) and the tree's leaves (transpiration). These losses are combined into the term *evapotranspiration* (ETc), or, for our purposes, "almond water use." Almond water use can vary with climate, canopy size, existence of a planted cover crop or weeds, or reduced soil moisture.

The orchard water requirement is met by soil moisture stored in the root zone (including frost protection water applications if stored in the root zone), in-season rainfall stored in the soil, and applied irrigation water. In-season rainfall that enters the root zone for orchard use tends to occur in the first few months of the season. Likewise, stored soil moisture usually is at a maximum at the beginning of the season. It is not uncommon for these two water sources to supply the entire crop water use in the first 4 to 5 weeks of the season and up to 15 to 35% on a seasonal basis.

The amount of water available to the orchard from these sources can vary widely, since the rainfall stored in the root zone and in-season effective rainfall (rain that is ultimately used by the orchard) varies with geographic location, rainfall duration and frequency, as well as with root zone water-holding capacity. As an example of the variability, annual rainfall in Bakersfield (ET Zone 15) averages 6.45 inches, while northern almond regions such as Red Bluff (ET Zone 14) average 24.5 inches. It is important to account for the orchard's use of soil-stored moisture and in-season effective rainfall in all cases, but particularly important in the northern regions. The result will likely be a delay in irrigation in the spring months and an overall reduction in applied water for the season. In southern almond regions, effective in-season rainfall is small and soil storage is largely a function of dormant season irrigation for soil recharge and leaching.

2.0 Practice:

Estimate orchard water requirements using "normal year" regional crop evapotranspiration and other site-specific factors to determine irrigation applications on a biweekly basis.

ESTIMATING MATURE ALMOND ORCHARD WATER USE

Orchard water use, or evapotranspiration (ETc), is the sum of the orchard water use through transpiration and water lost through evaporation from the soil surface. Climatic factors affecting evapotranspiration include direct solar radiation (sunlight), temperature, wind and humidity. Tree, irrigation system type, and soil factors affecting evapotranspiration include canopy size, health of the tree, how tree row middles are managed (i.e., cover crop/weeds), and amount of surface wetting by the irrigation system and available soil moisture. Added to the orchard water use are other beneficial water uses that determine the orchard's water requirement, such as water used for salt leaching and for irrigation nonuniformity.

This section reviews calculations to determine the orchard water requirement for mature orchards without cover crops or vegetation in row middles (Fig. 1). The best way to estimate a mature orchard's water requirement is by using weather data and the orchard's specific characteristics.[1] An almond orchard is considered to be mature when about 70% or more of the orchard floor is shaded at midday during the middle of the growing season. More than 70% canopy coverage may result in increased water use; however, that level of coverage is considered to be the common practical limit based on necessary cultural activities. If the shaded area of your orchard is less than 70%, refer to the section "Adjusting for Small-Canopy or Young Orchards."

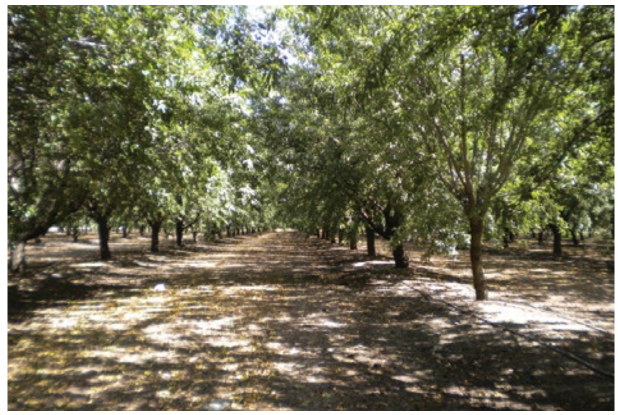


Figure 1. Mature almond orchard with no cover crop. An almond orchard is considered mature when about 70% or more of the orchard floor is shaded at midday during the middle of the growing season. (Photo by T. Prichard)

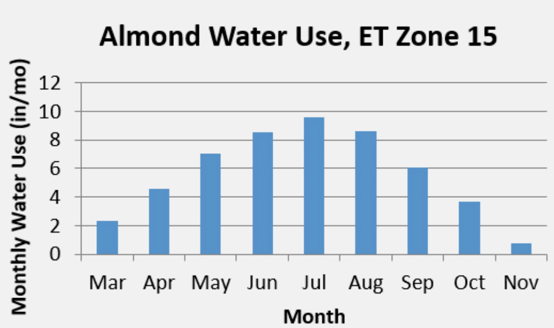


Figure 2. Monthly almond water use by a mature orchard with no cover crop and no significant water stress in climate zone 15 (Bakersfield to Los Banos), one of the four major climatic zones where California almonds are grown.

DETERMINING THE ORCHARD FLOOR SHADED AREA

The orchard floor shaded area is the percentage of tree spacing that is shaded when measured at midday. The percentage of ground shading can be estimated by visually examining the extent of the orchard floor shaded at midday or with the use of iPAR, an iPhone app created by Bruce Lampinen. For example, a tree spacing of 17 x 24 feet equals 408 square feet per tree. If the shaded area is 285 square feet, 70% of the tree spacing would be shaded.

MATURE ALMOND ORCHARD WATER USE

Each year, almond trees begin using water as the leaves develop and shoot growth begins. As the growing season progresses and concurrent with canopy development, the water needed due to the warming climate increases, driven by longer days, higher temperatures, and lower humidity. Together, these factors cause seasonal orchard water use to start at a low level, peak in midseason, and decrease as the growing season comes to an end (Fig. 2).

Once an orchard's mature water use has been determined, that amount may need to be modified to account for orchard-specific factors, such as soil or water salinity levels and irrigation system nonuniformity.

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[1] Allen, R.G., Pereira, L.S., Raes, D. & Smith, M. 1998. Crop Water Requirements. FAO Irrigation and Drainage. Paper No. 56, Rome, FAO. http://www.kimberly.uidaho.edu/water/fao56/fao56.pdf.

CALCULATING ORCHARD WATER USE

Calculate almond orchard evapotranspiration ETc by multiplying the weather-based reference crop ETo by a canopy-based crop coefficient (Kc):

Crop water use (ETc) = Reference evaporation (ETo) × Crop coefficient (Kc)

- ETc (almond water use) in inches of water can be based on the day, week, month or season in order to assess the orchard's water requirements for irrigation scheduling purposes.
- ETo (reference ET) information is available from a variety of sources. The most well-known is the California Department of Water Resources CIMIS network of nearly 100 California weather stations that provide daily reference evapotranspiration values (www.cimis.water.ca.gov). CIMIS provides real-time current-season values and ETo in inches of water and can be based on the day, week, month or season (Table 1; see page 28).
- Another source for this ETo data is the UC Statewide Integrated Pest Management website. Additionally, some newspapers and irrigation districts regularly publish CIMIS ETo data. While some in-orchard weather stations have the necessary inputs to calculate ETo, their accuracy depends on instrument siting. Use caution when using these ETo values. Best practices suggest verifying the values obtained in an orchard with the closest CIMIS station or to those obtained using spatial CIMIS (www.cimis.water.ca.gov).
- Kc (crop coefficient) for almonds has been experimentally determined for various times throughout the growing season. A crop coefficient is necessary to convert ETo, or reference ET, to an almond-specific number, as ETo represents the reference crop (grass pasture) used at CIMIS stations. Kc is the ratio at which the almond crop uses water compared with the ETo of the grass pasture. The Kc is developed under conditions where soil moisture is not limited and the crop is not under any water stress.

Historical "normal year," or long-term average ETo, can be more convenient than real-time ETo information because it is easier to access. It can also be used to prepare an irrigation plan in advance of an entire irrigation season. The California climate zones from which regional ETo information is derived and from where almonds are grown are shown in Table 1. If more accuracy is desired, click here bit.ly/EToZones to download a Google Earth file that includes CIMIS ETo Zones for the California almond growing region. Table 1 lists historical biweekly ETo values and ETc almond crop water use derived from Kc values for the four climatic zones where almonds are grown in California (Fig. 3).

Biweekly crop water use estimates more accurately describe the variability in ETo over the month than do the monthly estimates. In the months leading up to the ETo peak in July during the first two weeks of the month, ETo values are lower than the monthly average and the last two weeks are higher than the monthly average. After the ETo peak in August, the opposite is true. These biweekly almond crop water use values are applicable to a mature almond orchard that has 70% or more of the orchard floor shaded at midday during the middle of the growing season, no middle cover, and no water stress.

		Zone 12[4]		Zone 14[5]		Zone 15[6]		Zone 16[7]	
	Kc[3]	**ETo**	**ETc**	**ETo**	**ETc**	**ETo**	**ETc**	**ETo**	**ETc**
Jan 1-15	0.40	0.54	0.22	0.74	0.29	0.56	0.23	0.72	0.29
Jan 16-31	0.40	0.74	0.30	0.87	0.35	0.76	0.30	0.92	0.37
Feb 1-15	0.41	0.86	0.35	0.99	0.41	0.97	0.40	1.10	0.45
Feb 16-28	0.41	0.96	0.39	1.09	0.45	1.09	0.45	1.22	0.50
Mar 1-15	0.62	1.44	0.89	1.61	1.00	1.59	0.99	1.75	1.09
Mar 16-31	0.62	1.97	1.22	2.10	1.30	2.16	1.34	2.29	1.42
Apr 1-15	0.80	2.26	1.81	2.30	1.84	2.51	2.01	2.54	2.03
Apr 16-30	0.80	2.69	2.15	2.68	2.14	3.00	2.40	3.01	2.41
May 1-15	0.94	3.12	2.94	3.12	2.93	3.45	3.24	3.54	3.33
May 16-31	0.94	3.72	3.50	3.71	3.49	4.01	3.77	4.21	3.96
Jun 1-15	1.05	3.74	3.92	3.71	3.90	3.91	4.10	4.18	4.39
Jun 16-30	1.05	3.89	4.09	3.94	4.14	4.06	4.26	4.36	4.58
July 1-15	1.11	3.97	4.41	4.19	4.65	4.22	4.68	4.53	5.03
July 16-31	1.11	4.18	4.64	4.54	5.04	4.53	5.03	4.85	5.38
Aug 1-15	1.11	3.70	4.11	4.04	4.48	4.03	4.48	4.33	4.81
Aug 16-31	1.11	3.56	3.95	3.84	4.27	3.85	4.27	4.18	4.64
Sept 1-15	1.06	2.89	3.06	3.07	3.25	3.07	3.26	3.38	3.58
Sept 16-30	1.06	2.47	2.62	2.61	2.77	2.61	2.77	2.88	3.05
Oct 1-15	0.92	2.08	1.92	2.23	2.05	2.23	2.05	2.42	2.22
Oct 16-31	0.92	1.73	1.59	1.89	1.73	1.89	1.74	2.04	1.88
Nov 1-15	0.69	1.12	0.77	1.25	0.87	1.27	0.87	1.41	0.97
Nov 16-30	0.69	0.73	0.51	0.92	0.63	0.89	0.61	1.04	0.72
Dec 1-15	0.43	0.52	0.22	0.79	0.34	0.69	0.29	0.84	0.36
Dec 16-31	0.43	0.49	0.21	0.79	0.34	0.61	0.26	0.77	0.33
Totals (in.)									
Yearly			49.78		52.67		53.80		57.78
Crop season[8]			47.59		49.85		51.25		54.77
Non-crop season[9]			2.20		2.81		2.54		3.02

Notes:

[1] Normal year evapotranspiration of unstressed grass (reference crop, ETo) 30-year CIMIS average for the respective zone.

[2] Evapotranspiration rates for almonds were calculated by multiplying ETo by the crop coefficient.

[3] Almond crop coefficient.

[4] Zone 12 ETo rates from Chico, Fresno, Madera, Merced, Modesto and Visalia.

[5] Zone 14 ETo rates from Newman, Red Bluff and Woodland.

[6] Zone 15 ETo rates from Bakersfield, Los Banos and westside San Joaquin Valley.

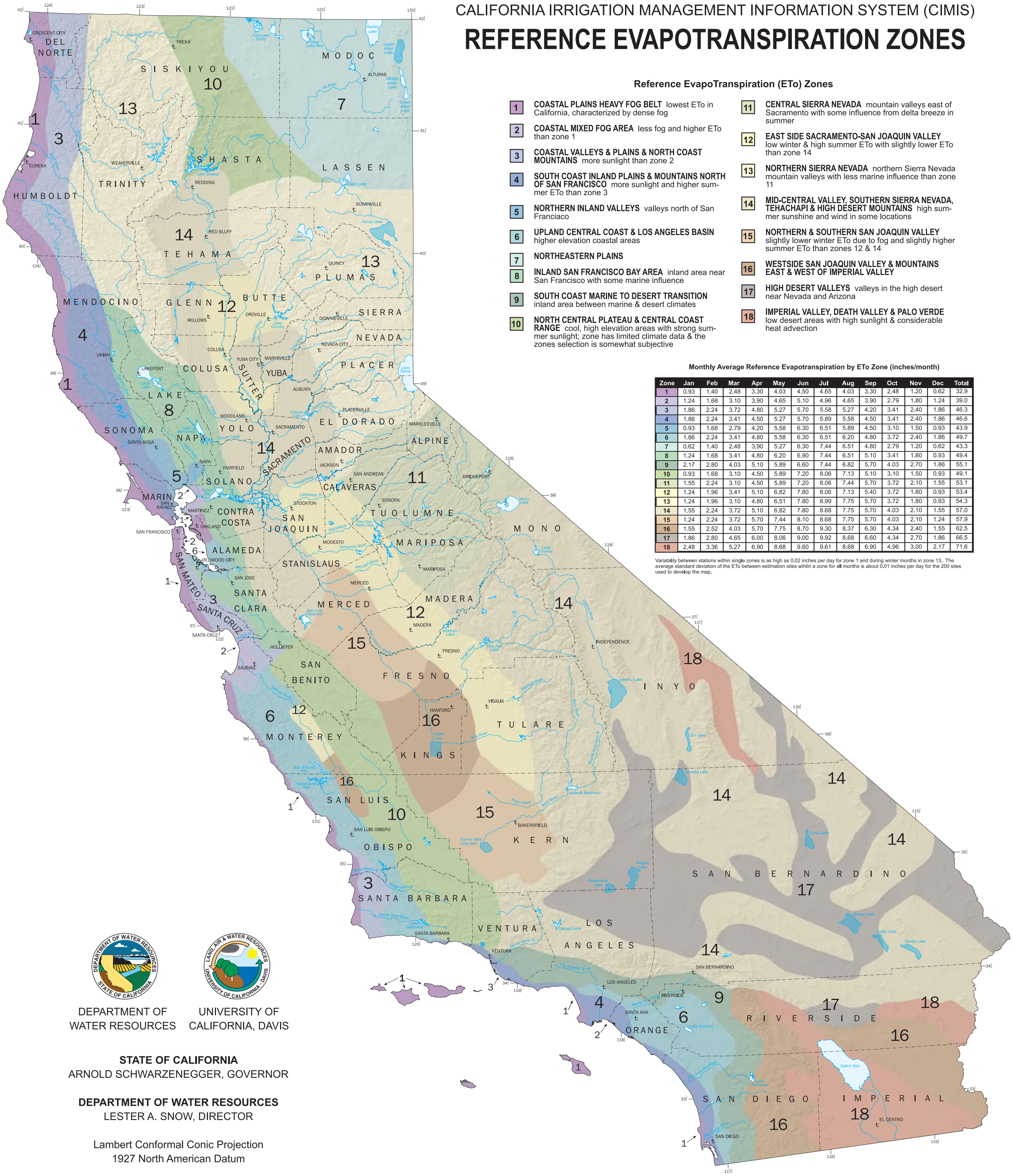
[7] Zone 16 ETo rates from Coalinga and Hanford.

[8] Crop season ETc rates for March to Nov 15.

[9] Noncrop season ETc rates for Jan, Feb, Nov 16–30 and Dec.

(Source: Adapted from Doll and Schackel 2015)

Table 1. Thirty-year average evapotranspiration reference rates (ETo)[1] and almonds (ETc)[2] for selected CIMIS zones in almond-producing areas of California.



CALIFORNIA IRRIGATION MANAGEMENT INFORMATION SYSTEM (CIMIS)

REFERENCE EVAPOTRANSPIRATION ZONES

Reference EvapoTranspiration (ETo) Zones

1. **COASTAL PLAINS HEAVY FOG BELT** lowest ETo in California, characterized by dense fog
2. **COASTAL MIXED FOG AREA** less fog and higher ETo than zone 1
3. **COASTAL VALLEYS & PLAINS & NORTH COAST MOUNTAINS** more sunlight than zone 2
4. **SOUTH COAST INLAND PLAINS & MOUNTAINS NORTH OF SAN FRANCISCO** more sunlight and higher summer ETo than zone 3
5. **NORTHERN INLAND VALLEYS** valleys north of San Franciaco
6. **UPLAND CENTRAL COAST & LOS ANGELES BASIN** higher elevation coastal areas
7. **NORTHEASTERN PLAINS**
8. **INLAND SAN FRANCISCO BAY AREA** inland area near San Francisco with some marine influence
9. **SOUTH COAST MARINE TO DESERT TRANSITION** inland area between marine & desert climates
10. **NORTH CENTRAL PLATEAU & CENTRAL COAST RANGE** cool, high elevation areas with strong summer sunlight; zone has limited climate data & the zones selection is somewhat subjective
11. **CENTRAL SIERRA NEVADA** mountain valleys east of Sacramento with some influence from delta breeze in summer
12. **EAST SIDE SACRAMENTO-SAN JOAQUIN VALLEY** low winter & high summer ETo with slightly lower ETo than zone 14
13. **NORTHERN SIERRA NEVADA** northern Sierra Nevada mountain valleys with less marine influence than zone 11
14. **MID-CENTRAL VALLEY, SOUTHERN SIERRA NEVADA, TEHACHAPI & HIGH DESERT MOUNTAINS** high summer sunshine and wind in some locations
15. **NORTHERN & SOUTHERN SAN JOAQUIN VALLEY** slightly lower winter ETo due to fog and slightly higher summer ETo than zones 12 & 14
16. **WESTSIDE SAN JOAQUIN VALLEY & MOUNTAINS EAST & WEST OF IMPERIAL VALLEY**
17. **HIGH DESERT VALLEYS** valleys in the high desert near Nevada and Arizona
18. **IMPERIAL VALLEY, DEATH VALLEY & PALO VERDE** low desert areas with high sunlight & considerable heat advection

Monthly Average Reference Evapotranspiration by ETo Zone (inches/month)

Zone	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1	0.93	1.40	2.48	3.30	4.03	4.50	4.65	4.03	3.30	2.48	1.20	0.62	32.9
2	1.24	1.68	3.10	3.90	4.65	5.10	4.96	4.65	3.90	2.79	1.80	1.24	39.0
3	1.86	2.24	3.72	4.80	5.27	5.70	5.58	5.27	4.20	3.41	2.40	1.86	46.3
4	1.86	2.24	3.41	4.50	5.27	5.70	5.89	5.58	4.50	3.41	2.40	1.86	46.6
5	0.93	1.68	2.79	4.20	5.58	6.30	6.51	5.89	4.50	3.10	1.50	0.93	43.9
6	1.86	2.24	3.41	4.80	5.58	6.30	6.51	6.20	4.80	3.72	2.40	1.86	49.7
7	0.62	1.40	2.48	3.90	5.27	6.30	7.44	6.51	4.80	2.79	1.20	0.62	43.3
8	1.24	1.68	3.41	4.80	6.20	6.90	7.44	6.51	5.10	3.41	1.80	0.93	49.4
9	2.17	2.80	4.03	5.10	5.89	6.60	7.44	6.82	5.70	4.03	2.70	1.86	55.1
10	0.93	1.68	3.10	4.50	5.89	7.20	8.06	7.13	5.10	3.10	1.50	0.93	49.1
11	1.55	2.24	3.10	4.50	5.89	7.20	8.06	7.44	5.70	3.72	2.10	1.55	53.1
12	1.24	1.96	3.41	5.10	6.82	7.80	8.06	7.13	5.40	3.72	1.80	0.93	53.4
13	1.24	1.96	3.10	4.80	6.51	7.80	8.99	7.75	5.70	3.72	1.80	0.93	54.3
14	1.55	2.24	3.72	5.10	6.82	7.80	8.68	7.75	5.70	4.03	2.10	1.55	57.0
15	1.24	2.24	3.72	5.70	7.44	8.10	8.68	7.75	5.70	4.03	2.10	1.24	57.9
16	1.55	2.52	4.03	5.70	7.75	8.70	9.30	8.37	6.30	4.34	2.40	1.55	62.5
17	1.86	2.80	4.65	6.00	8.06	9.00	9.92	8.68	6.60	4.34	2.70	1.86	66.5
18	2.48	3.36	5.27	6.90	8.68	9.60	9.61	8.68	6.90	4.96	3.00	2.17	71.6

Variability between stations within single zones is as high as 0.02 inches per day for zone 1 and during winter months in zone 13. The average standard deviation of the ETo between estimation sites wihtin a zone for all months is about 0.01 inches per day for the 200 sites used to develop the map.

DEPARTMENT OF WATER RESOURCES　　UNIVERSITY OF CALIFORNIA, DAVIS

STATE OF CALIFORNIA
ARNOLD SCHWARZENEGGER, GOVERNOR

DEPARTMENT OF WATER RESOURCES
LESTER A. SNOW, DIRECTOR

Lambert Conformal Conic Projection
1927 North American Datum

Figure 3. Reference evapotranspiration (ETo) zones in California. Most almonds are grown commercially in Zones 12, 14, 15 and 16. (Source: http://wwwcimis.water.ca.gov/Content/pdf/CimisRefEvapZones.pdf)

ACCOUNTING FOR COVER CROP WATER USE

A cover crop is a noneconomic crop that is grown in the tree row middles. Cover crops are classified based on the season of growth or species. Resident vegetation, or weeds, that is simply allowed to grow in the tree row middles can be managed like a cover crop. The water used by cover crops must be accounted for in determining the orchard water use. Orchards with cover crops in the row middles have higher evapotranspiration rates than orchards without them.[2]

Orchard middles are managed periodically by mowing, cultivation or herbicide application. Orchard managers may allow cover to grow in row middles at the beginning of the growing season, then remove it as harvest approaches. The orchard water requirement at the beginning of the irrigation season could be calculated using the following approach, but once the cover crops are removed or killed with herbicide, orchard managers should disregard this calculation.

The water-use rate of cover crops in orchards is difficult to measure and has not been thoroughly investigated. Water use by cover crops depends on the mowing or cultivation frequency, plant density, degree of shading by the tree canopies, and whether the cover crop has sufficient water available (whether it is fully wetted by irrigation applications). Estimates of increased water use due to the presence of cover crops are site specific.

Approximating the orchard water use increase due to cover crops depends mostly on the fraction of orchard ground surface occupied by the cover crop and the density of the cover crop (Figs. 4 and 5).

Figure 4. Almond orchard with fairly dense cover crop (top); almond orchard with fairly sparse cover crop (bottom). (Photos by T. Prichard)

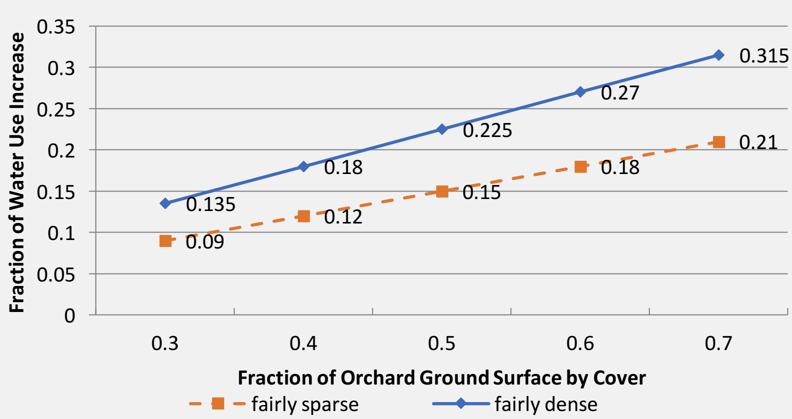


Figure 5. Fraction of orchard row covered by vegetation and the percentage of water use increase. Growers can use this chart to determine the additional water use of their orchard attributed to cover crops. (Source: Fereres et al 2012)

[2] Prichard, T., W. Sills, W. Asai, L. Hendreicks, and C. Elmore. 1989. Orchard Water Use and Soil Characteristics. California Agriculture 43(4): 23–25.

When a cover crop has water available and is green and growing, the increased water use varies from 10 to 30%. The approach to account for this increase during the time the cover is green and using water is as follows:[3]

Almond water use with middles cover =
Monthly water use ETc ÷ (1 – % water use increase)

EXAMPLE

Climate Zone 12: May 16–31 ETc = 3.50 inches
Full-coverage irrigation system
Cover crop is active but density is fairly sparse
Tree row spacing = 22 feet
Cover crop in middles = 15 feet wide
Fraction of orchard ground surface with middles cover = 15 feet ÷ 22 feet = 0.68 or 68%
Fraction of water use increase (from Fig. 5) = 0.20 or 20%

It would be necessary to provide 3.5 in ÷ (1 – 0.2) = 4.4 inches of water for that month to adequately provide water for the trees and the cover crop.

For irrigation systems that are not full coverage (drip and microsprinkler), use only the green growing area to determine the fraction of the orchard that has cover.

For young orchards or orchards with less than 30% canopy shaded area and cover crops in the middles, the best approach is frequent soil moisture monitoring in the tree root zone to ensure adequate moisture.

ADJUSTING FOR SMALL-CANOPY OR YOUNG ORCHARDS

The smaller canopy of a young orchard (Fig. 6) uses less water than an orchard with mature trees (canopy at or near 70% shaded ground surface at midday). Additionally, the small root zone may not access the entire area where the water is applied, making the use of ET estimation less accurate than for mature trees.

Three methods used for scheduling irrigations for young orchards will be discussed: ET estimation with a canopy size modification, soil-based monitoring, and plant-based monitoring.

Figure 6. Because young orchards do not have a full canopy, they use less water than mature orchards, and the irrigation amount must be adjusted to account for this. (Photo by T. Prichard)

[3] Fereres, E., D. Goldhamer, and V. Sadras. 2012. Yield Response to Water of Fruit Trees and Vines: Guidlines. In P. Steduto, T. Hsiao, E. Fereres, and D. Raes, eds., Crop Yield Response to Water. FAO Irrigation and Drainage Paper 66:246-295. FAO website, www.fao.org/nr/water/docs/irrigationdrainage66.pdf.

ET ESTIMATION

The evapotranspiration of young trees can be estimated by making in-orchard measurements of the shaded area at midday to determine the crop coefficient (Kc) then multiplying that Kc by the ETo just as in the method described for mature orchards. The percentage of ground shading can be estimated by visually examining the extent of the orchard floor shaded at midday or with the use of iPAR, an iPhone app created by Bruce Lampinen. Since the shaded area in young orchards increases over the season, the shaded area should be evaluated monthly. The shaded area is the percentage of the tree spacing that is shaded when measured at midday. For example, a tree spacing of 17 x 24 feet yields 408 square feet of growing area per tree. If the shaded area is measured at 163 square feet, the shaded floor area would be 40% of the tree spacing.

Studies relating the shaded area to tree ET have been conducted over the past 30 years using soil-based measurements of water use, and more recently using a more accurate measurement using a weighing lysimeter. The combined results of these studies are shown in Figure 7.[4,5,6,7,8] Evapotranspiration increases at a rate approximately 1.26 times the percent of ground shading. Current research is underway in almonds to measure shaded area and water use in a weighing lysimeter, which is much more accurate than the previously used soil-based water-use measuring methods. When results are available this relationship — if different — will be updated.

For convenience the relationship presented in Figure 7 is shown in tabular form in Table 2 for each 10% increase in shaded area.

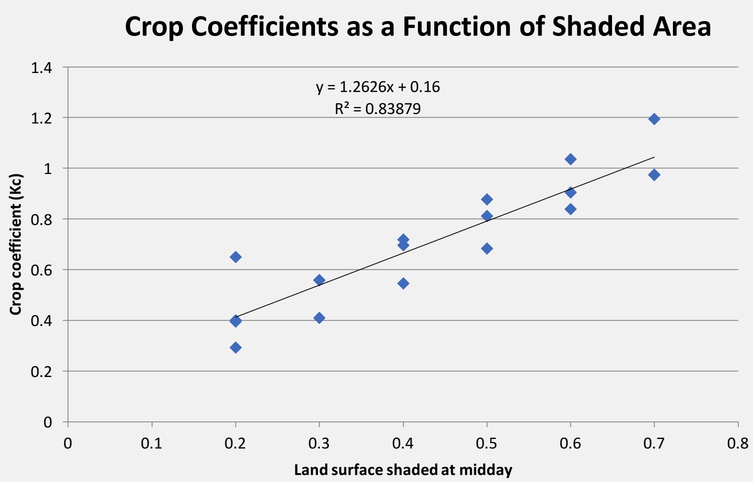


Figure 7. Relationship between the percentage of ground shading and crop coefficient (Kc).

% Shaded area	Crop Coefficient
20	41
30	54
40	67
55	79
60	92
70	100

Table 2. Growers can use this table to determine from the percent of midday ground shading in their orchard to estimate the crop coefficient of less than full canopy orchards.

[4] E. Fereres, D. Martinich, T. Aldrich, J. Castel, E. Holzapfel, and H. Schulbach.1982. Drip Irrigation Saves Money in Young Almond Orchards. California Agriculture 36:12–13.

[5] E. Fereres, D. Goldhamer, and V. Sadras. 2012. Yield Response to Water of Fruit Trees and Vines: Guidelines. In P. Steduto, T. Hsiao, E. Fereres, and D. Raes, eds., Crop Yield Response to Water. FAO Irrigation and Drainage Paper 66:246-295. FAO website, www. Rome: FAO. fao.org/nr/water/docs/irrigationdrainage66.pdf.

[6] Ayars, J.E., Johnson, R.S., Phene, C.J. et al. Irrig Sci (2003) 22: 187. https://doi.org/10.1007/s00271-003-0084-4.

[7] Lampinen, B., personal communication 2017.

[8] Shackel, K., personal communication 2017.

Use the following formula to adjust mature crop water use to that of a young orchard:

Young orchard water use (ETc) =
Biweekly (ETo) x crop coefficient (based on shaded area) = ETc (Fig. 7 or Table 2)

EXAMPLE

Zone 12 May 15–31 ETc = 3.50 inches without middles cover
Young orchard ground surface shading at midday = 0.40 or 40%
Crop coefficient at 40% shading = 0.67 (Fig. 7 or Table 2)
3.50 in. x 0.67 = 2.35 inches for the 40% coverage orchard

This method of using the percent of shading to determine the crop coefficient and ultimately water use is not recommended until the canopy reaches at least 30% shaded area when the roots will have expanded to most of the area where the irrigation water is applied.

Under-irrigation can occur if the calculated water is applied, but the root zone is not large enough to access the applied water. This is especially true when using irrigation systems which apply to the entire orchard surface (e.g., by solid-set sprinklers or surface irrigation) and the tree roots occupy only a small portion of the area, most of the applied water will not be accessible by the orchard, and the orchard may be under-irrigated. Irrigation systems which target the irrigation application to the root zone of the young tree are more likely to be successful in using this method. An additional consideration when using this method for estimating the water required for young trees is that as the root system expands into areas of the soil containing winter stored water, water required by irrigation will be reduced and should be accounted for when using this method. Frequent soil moisture or plant-based monitoring are more reliable methods to ensure adequate irrigation in an orchard with less than 30% shaded area.

Soil-Based Monitoring

Soil moisture monitoring devices can be used to maintain optimal moisture conditions in the young trees' root zone. The selection, placement and guidelines for use of these devices are discussed in the section "Soil Moisture."

Plant-Based Monitoring

Plant-based monitoring most commonly uses the measurement of stem water potential to assess plant water stress. These measurements, made with a pressure chamber, can be used to schedule irrigations as described in the section "Measuring Plant Water Status."

Irrigation systems that direct all of the irrigation water to the root zone, such as drip, can work well for the orchards with lower amounts of shaded area.

ADJUSTING WATER USE FOR OTHER ORCHARD WATER REQUIREMENTS

In addition to the topics on orchard water covered in the previous sections, a variety of factors can impact the actual water requirement of an orchard. These include the additional water needed to address factors such as salinity and irrigation system nonuniformity, or reductions in water use due to factors such as disease management and inadequate water supplies.

IRRIGATION SYSTEM NONUNIFORMITY

In addition to orchard water use described and calculated in the previous sections, other factors can impact the actual water requirement of an orchard. One of these is increasing the orchard irrigation amount to overcome irrigation system nonuniformity. System uniformity is determined by measuring the distribution uniformity (DU) of the orchard irrigation system. This discussion focuses on three issues:

- How the distribution of water throughout the orchard is related through the measurement of DU;
- Whether the measured distribution should be used as a modifier to increase the average irrigation application to ensure that less of the orchard is under-irrigated while over-irrigating a greater portion of the orchard; and
- The effect of over- or under-irrigation on orchard production and longevity.

Distribution Uniformity

The amount of over- or under-irrigation in an orchard depends on the distribution uniformity of the irrigation application, which is affected by pressure variations in the system, emitter clogging, slope and other factors. As described in the section "Irrigation System Performance" in *Continuum Level 2.0*, it is essential to evaluate your irrigation system for pressure or discharge differential and then estimate the distribution uniformity. If your system has low distribution uniformity, determine the causes and solutions to prevent over- and under-irrigation.

- **High DU Example:** High DU Example: Using the example of an average irrigation application of 1.0 inch and a measured DU of 90% (Fig. 8), the average area of the orchard (the 1/2 point on the graph) receives 1.0 inch (100%) of the target application. At the 1/8 points of the graph, the area of the orchard receiving the least water gets about 12% less water than the average, and the area receiving the most water gets about 12% more than the average.
- **Low DU Example:** Using the example of an average irrigation application of 1.0 inch and a measured DU of 75% (Fig. 8), the average area of the orchard receives 1.0 inch (100%) of the target application. At the 1/8 points on the graph, the orchard receiving the least water gets 30% less than the average (0.7 inch), and the area receiving the most water gets about 30% (1.3 inches) more than the average, which is almost double the drier 1/8 area.

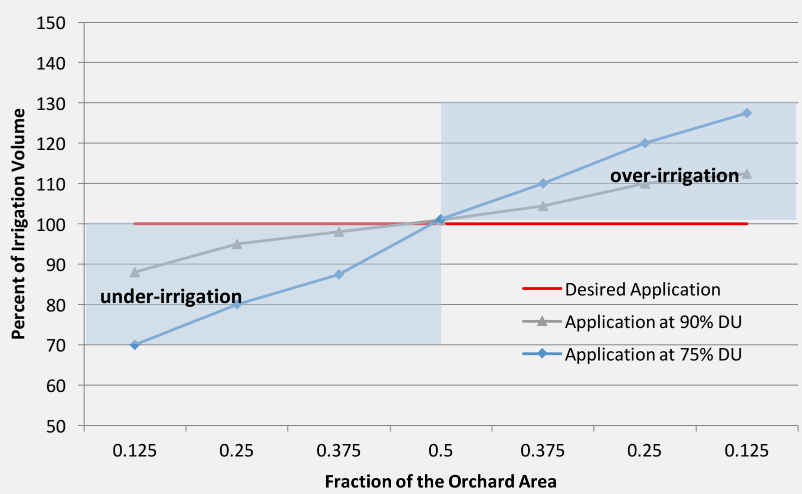


Figure 8. Irrigation distribution across an orchard measured 90 and 75% DU.

Using Distribution Uniformity to Adjust Water Application

It is possible to use distribution uniformity to adjust the water application by applying more water to ensure that most of the orchard receives the planned amount of water. The procedure is as follows:

$$\frac{\text{Orchard Irrigation Water Application}}{\text{Distribution Uniformity (DU)}} = \text{Applied Water Application considering DU}$$

- **High DU Example:** An average irrigation application of 1.0 inch at a distribution uniformity of 90% requires 1.11 inches of applied water. This is an 11% increase over the 1.0 inch of water applied if the DU were not a factor and assures that only 12.5% of the orchard will have less than the target application. However, that 11% is an increase in the average applied, since the distribution of the water is not changed. The 1/8 area of the orchard receiving the least water gets about 3% less than the 1.0 inch target. On the other end of the spectrum, the 1/8 area receiving the most water gets about 24% more than the 1.0 inch target (Fig. 9).
- **Low DU Example:** A 1.0 inch average irrigation application at a DU of 75% requires 1.33 inches of water. This is a 33% increase over the 1.0 inch if DU were not a factor (Fig. 10). However, that 33% is an increase in the average since the distribution of the water is not changed. The 1/8 area of the orchard receiving the least water gets about 7% less than the 1.0 inch target. On the other end of the spectrum, the 1/8 area receiving the most water gets about 69% more than the 1.0 inch target.

It is a simple fact that increasing the amount of water applied to overcome poor distribution uniformity to assure that less of the orchard is under-irrigated comes at the expense of overwatering the bulk of the orchard, which can lead to fertilizer leaching, disease, tree loss and inefficient use of water.

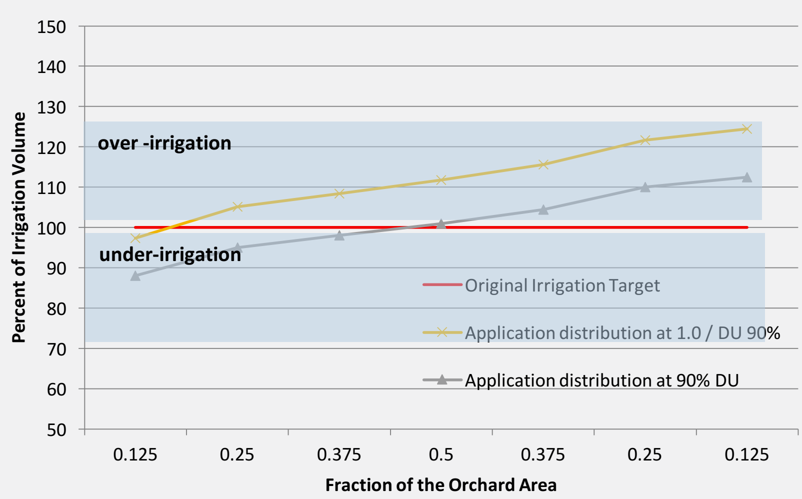


Figure 9. Irrigation distribution across the orchard measured at 90% DU and DU at 1.0 inch application divided by 90% DU.

Effect on Orchard Production and Longevity

When using the DU as a modifier, the amount of water going to the lowest-application areas of the orchard approaches the target average application, but the water applied in over-irrigated areas increases — in the case of 75% DU, up to 69% more water than desired (Fig. 10).

This over-irrigation can cause production losses and reduce orchard longevity. In contrast, if more water is not added to compensate for poor DU, some of the orchard will be under-irrigated. The solution lies in improving DU to a point where there is minimal difference in the over- and under-irrigation levels in the orchard. A DU of about 90% is probably optimal, as research has shown that trees are able to produce optimally with about 90% of full irrigation.[9] Orchards with lower DU should be analyzed to determine the problem and solutions implemented to improve DU.

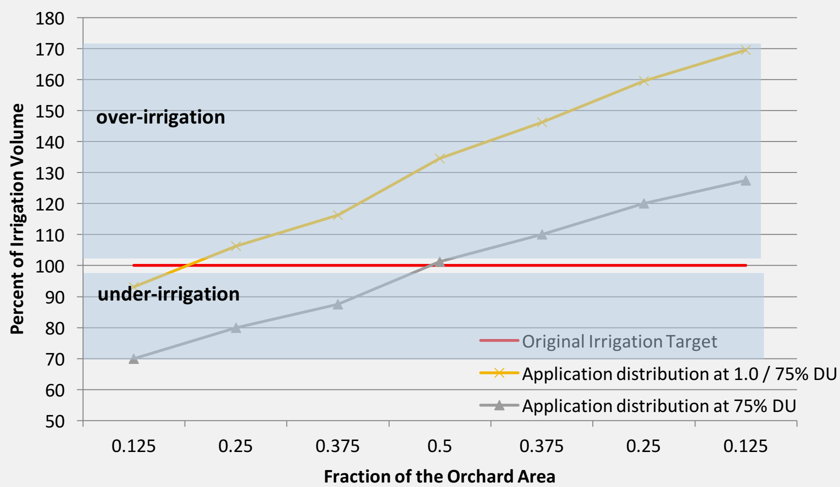


Figure 10. Irrigation distribution across the orchard measured at 75% DU and DU at 1.0 inch application divided by 75% DU.

IRRIGATION WATER AND SOIL SALINITY

This section describes the effects of irrigating almonds with waters that contain salts, how they build up in the root zone, and how the irrigation schedule may be altered to reduce soil salinity caused by irrigation waters. It is not meant to be a discussion on salt leaching or soil reclamation methodology.

All irrigation water contains dissolved mineral salts, but the concentration and composition of the salts depend on the specific water source. Over time, salts can build up in the root zone and can reduce orchard production if not removed by leaching. Salt buildup poses two distinct hazards to almond orchards in the root zone: the total salt content and the toxic effect of specific salts such as sodium, chloride and boron.

Excess total salinity from concentrating salts in the crop root zone creates an osmotic stress, which reduces crop growth. The most common positively charged ions, or cations, are calcium, magnesium and sodium, while the most common negatively charged ions or anions, are chloride, sulfate and bicarbonate. To overcome increased osmotic stress, plants must expend more energy to absorb water from the saline soil, leaving less energy for plant growth. The more saline the irrigation water, the faster salts build up in the soil, potentially reaching a level that reduces production.

Higher irrigation water salinity requires applying more water than required by normal orchard water use or using rainfall to leach salts below the root zone and maintain production. In areas where irrigation water salinity levels are low or rainfall is high, rainfall may be all that is needed to maintain an acceptable level of salts in the root zone. When salts in irrigation water are higher and coupled with lower rainfall, the irrigation amounts may need to be increased to ensure adequate salt leaching. Additionally, in orchards with poor irrigation distribution uniformity, some areas of the orchard may receive enough water to leach salts, while 50% of the orchard gets less than the average amount of water, causing less or no leaching.

The salinity of the water used for irrigation and the salinity of the saturated soil extract is reported as electrical conductivity (EC) in units of decisiemens per meter (dS/m) (which is the same as the older unit, millimho per centimeter, or mmho/cm). The maximum soil salinity that does not reduce yield below that obtained under nonsaline conditions is

[9] Shackel, K. et.al. 2017 ABC Water Production Function Report.

known as the salinity threshold. For almonds, this is an average root zone salinity 1.5 dS/m. Irrigation water salinity concentrates over time by a factor of 1.5 in the soil when about 15% of the applied water passes through the root zone as deep percolation. Therefore under these conditions, a water salinity of 1.0 dS/m concentrates to 1.5 dS/m as the average root zone salinity.

Figure 11 illustrates the yield response of almonds to increasing salinity of the irrigation water using this 1.5 concentration factor.[10] Note that yield is not reduced until the threshold salinity is reached.

To maintain a favorable salt balance, deep percolation of water is needed to transport the salt introduced by the irrigation water out of the root zone. The amount of deep percolation required is referred to as the leaching requirement (LR), and it depends on irrigation water quality, as well as the crop sensitivity to salinity, which can vary by rootstock and variety. LR is expressed as a percentage of the applied irrigation water.[10] The leaching requirement is the minimum leaching to prevent yield loss; another common term, “leaching fraction,” is the fraction or percentage of water applied to the orchard that actually drains below the root zone.

As the concentration of the salts in the water increases, more salinity is transported into the orchard, and more leaching is required to leach salts below the root zone.

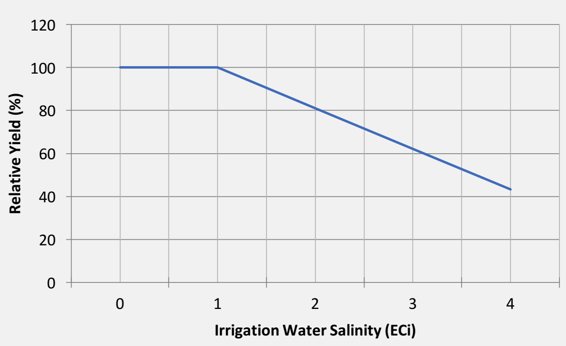


*Figure 11. Relative almond yield (percent) as a function of **irrigation water salinity** (dS/m) assuming a 15% leaching fraction, as defined in Maas and Hoffman 1977.*[11]

Irrigation water electrical conductivity (dS/m)	Leaching requirement % to maintain root zone salinity at 1.5dS/m
0.25	3
0.50	7
0.75	11
1.00	15
1.20	19
1.50	30

Table 3. Leaching fraction required to maintain average root zone salinity at the threshold with increasing salinity in the irrigation water.

Table 3 gives the leaching requirement expressed as the percentage of crop water use necessary to maintain the average salt concentration in the root zone at the salinity threshold at various irrigation water salinities. The purpose of these leaching requirements is to understand the long-term effect of the salinity buildup in the soil, and the amount of water required to maintain a favorable salt content in the soil to prevent crop loss. In soils of high permeability, employing these leaching fractions can effectively reduce average root zone salinity, especially if beginning the season at or near the soil salinity threshold. Experience has shown in-season leaching practices on heavier or poor water infiltration soils to be difficult to achieve — especially when combined with hullsplit deficit irrigation. Often times, more damage is done to the trees due to soil water-logging and subsequent root death with minimal reduction in root zone salts. In this case off-season leaching is recommended.

In addition to the effect of salinity on the orchard, elements such as sodium (Na), chloride (Cl) and boron (B) can build up in the root zone and be taken up by the tree to a toxic level, burning the leaves and reducing photosynthesis. Because there are differences in tolerance to these elements among rootstocks and varieties, tissue analysis is the best indicator of the toxic element hazard. Boron and sodium can be leached — just as with total salts — but are more difficult to remove than the other salts.

[10] R. S. Ayers and D. W. Westcot. 1985. Water Quality for Agriculture. FAO Irrigation and Drainage Paper no. 29. Rev 1. Rome: FAO. http://www.calwater.ca.gov/Admin_Record/C-110101.pdf.

[11] Maas, E. V., and G. J. Hoffman. 1977. Crop Salt Tolerance: Current Assessment. Journal of the Irrigation and Drainage Division, ASCE 103 (IR2): 115–134.

LEACHING MANAGEMENT CONSIDERATIONS

- Leaching may not be needed every season.
  - Soil testing will help determine when leaching is necessary or how much is needed.
- Rainfall may adequately reduce salts when it fills the root zone to field capacity and then provides the leaching water requirement.
  - In areas of lower rainfall, early-fall dormant irrigation can recharge the root zone and reduce the rainfall amount required to meet the leaching requirement.
- To the extent possible, time irrigations to leach salinity during fallow or dormant periods. This will avoid critical periods of crop growth and development when nitrogen uptake and fertilization should not be occurring.
- If the root zone starts the season at the salinity threshold, in-season leaching will be necessary to prevent yield loss.
- Poor irrigation distribution uniformity, if used to increase the average application of irrigation water, may achieve the leaching requirement in some parts of the orchard.
  - If a DU of 75% is used, 63% of the orchard would meet or exceed the leaching requirement, while 37% of the orchard would not.
  - If a DU of 90% is used, about half of the orchard would meet or exceed the leaching requirement, while the other half would not.
- The use of partial-coverage irrigation systems — drip and microirrigation — results in different salt buildup patterns than with full-coverage systems like surface irrigation and full-coverage sprinklers. Typically, the salts build up on the edge of the wetted zone. Leaching with the irrigation system is not as effective as with traditional surface-applied full-coverage systems. Irrigate to fill the root zone near the end of the season to leverage effective rainfall. This practice tends to keep accumulated salts moving away from rather than into the root zone.

Determine the applied water required to leach salts from orchards without adequate rainfall using the formula and required information below:

$$\text{Applied Water} = \frac{\text{ETc}}{1 - \text{LR}}$$

1. Determine the crop water use (ETc) for the orchard with information in the section “Calculating Orchard Water Use.”
2. Select the leaching fraction (LR) from Table 3 based on the irrigation water salinity.
3. Using the following example or your own data, calculate the amount of water required to adequately irrigate the orchard and leach salts.

EXAMPLE

Example: ETc = 47.5 in

EC irrigation water = 1.0 dS/m

LR = 0.15 or 15% (from Table 3)

Applied water = 47.5÷(1–0.15) = 55.9 in

IRRIGATION WITH INADEQUATE WATER SUPPLIES

Deficit irrigation is the practice of supplying less water to the orchard than what is required to meet full crop (ETc) water use. Recently, this practice has been employed by growers during the drought, when not enough water was available to meet the needs of the orchard.

Water deficits occur when a tree's water demand exceeds the amount of water available in the soil. These deficits increase water tension within the plant; when this stress is high enough, it negatively affects many plant processes. Unless severe water supply issues are present, deficit irrigation should not be practiced on young orchards because it delays orchards from coming into production.

Deficit irrigation can be done in developed orchards at a proportional deficit at some percentage of full water use across the entire season, or at specific growth or nut development stages.[12] The method and or timing are usually directed at solving a water supply problem or a specific disease issue, as described in the section "Irrigation and Hull Rot Disease Management," below.

Since deficit irrigation programs are designed to provide a percentage of full water use, accounting for the deficit is straightforward. For example, if conditions dictate that a grower will receive 30% less water than they normally receive (70% of full irrigation), the following formula would apply:

$$\text{ETc under deficit irrigation} = \text{ETc under full irrigation} \times 0.7$$

For specific deficit irrigation strategies and their impact on almond growth and yield, see UC ANR Publication 8515, Drought Management for California Almonds.[13]

IRRIGATION AND HULL ROT DISEASE MANAGEMENT

Hull rot is an infection of almond hulls caused by *Rhizopus stolinifer* or *Monilinia fructicola*. Upon infection, pathogens release toxins that are translocated into the fruiting wood, which kills the wood and causes crop loss. Research conducted from 1990–2000 has shown that incidence of this disease can be reduced with balanced nitrogen applications and hullsplit deficit irrigation from post-kernel fill through 90% hullsplit.[14] This phase of nut development corresponds to the first sign of hullsplit and extends about three weeks into hullsplit depending on the season. The actual calendar dates are dependent on the almond variety and the weather patterns for the specific season. Properly timed and applied irrigation deficit can reduce hull rot by 80 to 90%. Throughout the duration of the study, the application of this practice did not affect yield or kernel size.

Typically, a 10 to 20% reduction in applied water will be needed, but because this depends on the orchard's soil and irrigation system, it must be determined on an orchard-by-orchard basis.[13] To effectively implement this technique, a pressure chamber is used to schedule the irrigations from post-kernel fill through 90% hullsplit. The use of the pressure chamber is described in the section "Plant Water Status." Beginning at the onset of hullsplit, irrigation should occur when the average stem water potential is usually between –14 and –18 bars, depending on the weather. After 90% hullsplit, full irrigation should resume until the harvest dry-down period. On deep soils in the northern part of the state, deficit irrigation might have to be started weeks early in order to reach the desired stress level during hullsplit.

More information on implementing hullsplit deficit irrigation can be found in the UC ANR publication 8515, Drought Management for California Almonds,[13] which discusses implementation, considerations and trade-offs associated with deficit irrigation in almonds.

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[12] D. Goldhamer and J. Girona. 2012. Almond. In P. Steduto, T. Hsiao, E. Fereres, and D. Raes, eds., Crop Yield Response to Water. FAO Irrigation and Drainage Paper 66:358-373. FAO website, www.fao.org/nr/water/docs/irrigationdrainage66.pdf.

[13] D. Doll and K. Shackel. 2015. Drought Tips: Drought Management for California Almonds. Oakland: University of California Agriculture and Natural Resources Publication 8515. UC ANR catalog website, http://anrcatalog.ucanr.edu/Details.aspx?itemNo=8515.

[14] B. Teviotdale, D. Goldhamer, and M. Viveros. 2001. The Effects of Deficit Irrigation on Hull Rot of Almond Trees Caused by *Monilinia fructicola* and *Rhizopus stolonifer*. Plant Disease 85(4): 399-403. ASP Journals website, http://apsjournals.apsnet.org/doi/abs/10.1094/PDIS.2001.85.4.399.

MEETING THE ORCHARD WATER REQUIREMENT

The orchard water requirement is met by the available soil moisture stored in the root zone at the beginning of the season plus in-season rainfall stored in the soil (including frost protection water applications if stored in the root zone), and applied irrigation water.

In-season rainfall that enters the root zone for orchard use tends to occur in the first few months of the season, and stored soil moisture is at a maximum at the beginning of the season. It is not uncommon for in-season effective rainfall and stored soil moisture to meet the entire crop water use in the first month and from 15 to 35% on a seasonal basis. The remainder of the orchard water requirement must come from irrigation.

ESTIMATING IN-SEASON EFFECTIVE RAINFALL

For areas likely to experience significant rainfall during the season, the following method is suggested to estimate the effective rainfall in a given rainfall event. A rainfall event can be a single day or multiple sequential days of rainfall. It utilizes your rainfall data and the daily ETo from a nearby CIMIS station. CIMIS data can be obtained from the California Irrigation Management Information System (CIMIS) website, http://www.cimis.water.ca.gov/.

Effective Rainfall (inches) =
(Rainfall (inches) from event – 3 days of ETo (inches) after the event) x 0.75

Example 1

Merced CIMIS Station 148, April 8–10, 2016: 2.65 inches of rain. ETo April 11-13, 0.5 inches

Effective Rainfall (inches) = (2.65 – 0.5) x 0.75 = 1.7 inches

Example 2

Shafter CIMIS Station 5, April 7–10, 2016: 1.01 inches of rain. ETo April 11-13, 0.41 inches

Effective Rainfall (inches) = (1.01 – 0.41) x 0.75 = 0.7 inches

ESTIMATING SOIL-STORED WINTER RAINFALL

Winter rain can help meet part of the water use of orchards because rainwater can infiltrate the soil and remains as stored soil-water until the following growing season. The estimation of soil-stored winter rainfall is a two-step process. First, the amount of rainfall is reduced by some evaporative losses; this final quantity is known as effective rainfall. Secondly, the soil must have the capacity to store the effective rainfall within the root zone of the crop. Effective rainfall in excess of the root zone capacity is lost to deep percolation and is not available to the orchard.

EFFECTIVE RAINFALL

Relatively involved techniques have been developed to account for winter rains stored in the soil when determining crop evapotranspiration (ETc).[15] However, a simple but practical method exists that works well for California almond-growing areas. It relies on the use of monthly total rainfall and ETc during the crop nongrowing season (Table 1). For almond the non-growing season is from Nov. 15 (approximate leaf-drop date) through the month of February. Effective rainfall was calculated based on these relationships using average year monthly rainfall totals for six valley locations (Table 4).

This table provides a good starting point for planning an irrigation schedule; however, actual winter rainfall data will provide a better estimate.

ET Zone	12			15			12			14			12			12		
	Arbuckle			**Bakersfield**			**Chico**			**Dixon**			**Fresno**			**Merced**		
	Rain	ETc	Effective Rainfall	Rain	ETc	Effective Rainfall	Rain	ETc	Effective Rainfall	Rain	ETc	Effective Rainfall	Rain	ETc	Effective Rainfall	Rain	ETc	Effective Rainfall
	Inches																	
Nov 16-30	1.07	0.51	0.56	0.32	0.60	0.00	1.64	0.51	1.13	1.47	0.63	0.84	0.59	0.51	0.08	0.67	0.51	0.16
Dec	2.99	0.43	2.56	1.02	0.50	0.53	4.61	0.43	4.18	4.75	0.61	4.11	2.01	0.43	1.58	2.09	0.43	1.66
Jan	3.91	0.52	3.39	1.14	0.60	0.52	4.84	0.52	4.32	4.82	0.64	4.18	2.28	0.52	1.76	2.60	0.52	2.08
Feb	3.00	0.74	2.26	1.22	0.90	0.37	4.41	0.74	3.67	4.76	0.86	3.90	2.01	0.74	1.27	2.36	0.74	1.62
Total			8.77			1.42			13.30			13.03			4.69			5.52

Table 4. Average rainfall and effective rainfall for seven Central Valley locations. (Source: usclimatedata.com)

Determining the soil moisture stored in the tree's root zone is important information for good irrigation water management. Stored soil moisture serves as a bank account of water available for the orchard. As the trees "withdraw" water from the stored soil moisture bank account, irrigation "deposits" must be made throughout the growing season to maintain available water in the account. Maintaining available water in the root zone provides the orchard with a cushion in case of under-irrigation due to management miscalculations, equipment failure or other factors that affect the availability of water.

Growers should evaluate soil moisture by monitoring on a frequent basis to inform irrigation management decisions. Stored soil moisture is accessed by the tree's roots and is withdrawn to satisfy the tree water needs; this should be accounted for in irrigation decision making. Refer to the section "Soil Moisture."

[15] R. G. Allen, J. L. Wright, W. O. Pruitt, L. S. Pereira, and M. E. Jensen. 2007. Water Requirements. Chapter 8 in G. J. Hoffman,, R. G. Evans, M. E. Jensen, D. L. Martin, and R. L. Elliott, eds., Design and Operation of Farm Irrigation Systems. 2nd ed. St. Joseph, MI: American Society of Biological and Agricultural Engineering.

ROOT ZONE WATER-HOLDING CAPACITY

Controlling factors of root zone water-holding capacity include soil texture and structure, depth of root zone, and root extensiveness.

Use the information presented in the section "Soil Moisture" to determine the extent of the root zone and its estimated water-holding capacity. Then compare the effective rainfall with the root zone capacity. The amount of stored moisture cannot exceed the maximum root zone capacity, regardless of the amount of effective rainfall.

Table 5 shows the plant-available water held by soils of different texture when fully wet or field capacity. Plant-available water is the amount of water stored in the soil that plants can take up. It is the difference in soil water content between field capacity and the permanent wilting point. Since some water is held so tightly by the soil that plants cannot take it up, available water content is less than the total amount of water held in soil.

Soil texture	**Plant-available water-holding capacity** (in. of water per ft. of soil)
Very coarse sand	0.40 – 0.75
Coarse sand, fine sand, loamy sand	0.75 – 1.25
Sandy loam, fine sandy loam	1.25 – 1.75
Very fine sandy loam, loam, silt loam	1.50 – 2.30
Clay loam, silty clay loam, sandy clay loam	1.75 – 2.50
Sandy clay, silty clay, clay	1.60 – 2.50

Table 5. Plant-available water-holding capacities of various textured soil.[16] (Source: Adapted from Schwankl and Prichard. 2009)

ESTIMATING SOIL-STORED WINTER RAINFALL EXAMPLE

Location and Conditions

Merced, California: Mature trees; loam soil; solid-set sprinkler irrigation; root zone depth 4 feet

Plant-available water-holding capacity = 2.0 inches of water per foot (from Table 5)

Root zone plant-available water-holding capacity:

Root zone depth = 4 feet x 2.0 inches water = 8.0 inches plant-available water

Effective nongrowing season rainfall: Merced, average year 5.5 inches (from Table 4)

Estimating Root Zone Water-Holding Amount

Since the average effective rainfall does not exceed the estimated root zone water-holding capacity of 5.5 inches, use 5.5 inches as the estimated root zone water-holding amount.

If a postharvest irrigation was applied, the unused portion can be added to the effective rainfall. Additionally, irrigation water applied in the off-season and water applied for frost protection can also be a source of stored soil moisture and can be added to the root zone water amount if the root zone's capacity is not exceeded.

[16] Schwankl, L. J., and T. L. Prichard. 2009. University of California Drought Management website. http://UCManageDrought.ucdavis.edu.

USING IN-SEASON EFFECTIVE RAINFALL AND SOIL STORAGE IN AN IRRIGATION SCHEDULE

Effective in-season rainfall and stored soil moisture can be a significant source of water that should be accounted for in an irrigation schedule. In almond-growing regions of the northern San Joaquin Valley and the Sacramento Valley, where rainfall is higher, effective rainfall can commonly contribute from 10 to 35% of the seasonal crop water use, depending on orchard soil and root characteristics. Simple steps to account for the effectiveness of rainfall and soil storage to partially supply the crop water use are outlined below.

The procedure begins with calculating the orchard water use as modified by the factors such as any necessary leaching fraction, as discussed in the above sections.

Once the orchard water requirement is determined, account for the contribution from in-season effective rainfall and stored moisture, both of which reduce the irrigation amount.

In-Season Effective Rainfall

In the Merced example above, a single rainfall event was used to illustrate the method of calculation. For the year 2016 three significant rainfall events occurred from March through April. Using the same calculation method described above then adding them together, this period supplied 4.3 inches in-season effective rainfall.

Stored Soil Moisture from Winter Rainfall

Continuing with the Merced example, the nongrowing season of Nov. 15 through Feb. 29, 2016, had 6.7 inches of effective rainfall (Table 6), which does not exceed the root zone capacity of 8.0 inches. So we will use the 6.7 inches for our stored moisture content.

About 50% of the plant-available water stored in the root zone can be used before tree stress begins. It is good practice to maintain the soil moisture no lower than that level to avoid plant water stress, especially early and in midseason, during tree growth and nut sizing. If water stress is desired for hullsplit and disease management later during the season, the soil moisture level must be kept below this level and best determined using the pressure chamber. In our example, 6.7 inches of effective rainfall would be reduced by half, to 3.3 inches. If used over a three-month period, the amount would be about 1.1 inches per month.

Table 7 shows the accounting for effective rainfall and soil-stored moisture based on our example conditions above in determining the irrigation schedule.

	Rain	ETc	Effective Rainfall
	Inches		
Nov 15-31	0.45	0.45	0.00
Dec	2.39	0.48	1.91
Jan	5.26	0.49	4.77
Feb	0.44	1.54	0.00
Total			6.68

Table 6. Effective rainfall Merced CIMIS Station 148, 2015-16 nongrowing season.

	Zone 12 Merced 2016			
	ETc	Effective rainfall	Stored moisture	Irrigation application
	(in)	(in)	(in)	(in)
March	2.1	2.7	0.0	
April	4.1	1.6	1.1	1.4
May	6.4	0.0	1.1	5.3
June	8.2	0.0	1.1	7.1
July	8.9	0.0		8.9
August	7.9	0.0		7.9
September	5.7	0.0		5.7
October	3.4	0.0		3.4
Nov 1–15	0.6	0.0		0.6
Season	**47.4**	**4.3**	**3.3**	**40.4**
Mar-June	*20.8*			*13.8*

Table 7. Accounting for in-season rainfall and stored moisture using 2016 Merced conditions and Zone 12 monthly orchard water requirements.

In our Merced example, the irrigation water application was reduced by 36% from March through June, or by 16% on a seasonal basis. Rainfall varies between different almond-growing regions of the Central Valley, and the amount of the rainfall contribution can be more or less than this example.

Determine the difference between the estimated crop water use and the effective rainfall and available soil storage:

Estimated orchard water requirement – Effective rainfall – Available moisture = Irrigation application

This is the estimated amount of water that will need to be allocated throughout the growing season using timely, efficient irrigation.

NEXT STEPS

Once the estimated orchard water requirements of a specific orchard have been determined, use the irrigation system application rate to determine the appropriate irrigation system operation time. "Irrigation System Performance" provides guidance to measure the system application rate and distribution performance.

MOVING UP THE CONTINUUM

"Orchard Water Requirements" practices in *Level 2.0* rely on biweekly estimates of orchard water use to develop an irrigation schedule. "Orchard Water Requirements" in *Continuum Level 3.0* maintains the same time basis but adds a method to account for the biweekly over- and under-estimation of ET and irrigation applications, using real-time ET.

DETERMINING AND MEETING ORCHARD WATER REQUIREMENTS

"Orchard Water Requirements" in *Continuum Level 3.0* maintains the same time basis for estimating orchard water use and irrigation schedule development, but adds a method to account for the biweekly over- and under-estimation of ET and irrigation applications, using real-time ET. Please refer to "Orchard Water Requirements" in *Continuum Level 2.0* for a detailed explanation of estimating orchard water requirements using "normal year" regional crop evapotranspiration and other site-specific factors to schedule irrigation applications on a biweekly basis.

USING METHODS ALTERNATIVE TO HISTORICAL ET TO ESTIMATE ALMOND WATER USE

Using Current Season's Evapotranspiration to Improve Historical ET Estimates

Using biweekly estimates of almond water use (Table 1, *Level 2.0*) can be improved by using the current season's evapotranspiration data (ETo) to account for differences between the historical average and actual water use. Using the current season's data still relies, for the purpose of our example, on the biweekly estimate to schedule the irrigation, then uses current season's ETo to assess the over- or under-irrigation during that irrigation period. In scheduling the next irrigation period, the difference is used to adjust the next scheduled irrigation amount. The current year's ETo can be used only after it is measured during the scheduled irrigation.

Estimated water use – Current season's use for the same time period
= Over- or under-irrigation application

Estimated water use for the next irrigation period – or + the difference
= New irrigation period application

Using Current Season's ETo to Adjust the Irrigation Schedule

Calculate almond orchard evapotranspiration ETc by multiplying the weather-based reference crop ETo by a canopy-based crop coefficient (Kc):

Crop water use (ETc) =
Reference evaporation (ETo) × Crop coefficient (Kc)

- ETc (almond water use) in inches of water can be based on the day, week, month or season in order to assess the orchard's water requirements for irrigation scheduling purposes.
- ETo (reference ET) information is available from a variety of sources. The most well-known is the California Department of Water Resources CIMIS network (www.cimis.water.ca.gov) of nearly 100 California weather stations that provide daily

3.0 Practice:

Estimate orchard water requirements using "normal year" regional crop evapotranspiration and other site-specific factors to schedule irrigation applications on a biweekly basis. After the scheduling period is complete, current-year reference evapotranspiration from that period is used to make adjustments going forward in the next irrigation period.

reference evapotranspiration values. CIMIS provides real-time current-season values and ETo in inches of water and can be based on the day, week, month or season. ETo information is available the day after collection. Another source for this ETo data is the UC Statewide Integrated Pest Management website. Additionally, some newspapers and irrigation districts regularly publish CIMIS ETo data. While some in-orchard weather stations have the necessary inputs to calculate ETo or ETc, their accuracy depends on instrument siting. Use caution when using these ETo values. Best practices suggest verifying the values obtained in an orchard with the closest CIMIS station or to those obtained using spatial CIMIS (www.cimis.water.ca.gov).

- Kc (crop coefficient) for almond has been experimentally determined for various times throughout the growing season. A crop coefficient is necessary to convert ETo, or reference ET, to an almond-specific number, as ETo represents the reference crop (grass pasture) used at CIMIS stations. Kc is the ratio at which the almond crop uses water compared with the ETo of the grass pasture. The Kc is developed under conditions where soil moisture is not limited and the crop is not under any water stress. Kc values for almonds are contained in Table 1, *Level 2.0*.

EXAMPLE

Using ET information from (Table 1, *Level 2.0*) for the period July 16-31 in Zone 16, the estimated water use is 5.38 inches, which was applied in that period. When that irrigation period is complete, the real-time ETo is obtained (from the CIMIS station) and multiplied by the Kc listed in Table 1, *Level 2.0* for each day in the irrigation period (Table 8). The total is 4.81 inches. The historical ETc was 0.57 inches, or about 10% higher than the actual ETc for this irrigation period. Since the applied water was based on the historical average ETc, 0.57 inches of water was applied in excess of the crop use.

Date	ETo (in.)	Kc	ETc 2016 (in.)	Historical ETc (in.)	Difference (in.)
16-Jul-16	0.30	1.11	0.333		
17-Jul-16	0.29	1.11	0.322		
18-Jul-16	0.27	1.11	0.300		
19-Jul-16	0.26	1.11	0.289		
20-Jul-16	0.26	1.11	0.289		
21-Jul-16	0.26	1.11	0.289		
22-Jul-16	0.26	1.11	0.289		
23-Jul-16	0.26	1.11	0.289		
24-Jul-16	0.29	1.11	0.322		
25-Jul-16	0.27	1.11	0.300		
26-Jul-16	0.27	1.11	0.300		
27-Jul-16	0.27	1.11	0.300		
28-Jul-16	0.25	1.11	0.278		
29-Jul-16	0.26	1.11	0.289		
30-Jul-16	0.28	1.11	0.311		
31-Jul-16	0.28	1.11	0.311		
Totals			4.810	5.38	-0.57

Table 8. Scheduling irrigations using historical averages and adjusting the next irrigation based on current year's ETc. Example using ET Zone 16, irrigation period July 16-31.

To adjust for the next two-week irrigation period:
Zone 16 ETo historical estimate of 4.81 inches (Aug 1-15) – 0.57 = 4.24 inches

By using this approach for the 2016 season, the schedule was only off by maximum of 10% for any two-week irrigation period. If historical ETc was used without adjustment over the entire season, 3.5 inches of water would have been applied in excess of the water requirement.

Using In-Field Devices to Estimate Almond ET

The Tule (www.tuletechnologies.com) in-field crop water use (ET) measurement system consists of an in-field device that logs and transfers sensor data via cell phone connection for data analysis. Unlike California Irrigation Management Information System (CIMIS) reference ET, which estimates the ET from a well-watered grass crop and relies on crop coefficients to estimate almond ETc, the Tule system estimates the amount of water that has evaporated from your specific orchard. Tule uses the surface renewal method to estimate how much water is evaporating from the orchard. It can be further described as using an energy balance method to obtain the mass flux density of water vapor (or crop ETc) from the surface. A crop- and field-specific ET estimate is then available via the web, mobile application and email reports. The hardware device is installed within your field above the plant canopy (Fig. 12).

This technology, developed and licensed from UC Davis is currently (as of 2017) in 1,100 fields, including 200 almond orchards. Siting of the in-field device and sensors is very important to ensure accurate measurement of ETc. Typically, a single device represents the ETc of a 10-acre area. If the soils are not uniform in the root zone water-holding capacity, more than one surface renewal system may be required to characterize the ET of the entire orchard block.

Figure 12. Tule in-field hardware used to collect data for ET estimation. (Photo by tuletechnologies.com)

NEXT STEPS

Once the estimated orchard water requirements of a specific orchard have been determined, use the irrigation system application rate to determine the appropriate irrigation system operation time. “Irrigation System Performance” provides guidance to measure the system application rate and distribution performance.

Irrigation System Performance

INTRODUCTION

Up-to-date irrigation system performance information is essential in irrigation water management. An orchard's irrigation system should be evaluated at a minimum of every three years. The two important steps required for good irrigation water management are knowing how much water needs to be applied and operating the irrigation system to apply that desired amount.

Before you take steps to personally evaluate your irrigation system, check to see if there is a mobile irrigation lab in your area. These mobile labs are sponsored by a local agency (county, resource conservation district, water district, etc.) in partnership with the California Department of Water Resources. They are experts in irrigation system evaluation and will do the evaluation for minimal or no charge. Currently there are 12 to 15 mobile labs working in California, with five in the Central Valley. Commercial companies in your area may also do irrigation system evaluations for a fee.

To operate a given irrigation system for the correct amount of time, two important irrigation system performance criteria are needed:

1. Application rate, measured in inches/hour
2. A measure of how evenly or uniformly water is applied

For more information on determining the irrigation system application rate and uniformity, refer to the system-specific information on the following pages: surface (flood or furrow) irrigation systems; sprinkler irrigation systems; microirrigation (drip/microsprinkler) systems.

1.0 Practice:

Evaluate irrigation systems for pressure variation and average application rate at least once every three years. Correct any diagnosed system performance problems.

SURFACE IRRIGATION SYSTEMS

INTRODUCTION

Surface irrigation systems include furrow and border strip systems. Border strip systems that flood the area between tree rows (middles) are more common in almonds, but irrigation is also done using a number of furrows paralleling the tree rows.

Determining the application rate and especially the application uniformity of surface irrigation systems is very difficult and is almost always done by a professional irrigation system evaluator. A grower can determine how much water is applied during an irrigation set, an important piece of water management information.

INFORMATION TO GATHER

Determining the amount of applied water during an irrigation set requires knowing:
• flow rate to the orchard
• orchard area irrigated during the set
• irrigation set time (duration)

DETERMINING THE VOLUME OF WATER APPLIED

With the above information, use one of the following formulas to determine the applied water (inches; abbreviated as “in”) during the irrigation set.

$$\frac{\text{Flow Rate to Orchard (gpm)} \times \text{Irrigation Set Time (min)} \times 1.6}{\text{Orchard Area Irrigated (ft}^2\text{)}} = \text{Applied Water (in)}$$

$$\frac{\text{Flow Rate to Orchard (gpm)} \times \text{Irrigation Set Time (min)} \div 27{,}152}{\text{Orchard Area Irrigated (acres)}} = \text{Applied Water (in)}$$

Water may also be applied to the orchard measured in acre-inches (ac-in).
To determine the inches of water applied, use the following formula:

$$\frac{\text{Water Applied (ac-in)}}{\text{Orchard Area Irrigated (ac)}} = \text{Applied Water (in)}$$

Note that the following conversions may be helpful in working through the formulas above:
• 1 acre = 43,560 ft^2
• 1 cubic foot per second (cfs) = 449 gallons per minute (gpm)

In addition to water applied, if runoff from the orchard is reused somewhere else on the property, the runoff volume should be removed from the total water applied during the irrigation. It is often extremely difficult to measure the runoff volume, so an estimate may need to be made. Previous studies have shown that a reasonable estimate of the runoff volume is 15-20% of the applied water.[1]

NEXT STEPS

Compare the amount of irrigation water applied with the estimated orchard water use as described in the *Almond Irrigation Improvement Continuum Level 1.0* fundamental “Orchard Water Requirements” section. This can be done after each irrigation event or on an annual basis. If you find that you are applying significantly more irrigation water than is needed to meet the orchard’s water needs, strongly consider a professional system evaluation to improve your irrigation practices.

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[1] L. Schwankl, T. Prichard, and B. Hanson. 2007. Reducing Runoff from Irrigated Lands: Tailwater Return Systems. UC ANR Publication 8225. http://anrcatalog.ucanr.edu/pdf/8225.pdf.

MOVING UP THE CONTINUUM

Moving up to the intermediate practices described in "Irrigation System Performance" in *Continuum Level 2.0* involves estimating the irrigation distribution uniformity in addition to measuring the applied water.

For surface irrigation systems, measuring the distribution uniformity is complicated and will require the assistance of an irrigation system evaluation professional. In some areas, a mobile lab team may be available to provide assistance. If you have access to a mobile lab, take advantage of their services.

Figure 1. Impact sprinkler. (Photo by L. Schwankl)

Figure 2. Rotator-type sprinkler. (Photo by T. Prichard)

SPRINKLER IRRIGATION SYSTEMS

Two types of sprinkler irrigation systems are used in almond orchards: impact sprinklers (Fig. 1) and rotator-type sprinklers (Fig. 2). These types of sprinklers will be discussed separately, as pressure measurement techniques vary between the two. Please consult the sections below that apply to your system(s).

Pressure measurements can be taken relatively quickly and easily in sprinkler irrigation systems. These measurements allow you to determine the irrigation application rate (most often measured in inches/hour) and give you an indication of the application uniformity.

IMPACT SPRINKLERS

Information to Gather

The following information should be gathered and recorded for orchards irrigated with impact sprinklers:

1. Spacing between sprinklers in a tree row and spacing between sprinklers across the tree row; and
2. At each sprinkler sampled, the nozzle orifice size should be determined and the operating pressure measured.

WHEN TO TAKE MEASUREMENTS

It is recommended that the sprinkler system be evaluated at a minimum of every three years. The evaluation can be done at any time during the irrigation season.

Before any measurements are taken in the orchard, the filters (if any), mainlines and submains should be flushed to ensure that the sprinkler system is working optimally. If sprinklers need to be cleaned, this should be done at this time.

The objective in gathering the pressure measurements is to characterize the pressure for the orchard or irrigation set as a whole. Pressure measurements should be taken at (Fig. 3):

- The head (from the pump or head of the system), middle and tail end of the orchard or irrigation set.
- The head, middle and tail end of sprinkler lateral lines.
- If there are high- or low-elevation areas in the orchard or irrigation set, extra measurements may be needed in those locations. Equally distribute these additional measurements between high- and low-elevation locations so that the measurements are not biased.

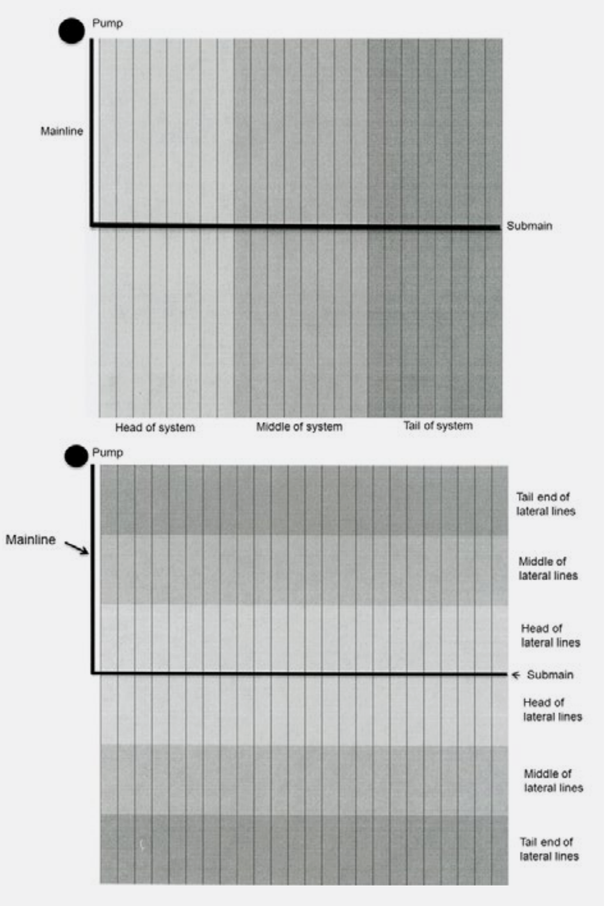


Figure 3. Irrigation system pressure measurements should be taken at a variety of locations within the system. Use the descriptions above to understand how these relate to your setup. (Source: L. Schwankl)

Since the sprinkler system mainlines, submains and lateral lines are most often below ground, having an irrigation system layout plan or map is extremely useful in planning where to take measurements and for recording where measurements were taken. If it is known that some sprinkler lateral lines are longer than others, measure the pressure on the longer lines since the pressure loss will be greater in these laterals.

When the pressure is measured at a sprinkler head, the record of its location should be good enough that the same sprinkler could be located and remeasured at a later date. Spray painting the sprinkler riser can assist in locating the sprinkler in the future.

HOW MANY SPRINKLERS TO SAMPLE?

As with all sampling, the answer to how many samples should be collected is that more is always better. At a minimum, 30 to 40 sprinklers should be sampled, even on a small-acreage orchard. As the acreage increases, use the guideline of two or more sprinklers sampled per acre.

If when sampling it becomes evident that there is significant variability between sprinkler pressures, consider increasing the number of sprinklers sampled. Additional sampling increases the probability of diagnosing the cause of the variability. If the sprinkler pressure variability seems to be associated with high- or low-elevation areas of the orchard, additional sampling of sprinkler pressure in those areas is warranted.

SPRINKLER NOZZLE ORIFICE SIZE

Orchards are most often designed to have the same sprinkler nozzle size throughout. However, do not simply assume that this is true for your orchard. For older sprinkler systems, it is not uncommon for sprinklers to have been replaced during maintenance and substituted with nozzle sizes other than the design size.

The size of brass nozzles is often stamped on the side of the nozzles (Fig. 4). This can be

Figure 4. Impact sprinkler nozzle size is often stamped onto the side of the nozzle. On this sprinkler it is noted as "7/64" and circled in red. (Photo by L. Schwankl)

very difficult to see, especially in the field, so using a set of drill bits to determine the orifice size is often easier. The correct size bit should just fit into the orifice; keep that drill bit handy, as it can be used to quickly check each sprinkler sampled.

MEASURING SPRINKLER OPERATING PRESSURE

The easiest way to measure the operating pressure of an impact sprinkler is to use a pressure gauge fitted with a pitot tube (Fig. 5). The pitot tube is a

Figure 5. A pitot tube fitted with a pressure gauge works well for taking sprinkler pressure measurements. (Photo by L. Schwankl)

small, curved, hollow brass tube that should be available for purchase from your local irrigation equipment supplier. A 0–60 psi or a 0–100 psi liquid-filled pressure gauge works well for taking the measurements.

It is recommended that the same new pressure gauge be used to measure all the pressures when sampling. A new pressure gauge is advantageous

Figure 6. Water pressure is read by positioning the pitot tube directly in the sprinkler's water stream. (Photo by L. Schwankl)

because pressure gauges often become less accurate with use. If multiple pressure gauges are to be used, confirm that they all read the same pressure by measuring a single location with each gauge.

Once fitted with a pressure gauge, hold the pitot tube in the water stream just outside the sprinkler nozzle and read the pressure on the gauge (Fig. 6). Move the pitot tube around in the water stream until the maximum pressure is noted. With practice, the pressure can be measured at a sprinkler head in only a few seconds. When the measurement is taken, record its location within the orchard on an orchard plot map or write a good description of its location.

USING PRESSURE MEASUREMENTS AS A UNIFORMITY INDICATOR

The variability of the pressure measurements is an indicator of the uniformity of sprinkler discharge in the orchard. High variability between sprinkler pressures leads to over-application of water in areas of higher pressure and under-irrigation in areas of lower pressure. While this guide provides recommendations for *Level 1.0* fundamental practices, growers can further improve their practices by consulting the "Irrigation System Performance" section in *Continuum Level 2.0* and *Level 3.0* recommendations, which require increased frequency and detail in monitoring and improvement.

If there is more than a 20% difference between pressure readings, it is likely that the application uniformity is not as good as desired; consult an irrigation professional who may be able to make recommendations to improve the pressure uniformity.

DETERMINING THE AVERAGE APPLICATION RATE

A sprinkler system's average application rate is critical information for applying the correct amount of water. The sprinkler application rate is measured in inches per hour (in/hr), so it can be easily calculated with almond orchard water use estimates that are usually provided in inches. With the sprinkler nozzle orifice size and the operating pressure collected using the guidance above, use the figure below (Fig. 7) to determine the sprinkler discharge rate (gpm) for each sprinkler measured.

Nozzle size (in)	Pressure (psi) 30	35	40	45	50	55	60	65
	Discharge rate (gpm)							
3/32	1.7	1.5	1.6	1.7	1.8	1.9	2.0	2.1
7/64	1.9	2.0	2.2	2.3	2.4	2.6	2.7	2.8
1/8	2.5	2.7	2.9	3.1	3.2	3.4	3.6	3.7
9/64	3.1	3.4	3.6	3.8	4.1	4.2	4.4	4.6
5/32	3.9	4.2	4.5	4.7	5.0	5.2	5.5	5.8
11/64	4.7	5.1	5.4	5.7	6.1	6.3	6.6	6.9
3/16	5.6	6.0	6.4	6.8	7.2	7.6	7.9	8.2
13/64	6.5	7.1	7.6	8.1	8.5	9.2	9.2	9.5

Figure 7. Sprinkler discharge rates can be determined with measured nozzle orifice size and operating pressure. (Source: UC ANR Publication 3527)

If colored plastic sprinkler nozzles (e.g., from Nelson Rotator sprinklers) are used instead of brass nozzles, visit the manufacturer's website to get the nozzle discharge rate for the field-measured operating pressure.

Note that as the pressure goes up, the sprinkler discharge also goes up. The reverse also holds true. If sprinklers in an area of the orchard consistently have lower pressures, and therefore lower sprinkler discharges, that section of the orchard will be under-irrigated compared with orchard areas with higher pressures.

Use the following steps to determine the average application rate (in/hr) for orchards irrigated with impact sprinklers.

1. Average the sprinkler discharge rates (gpm) of all the sprinklers sampled.
2. With the tree spacing information collected at the beginning of this section, use the following formula to determine the average application rate for the orchard.

$$\text{Average Sprinkler Application Rate (in/hr)} = \frac{96.3 \times (\text{Sprinkler discharge – gpm})}{\text{Sprinkler spacing in the tree row (ft)} \times \text{Sprinkler spacing across the tree row (ft)}}$$

NEXT STEPS

1. The average application rate is a very important piece of information regarding your sprinkler system. Keep it handy, since it will be used extensively when scheduling irrigations. It should not change significantly unless the pressure in the system changes. If you have filters in the system, be sure to keep them flushed and clean, since they are a frequent source of pressure loss.
2. Variability in measured pressures in the orchard greater than 20% can cause significant irrigation application nonuniformity. Consider calling in an irrigation professional to see what is causing the differences and what can be done to improve it.
3. Recheck your sprinklers every three years. It is recommended that you recheck the same sprinklers originally evaluated. This will provide an excellent measure of any changes that may have occurred. Consider measuring additional sprinklers to provide even better information.

MOVING UP THE CONTINUUM

Moving up to the intermediate practices described in the section "Irrigation System Performance" in *Continuum Level 2.0* involves a closer look at evaluating the sprinkler information collected and addresses how to account for the sprinkler discharge rate variability.

ROTATOR SPRINKLERS

Information to Be Gathered

The following information should be gathered and recorded for orchards irrigated with rotator sprinklers.

1. Spacing between sprinklers in a tree row and spacing between sprinkler lines across the tree row.
2. At each sprinkler sampled, note the model of the rotator sprinkler (e.g., R5, R10), the color of the top plate deflector, the color of the nozzle in the sprinkler, and the operating pressure measured.

WHEN TO TAKE MEASUREMENTS

It is recommended that the sprinkler system be evaluated at a minimum of every three years. The evaluation can be done at any time during the irrigation season. Before any measurements are taken in the orchard, the filters (if any), mainlines and submains should be flushed to ensure that the sprinkler system is working optimally. If sprinklers need to be cleaned, this should be done.

The objective in gathering the pressure measurements is to characterize the pressure for the orchard or irrigation set as a whole. Pressure measurements should be taken at (Fig. 8):

- The head, middle and tail end (from the pump or head of the system) of the orchard or irrigation set.
- The head, middle and tail end of sprinkler lateral lines.
- If there are high- or low-elevation areas in the orchard, extra measurements may be needed in those locations. Distribute these additional measurements equally between high- and low-elevation locations so that the measurements are not biased.

Since the sprinkler system mainlines, submains and lateral lines are most often below ground, having an irrigation system layout map is extremely useful in planning where to take measurements and for recording where measurements were taken. If it is known that some sprinkler lateral lines are longer than others, measure the pressures on the longer lines, since the pressure loss will be greater in these laterals.

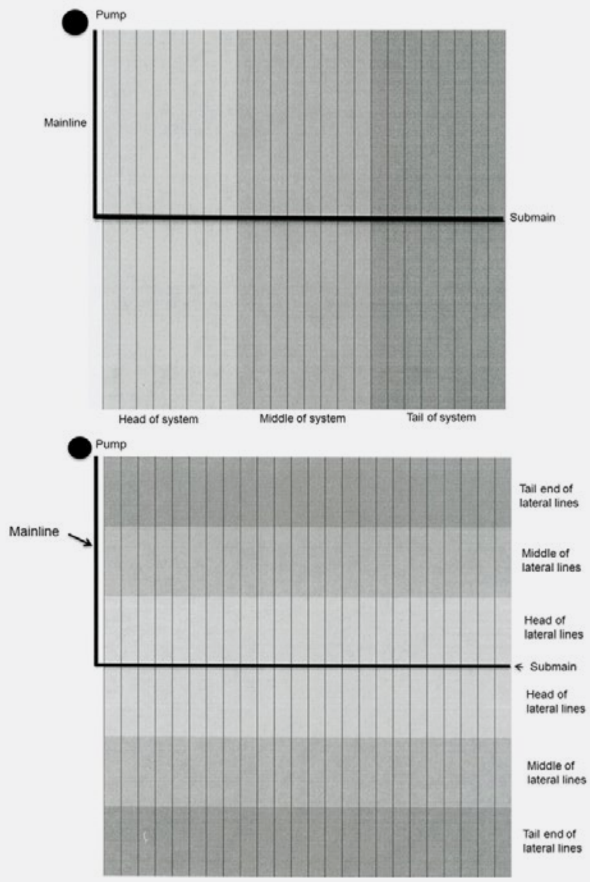


Figure 8. Irrigation system pressure measurements should be taken at a variety of locations within the system. Use the descriptions above to understand how these relate to your setup. (Source: L. Schwankl)

When the pressure is measured at a sprinkler head, the record of its location should be good enough that the same sprinkler could be located and remeasured at a later date. Spray painting the sprinkler riser can assist in locating the sprinkler in the future.

HOW MANY SPRINKLERS TO SAMPLE?

As with all sampling, the answer to how many samples should be collected is that more is always better. At a minimum, 30 to 40 sprinklers should be sampled, even on a small-acreage orchard. As the acreage increases, sample two or more sprinklers per acre.

If it becomes evident that there is significant variability between sprinkler pressures, consider increasing the number of sprinklers sampled.

Additional sampling increases the probability of diagnosing the cause of the variability. If the sprinkler pressure variability seems to be associated with high- or low-elevation areas of the orchard, additional sampling of sprinkler pressure in those areas is warranted.

MEASURING SPRINKLER OPERATING PRESSURE

Because of the rotator sprinkler design, pressure cannot be measured using the simple method described for impact sprinklers. Instead, remove the rotator sprinkler head and install a pressure gauge fitted with the same thread configuration as a sprinkler head to determine the operating pressure. A 0–60 psi or 0–100 psi liquid-filled pressure gauge works well for taking the measurements. Many rotator sprinklers have Acme threads, which allow for rapid installation and removal; in that case, use an adaptor on the pressure gauge.

Use the same, new pressure gauge to measure all the pressures when sampling. A new pressure gauge is advantageous because pressure gauges often become less accurate with use. If multiple pressure gauges are to be used, confirm that they all read the same by measuring a single location with each gauge.

USING PRESSURE MEASUREMENTS AS A UNIFORMITY INDICATOR

The variability of the pressure measurements is an indicator of the uniformity of sprinkler discharge in the orchard. High variability among sprinkler pressures leads to overapplication of water in areas of higher pressure and under-irrigation in areas of lower pressure. While this guide provides recommendations for *Level 1.0* fundamental practices, growers can further improve their practices by consulting “Irrigation System Performance” in *Continuum Level 2.0* and *Level 3.0* recommendations which require increased frequency and detail in monitoring and improvement.

If there is more than a 20% difference between pressure readings, it is likely that the application uniformity is not as good as desired. Pressure variability greater than 20% can result in significant irrigation application nonuniformity and is cause to consult an irrigation professional who may be able to make recommendations to improve the pressure uniformity.

DETERMINING THE AVERAGE APPLICATION RATE

With the sprinkler nozzle color and the operating pressure, visit the Nelson Irrigation online Rotator Technology Pocket Guide to get the nozzle color, pressure and flow rate for the sprinkler model being evaluated. For example, the figure below is for the R2000 model sprinkler (Fig. 9). The tables available from Nelson Irrigation are provided in pressure increments of 5 psi, so interpolation will be required to determine the sprinkler discharge rate.

Note that as the pressure goes up, the sprinkler discharge also goes up. The reverse holds true. If sprinklers in an area of the orchard consistently have lower pressures and therefore lower sprinkler discharges, that section of the orchard will be under-irrigated as compared with other orchard areas with higher pressures.

Use the following steps to determine the average application rate (in/hr) of orchards irrigated with impact sprinklers.

1. Average the sprinkler discharge rates (gpm) of all the sprinklers sampled.
2. With the tree spacing information collected at the beginning of this section, use the following formula to determine the average application rate for the orchard.

$$\text{Average Sprinkler Application Rate (in/hr)} = \frac{96.3 \times (\text{Sprinkler discharge – gpm})}{\text{Sprinkler spacing in the tree row (ft)} \times \text{Sprinkler spacing across the tree row (ft)}}$$

PLATE/NOZZLE OPTIONS AND FLOW PERFORMANCE IN GPM AND LPH

Plate Series	Plate Options	Recommended Nozzles	PSI							BAR				
			30	35	40	45	50	55	60	2.0	2.5	3.0	3.5	4.0
K1	**K1 6° Cream** Radius: 21-25′ (6.4-7.6 m) Stream Ht.: 15-25″ (38-64 cm)	Gray #8.3	.67	.72	.77	.82	.86	.90	.94	150	166	183	197	210
		.85 2000FC	Within the recommended pressure range of 30-60 PSI (2.0-4.0 BAR), the .85 2000 FC flow control nozzle is flow regulating within a flow range of no more than 3.5% greater and 8% less than the nominal flow of .85 GPM (193 LPH).												
K2	**K2 6° Light Blue** Radius: 22-26′ (6.7-7.9 m) Stream Ht.: 15-32″ (38-81 cm)	White #9	.77	.83	.89	.94	1.00	1.05	1.10	172	192	210	229	245
		Dark Blue #10	.97	1.05	1.12	1.19	1.25	1.31	1.37	217	242	266	286	306
		1.0 2000FC	Within the recommended pressure range of 30-60 PSI (2.0-4.0 BAR), the 1.0 2000 FC flow control nozzle is flow regulating within a flow range of no more than 3.5% greater and 8% less than the nominal flow of 1.0 GPM (227 LPH).												
	K2 9° Green Radius: 23-27′ (7.0-8.2 m) Stream Ht.: 18-37″ (46-94cm)	Gray #8.3	.67	.72	.77	.82	.86	.90	.94	150	166	183	197	210
		White #9	.77	.83	.89	.94	1.00	1.05	1.10	172	192	210	229	245
		Dark Blue #10	.97	1.05	1.12	1.19	1.25	1.31	1.37	217	242	266	286	306
	K2 15° Yellow Radius: 27-30′ (8.2-9.1 m) Stream Ht.: 31-55″ (79-140 cm)	.85 2000FC	Within the recommended pressure range of 30-60 PSI (2.0-4.0 BAR), the .85 2000 FC flow control nozzle is flow regulating within a flow range of no more than 3.5% greater and 8% less than the nominal flow of .85 GPM (193 LPH).												
		1.0 2000FC	Within the recommended pressure range of 30-60 PSI (2.0-4.0 BAR), the 1.0 2000 FC flow control nozzle is flow regulating within a flow range of no more than 3.5% greater and 8% less than the nominal flow of 1.0 GPM (227 LPH).												
K3	**K3 9° Brown** Radius: 25-28′ (7.6-8.5 m) Stream Ht.: 19-33″ (48-84 cm)	Orange #11	1.17	1.27	1.36	1.45	1.53	1.61	1.68	261	294	323	350	375
		Purple #12	1.39	1.50	1.61	1.70	1.80	1.89	1.98	311	347	380	412	442
	K3 15° Red Radius: 27-31′ (8.2-9.4 m) Stream Ht.: 38-63″ (97-160 cm)	1.25 2000FC	Within the recommended pressure range of 30-60 PSI (2.0-4.0 BAR), the 1.25 2000 FC flow control nozzle is flow regulating within a flow range of no more than 3.5% greater and 8% less than the nominal flow of 1.25 GPM (284 LPH).												
		1.5 2000FC	Within the recommended pressure range of 30-60 PSI (2.0-4.0 BAR), the 1.5 2000 FC flow control nozzle is flow regulating within a flow range of no more than 3.5% greater and 8% less than the nominal flow of 1.5 GPM (341 LPH).												
	K3 24° Gray Radius: 29-35′ (8.8-10.7 m) Stream Ht.: 68-103″ (173-262 cm)													
K4	**K4 6° Turquoise** Radius: 21-25′ (6.1-7.6 m) Stream Ht.: 10-24″ (25-61 cm)	Yellow #13	1.64	1.78	1.90	2.02	2.13	2.23	2.34	366	411	451	487	521
		Green #14	1.85	2.00	2.15	2.28	2.40	2.53	2.64	413	463	509	550	590
	K4 9° Purple Radius: 26-32′ (7.9-9.4 m) Stream Ht.: 28-42″ (71-107 cm)	1.5 2000 FC	Within the recommended pressure range of 30-60 PSI (2.0-4.0 BAR), the 1.5 2000 FC flow control nozzle is flow regulating within a flow range of no more than 3.5% greater and 8% less than the nominal flow of 1.5 GPM (341 LPH).												
		2.0 2000 FC	Within the recommended pressure range of 30-60 PSI (2.0-4.0 BAR), the 2.0 2000 FC flow control nozzle is flow regulating within a flow range of no more than 3.5% greater and 8% less than the nominal flow of 2.0 GPM (454 LPH).												
	K4 12° Wine Radius: 27-31′ (8.2-9.4 m) Stream Ht.: 32-51″ (81-130 cm)													
	K4 15° Gold Radius: 27-33′ (8.2-10.1 m) Stream Ht.: 40-60″ (102-152 cm)													
	K4 24° Black Radius: 28-36′ (8.5-11.0 m) Stream Ht.: 65-100″ (165-254 cm)													
K5	**K5 9° Orange** Radius: 27-31′ (8.2-9.4 m) Stream Ht.: 25-42″ (54-107 cm)	Tan #15	2.17	2.35	2.53	2.67	2.82	2.97	3.11	485	544	597	647	695
		Dark Red #16	2.50	2.70	2.89	3.07	3.23	3.40	3.54	559	624	685	739	792
	K5 15° Tan Radius: 31-36′ (9.4-11.0 m) Stream Ht.: 36-49″ (91-124 cm)	2.5 2000FC	Within the recommended pressure range of 30-60 PSI (2.0-4.0 BAR), the 2.5 2000 FC flow control nozzle is flow regulating within a flow range of no more than 3.5% greater and 8% less than the nominal flow of 2.5 GPM (568 LPH).												
	K5 24° Blue Radius: 32-37′ (9.8-11.3 m) Stream Ht.: 76-104″ (193-264 cm)													

Figure 9. Sample model information for Nelson rotator sprinklers (R2000) which indicates what a given model's nozzle color, pressure and flow rate should be. (Source: Nelson Irrigation)

NEXT STEPS

1. The average application rate is a very important piece of information regarding your sprinkler system. Keep it handy since it will be used extensively when scheduling your irrigations. It should not change significantly unless the pressure in the system changes. If you have filters in the system, be sure to keep them flushed and clean since they are frequently a source of pressure loss.
2. Variability in measured pressures in the orchard of more than 20% can cause significant irrigation application nonuniformity. Consider calling in an irrigation professional to find the cause and what can be done to improve it. Using flow control (FC) nozzles may improve irrigation uniformity on some rotator-type sprinkler systems, as they discharge at a more uniform rate across a range of operating pressures. Flow control nozzles are not available for all rotator sprinklers.
3. Recheck your sprinklers in three years. It is recommended that you recheck the same sprinklers originally evaluated. This will give an excellent measure of changes that may have occurred. Consider measuring additional sprinklers to provide even better information.

MOVING UP THE CONTINUUM

Moving up to the intermediate practices described in the section "Irrigation System Performance" in *Continuum Level 2.0* involves a closer look at evaluating sprinkler information collected, and addresses how to account for the sprinkler discharge rate variability.

MICROIRRIGATION SYSTEMS

Microirrigation systems come in the form of microsprinklers or drip (Figs. 10 and 11). Pressure measurements for these systems are useful since the discharge from nonpressure-compensating drippers and microsprinklers is significantly impacted by the operating pressure. The discharge from pressure-compensating (PC) drippers and microsprinklers is not as affected by differences in system pressure.

Pressure measurements will allow you to determine the application rate, most often measured in inches per hour (in/hr), and also give you an indication of the application uniformity.

Figure 10. Microsprinkler irrigation system. (Photo by L. Schwankl)

Figure 11. Drip irrigation system. (Photo by ANR Communications Advisory Board)

INFORMATION TO BE GATHERED

The following information should be gathered and recorded for orchards irrigated with micro-irrigation systems.

1. Spacing between trees in the row and spacing between tree rows.
2. Spacing between drip emitters or microsprinklers along the row. Note whether there is double-line drip (two lines of drip tubing and emitters per tree row). The objective of gathering this information is to determine the amount of applied water (gallons per hour) per tree.

3. If the orchard is irrigated in sets (sections or blocks of the orchard that are irrigated separately) monitor and evaluate the sets individually. The sets may not be the same hydraulically. They may differ in size, pressure and flow rate.
4. Record the make and model of the microirrigation emitters used in the orchard. Use a camera or a smartphone to get a good close-up of the dripper or microsprinkler being used. Of particular importance is whether the emitters or microsprinklers are pressure compensating (PC). The discharge rate from nonpressure compensating drippers or microsprinklers is significantly affected by pressure (Fig. 12). Pressure-compensating drippers or microsprinklers discharge at a constant rate even as operating pressure changes (Fig. 13). If you are unsure whether your emitters are pressure compensating, take a sample emitter to your local irrigation equipment supplier for identification.

FLOW VS. PRESSURE

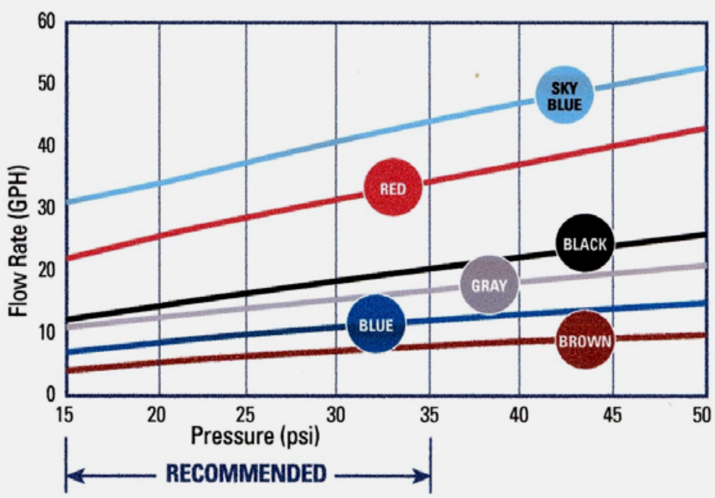
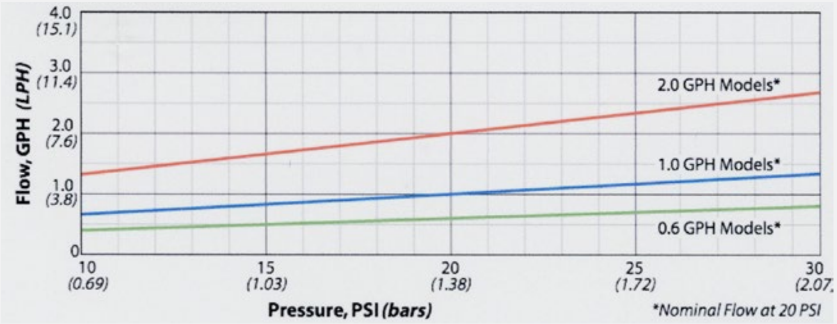
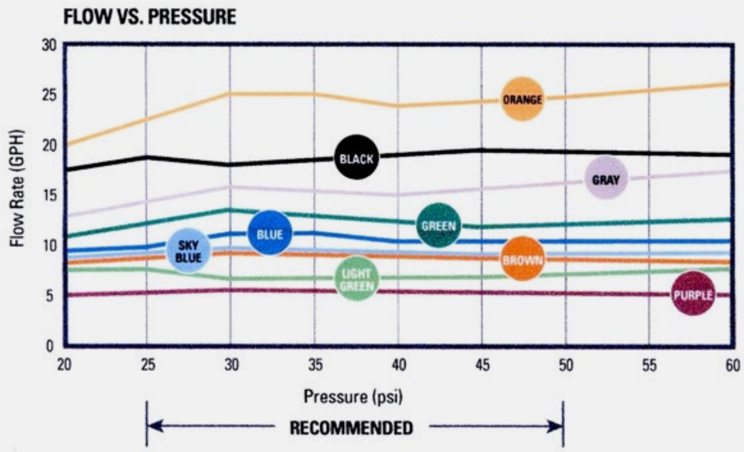


Figure 12. The discharge rate for nonpressure compensating microsprinklers (top) or drippers (bottom) varies with operating pressure. The pressure-discharge rate relationship will vary by manufacturer. (Source: Bowsmith)

NOMINAL PERFORMANCE



PRESSURE-COMPENSATING (PC) MICROSPRINKLER



PRESSURE-COMPENSATING (PC) DRIP EMITTER

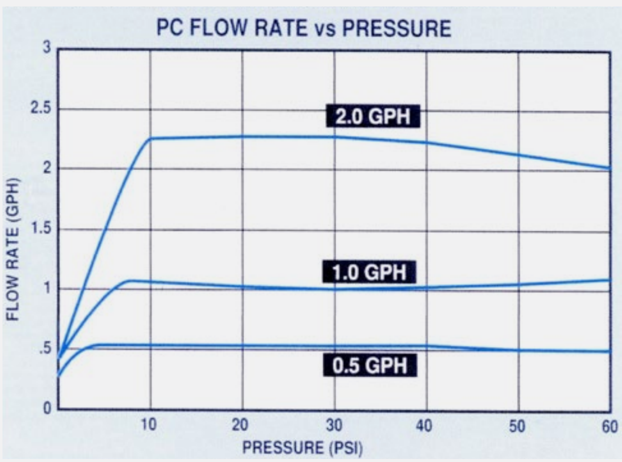


Figure 13. Pressure-compensating microsprinklers (top) and drippers (bottom) adjust to discharge at a constant rate even as operating pressure changes. (Source: Bowsmith and Netafim Irrigation)

WHEN TO TAKE MEASUREMENTS

Microirrigation systems should be evaluated every three years to achieve good irrigation water management. Evaluation every three years will be adequate to diagnose any problems associated with pressure variability, but evaluations should be done even more frequently, even yearly, if there is clogging in the system.

For new microirrigation systems, an excellent strategy is to do a system evaluation shortly after installation. This provides a baseline with which future evaluations can be compared. Do not simply rely on design criteria or “as planned” performance.

Before taking any measurements in the orchard, flush the filters, mainlines, submains and lateral lines to ensure that the system is working optimally. Also check pressure-regulating devices to make sure they are operating at the correct pressure. This includes adjustable pressure-regulating valve(s) at the head of the system and/or pressure regulators on the separate blocks (Fig. 14).

Figure 14. In-field pressure regulator used to regulate the pressure to a block of the orchard. (Photo by B. Sanden)

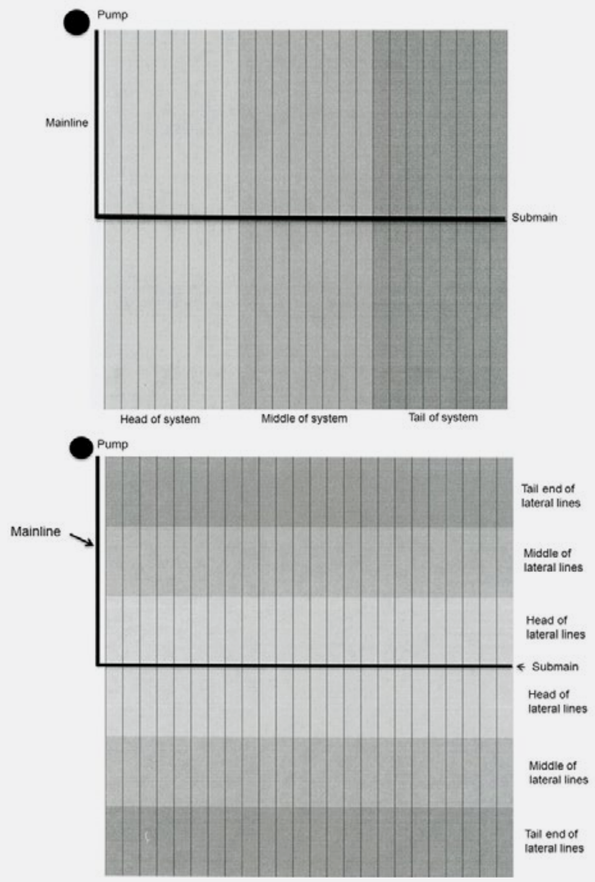


Figure 15. Irrigation system pressure measurements should be taken at a variety of locations within the system. Use the descriptions above to understand where these are relative to your setup. (Source: L. Schwankl)

A 0–30 psi or 0–60 psi liquid-filled pressure gauge works well for taking the measurements. Use the same, new pressure gauge to measure all the pressures. Using a new pressure gauge is advantageous because pressure gauges often become less accurate with use. If multiple pressure gauges are to be used, confirm that they all read the same pressure by measuring a single location with each gauge.

The objective in gathering the pressure measurements is to characterize the pressure for the orchard as a whole. Pressure measurements should be taken at (Fig. 15):

- The head, middle and tail end (from the pump or head of the system) of the orchard.
- The head, middle and tail end of the drip or microsprinkler lateral lines.
- Extra measurements may be needed in areas of high or low elevation in the orchard. Equally distribute these additional measurements between high- and low-elevation locations so that the measurements are not biased.

Since the microirrigation system mainlines and submains are most often below ground, having an irrigation system layout plan map is extremely useful in planning where to take measurements and for recording where measurements were taken.

When the pressure is measured at a dripper or microsprinkler, the record of its location should be good enough that the same emitter could be located and remeasured at a later date. Spray painting the drip hose on either side of the sampled emitter can be helpful in locating the sampled emitter in the future.

HOW MANY EMITTERS TO SAMPLE?

As with all sampling, the answer to how many samples should be collected is that more is always better. At a minimum, 30 to 40 pressure locations should be sampled, even on a small-acreage orchard. As the acreage increases, use the guideline of two or more pressure locations sampled per acre.

If it becomes evident during sampling that there is significant variability in pressures, consider increasing the number of locations sampled. Additional sampling increases the probability of diagnosing the cause of the pressure variability. If the pressure variability seems to be associated with areas of high or low elevation in the orchard, additional sampling of pressures in those areas is warranted.

MEASURING OPERATION PRESSURE

Pressure measurements can be readily taken throughout a microirrigation system. The following are typical and recommended pressure monitoring locations.

1. At the tail end of lateral lines. There is either an end cap fitting (3/4-inch female hose thread) or the tubing is simply folded over and held closed by a figure-8 fitting or by a 1-inch PVC pipe "ring." Use a pressure gauge that is adapted to the appropriately sized drip fitting and can be temporarily slid over the end of the tubing while the pressure measurement is taken (Fig. 16).

   Measurements at the end of a lateral line account for frictional pressure losses through mainlines, submains and lateral lines. For orchards with little elevation variability, the end of lateral line pressure measurements will be the lowest pressure levels in the system.

Figure 16. Pressure gauge adapted for measurement at tail end of lateral line microirrigation system tubing. (Photo by L. Schwankl)

2. At the head of the lateral lines. It is very common for there to be an accessible connection where each lateral line connects to the submain system. Often, there is a fitting on the head of the lateral line similar to the female end of a garden hose. These connections should be the same throughout the system, so once you have the pressure gauge adapted to fit it should work throughout the system.

   There is often a hose-end ball valve at this connection that allows the water to be temporarily shut off while the lateral line is disconnected and the adapted pressure gauges installed. Turn the valve back on to take the pressure reading, and turn it off while the lateral line is reinstalled. If no shut-off valve is present, install a temporary pressure gauge. This will be a wet process, so it is best done on a warm day.

   As an alternative, measuring the pressure at the first dripper or microsprinkler at the head of a lateral line will give an accurate measure of the pressure at the head of the lateral line.

3. Through the tubing system. The pressure can be taken anywhere in the tubing system by punching a hole in the tubing with a drip punch and measuring the pressure using a pressure gauge fitted with a pitot tube (Fig. 17) that fits into the punched hole.

   The pitot tube is a small, curved, hollow brass tube that should be available for purchase from your local irrigation equipment supplier. A 0–30 psi or 0–60 psi liquid-filled pressure gauge works well for taking the measurements.

   Once the pressure measurement is taken, close the punched hole using a "goof plug." This method of pressure measurement is preferred by many evaluators because it can be done quickly and allows access to measure the pressure anywhere in the tubing system.

   In microsprinkler systems, an alternative to punching a hole in the drip lateral line is to disconnect the tubing (often 1/4-inch tubing) leading to the microsprinkler and temporarily attaching the pressure gauge, fitted with a pitot tube, to the open end of the tubing. Replace the microsprinkler tubing once the measurement is complete.

Figure 17. A pitot tube fitted with a pressure gauge adapted for measurement within microirrigation tubing system. (Photo by L. Schwankl)

LIMITATIONS OF PRESSURE MEASUREMENTS IN MICROIRRIGATION SYSTEMS

Whereas pressure measurements provide a great deal of system performance information in sprinkler systems, they are not as informative in microirrigation systems for the following reasons.

- Microirrigation emitter clogging is not generally detected through pressure measurements. Clogged emitters may be observed while collecting pressure measurements, but the pressure measurements themselves do not provide evidence of clogging. To gather information on clogging, emitter discharge measurements (gph per emitter) must be gathered. This is as easily done as collecting pressure measurements and is addressed in *Almond Irrigation Improvement Continuum Level 2.0* and *Level 3.0* recommendations.
- Numerous pressure-compensating (PC) drip emitters and microsprinklers are used in almond irrigation that yield a greater acceptable pressure variability in a PC emitter system design than would be acceptable in a non-PC emitter system design.

One caution when evaluating systems with pressure-compensating drippers or microsprinklers is that the devices have a minimum operating pressure below which the pressure-compensating feature does not work. This minimum pressure will be evident in the manufacturer's pressure versus discharge rate charts for their devices (see Fig. 13 for an example) or the manufacturer will specify a minimum recommended operating pressure. If during the field evaluation you find system operating pressures below this minimum recommended operating pressure, be aware that the emitters in those low-pressure areas are no longer operating as pressure-compensating and their discharge rates will be lower.

WHAT TO DO WITH PRESSURE READINGS

Pressure differences in a microirrigation system are the result of elevation differences and friction from water flowing through the pipeline or tubing. An elevation change of 2.3 feet is equivalent to 1 psi of pressure: lifting water 2.3 feet in elevation requires 1 psi of pressure (a loss of 1 psi) while water falling 2.3 feet in elevation results in a 1 psi gain in pressure.

For the drip emitter or microsprinkler product evaluated in the orchard, go to the manufacturer's website to find a chart or graph of the discharge rate versus pressure relationship for the emitter or microsprinkler. If you are unsure what drip emitter or microsprinkler you have in your orchard or are unable to access it online, take a sample emitter to your local irrigation equipment supplier to have them identify it for you. As examples, see the associated graphs (Figs. 12 and 13) for different microirrigation products.

For a pressure measured in the orchard, consult the appropriate graph from your manufacturer for the expected emitter discharge rate.

DETERMINING THE AVERAGE APPLICATION RATE

Estimate the average application rate in the orchard using the field-measured pressure measurements and the manufacturer-provided pressure versus emitter discharge rate information for the emission devices used in the orchard. This is only an estimate, since it assumes minimal emitter clogging. In the section "Irrigation System Performance" in *Continuum Level 2.0* and *Level 3.0*, field measurements will be gathered which account for clogging, if any.

Follow these steps to estimate the average application rate.

1. Determine the average emitter discharge rate from the average operating pressure measured in the field and the manufacturer's pressure versus emitter discharge information for the orchard's emission device.

   DRIP EMITTER EXAMPLE:
   A drip-irrigated orchard with the non-PC drip emitter (1.0 GPH Model) illustrated in Figure 18 had an average field-measured operating pressure of 16 psi.

   From the emitter discharge rate versus pressure (Fig. 18), the estimated emitter discharge rate would be 0.9 gph.

MICROSPRINKLER EXAMPLE:
A microsprinkler-irrigated orchard with the non-PC "Blue" microsprinkler illustrated in Figure 19 had an average operating pressure of 30 psi.

From the manufacturer's microsprinkler (Blue) discharge rate versus pressure graph (Fig. 19), the estimated microsprinkler discharge rate would be 10.0 gph.

2. Using the average emitter discharge rate (gph) and the number of emitters per tree, determine the average tree discharge rate (gph).

DRIP EMITTER EXAMPLE:
The emitter average discharge rate for a drip emitter system was 0.9 gph (from above) and there were five drip emitters per tree, the average tree discharge rate (gph) would be 4.5 gph (5 drippers/tree x 0.9 gph/dripper = 4.5 gph).

MICROSPRINKLER EXAMPLE:
If the emitter average application rate was 10.0 gph (from above) for the microsprinkler system, and there was a single microsprinkler per tree, the average tree discharge rate would be 10.0 gph (1 microsprinkler/tree x 10.0 gph/microsprinkler = 10.0 gph).

NOMINAL PERFORMANCE

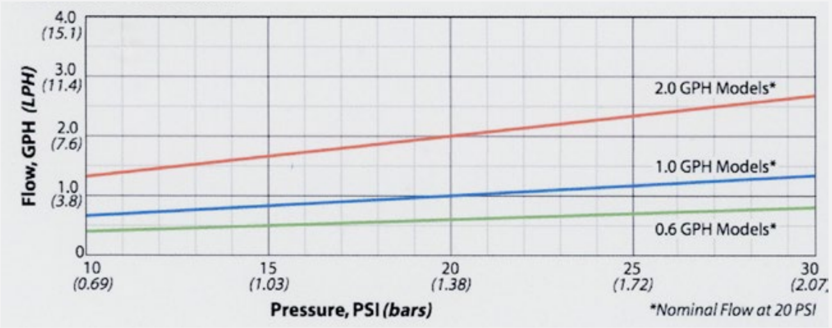


Figure 18. Pressure vs. discharge rate relationship for a drip emitter. Will vary by manufacturer. (Source: Bowsmith)

FLOW VS. PRESSURE

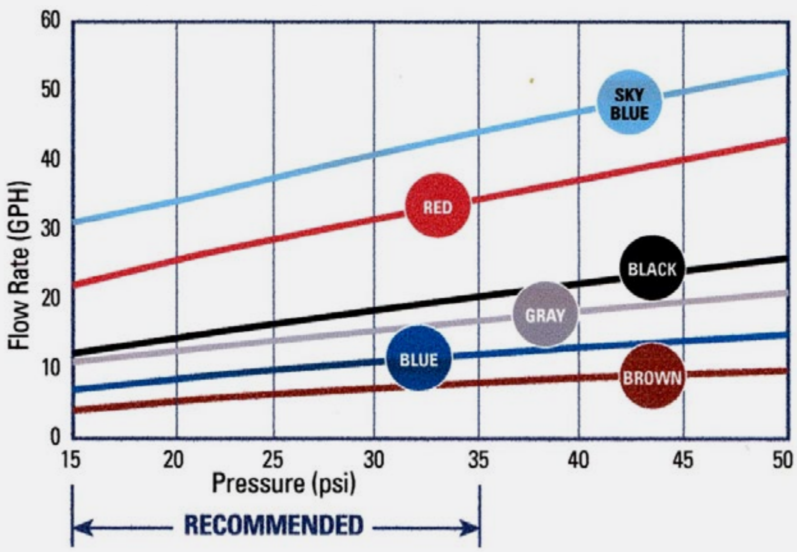


Figure 19. Pressure vs. discharge relationship for microsprinklers. Will vary by manufacturer. (Source: Bowsmith)

3. Calculate the microirrigation system average application rate (in/hr) using the following formula:

$$\text{Microirrigation system average Application rate (in/hr)} = \frac{\text{Average tree discharge rate (gph)}}{\text{Tree spacing (ft}^2\text{)}} \times 1.6$$

DRIP EMITTER EXAMPLE (continued)**:**

For an almond orchard with a tree spacing of 16 x 22 feet and a drip system with an average tree discharge rate of 4.5 gph (from above), the average application rate would be:

Tree spacing = 16 feet x 22 feet = 352 ft^2

$$\text{Microirrigation system average Application rate (in/hr)} = \frac{4.5 \text{ gph}}{352 \text{ ft}^2} \times 1.6 = 0.02 \text{ in/hr}$$

MICROSPRINKLER EXAMPLE (continued)**:**

For an almond orchard with a tree spacing of 16 x 22 feet and a microsprinkler system with a tree average discharge rate of 10.0 gph, the average application rate would be:

Tree spacing = 16 feet x 22 feet = 352 ft^2

$$\text{Microirrigation system average Application rate (in/hr)} = \frac{10.0 \text{ gph}}{352 \text{ ft}^2} \times 1.6 = 0.045 \text{ in/hr}$$

EQUATING PRESSURE DIFFERENCES TO DISTRIBUTION UNIFORMITY

The uniformity of a microirrigation system, a measure of how evenly or uniformly water is applied to the almond orchard, is quantified by distribution uniformity. A nonuniform irrigation system will over-irrigate some trees and under-irrigate others.

Using "Irrigation System Performance" fundamental 1.0 practices where only pressure measurements are field-collected, distribution uniformity can at best be estimated. In the section "Irrigation System Performance" in *Continuum Level 2.0* and *Level 3.0*, distribution uniformity will be determined from actual emitter discharge rates.

When only pressure measurements are collected, distribution uniformity can be estimated as follows.

1. Non-PC drippers and microsprinklers with minimal emission device clogging:

Field pressure differences (%)	Estimated distribution uniformity (%)
10 or less	85–90
10–20	80–85
Greater than 20	80 or less

2. PC drippers and microsprinklers with minimal emission device clogging and operating within the manufacturer's recommended operation pressure range: Assume distribution uniformity of 85–90%

NEXT STEPS

1. The average application rate is a very important piece of information regarding your micro-irrigation system. Keep it handy since it will be used extensively when scheduling your irrigations. It should not change significantly unless the pressure in the system changes.
2. Variability in measured pressures in the orchard of greater than 20% can cause significant irrigation application nonuniformity. Consider calling in an irrigation professional to see what is causing the differences and what can be done to improve it.
3. Recheck your microirrigation system in three years. At a minimum, recheck the same locations originally evaluated. This will give an excellent measure of any changes that may have occurred. Consider measuring some additional locations to provide even better information.

MOVING UP THE CONTINUUM

Moving up to the intermediate practices described in "Irrigation System Performance" in *Continuum Level 2.0* involves a closer look at the micro-irrigation system information collected here and addresses how to account for microsprinkler or drip emitter discharge rate variability.

IRRIGATION SYSTEM PERFORMANCE

INTRODUCTION

Up-to-date irrigation system performance information is essential in irrigation water management. An orchard's irrigation system should be evaluated at a minimum of every three years. The two important steps required for good irrigation water management are knowing how much water needs to be applied and operating the irrigation system to apply that desired amount.

Before you take steps to personally evaluate your irrigation system, check to see if there is a mobile irrigation lab in your area. These mobile labs are sponsored by a local agency (county, resource conservation district, water district, etc.) in partnership with the California Department of Water Resources. They are experts in irrigation system evaluation and will do the evaluation for minimal or no charge. Currently there are 12 to 15 mobile labs working in California, five in the Central Valley. Commercial companies in your area may also do irrigation system evaluations for a fee.

For more information on determining the irrigation system application rate and uniformity, refer to the system-specific information on the following pages. Systems include:

2.0 Practice:

Assess distribution uniformity and average application rate by measuring water volume at least every three years. Correct any diagnosed system performance problems.

What's New in "Irrigation System Performance" Level 2.0?

In *Level 1.0* of "Irrigation System Performance," only pressure measurements were gathered to determine the average application rate and estimate distribution uniformity. In *Level 2.0*, discharge rates from sprinklers or micro-irrigation emitters were collected, along with pressure measurements, to better estimate the average application rate and distribution uniformity.

To keep you from having to refer back to "Irrigation System Performance" *Level 1.0*, the pertinent information from "Irrigation System Performance" *Level 1.0* has been repeated in "Irrigation System Performance" *Level 2.0* to make it easier to use.

SURFACE IRRIGATION SYSTEMS

INTRODUCTION

Surface irrigation systems include furrow and border strip systems. Border strip systems that flood the area between tree rows (middles) are more common in almonds, but irrigation is also done using a number of furrows paralleling the tree rows.

Determining the application rate and especially the application uniformity of surface irrigation systems is very difficult and is almost always done by a professional irrigation system evaluator. A grower can determine how much water is applied during an irrigation set, an important piece of water management information, but to move on to "Irrigation System Performance" *Levels 2.0* and *3.0*, in which the irrigation application uniformity is measured, the assistance of a professional irrigation evaluator is recommended.

INFORMATION TO BE GATHERED

Determining the amount of applied water during an irrigation set requires knowing:

- flow rate to the orchard
- orchard area irrigated during the set
- irrigation set time (duration)
- amount of time it takes water to reach the tail end and final recession time when infiltration over the bottom 1/4 of the border/furrow has been completed

DETERMINING THE VOLUME OF WATER APPLIED

With the above information, use one of the following formulas to determine the applied water (inches; abbreviated as "in") during the irrigation set.

$$\frac{\text{Flow Rate to Orchard (gpm)} \times \text{Irrigation Set Time (min)} \times 1.6}{\text{Orchard Area Irrigated (ft}^2\text{)}} = \text{Applied Water (in)}$$

$$\frac{\text{Flow Rate to Orchard (gpm)} \times \text{Irrigation Set Time (min)} \div 27{,}152}{\text{Orchard Area Irrigated (ac)}} = \text{Applied Water (in)}$$

Water may also be applied to the orchard measured in acre-inches (ac-in).
To determine the inches of water applied, use the following formula:

$$\frac{\text{Water Applied (ac-in)}}{\text{Orchard Area Irrigated (ac)}} = \text{Applied Water (in)}$$

Note that the following conversions may be helpful in working through the formulas above:

- 1 acre = 43,560 ft^2
- 1 cubic foot per second (cfs) = 449 gallons per minute (gpm) = 1.98 ac-ft/day
- 1 cubic foot = 7.48 gallons

In addition to water applied, if runoff from the orchard is reused somewhere else on the property, the runoff volume should be removed from the total water applied during the irrigation. It is often extremely difficult to measure the runoff volume, so an estimate may need to be made. Previous studies have shown that a reasonable estimate of the runoff volume is 15 to 20% of the applied water.[1] If you have a tailwater return system that pushes water back to the head pipe and the same set, this is not an issue.

[1] L. Schwankl, T. Prichard, and B. Hanson. 2007. Reducing Runoff from Irrigated Lands: Tailwater Return Systems. UC ANR Publication 8225. http://anrcatalog.ucanr.edu/pdf/8225.pdf.

APPROXIMATING THE DISTRIBUTION UNIFORMITY

Except for a coarse sandy soil, most infiltration functions are not linear but exponential; meaning you get most of the infiltration in the first few hours of "on time."

EXAMPLE
If the "on time" at the head end = 12 hours (open valve to shut valve) and it took 8 hours to get the water to the tail end, then it took an additional 4 hours for the remaining water in the check to advance, infiltrate totally and finally recedes over the tail end, this equals a total tail end "on time" of 12 – 8 + 4 = 8 hours. The ratio of "on time" = 8/12, but the ratio of infiltration is higher. For a rough proportional comparison of infiltration Distribution Uniformity (DU) use this formula:

Infiltration DU ~= square root (tail "on time" / head "on time") = (8/12)^0.5 = 82%

NEXT STEPS

Compare the amount of irrigation water applied with the estimated orchard water use as described in the *Almond Irrigation Improvement Continuum Level 1.0* fundamental "Orchard Water Requirements" section. This can be done after each irrigation event or on an annual basis. If you find that you are applying significantly more irrigation water than is needed to meet the orchard's water needs, strongly consider a professional system evaluation to improve your irrigation practices.

MOVING UP THE CONTINUUM

Moving up to the intermediate practices described in "Irrigation System Performance" *Level 3.0* entails making estimates of irrigation uniformity in addition to measuring the applied water.

For surface irrigation systems, measuring the irrigation uniformity is complicated and will require the assistance of an irrigation system evaluation professional. In some areas, an irrigation system evaluation team (mobile lab) is available to provide assistance. If you have access to a mobile lab, take advantage of its services.

Figure 1. Impact sprinkler. (Photo by L. Schwankl)

SPRINKLER IRRIGATION SYSTEMS

INTRODUCTION

Two types of sprinkler irrigation systems are used in almond orchards: impact sprinklers (Fig. 1) and rotator-type sprinklers (Fig. 2). These types of sprinklers will be discussed separately, as pressure measurement techniques vary between the two. Please consult the sections below that apply to your system(s).

Almond sprinkler irrigation systems allow for useful pressure measurements to be taken quickly and easily. Sprinkler discharge measurements are easily collected in impact sprinklers, but are difficult to gather in rotator-type sprinklers.

Figure 2. Rotator-type sprinkler. (Photo by T. Prichard)

IMPACT SPRINKLERS

INFORMATION TO BE GATHERED

The following information should be gathered and recorded for orchards irrigated with impact sprinklers.

1. Spacing between sprinklers in the tree row and spacing between sprinklers across the tree row.
2. At each sprinkler sampled, the nozzle orifice size, operating pressure and emitter discharge should be measured.

WHEN TO TAKE MEASUREMENTS

It is recommended that the sprinkler system be evaluated at a minimum every three years. The evaluation can be done at any time during the irrigation season but evaluating the irrigation system early in the season provides the opportunity to correct any problems and allows the system to be operated optimally during the upcoming irrigation period. If you are aware of important operating condition changes, such as groundwater levels changing significantly, additional evaluations may be warranted.

WHERE TO TAKE MEASUREMENTS

Before any measurements are taken in the orchard, the filters (if any), mainlines and submains should be flushed to ensure that the sprinkler system is working optimally. This is also a good time to ensure that the pressure regulation (if any) is working properly. If sprinklers need to be cleaned, this should be done at this time.

The objective in gathering the pressure measurements is to characterize the pressure for the orchard or irrigation set as a whole. Pressure measurements should be taken at (Fig. 3):

- The head, middle and tail end (from the pump or head of the system) areas of the orchard or irrigation set.
- The head, middle and tail end of sprinkler lateral lines.
- High- or low-elevation areas in the orchard or irrigation set. Extra measurements may be needed in these locations. Equally distribute these additional measurements between high- and low-elevation locations so that the measurements are not biased.

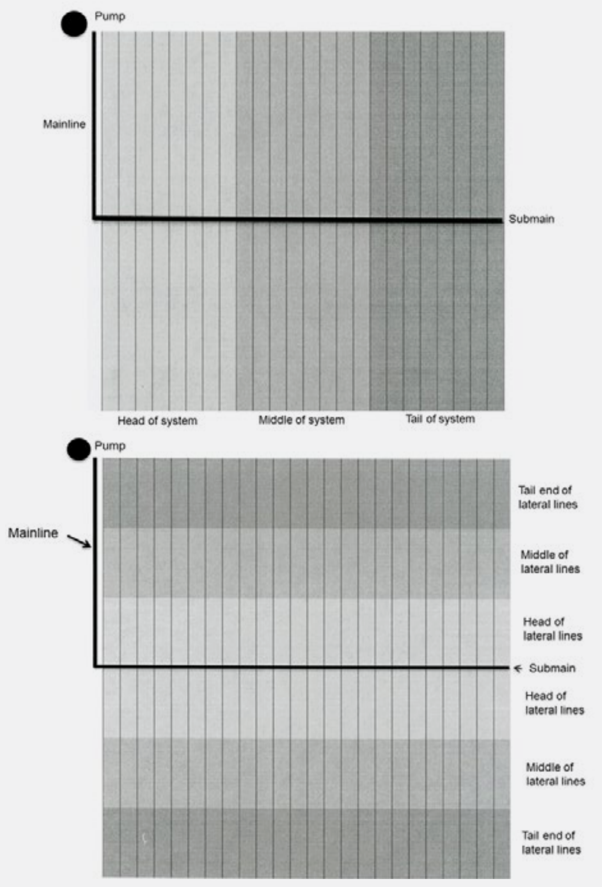


Figure 3. Irrigation system pressure measurements should be taken at a variety of locations within the system. Use the descriptions above to understand how these relate to your setup. (Source: L. Schwankl)

Since the sprinkler system mainlines, submains and lateral lines are most often below ground, having an irrigation system layout plan or map is extremely useful in planning where to take measurements and for recording where measurements were taken. If it is known that some sprinkler lateral lines are longer than others, measure the pressure on the longer lines, since the pressure loss will be greater in these laterals.

SYSTEM SUBUNIT PRESSURE REGULATORS

Many large acreage orchards in California can have large pressure differences in the mainlines and submains of the orchard. A good designer can use mainline pressure (friction) loss to even out this pressure difference down the field, but most good designs incorporate some kind of pressure regulation valves across the field — often adjacent to set changing valves. These may be sophisticated three-way automatic compensation valves with a side-mounted spring-loaded pressure compensation adjuster or just a secondary simple gate valve that is partially closed and left in that position to reduce pressure. Schrader-type valve stems (like a tire valve) should be mounted on the upstream and downstream sides of these valves. Check the downstream pressure just after these valves. If these pressures vary by more than 3-5 psi across the orchard the distribution uniformity will not be acceptable. Adjust the pressure regulating valves to achieve a uniform pressure, which will maximize your potential distribution uniformity.

HOW MANY SPRINKLERS TO SAMPLE

As with all sampling, the answer to how many samples should be collected is that more is always better. At a minimum, 30 to 40 sprinklers should be sampled, even on a small-acreage orchard. As the acreage increases, use the guideline of sampling two or more sprinklers per acre.

When the pressure is measured at a sprinkler head, the record of its location should be good enough that the same sprinkler could be located and remeasured at a later date. Spray painting the sprinkler riser can assist in locating the sprinkler in the future.

If it becomes evident during sampling that there is significant variability between sprinkler pressures, consider increasing the number of sprinklers sampled. Additional sampling increases the probability of diagnosing the cause of the variability. If the sprinkler pressure variability seems to be associated with high- or low-elevation areas of the orchard, additional sampling of sprinkler pressure in those areas is warranted.

SPRINKLER NOZZLE ORIFICE SIZE

Orchards are most often designed to have the same sprinkler nozzle size throughout. However, do not simply assume that this is true for your orchard. For older sprinkler systems, it is not uncommon for sprinklers to have been replaced during maintenance and substituted with nozzle sizes other than the design size.

The size of brass nozzles is often stamped on the side of the nozzles (Fig. 4). This can be very difficult to see, especially in the field, so using a set of drill bits to determine the orifice size is often easier. Depending on how much sand is pumped in the water, 3+ year-old nozzles can be worn as much as 1/64 inch beyond their original size. The correct size bit should just fit into the orifice; keep that drill bit handy, as it can be used to quickly check each sprinkler sampled.

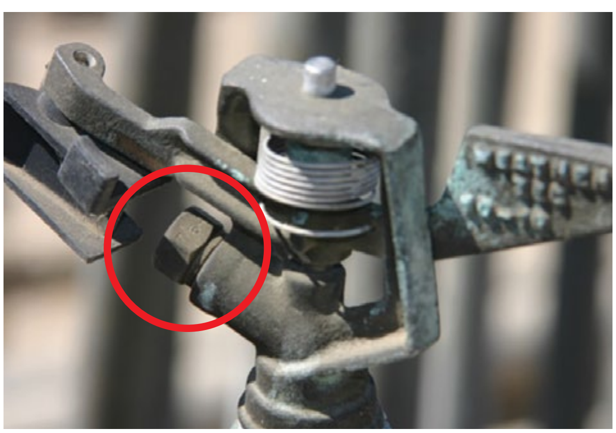


Figure 4. Impact sprinkler nozzle size is often stamped onto the side of the nozzle. On this sprinkler it is noted as "7/64" and circled in red. (Photo by L. Schwankl)

Figure 5. A pitot tube fitted with a pressure gauge works well for taking sprinkler pressure measurements. (Photo by L. Schwankl)

MEASURING SPRINKLER OPERATING PRESSURE

The easiest way to measure the operating pressure of an impact sprinkler is to use a pressure gauge fitted with a pitot tube (Fig. 5). The pitot tube is a small, curved, hollow brass tube that should be available for purchase from your local irrigation equipment supplier. A 0–60 psi or a 0–100 psi liquid-filled pressure gauge works well for taking the measurements.

The same new pressure gauge should be used to measure all the pressures when sampling. A new pressure gauge is advantageous because pressure gauges often become less accurate with use. If multiple pressure gauges are to be used, confirm that they all read the same pressure by measuring a single location with each gauge.

Once fitted with a pressure gauge, hold the pitot tube in the water stream just outside the sprinkler nozzle and read the pressure on the gauge (Fig. 6). Move the pitot tube around in the water stream until the maximum pressure is noted. With practice, the pressure can be measured at a sprinkler head in only a few seconds. When the measurement is taken, record its location within the orchard on an orchard plot map or write a good description of its location.

Figure 6. Water pressure is read by positioning the pitot tube directly in the sprinkler's water stream.

Figure 7. Collecting discharge from an impact sprinkler.

MEASURING SPRINKLER DISCHARGE RATE

Using a short (3 to 5 foot) section of hose (garden hose works well), place one end of the hose over the sprinkler nozzle and direct the discharge into a container of known volume (a 5 gallon bucket, marked in 1 gallon increments works well) (Fig. 7). Keep track of the time it takes to collect a known volume of water. Calculate the sprinkler discharge rate (gallons per minute).

EXAMPLE

It takes 100 seconds to collect 2 gallons of water from a sprinkler head.
What is the discharge rate (gallons per minute) from the sprinkler?

100 seconds x min ÷ 60 sec = 1.67 minutes

2 gallons ÷ 1.67 minutes = 1.2 gpm Sprinkler Discharge Rate

DETERMINING THE AVERAGE APPLICATION RATE

Use the following steps to determine the average application rate (in/hr) for orchards irrigated with impact sprinklers:

1. Average the sprinkler discharge rates (gpm) of all the sprinklers sampled. If there are any sprinkler(s) whose discharge rate seems to uncharacteristically stand out as being too high or too low, confirm that the correct nozzle was installed. A different nozzle size may have been incorrectly installed during past maintenance or high flow may be the result of excessive wear.

2. With the tree spacing information collected at the beginning of this section, use the following formula to determine the average application rate for the orchard.

$$\text{Average Sprinkler Application Rate (in/hr)} = \frac{96.3 \times (\text{Average sprinkler discharge rate – gpm})}{\text{Sprinkler spacing in the tree row (ft)} \times \text{Sprinkler spacing across the tree row (ft)}}$$

DETERMINING THE DISTRIBUTION UNIFORMITY

1. Rank all the sprinkler discharge rates (gpm) from the lowest to the highest. This can be done manually or with the use of a spreadsheet program like Microsoft Excel. Determine the average of the low 25% of sprinkler discharge rates measured. For example, if 40 sprinklers were evaluated, the average of the 10 sprinklers with the lowest discharge rates would be the average of the low 25% of sprinkler discharge rates measured (gpm). Also calculate the average application rate of all 40 sprinklers.

2. Determine the Distribution Uniformity (DU) using the following formula.

$$\text{Distribution Uniformity (DU-\%)} = \frac{\text{Avg. of the low 25\% of sprinkler discharge rates measured}}{\text{Avg. of all sprinkler discharge rates measured}} \times 100$$

NEXT STEPS

1. The average application rate is a very important piece of information regarding your sprinkler system. Keep it handy, since it will be used extensively when scheduling irrigations. It should not change significantly unless the pressure in the system changes. If you have filters in the system, be sure to keep them flushed and clean, since they are a frequent source of pressure loss.

2. If the distribution uniformity is below 80%, diagnose the problem. Often, the sprinkler system nonuniformity is a result of excessive system pressure differences. The pressure differences may be caused by elevation changes (2.3 feet of elevation change = 1 psi of pressure difference), or by excessive frictional pressure losses in the underground piping system. The pressure measurements collected during the field evaluation will provide valuable information regarding any excessive pressure differences.

   A solution to minimizing sprinkler discharge rate variability due to pressure differences may be to install flow control nozzles that provide a more constant discharge rate with changes in operating pressure. For systems more than five years old, if the pressure differences seem acceptable but the distribution uniformity is below 85% when nozzle discharges are measured, it may be excessive nozzle wear that is the issue and installing new nozzles may be a solution. It is always a good idea to consult an irrigation professional when considering any significant changes to your sprinkler system.

3. Recheck your sprinklers every three years. It is recommended that you recheck the same sprinklers originally evaluated. This will provide an excellent measure of any changes that may have occurred. Consider measuring additional sprinklers to provide even better information.

MOVING UP THE CONTINUUM

Moving up to the advanced practices described in "Irrigation System Performance" *Level 3.0* involves evaluating your sprinkler system on a more frequent schedule (every two years) and making sure any diagnosed problems are addressed.

ROTATOR SPRINKLERS

INFORMATION TO BE GATHERED

The following information should be gathered and recorded for orchards irrigated with rotator sprinklers (Fig. 8).

1. Spacing between sprinklers in a tree row and spacing between sprinkler lines across the tree row.
2. At each sprinkler sampled, note the model of the Rotator sprinkler (e.g., R5, R10), the color of the top plate deflector, the color of the nozzle in the sprinkler and the operating pressure measured.

Figure 8. Rotator-type sprinkler. (Photo by T. Prichard)

WHEN TO TAKE MEASUREMENTS

It is recommended that the sprinkler system be evaluated at a minimum of every three years. The evaluation can be done at any time during the irrigation season, but evaluating the irrigation system early in the season provides the opportunity to correct any problems and allows the system to be operated optimally during the upcoming irrigation period. If you are aware of important operating condition changes, such as groundwater levels changing significantly, additional evaluations may be warranted.

WHERE TO TAKE MEASUREMENTS

Before any measurements are taken in the orchard, the filters (if any), mainlines and submains should be flushed to ensure that the sprinkler system is working optimally. This is also a good time to ensure that the pressure regulation (if any) is working properly. If filters or sprinklers need to be cleaned, this should be done first.

The objective in gathering the pressure measurements is to characterize the pressure for the orchard or irrigation set as a whole. Pressure measurements should be taken at (Fig. 9):

- The head, middle and tail end (from the pump or head of the system) of the orchard or irrigation set.

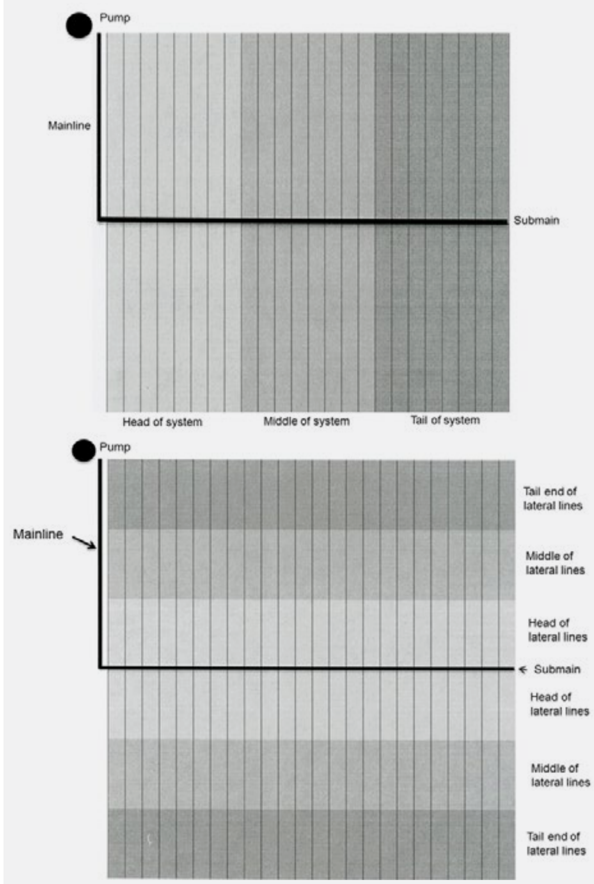


Figure 9. Irrigation system pressure measurements should be taken at a variety of locations within the system. Use the descriptions above to understand how these relate to your setup. (Source: L. Schwankl)

- The head, middle and tail end of sprinkler lateral lines.
- If there are high- or low-elevation areas in the orchard, extra measurements may be needed in those locations. Equally distribute these additional measurements between high- and low-elevation locations so that the measurements are not biased.

Since the sprinkler system mainlines, submains and lateral lines are most often below ground, having an irrigation system layout map is extremely useful in planning where to take measurements and for recording where measurements were taken. If it is known that some sprinkler lateral lines are longer than others, measure the pressures on the longer lines, since the pressure loss will be greater in these laterals.

SYSTEM SUBUNIT PRESSURE REGULATORS

Many large acreage orchards in California can have large pressure differences in the mainlines and submains of the orchard. A good designer can use mainline pressure (friction) loss to even out this pressure difference down the field, but most good designs incorporate some kind of pressure regulation valves across the field – often adjacent to the set changing valves. These may be sophisticated three-way automatic compensation valves with a side-mounted spring-loaded pressure compensation adjuster or just a secondary simple gate valve that is partially closed and left in that position to reduce pressure. Schrader-type valve stems (like a tire valve) should be mounted on the upstream and downstream sides of these valves. Check the downstream pressure just after these valves. If these pressures vary by more than 3-5 psi across the orchard the distribution uniformity will not be acceptable. Adjust the pressure regulating valves to achieve a uniform pressure that will maximize your potential distribution uniformity.

HOW MANY SPRINKLERS TO SAMPLE

As with all sampling, the answer to how many samples should be collected is that more is always better. At a minimum, 30 to 40 sprinklers should be sampled, even on a small-acreage orchard. As the acreage increases, use the guideline of sampling two or more sprinklers per acre.

When the pressure is measured at a sprinkler head, the record of its location should be good enough that the same sprinkler could be located and remeasured at a later date. Spray painting the sprinkler riser can assist in locating the sprinkler in the future.

If it becomes evident that there is significant variability between sprinkler pressures, consider increasing the number of sprinklers sampled. Additional sampling increases the probability of diagnosing the cause of the variability. If the sprinkler pressure variability seems to be associated with high- or low-elevation areas of the orchard, additional sampling of sprinkler pressure in those areas is warranted.

MEASURING SPRINKLER OPERATING PRESSURE

Because of the rotator sprinkler design, pressure cannot be easily measured using the simple method described for impact sprinklers. Instead, remove the rotator sprinkler head and install a pressure gauge fitted with the same thread configuration as a sprinkler head to determine the operating pressure (Fig. 10). A 0–60 psi or 0–100 psi liquid-filled pressure gauge works well for taking the measurements. Many rotator sprinklers have Acme threads, which allow for rapid installation and removal; in that case, use an adaptor on the pressure gauge. This is a wet job since you need to move the gauge from one sprinkler to the next while the system is running.

Use the same, new pressure gauge to measure all the pressures when sampling. A new pressure gauge is advantageous because pressure gauges often become less accurate with use. If multiple pressure gauges are to be used, confirm that they all read the same by measuring a single location with each gauge.

Figure 10. Rotator sprinkler with pressure gauge attachment temporarily installed during field evaluation to measure the pressure at the sprinkler head.

PLATE/NOZZLE OPTIONS AND FLOW PERFORMANCE IN GPM AND LPH

Plate Series	Plate Options	Recommended Nozzles	PSI 30	PSI 35	PSI 40	PSI 45	PSI 50	PSI 55	PSI 60	BAR 2.0	BAR 2.5	BAR 3.0	BAR 3.5	BAR 4.0
K1	**K1 6° Cream** Radius: 21-25' (6.4-7.6 m) Stream Ht.: 15-25" (38-64 cm)	Gray #8.3	.67	.72	.77	.82	.86	.90	.94	150	166	183	197	210
		.85 2000FC	Within the recommended pressure range of 30-60 PSI (2.0-4.0 BAR), the .85 2000 FC flow control nozzle is flow regulating within a flow range of no more than 3.5% greater and 8% less than the nominal flow of .85 GPM (193 LPH).											
K2	**K2 6° Light Blue** Radius: 22-26' (6.7-7.9 m) Stream Ht.: 15-32" (38-81 cm)	White #9	.77	.83	.89	.94	1.00	1.05	1.10	172	192	210	229	245
		Dark Blue #10	.97	1.05	1.12	1.19	1.25	1.31	1.37	217	242	266	286	306
		1.0 2000FC	Within the recommended pressure range of 30-60 PSI (2.0-4.0 BAR), the 1.0 2000 FC flow control nozzle is flow regulating within a flow range of no more than 3.5% greater and 8% less than the nominal flow of 1.0 GPM (227 LPH).											
	K2 9° Green Radius: 23-27' (7.0-8.2 m) Stream Ht.: 18-37" (46-94cm)	Gray #8.3	.67	.72	.77	.82	.86	.90	.94	150	166	183	197	210
		White #9	.77	.83	.89	.94	1.00	1.05	1.10	172	192	210	229	245
		Dark Blue #10	.97	1.05	1.12	1.19	1.25	1.31	1.37	217	242	266	286	306
	K2 15° Yellow Radius: 27-30' (8.2-9.1 m) Stream Ht.: 31-55" (79-140 cm)	.85 2000FC	Within the recommended pressure range of 30-60 PSI (2.0-4.0 BAR), the .85 2000 FC flow control nozzle is flow regulating within a flow range of no more than 3.5% greater and 8% less than the nominal flow of .85 GPM (193 LPH).											
		1.0 2000FC	Within the recommended pressure range of 30-60 PSI (2.0-4.0 BAR), the 1.0 2000 FC flow control nozzle is flow regulating within a flow range of no more than 3.5% greater and 8% less than the nominal flow of 1.0 GPM (227 LPH).											
K3	**K3 9° Brown** Radius: 25-28' (7.6-8.5 m) Stream Ht.: 19-33" (48-84 cm)	Orange #11	1.17	1.27	1.36	1.45	1.53	1.61	1.68	261	294	323	350	375
		Purple #12	1.39	1.50	1.61	1.70	1.80	1.89	1.98	311	347	380	412	442
	K3 15° Red Radius: 27-31' (8.2-9.4 m) Stream Ht.: 38-63" (97-160 cm)	1.25 2000FC	Within the recommended pressure range of 30-60 PSI (2.0-4.0 BAR), the 1.25 2000 FC flow control nozzle is flow regulating within a flow range of no more than 3.5% greater and 8% less than the nominal flow of 1.25 GPM (284 LPH).											
		1.5 2000FC	Within the recommended pressure range of 30-60 PSI (2.0-4.0 BAR), the 1.5 2000 FC flow control nozzle is flow regulating within a flow range of no more than 3.5% greater and 8% less than the nominal flow of 1.5 GPM (341 LPH).											
	K3 24° Gray Radius: 29-35' (8.8-10.7 m) Stream Ht.: 68-103" (173-262 cm)													
K4	**K4 6° Turquoise** Radius: 21-25' (6.1-7.6 m) Stream Ht.: 10-24" (25-61 cm)	Yellow #13	1.64	1.78	1.90	2.02	2.13	2.23	2.34	366	411	451	487	521
		Green #14	1.85	2.00	2.15	2.28	2.40	2.53	2.64	413	463	509	550	590
	K4 9° Purple Radius: 26-32' (7.9-9.4 m) Stream Ht.: 28-42" (71-107 cm)	1.5 2000 FC	Within the recommended pressure range of 30-60 PSI (2.0-4.0 BAR), the 1.5 2000 FC flow control nozzle is flow regulating within a flow range of no more than 3.5% greater and 8% less than the nominal flow of 1.5 GPM (341 LPH).											
		2.0 2000 FC	Within the recommended pressure range of 30-60 PSI (2.0-4.0 BAR), the 2.0 2000 FC flow control nozzle is flow regulating within a flow range of no more than 3.5% greater and 8% less than the nominal flow of 2.0 GPM (454 LPH).											
	K4 12° Wine Radius: 27-31' (8.2-9.4 m) Stream Ht.: 32-51" (81-130 cm)													
	K4 15° Gold Radius: 27-33' (8.2-10.1 m) Stream Ht.: 40-60" (102-152 cm)													
	K4 24° Black Radius: 28-36' (8.5-11.0 m) Stream Ht.: 65-100" (165-254 cm)													
K5	**K5 9° Orange** Radius: 27-31' (8.2-9.4 m) Stream Ht.: 25-42" (54-107 cm)	Tan #15	2.17	2.35	2.53	2.67	2.82	2.97	3.11	485	544	597	647	695
		Dark Red #16	2.50	2.70	2.89	3.07	3.23	3.40	3.54	559	624	685	739	792
	K5 15° Tan Radius: 31-36' (9.4-11.0 m) Stream Ht.: 36-49" (91-124 cm)	2.5 2000FC	Within the recommended pressure range of 30-60 PSI (2.0-4.0 BAR), the 2.5 2000 FC flow control nozzle is flow regulating within a flow range of no more than 3.5% greater and 8% less than the nominal flow of 2.5 GPM (568 LPH).											
	K5 24° Blue Radius: 32-37' (9.8-11.3 m) Stream Ht.: 76-104" (193-264 cm)													

Figure 11. Sample model information for Nelson rotator sprinklers (R2000) which indicates what a given model's nozzle color, pressure and flow rate should be. (Source: Nelson Irrigation)

DETERMINING THE AVERAGE APPLICATION RATE

With the sprinkler nozzle color and the operating pressure, visit the appropriate irrigation manufacturer or distributor's website to acquire the necessary technical information for the irrigation product installed in your orchard. In this example, visit Nelson Irrigation online Rotator Technology Pocket Guide at nelsonirrigation.com to get the nozzle color, pressure or flow rate for the sprinkler model being evaluated. For example, the figure below is for the R2000 model sprinkler (Fig. 11; see page 75). The tables available from Nelson Irrigation are provided in pressure increments of 5 psi, so interpolation will be required to determine the sprinkler discharge rate.

Note that as the pressure goes up, the sprinkler discharge also goes up. The reverse also holds true. If sprinklers in an area of the orchard consistently have lower pressures and therefore lower sprinkler discharges, that section of the orchard will be under-irrigated as compared with other orchard areas with higher pressures.

Convert each sprinkler pressure measurement collected to a sprinkler discharge rate using the appropriate manufacturer table.

Use the following steps to determine the average application rate (in/hr) of orchards irrigated with impact sprinklers:

1. Average the sprinkler discharge rates (gpm) of all the sprinklers sampled.

$$\text{Average Sprinkler Application Rate (in/hr)} = \frac{96.3 \text{ x (Average sprinkler discharge rate – gpm)}}{\text{Sprinkler spacing in the tree row (ft)} \text{ X } \text{Sprinkler spacing across the tree row (ft)}}$$

2. With the tree spacing information collected at the beginning of this section, use the following formula to determine the average application rate for the orchard.

DETERMINING THE DISTRIBUTION UNIFORMITY

Rank all the sprinkler discharge rates (gpm) from the lowest to the highest. This can be done manually or with the use of a spreadsheet program like Microsoft Excel. Determine the average of the low 25% of sprinkler discharge rates measured. For example, if 40 sprinklers were evaluated, the average of the 10 sprinklers with the lowest discharge rates would be the average of the low 25% of sprinkler discharge rates measured (gpm). Also calculate the average application rate of all 40 sprinklers.

Determine the distribution uniformity (DU) using the following formula.

$$\text{Distribution Uniformity (DU\%)} = \frac{\text{Avg. of the low 25\% of sprinkler discharge rates measured}}{\text{Avg. of all sprinkler discharge rates measured}} \text{ x } 100$$

NEXT STEPS

1. The average application rate is a very important piece of information regarding your sprinkler system. Keep it handy since it will be used extensively when scheduling your irrigations. It should not change significantly unless the pressure in the system changes. If you have filters in the system, be sure to keep them flushed and clean since they are frequently a source of pressure loss.

2. If the distribution uniformity is below 80%, diagnose the problem. Often, the sprinkler system nonuniformity is a result of excessive system pressure differences. The pressure differences may be caused by elevation changes (2.3 feet of elevation change = 1 psi of pressure difference), or by excessive frictional pressure losses in the underground piping system. The pressure measurements collected during the field evaluation will provide valuable information regarding any excessive pressure differences.

Use of flow control (FC) nozzles may be a solution to improving irrigation uniformity on some rotator-type sprinkler systems. They discharge at a more uniform rate across a range of operating pressures. Flow control nozzles are not available for all rotator sprinklers, so check to see if they are available for your sprinklers. Pressure regulators that screw into the base of the nozzle are also available to deliver more consistent pressure across the orchard. It is always a good idea to consult with an irrigation professional when considering any significant changes to your sprinkler system.

3. Recheck your sprinklers in three years. It is recommended that you recheck the same sprinklers originally evaluated. This will give an excellent measure of changes that may have occurred. Consider measuring additional sprinklers to provide even better information.

MOVING UP THE CONTINUUM

Moving up to the advanced practices described in “Irrigation System Performance” *Level 3.0* involves evaluating your sprinkler system on a more frequent schedule (every two years) and making sure any diagnosed problems are addressed.

MICROIRRIGATION SYSTEMS

INTRODUCTION

Microirrigation systems come in the form of microsprinklers (Fig.12) or drip (Fig.13). In “Irrigation System Performance” *Level 1.0*, only pressure measurements were collected, but in “Irrigation System Performance” *Level 2.0* both pressure measurements and emission device discharge rates will be collected to determine the irrigation system’s average application rate and the distribution uniformity. Collecting emission device discharge rate is an important step to improving irrigation water management in microirrigation systems since their measurement provides valuable information on emission device clogging.

Figure 12. Microsprinkler irrigation system. (Photo by L. Schwankl)

Figure 13. Drip irrigation system. (Photo by ANR Communications Advisory Board)

MAINTENANCE OF MICROIRRIGATION SYSTEMS

Maintenance of microirrigation systems is a key to their peak performance. The following information includes some of the key maintenance tasks to keep a microirrigation system running well.

You may want to run through these maintenance tasks prior to doing a system evaluation. A field evaluation of a microirrigation system that has serious maintenance issues (e.g., leaks, dirty filters, pressure regulators improperly adjusted, etc.) will not give you good system performance information that you can reliably use for irrigation water management.

See sections: leaks; clogged emission devices; flushing; filters: cleaning and maintenance; checking pressure-regulating valves and pressure gauges.

INFORMATION TO BE GATHERED

Gather and record the following information for orchards irrigated with microirrigation systems.

1. Spacing between trees in the row and spacing between tree rows.
2. Spacing between drip emitters or microsprinklers along the row. Note whether there is double-line drip (two lines of drip tubing and emitters per tree row). The objective of gathering this information is to determine the amount of applied water (gallons per hour) per tree.
3. If the orchard is irrigated in sets (sections or blocks of the orchard that are irrigated separately), monitor and evaluate the sets individually. The sets may not be the same hydraulically: they may differ in size, pressure and flow rate.
4. Record the make and model of the microirrigation emitters used in the orchard. Use a camera or a smartphone to get a good close-up of the dripper or microsprinkler being used. Of particular importance is whether the emitters or microsprinklers are pressure compensating (PC). The discharge rate from nonpressure-compensating drippers or microsprinklers is significantly affected by pressure (Fig. 14). Pressure-compensating drippers or microsprinklers discharge at a constant flow rate even as operating pressure changes (Fig. 15). If you are unsure whether your emitters are pressure compensating, take a sample emitter to your local irrigation equipment supplier for identification.

FLOW VS. PRESSURE

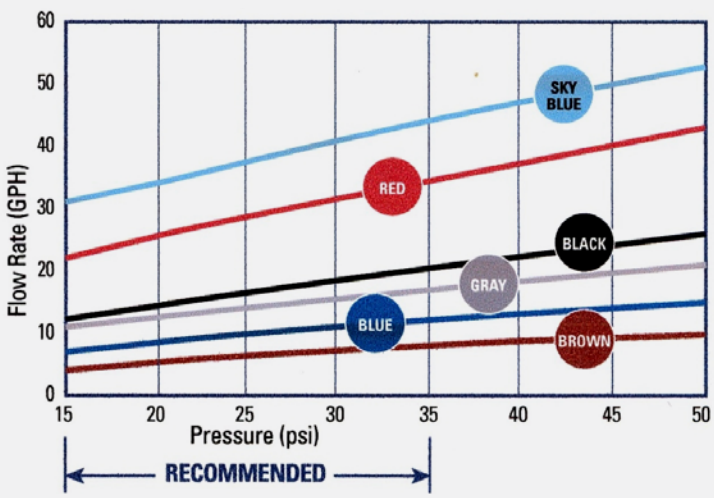
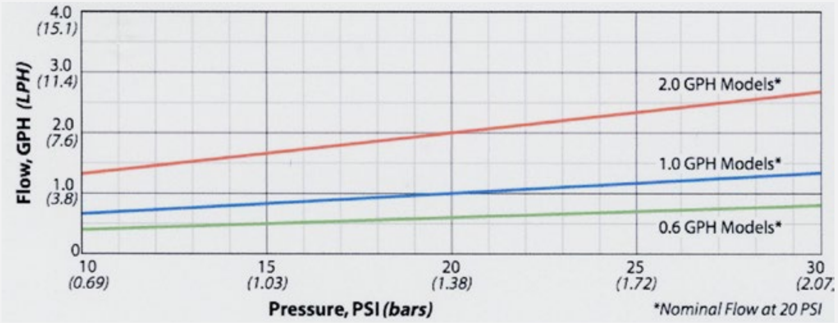
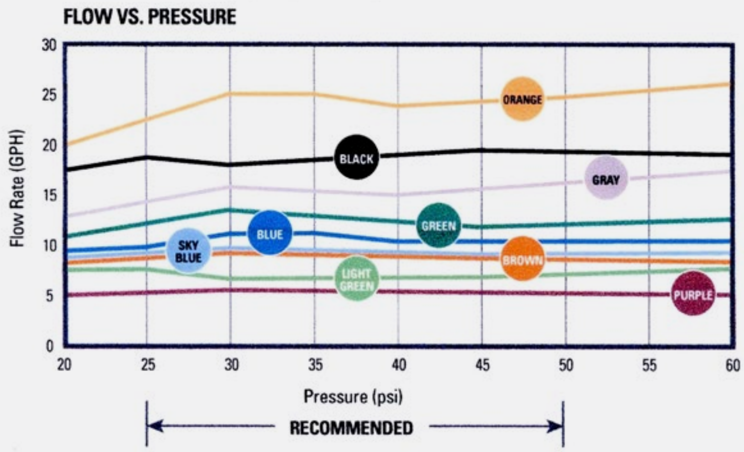


Figure 14. The discharge rate for nonpressure compensating microsprinklers (top) or drippers (bottom) varies with operating pressure. The pressure-discharge rate relationship will vary by manufacturer. (Source: Bowsmith)

NOMINAL PERFORMANCE



PRESSURE-COMPENSATING (PC) MICROSPRINKLER



PRESSURE-COMPENSATING (PC) DRIP EMITTER

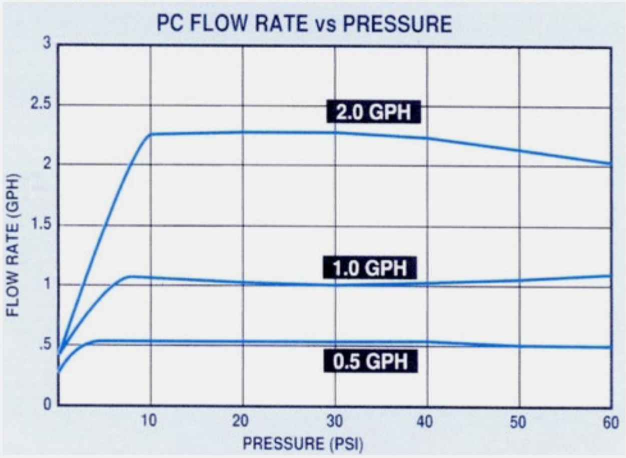


Figure 15. Pressure-compensating microsprinklers (top) and drippers (bottom) adjust to discharge at a constant rate even as operating pressure changes. (Source: Bowsmith and Netafim Irrigation)

WHEN TO TAKE MEASUREMENTS

Microirrigation systems should be evaluated every three years to achieve good irrigation water management. An evaluation every three years will be adequate to diagnose any problems associated with pressure variability, but evaluations should be done even more frequently, even yearly, if there is clogging in the system.

For new microirrigation systems, an excellent strategy is to do a system evaluation shortly after installation. This provides a baseline with which future evaluations can be compared. Do not simply rely on design criteria or "as planned" performance.

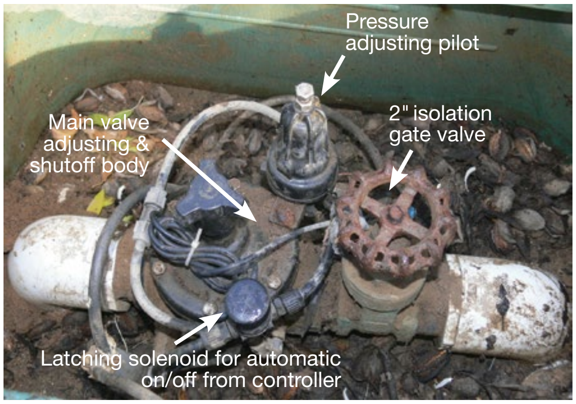


Figure 16. Adjustable pressure-regulating valves installed in separate blocks of the orchard. (Photo by B. Sanden)

WHERE TO TAKE MEASUREMENTS

Before taking any measurements in the orchard, flush the filters, mainlines, submains and lateral lines to ensure that the system is working optimally. Also check pressure-regulating devices to make sure they are operating at the correct pressure. This includes adjustable pressure-regulating valve(s) at the head of the system and/or pressure regulators on the separate blocks (Fig. 16), if any.

The objective in gathering the pressure measurements is to characterize the pressure for the orchard as a whole. Pressure measurements should be taken at (Fig. 17):

- The head, middle and tail end (from the pump or head of the system) of the orchard.
- The head, middle and tail end of the drip or microsprinkler lateral lines.
- If there are high- or low-elevation areas in the orchard, extra measurements may be needed in those locations. Equally distribute these additional measurements between high- and low-elevation locations so that the measurements are not biased.

Since the microirrigation system mainlines and submains are most often below ground, having an irrigation system layout plan map is extremely useful in planning where to take measurements and for recording where measurements were taken.

When the pressure is measured at a dripper or microsprinkler, the record of its location should be good enough that the same emitter could be located and remeasured at a later date. Spray painting the drip hose on either side of the sampled emitter can be helpful in locating the sampled emitter in the future.

HOW MANY EMITTERS TO SAMPLE

As with all sampling, the answer to how many samples should be collected is that more is always better. At a minimum, 30 to 40 pressure locations should be sampled, even on a small-acreage orchard. As the acreage increases, use the guideline of sampling two or more pressure locations per acre.

If it becomes evident during sampling that there is significant variability in pressures, consider increasing the number of locations sampled. Additional sampling increases the probability

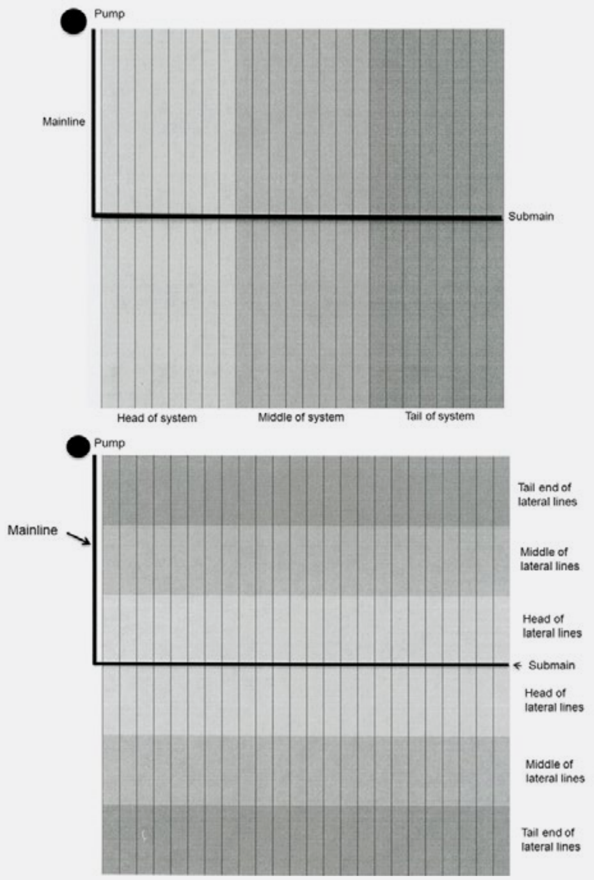


Figure 17. Irrigation system pressure measurements should be taken at a variety of locations within the system. Use the descriptions above to understand where these are relative to your setup. (Source: L. Schwankl)

of diagnosing the cause of the pressure variability. If the pressure variability seems to be associated with areas of high or low elevation in the orchard, additional sampling of pressures in those areas is warranted.

MEASURING OPERATION PRESSURE

Pressure measurements can be readily taken throughout a microirrigation system. A 0–30 psi or 0–60 psi liquid-filled pressure gauge works well for taking the measurements. Use the same, new pressure gauge to measure all the pressures. Using a new pressure gauge is advantageous because pressure gauges often become less accurate with use. If multiple pressure gauges are to be used, confirm that they all read the same pressure by measuring a single location with each gauge.

The following are typical and recommended pressure monitoring locations.

1. At the tail end of lateral lines. There is either an end cap fitting (3/4-inch female hose thread) or the tubing is simply folded over and held closed by a figure-8 fitting or by a 1-inch PVC pipe "ring." Use a pressure gauge that is adapted to the appropriately sized drip fitting and can be temporarily slid over the end of the tubing while the pressure measurement is taken (Fig. 18).

   Measurements at the end of a lateral line account for frictional pressure losses through mainlines, submains and lateral lines. For orchards with little elevation variability, the end of lateral line pressure measurements will be the lowest pressure levels in the system.

2. At the head of the lateral lines. It is very common for there to be an accessible connection where each lateral line connects to the submain system. Often, there is a fitting on the head of the lateral line similar to the female end of a garden hose. These connections should be the same throughout the system, so once you have the pressure gauge adapted to fit it should work throughout the system.

   There is often a hose-end ball valve at this connection that allows the water to be temporarily shut off while the lateral line is disconnected and the adapted pressure gauges installed. Turn the valve back on to take the pressure reading, and turn it off while the lateral line is reinstalled. If no shutoff valve is present, install a temporary pressure gauge. This will be a wet process, so it is best done on a warm day.

Figure 18. Pressure gauge adapted for measurement at tail end of lateral line microirrigation system tubing. (Photo by L. Schwankl)

   As an alternative, measuring the pressure at the first dripper or microsprinkler at the head of a lateral line will give an accurate measure of the pressure at the head of the lateral line.

3. Through tubing system. The pressure can be taken anywhere in the tubing system by punching a hole in the tubing with a drip punch and measuring the pressure using a pressure gauge fitted with a pitot tube (Fig. 19) that will just fit into the punched hole.

Figure 19. A pitot tube fitted with a pressure gauge adapted for measurement within microirrigation tubing system.

   The pitot tube is a small, curved, hollow brass tube that should be available for purchase from your local irrigation equipment supplier. A 0–30 psi or 0–60 psi liquid-filled pressure gauge works well for taking the measurements.

   Once the pressure measurement is taken, close the punched hole using a "goof plug." This method of pressure measurement is preferred by many evaluators because it can be done quickly and allows access to measure the pressure anywhere in the tubing system.

   In microsprinkler systems, an alternative to punching a hole in the drip lateral line is to disconnect the tubing (often 1/4-inch tubing) leading to the microsprinkler and temporarily attaching the pressure gauge, fitted with a pitot tube, to the open end of the tubing. Replace the microsprinkler tubing once the measurement is complete.

Neither punching a hole in the lateral line hose nor connecting the pressure gauge/pitot tube to the microsprinkler will deliver the exact pressure at the microsprinkler since there is some pressure loss (1 to 3 psi) in the smaller, microsprinkler "feeder" line when the microsprinkler is operating. Doing the pressure measurement the same way across the entire system though will provide you with an important measurement of how evenly the pressure is distributed across the system.

LOW PRESSURE CAUTION FOR PRESSURE-COMPENSATING SYSTEMS

There are numerous pressure-compensating (PC) drip emitters and microsprinklers used in almond irrigation that translate to a greater acceptable pressure variability in a PC emitter system design than would be acceptable in a non-PC emitter system design. One caution when evaluating systems with pressure-compensating drippers or microsprinklers: The devices have a minimum operating pressure below which the pressure-compensating feature does not work. This minimum pressure will be evident in the manufacturer's pressure vs. discharge rate charts for their devices, or the manufacturer will specify a minimum recommended operating pressure. If during the field evaluation you find system operating pressures below this minimum recommended operating pressure, be aware that the emitters in those low pressure areas are no longer operating as pressure-compensating and their discharge rates will be lower.

MEASURING EMISSION DEVICE DISCHARGE

Wherever pressure measurements are taken in the system, emission device discharge rates should also be collected. Collecting the two sets of measurements in conjunction is important since pressure information may help explain differences in emission device discharges. If the pressure information does not explain emitter discharge variability, clogging problems then become the likely cause.

An issue that may arise is that some drippers or microsprinklers are completely clogged with no discharge. If this is common, you have already discovered a critical issue with your system that needs to be dealt with before you continue with the field evaluation. Steps should be immediately taken to remedy this clogging problem. Guidance is available at http://micromaintain.ucanr.edu and other web-based resources. Consulting an irrigation professional for expert assistance in cleaning up the clogging problem and initiating a maintenance program to prevent future clogging is often warranted. Remember, clogged drippers or microsprinklers mean that trees are being under-irrigated, and this can detrimentally impact orchard yield and quality. Tree health can even be impacted in cases of serious emitter clogging.

It is relatively easy to collect the discharge from either drip emitters or microsprinklers. For drip emitters, collecting the discharge is as simple as sliding a low-profile container (Fig. 20) under the

Figure 20. Collecting discharge from a drip emitter.

emitter. Make sure that the inflow into the can is only from the single dripper being measured. Sometimes water will run along the lateral hose due to surface tension and drip off at a low point along the lateral line. For “punch-in” drippers (Fig. 20 left) this is usually not a problem, but for “in-line” drip emitters with only a small hole in the tubing from which the water exits, this is a big problem. Simply cut a couple hose washers on one side then wrap them around the tubing on either side of the drip hole and inside the container (Fig. 20 right). Collect water for two minutes and then remove the can from below the emitter. Measure the collected water using a container graduated in milliliters (ml). Measuring the collected water in milliliters provides the accuracy needed. Containers graduated in milliliters are available at farm supply stores and on the internet. The emitter discharge can be determined in gallons per hour (gph) using the following:

_____ ml of water collected in 2 minutes x 0.008 = ____ gph

For example, if 135 ml of water was collected in 2 minutes from the drip emitter, the emitter discharge rate would be: 135 ml of water collected in 2 minutes x 0.008 = 1.08 gph

To measure the discharge rate of a microsprinkler, pull the microsprinkler/stake assembly out of the ground and put the microsprinkler head into a graduated cylinder (a 1000 ml or 2000 ml graduated cylinder usually works well). An alternative is to insert the microsprinkler into a 1 gallon plastic milk container and then measure the water collected with a graduated cylinder. Collect the discharge for one minute. Again, the microsprinkler discharge rate (gph) can be determined using the relationship of:

_____ ml of water collected in 1 minute x 0.016 = ____ gph

For example, if 650 ml of water was collected in 1 minute from a microsprinkler, its discharge rate would be: 650 ml of water collected in 1 minute x 0.016 = 10.4 gph

Note that a single emitter discharge rate measurement takes only a minute or two. A significant number of discharge rate measurements can be collected in a short period of time.

DETERMINING THE AVERAGE APPLICATION RATE

The field-collected emission device discharge rates will be used to determine the average application rate and the distribution uniformity of the microirrigation system. By using the discharge rate information, both pressure differences and any emitter clogging is accounted for.

Follow these steps to estimate the Average Application Rate:

1. Determine the average of all the individual, field-collected emission device discharge rates.
2. Using the Average Emitter Rate (gph) and the number of emitters per tree, determine the Average Tree Discharge Rate (gph).

DRIP EMITTER EXAMPLE

The average emitter discharge rate for a drip emitter system was 1.1 gph and there were 5 drip emitters per tree, the Average Tree Discharge Rate (gph) would be 5.50 gph (5 drippers/tree x 1.1 gph/dripper = 5.50 gph).

MICROSPRINKLER EXAMPLE

The average emitter discharge rate was 8.0 gph for the microsprinkler system and there was a single microsprinkler per tree, the Average Tree Discharge Rate would be 8.0 gph (1 microsprinkler/tree x 8.0 gph/microsprinkler = 8.0 gph).

3. Calculate the Microirrigation System Average Application Rate (in/hr) using the following formula:

$$\frac{\text{Microirrigation system average}}{\text{Application rate (in/hr)}} = \frac{\text{Average tree discharge rate (gph)}}{\text{Tree spacing (ft}^2\text{)}} \times 1.6$$

DRIP EMITTER EXAMPLE (continued)**:**

For an almond orchard with a tree spacing of 16 x 22 feet and a drip system with an average tree discharge rate of 5.50 gph (from above), the average application rate would be:

Tree spacing = 16 feet x 22 feet = 352 ft^2

$$\text{Microirrigation system average Application rate (in/hr)} = \frac{5.50 \text{ gph}}{352 \text{ ft}^2} \times 1.6 = 0.025 \text{ in/hr}$$

MICROSPRINKLER EXAMPLE (continued)**:**

For an almond orchard with a tree spacing of 16 x 22 feet and a microsprinkler system with a tree average discharge rate of 8.0 gph, the average application rate would be:

Tree spacing = 16 feet x 22 feet = 352 ft^2

$$\text{Microirrigation system average Application rate (in/hr)} = \frac{8.0 \text{ gph}}{352 \text{ ft}^2} \times 1.6 = 0.04 \text{ in/hr}$$

DETERMINING THE DISTRIBUTION UNIFORMITY

The uniformity of a microirrigation system, a measure of how evenly or uniformly water is applied to the almond orchard, is quantified by distribution uniformity. By quantifying the uniformity, it provides an opportunity to determine if an orchard or block has uniformity problems that need to be addressed. Remember that a nonuniform irrigation system will be over-irrigating some trees and under-irrigating others.

1. Rank all the emitter discharge rates (gpm) from the lowest to the highest. This can be done manually or with the use of a spreadsheet program like Microsoft Excel. Determine the average of the low 25% of sprinkler discharge rates measured. For example, if 40 drip emitters or microsprinklers were evaluated, the average of the 10 emission devices with the lowest discharge rates would be the average of the low 25% of emitter discharge rates measured (gpm). Also calculate the average emitter discharge rate for all 40 emitters measured.

2. Determine the Distribution Uniformity (DU) using the following formula.

$$\text{Distribution Uniformity (DU\%)} = \frac{\text{Avg. of the low 25\% of emitter discharge rates measured}}{\text{Avg. of all emitter discharge rates measured}} \times 100$$

NEXT STEPS

1. The average application rate is a very important piece of information regarding your microirrigation system. Keep it handy since it will be used extensively when scheduling your irrigations.

2. Distribution uniformity for microirrigation systems in almonds should be 80% or higher. If it is lower than that, it is likely a result of operating pressures being too variable (caused by elevation changes or excessive frictional pressure losses in pipelines) or a result of emitter clogging problems. Pressure measurements taken during the field evaluation will provide guidance as to whether emitter discharge variability is caused by pressure variability. If excessive pressure variability appears to be the problem, one solution is to install pressure-compensating drippers or microsprinklers. Another potential solution may be to install additional pressure regulators at key points in the system. Both of these remedies can be complicated, so it is recommended that you contact an irrigation professional for assistance.

If excessive emitter discharge variability does not appear to be caused by pressure variations, then emitter clogging is a likely cause. As mentioned earlier, consult web-based resources or contact an irrigation professional for help in remedying a clogging problem and setting up a maintenance program to prevent future clogging problems.

3. Recheck your microirrigation system in three years. At a minimum, recheck the same locations originally evaluated. This will give an excellent measure of any changes that may have occurred. Consider measuring some additional locations to provide even better information.

MOVING UP THE CONTINUUM

Moving up to the intermediate practices described in “Irrigation System Performance” *Level 3.0* involves a closer look at the evaluated micro-irrigation system information collected here and addresses how to account for microsprinkler or drip emitter discharge rate variability.

IRRIGATION SYSTEM MAINTENANCE AND TROUBLESHOOTING

LEAKS

Leaks in above ground microirrigation systems are easy to detect, but to do so you have to inspect the system. Leaks can be caused when hydraulic connections come loose or when a system component fails, but more often they are the result of damage caused by workers, animals or equipment.

In almond orchards, it is not uncommon to inspect the microirrigation system at each irrigation, often using a four-wheeler ATV or other motorized vehicle. Dealing with leaks in a microirrigation system requires frequent inspections to detect and repair them. Microirrigation systems are not low-maintenance or low-labor systems. They need constant attention if they are to operate at optimum performance.

CLOGGED EMISSION DEVICES

Partial clogging of emission devices, especially drip emitters, is often difficult to detect. Only by collecting the discharge from a sampling of emitters for a known period of time is it possible to detect partial clogging. Partial clogging in microsprinklers often shows up as a disruption in the spray pattern. This is particularly true for microsprinklers that throw out “fingers” of water. Microsprinklers that spin often exhibit partial clogging by the spinner becoming stuck.

Completely clogged drippers or microsprinklers are easier to detect. Completely clogged drip emitters are difficult to clean and may need to be replaced. Doing a quick inspection with an ATV while the system is running may show where the clogged emitters are. Many irrigators carry a stick with them as they inspect the system after startup. Sometimes a sharp rap or two on the emitter will break up the aggregated clay or silt plugging the emitter and restore flow. Partially clogged drippers can often be cleaned up by chemical maintenance procedures.

Microsprinklers that are completely or partially clogged can often be cleaned physically, but this is time consuming and potentially damaging to flow control orifices if they are present. Clogging prevention maintenance should be done to minimize future clogging.

FLUSHING

Even a 200-mesh filter (a filter with very small openings) will not remove particles of fine sand, silt and clay or fine particles of algae. They will pass through the filter and be deposited in the lateral lines, especially at the ends of the lateral lines where the flow velocity is reduced. Particles can also be deposited when the system is shut down. Periodic flushing is needed to prevent clogging from sediments, particularly at the ends of the lateral lines. To flush the lines, open the ends of the laterals and allow the resulting discharge from each lateral to carry the deposited material with it.

The key to adequate flushing is to provide an open-line flushing velocity of at least 1 foot per second at the end of the drip line. For a 5/8-inch-diameter lateral (0.600-inch hose), a flow rate of 1 gallon per minute at the end of the lateral is required to achieve that velocity. A flow rate of 2 gallons per minute is necessary for a 7/8-inch-diameter (0.900-inch) drip line. You may need to use a trial-and-error system to determine how many laterals you can flush at the same time while still maintaining the desired flushing flow rate.

The first steps in flushing a microirrigation system are to flush the mainlines and then the submains and manifolds using flush valves installed at the ends of these pipes and sized to allow sufficient pipeline flow velocity to flush out contaminants. All filters on the system should also be examined to make sure they are clean and operating properly.

Lateral lines in almonds are generally flushed by hand, with several (usually five to 20) lateral line ends opened at a time and allowed to flush clean. By opening only a few lateral lines at once, you ensure that there will be sufficient flow to thoroughly flush the lines. Start out by flushing the lines every two to three weeks. If the lines do not flush clean within a minute or two, you may need to flush more frequently and increase your chemical maintenance. If the lines appear to still be clean at the two- to three-week interval, you can flush less frequently.

Self-flushing lateral line end caps are also used in almond microirrigation systems. The end caps are normally open, but they close when the system reaches a certain pressure (usually 5 psi). That way they have a short flush at the beginning and end of each irrigation event. Periodic manual flushing is still recommended because self-flushing end caps do not provide a thorough, high-velocity flush. In some instances, the end caps may not close completely and may leak. It can also happen that the increased flow resulting from all the open end caps in a set is more than equal to the pumping capacity and sufficient hose pressure to close the end caps is not reached.

FLUSHING FREQUENCY

How often the system should be flushed depends on the irrigation water quality and the degree of filtration. Generally, flushing should be performed every two to three weeks, although less-frequent flushing may be sufficient in some cases, such as if you irrigate solely with well water. The laterals should also be flushed after any fertilizer or chemical injection and for periodic chlorine injections. A simple way to determine how often flushing is needed is to observe how many contaminants come out during flushing. If very few contaminants flow out, especially from the lateral lines, you can probably flush less often. The reverse also holds true: If large amounts of material wash out, taking two minutes or more to clear, flushing should be done more often.

FILTERS: CLEANING AND MAINTENANCE

Filters are most frequently located at the head of the microirrigation system, but they may also be located in the field. There may even be small, screen washers in the fittings at the head of lateral lines. A surprising amount of contamination may collect on the secondary filters and screen washers and because they are located out in the field, their inspection may be less regular. Due to the large number of these filters and their tendency to clog up quickly, many growers decide not to use screen washers in the lateral line fittings going into the hose; instead they depend on good primary and secondary filters to take care of contaminants. These filters require much less labor to clean.

Filters — whether screen, disk/ring, or media — should be backwashed periodically to clear out any collected particulate or organic matter. Clogged filters can reduce pressure to the system, lowering the water application rate. Backwashing can be done either manually or with an automatic timer. Depending on the design of the screen or disk filter, manual backwashing is accomplished either by physically removing and cleaning the screen or disks, or by opening a valve to allow the system's water pressure to scrub the screen or disks clean. To manually backwash a media filter you need to initiate a backwash cycle in which the filter circulates water from bottom to top, causing the media to be suspended and agitated, which washes the particulate matter out of the filter media.

Automatic backwashing of screen, disk, or media filters accomplishes the same task on a settable, automatic, time basis based on how dirty the water source is. Most automatic backwash systems have an overriding pressure-sensing system that will initiate backwashing if a preset pressure differential across the filter is exceeded. Check with the filter manufacturer or dealer for recommendations on the allowable pressure differential for your filters.

CHANGING SAND MEDIA

Checking the sand in media filters is a frequently neglected maintenance task. You need to inspect the sand in sand media filters periodically to see that the sand is not caking and cracking and that it is being adequately cleaned during the automatic backwash cycles. In addition, the unit will lose some sand during the backwash cycles, so even if the filter is in good shape, it may require additional sand from time to time. Typically, the top of the sand bed should be at least half the depth of the media tank and a maximum of 12 inches of free space from the top of the sand bed to the top of the tank.

During inspection you should also feel the sand. The sand grains should be sharp edged, not rounded smooth like beach sand. The sharp edges promote better filtration, but backwash cycles will wear the sand smooth over time. If this has occurred, replace the sand. The rounding of sand edges may take three to eight years, but it will eventually happen.

CHECKING PRESSURE-REGULATING VALVES

Pressure-regulating valves are used in a micro-irrigation system to maintain a desired, constant pressure downstream of the regulating valve even if the pressure upstream of the valve fluctuates. These valves can only reduce pressure, so they are often referred to as pressure-reducing valves. They are available as adjustable pressure-regulating valves and as pre-set pressure-regulating valves that you can buy to match the desired downstream pressure. For nonpressure-compensating drippers and microsprinklers, the pre-set regulating valves usually are installed on the “tee” at the head of each lateral line whereas the adjustable regulating valves are often installed at the head of each submain (set) or manifold to regulate the pressure of that set or subunit. Other designs may have a single, large, pressure-regulating valve at the head of the system in order to regulate the pressure of the entire system. Systems with pressure-compensating drippers or microsprinklers may omit the pressure-regulating valves entirely.

Both the adjustable and pre-set pressure-regulator valves should be periodically checked against new, high-quality pressure gauges to ensure they are delivering the desired pressure. The adjustable pressure-regulating valves usually feature a pressure tap at the valve or just downstream of the valve to aid in pressure adjustment. Some growers prefer to install a Schrader valve (like a tire valve) at these locations and then use a portable pressure gauge that connects to the Schrader valve. The advantage to this is that you are able to use the same, high-quality, pressure gauge at all the measurement sites and you don’t leave a pressure gauge exposed to the damaging elements. The disadvantage of the Schrader valve system is that you need to carry the pressure gauge with you in order to check the pressure. The convenience of simply being able to look at a permanently installed pressure gauge may outweigh the inconvenience of having to periodically (most likely once a year) replace the pressure gauge.

Checking pre-set pressure regulators is more difficult since you often have many of them in a system and they do not come with a pre-installed spot downstream where you can measure the pressure. Often the easiest way to check is to randomly choose laterals to monitor, punch a hole in the lateral line, measure the pressure using a pressure gauge outfitted with a pitot tube that you insert through the hole, and then plug the hole with a “goof plug.” If the randomly selected lines indicate no problems, it is likely that the rest of the regulating valves are also in good condition. An alternative is to install a fitting with a Schrader valve downstream of the pressure regulator to quickly measure the pressure. If measurements indicate problems, you need to conduct a more thorough and systematic evaluation.

PRESSURE GAUGES

Due to the elements, pressure gauges installed in a microirrigation system do go bad. It is important that any pressure gauges installed in key locations, such as upstream and downstream of filters and downstream of pressure-regulating valves, be accurate. Pressure gauges that are exposed to the sun may need to be replaced every year. While they are more expensive than other models, liquid-filled pressure gauges may be a good choice.

WHAT'S NEW IN "IRRIGATION SYSTEM PERFORMANCE" LEVEL 3.0?

In "Irrigation System Performance" *Level 1.0*, only pressure measurements were gathered to determine the average application rate and estimate distribution uniformity. In *Level 2.0*, discharge rates from sprinklers or microirrigation emitters were collected, along with pressure measurements, to better estimate the average application rate and distribution uniformity. *Level 3.0* is the same as *Level 2.0*, except irrigation system assessment will be done every two years instead of every three years.

For more information on determining the irrigation system application rate and uniformity, refer to the system-specific information on the following pages in "Irrigation System Performance" *Level 2.0*. Remember, system assessments should be completed every **two years in *Level 3.0***. Systems include:

3.0 Practice:

Assess distribution uniformity and average application rate by measuring water volume at least every two years. Correct any diagnosed system performance problems.

Applied Water

APPLIED WATER

Keeping good records of the amount of irrigation water applied may be one of the most important elements of good irrigation water management. The amount of irrigation water applied is critical to determining whether irrigation practices are keeping up with orchard water demands and determining the irrigation efficiency.

The following steps use the average application rate determined in the previous section, “Irrigation System Performance” *Continuum Level 1.0,* fundamental practices and the irrigation duration to determine the amount of water applied per irrigation event.

1.0 Practice:

Use application rate and duration of irrigation to determine water applied.

INFORMATION TO GATHER

1. Refer to the calculations completed in section “Irrigation System Performance” *Level 1.0* that describe fundamental practices to obtain the application rate (in/hr) for your irrigation system.
2. Keep careful records of irrigation times or durations for each irrigation set or block, for each orchard, or however your irrigation system(s) are operated. The following techniques used by water managers may prove useful.
   a. Keep a paper or electronic record of on/off times on a calendar. This calendar may also be used to record pest control treatments, fertilizer application, and other cultural practices in the orchard. Keeping these records on an electronic spreadsheet is a good option.
   b. Be diligent in recordkeeping. It is easy to get behind, and remembering specific details after time has passed can prove difficult.
   c. If irrigation events are operated by a controller using electric or hydraulic solenoid valves (Fig. 1), make sure they are operating correctly and record any changes to the controller. Any operation of the system on the manual setting should be recorded as well.
   d. If irrigation events are controlled manually, write down the times when the system is started and stopped on each block or set.
   e. If issues arise with losing records or in getting them from the field to the individual responsible for maintaining the records, consider using text messages to share information. The text message should indicate which orchard, block or set the information refers to, and also serves as a semipermanent record of when irrigation events were started and stopped.

Figure 1. RainBird LXME Pump and Valve Controller. (Photo by S. Cooper)

DETERMINING APPLIED WATER

For each irrigation block or irrigation management zone and each irrigation event, use the formula below to calculate the applied water (in inches) by multiplying the block or set's irrigation application rate (in/hr) by the irrigation time (hr).[1]

Applied Water (inches) = Irrigation Application Rate (in/hr) x Irrigation Set Time (hrs)

The determined amount of applied water per irrigation event should be recorded in a consistent manner that works best for your operation (calendar, spreadsheet, etc.).

NEXT STEPS

Total the applied irrigation water for the season and compare it with the seasonal almond water use estimates (ET) from the section "Orchard Water Requirements" *Level 1.0* or from the Almond Board's Irrigation Calculator. The values of the applied irrigation water and seasonal almond evapotranspiration (ET) should be close. Remember that some of the almond ET will also be supplied by the stored soil moisture at the beginning of the growing season.

MOVING UP THE CONTINUUM

Strongly consider installing a flow meter (Fig. 2) to better and more easily measure applied water. This will allow you to move to the *Almond Irrigation Improvement Continuum Level 2.0* intermediate and the *Level 3.0* advanced levels with regard to applied water, further improving your good irrigation water management practices.

Figure 2. Flow meter register (readout) of a propeller saddle-mount flow meter. Flow meters allow for more accurate and more easily obtainable measures of applied water. (Photo by L. Schwankl)

[1] Hanson, B., and L. Schwankl. 2009. Measuring Irrigation Water Flow Rates. Oakland: University of California Division of Agriculture and Natural Resources. Publication 21644. http://anrcatalog.ucanr.edu/Details.aspx?itemNo=21644.

APPLIED WATER

WHAT'S NEW IN "APPLIED WATER" LEVEL 2.0?

In *Level 1.0*, the irrigation system average application rate and irrigation duration were used to determine the applied water. An improvement in applied water determinations is recommended in *Level 2.0* — actually measuring the water flow in the irrigation system.

2.0 Practice:

Use flow meters to actually measure flow rates and water applied instead of relying on estimates based upon irrigation system design (as suggested in the simpler *Level 1.0* practice).

INTRODUCTION

Keeping good records of the amount of irrigation water applied may be one of the most important elements of good irrigation water management. Knowing the amount of irrigation water applied is critical to determining whether irrigation practices are keeping up with orchard water requirements. and determining the irrigation efficiency.

TYPES OF FLOW MEASUREMENT[1]

Two flow conditions are encountered in almond orchard irrigation: (1) flow in open channels or ditches, and (2) flow in pipelines. Flow in open channels or ditches is very difficult to measure accurately. There are flumes and weirs available to measure the open channel flow, but they are difficult to install and use. If there is a location where the water is in a pipeline prior to being in the channel or ditch, measure the water in the pipeline. An example would be a pump discharge delivering water to an open channel. Measure the flow rate in the discharge pipe.

Pipeline flow is easier and more accurate to measure than open channel flow, and there are a variety of flow meters appropriate for use in almond irrigation. It is recommended that an appropriately sized flow meter be installed at the head of the irrigation system. This meter will monitor all flow downstream of it.

Propeller flow meters (Fig. 1) are the most commonly used flow meters for measuring agricultural flows. They are available in various configurations to match the required installation conditions. They are sufficiently accurate to meet any agricultural water measurement needs and their price is reasonable. Often the installation costs, especially for a retrofit to an existing system, are greater than the meter cost. As with all pipeline flow meters, the pipe must be flowing full and the installation conditions must minimize turbulence that causes inaccuracies. The meter manufacturer will recommend installation conditions, usually in terms of straight lengths of pipe upstream and downstream of the meter.

Figure 1. Flow meter register (readout) of a propeller saddle-mount flow meter. Flow meters allow for more accurate and easily obtainable measures of applied water. (Photo by L. Schwankl)

Maintenance of the meter is important. Follow the manufacturer's recommendations on the service interval, but expect to send the

[1] Hanson, B., and L. Schwankl. 2009. Measuring Irrigation Water Flow Rates. Oakland: University of California Division of Agriculture and Natural Resources. Publication 21644 http://anrcatalog.ucanr.edu/Details.aspx?itemNo=21644.

meter in for maintenance and calibration about every four years.

For more information, see [propeller flow meters].

Electromagnetic flow meters (Fig. 2), often called “magmeters,” are an alternative to propeller meters. They have the advantages of having no propeller in the pipeline to potentially be entangled by trash, there are no moving parts so they often need less maintenance, and magmeters are generally more accurate than propeller meters. Often, they are less sensitive to turbulence than propeller meters so they can be installed with less distance of straight pipe upstream and downstream of the meter. The disadvantages of magmeters are that they need a power source (some models run on batteries), and they are more expensive than propeller meters.

For more information, see [electromagnetic flow meters].

Figure 2. Electromagnetic flow meter, often referred to as a magmeter.

INFORMATION TO BE GATHERED

1. For the orchard (if the orchard is irrigated as a whole) or each irrigation block; determine the acreage.

2. Record the flow meter totalized reading at the beginning and end of each irrigation event for the orchard or each irrigation block. Also keep track of the irrigation time associated with each block’s totalized flow measurements. This allows an accurate determination of the block’s average application rate (inches/hour); important to determining the irrigation time to match the orchard water requirements. If using the flow meter’s instantaneous readout, usually in gal/min (gpm) or cubic feet per second (cfs), record accurately the flow rate and the irrigation time for each irrigation block. It is very possible that the instantaneous flow rate to each block may be different. It is often difficult to accurately read the instantaneous flow rate register. For example, the needle of a propeller meter’s instantaneous readout often is not steady so an estimate must be made. Generally, use of totalized flow measurement is recommended over the instantaneous flow rate.

3. For each irrigation set or block, each orchard, or however your irrigation system(s) are operated, keep careful records of flow meter readings and irrigation times or durations. The following techniques used by water managers may prove useful:

   a. Keep a record of flow meter readings and on/off times on a calendar, either paper or electronic. This same calendar may also be used for recording pest control, fertilizer and other cultural events in the orchard. Keeping these records on an electronic spreadsheet is also an option.

   b. Be diligent in recordkeeping. It is easy to get behind, and remembering specific details after time has passed can prove difficult.

   c. If irrigation events are operated by a controller (Fig. 3) using electric or hydraulic solenoid valves (Fig. 3), make sure they are operating correctly and record any changes to the controller. Any operation of the system on the manual setting should be recorded as well. Remember, you still need to record the flow meter readings for each irrigation event.

Figure 3. Controller for an automated irrigation system. (Photo by S. Cooper)

d. If irrigation events are controlled manually, write down the times when the system is started and stopped on each block or set, as well as the corresponding flow meter readings.

e. If issues arise with losing records or in getting them from the field to the individual responsible for maintaining the records, consider utilizing text messages to share information instantaneously. The text message should indicate which orchard, block or set the information refers to and serve as a semi-permanent record, not easily lost, of flow meter readings and when irrigation events were started/stopped.

DETERMINING APPLIED WATER

The readout on a flow meter usually has a totalizing register recording the total flow (gallons, cubic feet, ac-in, etc.) passing through the meter. Many meters also have an instantaneous flow rate indicator (gpm, cfs, etc.) on the readout. The most reliable flow rate value comes from noting the change in the totalized flow across a known time interval. For example, if a flow meter measured 30,000 gallons passing through it in one hour, the flow rate would be 500 gpm.

Frequently, it is very useful to determine the application rate (in/hr) from the flow meter information. The following formulas can be useful. See the end of this section for some useful unit conversions.

___ gpm ÷ area irrigated (acres) x 0.0022 = ___ in/hr

___ cfs ÷ area irrigated (acres) x 0.992 = ___ in/hr

___ gallons ÷ time period over which measured (min) ÷ acres irrigated x 0.0022 = ___ in/hr

___ cubic feet ÷ time period over which measured (min) ÷ acres irrigated x 0.0165 = ___ in/hr

___ ac-ft ÷ time period over which measured (min) ÷ acres irrigated x 720 = ___ in/hr

A handy formula, frequently used to determine the inches of water applied during an irrigation, is:

$$\text{Inches Applied} = \frac{\text{Flow rate (gpm) x Irrigation time (hrs)}}{\text{449* x Acres irrigated}}$$

*449 is a unit conversion factor

The totalizing register of many flow meters displays in gallons. If reading the totalized flow at the beginning and end of an irrigation to determine the total gallons of water applied, the total gallons applied can be converted to inches of applied water using:

(Total Gallons Applied ÷ Irrigated Acres) ÷ 27,152 = Inches of Water Applied

In some cases, the totalizing register of the flow meter will record in acre-inches. Those readings can be easily converted to inches of applied water using:

Total ac-in Applied ÷ Irrigated Acres = Inches of Water Applied

The application rate (in/hr) was determined by field evaluating the irrigation system and included sampling sprinklers or microirrigation emitters (“Irrigation System Performance” *Level 2.0*). A flow meter in the system should give a very good check on this application rate. It is unlikely that they will agree exactly, but the application rate determined by field evaluation and by flow meter monitoring should be close. If they are not, go back through the calculations confirming that the correct irrigated acreage, the correct irrigation device spacing, etc., were used.

USEFUL UNIT CONVERSIONS:

1 cubic foot = 7.48 gallons

1 gallon = 3.785 liters

1 cubic meter = 264 gallons

1 ac-ft = 325,851 gallons = 43,560 cubic feet

1 ac-in = 27,158 gallons = 3,360 cubic feet

1 acre = 0.4 hectare = 43,560 square feet

1 cubic foot per second (cfs) = 449 gallons per minute (gpm)

450 gpm for 1 hour = 1 ac-in per hour

NEXT STEPS

Compare the applied water measured with the flow meter to the orchard water-use estimates from "Orchard Water Requirement" *Level 1.0* and *Level 2.0*. The Almond Board's Irrigation Calculator available online at SustainableAlmondGrowing.org also provides an orchard water-use estimate. How does the applied water compare to the predicted orchard water requirement? If you applied less water than recommended by the ET calculations and soil moisture storage does not appear sufficient to compensate, you may consider making up the deficit in your next irrigation. Checking soil moisture and/or plant water status may prove valuable by confirming the need for additional water in your next irrigation. They are excellent tools for checking that you are on track with your irrigation applications.

MOVING UP THE CONTINUUM

Now that you have a flow meter installed and are accurately recording how much water is being applied, you are ready to move to "Applied Water" *Level 3.0* where the applied water information and orchard water requirement information will be compared to determine the irrigation efficiency.

APPLIED WATER

WHAT'S NEW IN "APPLIED WATER" LEVEL 3.0?

In *Continuum Level 2.0*, flow meters were used to compare whether the amount of applied water matches favorably with orchard water requirements. In *Level 3.0*, flow meters will continue to be used but in addition to determining if applied water compares favorably with the crop water requirement, the water meter records can be used to evaluate the irrigation efficiency.

The portions of "Applied Water" *Level 3.0* describing use of flow meters is similar to the sections in "Applied Water" *Level 2.0*, but "Applied Water" *Level 3.0* contains new information on determining your irrigation efficiency.

3.0 Practice:

Use water meters to determine applied water and compare to crop water use (ETc, evapotranspiration) to determine irrigation efficiency.

INTRODUCTION

Keeping good records of the amount of irrigation water applied is one of the most important elements of good irrigation water management. Knowing the amount of irrigation water applied is critical to determining whether irrigation practices are keeping up with orchard water requirements and determining the irrigation efficiency.

TYPES OF FLOW MEASUREMENT[1]

Two flow conditions are encountered in almond orchard irrigation: (1) flow in open channels or ditches, and (2) flow in pipelines. Flow in open channels or ditches is very difficult to measure accurately. There are flumes and weirs available to measure the open channel flow, but they are difficult to install and use. If there is a location where the water is in a pipeline prior to being in the channel or ditch, measure the water in the pipeline. An example would be a pump discharge delivering water to an open channel. Measure the flow rate in the discharge pipe.

Pipeline flow is easier and more accurate to measure than open channel flow, and there are a variety of flow meters appropriate for use in almond irrigation. It is recommended that an appropriately sized flow meter be installed at the head of the irrigation system. This meter will monitor all flow downstream of it.

Propeller flow meters (Fig. 1) are the most commonly used flow meters for measuring agricultural flows. They are available in various configurations to match the required installation conditions. They are sufficiently accurate to meet any agricultural water measurement needs and their price is reasonable. Often the installation costs, especially for a retrofit to an existing system, are greater than the meter cost. As with all pipeline flow meters, the pipe must be flowing full and the installation conditions must minimize turbulence that causes inaccuracies. The meter manufacturer will recommend installation conditions, usually in terms of straight lengths of pipe upstream and downstream of the meter.

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Maintenance of the meter is important. Follow the manufacturer's recommendations on the service interval, but expect to send the meter in for maintenance and calibration about every four years.

For more information, see propeller flow meters.

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For more information, see electromagnetic flow meters.

Figure 2. Electromagnetic flow meter, often referred to as a magmeter.

INFORMATION TO BE GATHERED

1. For the orchard (if the orchard is irrigated as a whole) or each irrigation block, determine the acreage.
2. Record the totalized flow meter reading on all flow meters at the beginning of the irrigation season. This is important information because when combined with the flow meter(s) at the end of the season, the total applied water for the season can be determined. This is essential for determining the seasonal irrigation efficiency.
3. Record the flow meter totalized reading at the beginning and end of each irrigation event for the orchard or each irrigation block. Also, keep track of the irrigation time associated with each block's totalized flow measurements. This allows an accurate determination of the block's average application rate (inches/hour); important to determining the irrigation time to match the orchard water requirements. If using the flow meter's instantaneous readout, usually in gal/min (gpm) or cubic feet per second (cfs), record accurately the flow rate and the irrigation time for each irrigation block. It is often difficult to accurately read the instantaneous flow rate register. For example, the needle of a propeller meter's instantaneous readout often is not steady so an estimate must be made. Generally, use of totalized flow measurement is recommended. It is very possible that the instantaneous flow rate to each block may be different, especially if the acreage of each block is different.
4. For each irrigation set or block, each orchard, or however your irrigation system(s) are operated, keep careful records of flow meter readings and irrigation times or durations. The following techniques used by water managers may prove useful:
   a. Keep a record of flow meter readings and on/off times on a calendar, either paper or electronic. This same calendar may also be used for recording pest control, fertilizer and other cultural events in the orchard. Keeping these records on an electronic spreadsheet is also an option.

   b. Be diligent in recordkeeping. It is easy to get behind, and remembering specific details after time has passed can prove difficult.

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Figure 3. Controller for an automated irrigation system. (Photo by S. Cooper)

Any operation of the system on the manual setting should be recorded as well. Remember, you still need to record the flow meter readings for each irrigation event.

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Frequently, it is very useful to determine the application rate (in/hr) from the flow meter information. The following formulas can be useful. See the end of this section for some useful unit conversions.

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___ gallons ÷ time period over which measured (min) ÷ acres irrigated x 0.0022 = ___ in/hr

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___ ac-ft ÷ time period over which measured (min) ÷ acres irrigated x 720 = ___ in/hr

A handy formula, frequently used to determine the inches of water applied during an irrigation, is:

$$\text{Inches Applied} = \frac{\text{Flow rate (gpm)} \times \text{Irrigation time (hrs)}}{449^{*} \times \text{Acres irrigated}}$$

*449 is a unit conversion factor

The totalizing register of many flow meters displays in gallons. If reading the totalized flow at the beginning and end of an irrigation to determine the total gallons of water applied, the total gallons applied can be converted to inches of applied water using:

Inches of Water Applied = Total Gallons Applied ÷ Irrigated Acres ÷ 27,152

In some cases, the totalizing register of the flow meter will record in acre-inches. Those readings can be easily converted to inches of applied water using:

Inches of Water Applied = Total ac-in Applied ÷ Irrigated Acres

The application rate (in/hr) was determined by field evaluating the irrigation system and included sampling sprinklers or microirrigation emitters ("Irrigation System Performance" *Level 2.0*). A flow meter in the system should give a very good check on this application rate. It is unlikely that they will agree exactly, but the application rate determined by field evaluation and by flow meter monitoring should be close. If they are not, go back through the calculations confirming that the correct irrigated acreage, the correct irrigation device spacing, etc., were used.

USEFUL UNIT CONVERSIONS:

1 cubic foot = 7.48 gallons

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1 cubic foot per second (cfs) = 449 gallons per minute (gpm)

450 gpm for 1 hour = 1 ac-in per hour

DETERMINING SEASONAL IRRIGATION EFFICIENCY

Irrigation efficiency is a measure of how much of the applied irrigation water goes to beneficial uses. The water use (evapotranspiration) of the orchard is by far the most significant beneficial use. Other water uses such as salinity control and frost protection are also beneficial uses and are discussed in detail in the section “Orchard Water Requirements” *Levels 2.0* and *3.0*.

The following formula can be used to determine the seasonal irrigation efficiency.

$$\text{Seasonal Irrigation Efficiency (\%)} = \frac{\text{Seasonal Orchard Irrigation Water Requirement (in)}}{\text{Seasonal Applied Irrigation Water (in)}} \times 100$$

Seasonal irrigation efficiency can be determined using the following three-step procedure.

Step 1: Use flow meter measurements to determine the seasonal applied water. The seasonal applied water is determined by:

$$\text{Seasonal Applied Water (in)} = \text{Flow meter reading at the end of the irrigation season (in)} - \text{Flow meter reading at the beginning of the irrigation season (in)}$$

The seasonal applied water should be in units of inches of applied water to be consistent with the seasonal orchard water requirements measured in inches. The conversion of the flow meter readings to inches of applied water depends on the units the flow meter displays. If the flow meter displays in gallons, use the following:

$$\text{Inches of water applied} = \text{Total gallons applied} \div \text{Acres irrigated} \div 27{,}152$$

If the flow meter displays in acre-inches (ac-in), use the following:

$$\text{Inches of water applied} = \text{Total ac-in applied} \div \text{Acres irrigated}$$

If the flow meter displays in cubic feet, the following conversion can be used.

1 cubic foot = 7.48 gallons

Step 2: Determine the seasonal irrigation water requirement as determined in “Orchard Water Requirement” *Level 3.0*. The Almond Board’s Irrigation Calculator (Almonds.com/Irrigation) can also be used to calculate the seasonal orchard irrigation water requirement. If only historical almond water use (ET) is available, use that information, but if real-time almond water use is available, it should be used since it is more accurate.

Step 3: Determine the seasonal irrigation efficiency.

$$\text{Seasonal Irrigation Efficiency (\%)} = \frac{\text{Seasonal Orchard Irrigation Water Requirement (in)}}{\text{Seasonal Applied Irrigation Water (in)}} \times 100$$

Unless the orchard is under-irrigated, it is unlikely that the seasonal irrigation efficiency will be 100%.

EXAMPLE

Irrigation block = 10 acres
In Merced, it was determined, after accounting for effective rainfall and the stored soil water contribution, that the seasonal irrigation water requirement was 40 inches.
Flow meter records indicated that 460 ac-in of water was applied to the block across the season.

What was the seasonal irrigation efficiency?

Inches of water applied = Total ac-in applied ÷ Acres irrigated
Inches of water applied = 460 ac-in ÷ 10 acres = 46 inches

$$\text{Seasonal Irrigation Efficiency (\%)} = \frac{\text{Seasonal Orchard Irrigation Water Requirement (in)}}{\text{Seasonal Applied Irrigation Water (in)}} \times 100$$

$$\text{Seasonal Irrigation Efficiency (\%)} = \frac{\text{40 inches}}{\text{46 inches}} \times 100 = 87\%$$

NEXT STEPS

Using your flow meters to monitor how much water you're applying and comparing it with orchard water use estimates is operating at the advanced level of irrigation water management. Determining your seasonal irrigation efficiency allows you to quantify your irrigation water management. You should try to attain a seasonal irrigation efficiency of 85% or higher.

If your seasonal irrigation efficiency is lower than 85%, the following are some ideas to consider.

Are you satisfied with the orchard's look and yield? Even if you are, it could mean that you are over-irrigating but your drainage is good enough to prevent problems from occurring. You may still be paying to apply more water than the orchard needs.

Have you done the irrigation system evaluation as described in "Irrigation System Evaluation" *Levels 2.0* and *3.0*? If not, do so. If your irrigation system uniformity is less then 85%, it is difficult to irrigate at an irrigation efficiency of 85% or higher without significantly under-irrigating a portion of the orchard. The first step to having good irrigation efficiency is to have a highly uniform irrigation system.

Go back through your irrigation records and compare them with orchard water demands (ET). Was there a particular portion of the season when too much water was applied? Was it across the entire season? Armed with this information, consider strategies to more closely match your irrigation to orchard water needs.

If you are not currently using soil moisture monitoring and/or plant water status techniques, consider adding them to your irrigation water management tool chest. They can provide valuable information to help meet orchard water needs without over-irrigating, improving your irrigation efficiency.

Soil Moisture

SOIL MOISTURE

Determining the amount of moisture stored in the trees' root zone is important information for good irrigation water management. Stored soil moisture serves as a bank account of water available for the orchard. As the trees "withdraw" water from the stored soil moisture bank account, irrigation "deposits" must be made throughout the growing season to maintain available water in the account. Maintaining available water in the root zone provides the orchard with a cushion in case of under-irrigation due to management miscalculations, equipment failure or other factors that affect the availability of water.

Growers should evaluate soil moisture based on feel and appearance of the soil, as well as by soil monitoring on a monthly basis to inform irrigation management decisions. Stored soil moisture is accessed by tree roots and withdrawn to satisfy tree water needs, and must be accounted for in irrigation decision making.

1.0 Practice:

Evaluate soil moisture based upon feel and appearance by augering to at least 3 to 5 feet. Monitor on a monthly time step.

INFORMATION TO GATHER

Many sophisticated soil moisture monitoring tools are available, some of which will be described in the Almond Irrigation Improvement *Continuum Level 2.0* and *3.0* standards, but using a simple and inexpensive method for determining soil moisture, known as the feel and appearance method, can be effective. An excellent resource for guidelines on using this method is the Natural Resources Conservation Service's (NRCS) publication Estimating Soil Moisture by Feel and Appearance.[1] This publication provides guidelines for the feel and appearance of soils of various textures and moisture content and is available online at the NRCS website (http://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs144p2_051845.pdf) and at your local NRCS office.[2]

To use the feel and appearance method, perform the following steps.

1. Soil samples should be gathered at every foot to a depth from 3 to 5 feet using an auger (Fig. 1) or other sampling tool. A good selection of augers and other sampling tools are available from retailers, including Ben Meadows, Forestry Suppliers, and AMS Inc. Check online for other suppliers.

2. Determine the soil texture at the site being sampled. The soil texture can be identified by locating the sample site on USDA-NRCS online soils maps or by visiting your local NRCS office.

Increasingly applications are available for smartphones and tablets that can identify the soil texture of the site you are standing on,

Figure 1. Various types of augers that can be used to sample the soil moisture content. (Photo by B. Sanden)

[1] United States Department of Agriculture, Natural Resources Conservation Service. Estimating Soil Moisture by Feel and Appearance. Apr.1998. http://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs144p2_051845.pdf.

[2] To locate your local NRCS office, visit Almonds.com/Growers/Resources and filter by the 'NRCS' category.

including work done by UC Davis California Soil Resource Lab. However, note that some of these applications require Google Earth, a free software program, to be installed on your computer, tablet or smartphone.

ALMOND TREE ROOT ZONE

What is the root zone of an almond tree? This would seem like an easy question to answer, but it is not. An almond tree's root zone depends on the soil conditions the roots are growing in and the area to which irrigation water is applied. In areas of the almond growing region where winter rainfall is adequate to fill the root zone, the entire area that the tree roots can explore may be the root zone. Later in the season, after the soil moisture has been depleted, only the area where irrigation water is supplied is considered to be the root zone.

In terms of root zone depth, measurements have shown that almond trees withdraw water from as deep as 6 to 7 feet if the soil conditions allow root penetration.[3] More often, almond tree root depth is limited by soil conditions. Layers such as hardpans may restrict root growth, as can changes in soil texture between soil layers. Further complicating the issue is that orchard soil is by no means uniform. Some areas of an orchard may have breaks in restricting layers, and the soil texture may vary widely within an orchard.

Water is not taken up evenly throughout a tree's root zone, primarily because roots are not distributed evenly throughout the rooting volume (the soil volume explored by the roots). Greater concentrations of roots generally occur at shallower depths and closer to the tree's trunk, but this pattern may be modified by water availability resulting from irrigation practices.

Figure 2. Root concentration around a subsurface drip line. (Photo by L. Schwankl)

Soil moisture uptake under localized irrigation techniques such as drip irrigation can differ significantly from that observed in surface and sprinkler irrigation systems. In addition, by mid-to-late season, the rooting volume will be concentrated in the tree root zone (Fig. 2) where water is applied, as the roots proliferate where water is available and die in dry areas.

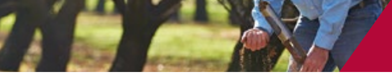
WHERE TO COLLECT SOIL MOISTURE SAMPLES

Collect and evaluate samples in a number of locations throughout the orchard, avoiding outside rows. Soil samples should be collected and evaluated at each foot while augering to 3- to 5-feet deep. If there are no restricting layers in the soil, assume the rooting depth is 3 to 5 feet. If there appears to be a consistent restricting layer in the orchard, use its depth as the bottom of the root zone, augering and collecting samples only to that depth.

If you know that there are various soil textures in the orchard, use a minimum of one sampling location in each of the soil textural areas. More sites provide better information, but it is better to sample the selected sites regularly rather than sampling many sites on an irregular basis. Select sampling sites that have healthy trees and are representative of that section of the orchard. Do not choose a sample site with a missing adjacent tree, as the missing tree will have local implications on soil moisture. Of course, if you are soil sampling to diagnose a problem with a tree or orchard location, you would choose areas to sample based on your best chance of solving the problem.

Sample approximately 6 feet from a tree, taking into account the soil volume wetted by the irrigation system. Sample in the wetted volume, since this is where the roots are active. This is particularly important for micro-irrigated trees. For example, under drip irrigation, the sampling should be done in the wetted volume but not right next to a drip emitter.

[3] Drought Survival Strategies for Established Almond Orchards – Shackel et al for CAB.



WHEN TO COLLECT SOIL MOISTURE MEASUREMENTS

With experience, gathering soil moisture information using the feel and appearance can be done almost as quickly as simply auguring.

The *Level 1.0* fundamental practice for measuring soil moisture recommends that soil moisture be monitored on a monthly basis. However, beyond each month there are times when having soil moisture information is of particular importance.

1. The stored soil moisture, as determined by the feel and appearance method, is particularly useful for determining the amount of water available to the trees prior to the first irrigation of the season. Most orchard managers would prefer to go into the irrigation season with the root zone full of water (a full soil profile). Measurements have shown that it is difficult to get deep water penetration with microsprinklers during periods of high water use in the summer, and drip systems wet only a portion of the soil volume.

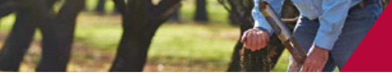
   Taking feel and appearance method measurements at this time also provides valuable insight into the actual feel of the soil when it is full of water, often referred to as field capacity. Table 1 gives the available water at field capacity for various soil textures. Also given is the length of a ribbon of soil you can squeeze out between your thumb and forefinger when the soil is at field capacity.

2. For surface and sprinkler irrigation systems, take a set of feel and appearance method soil moisture measurements just prior to an irrigation event, and then another set of measurements two to four days following the irrigation. Comparing these measurements provides valuable information on the depth of water penetration and how well the irrigation refilled the root zone.

3. Prior to irrigation cutbacks that may be planned prior to harvest, determine how much stored soil moisture is available. If the soil profile has little stored soil moisture, cutting back on irrigations may induce more water stress than desired and potentially harm yield the following year. The same holds true for cutting off irrigations during harvest.

Soil Category	**Soil Texture**	**Available Water-holding Capacity (in. per ft. of soil)**	**“Ribbon” Length at Field Capacity (in.)**
Coarse	Sand / Loamy Sand	0.6–1.2	none; ball only
Sandy	Loamy Sand / Sandy Loam / Loam	1.2–1.8	0.4–1
Medium	Loam / Sandy Clay Loam	1.4–2.2	1–2
Fine	Silty Loam / Silty Clay Loam / Clay / Silty Clay	1.7–2.4	>2

Table 1. Soil moisture at field capacity for soils of various textures. A ribbon of soil is formed by holding a ball of soil between your thumb and forefinger and sliding your thumb across the soil in a shearing motion to extrude a continuous ribbon of soil about 1/16-inch to 1/8-inch thick.



DETERMINING STORED SOIL MOISTURE

1. Collect soil samples at 1-foot intervals to a depth of 3 to 5 feet or to the depth where any restricting layers limit root growth. Select sampling locations that are representative of the orchard. If you are aware of different soil textures in the orchard, investigate each of these areas. Tree growth and health can also provide guidance as to where soil samples should be taken. Checking the soil conditions, including soil moisture, can often help explain tree performance problems.
2. For each sample, use the NRCS feel and appearance method to estimate the soil moisture content. As you get to "know" your soil, you will be more sensitive to the soil moisture content. Table 1 also provides a quick estimate of the available water-holding moisture.
3. Keep good records each time the soil moisture is sampled, including soil moisture content and orchard location, as well as where the samples were taken relative to the tree and irrigation system (especially important when drip or microsprinkler irrigation is used). Also note the date and the point in the irrigation cycle the samples were taken.

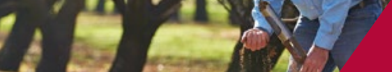
NEXT STEPS

Determining soil moisture is not an end in itself. Use the information to adjust your irrigation practices. When using evapotranspiration (ET) scheduling, soil moisture sampling is an excellent check to make sure the recommended irrigation amounts are correct. For example, following an irrigation, if you expect the soil profile to be full of water, check the soil moisture to confirm this. Even better would be to have also checked the soil moisture just prior to the irrigation. This would provide you valuable information on where and how deep the irrigation water penetrated.

MOVING UP THE CONTINUUM

To move up the practices described in *Levels 2.0* and *3.0*, consider installing soil moisture monitoring tools that provide information on soil moisture at various depths without having to gather an augered soil sample. Experience from using the feel and appearance method will provide you with guidance on where these monitoring tools are best installed, though cost may limit the number of locations where they can be installed.

Further information and guidance on this approach can be found in *Almond Irrigation Improvement Continuum Levels 2.0* and *3.0*.



SOIL MOISTURE

INTRODUCTION

Determining the soil moisture status in the root zone is important information for good irrigation water management. Measurements can act as an indicator of over- or under-irrigation when using other scheduling methods, or they can be used as a stand-alone indicator of when to irrigate. Stored soil moisture serves as a bank account of water available for the orchard. As the trees "withdraw" water from the stored soil moisture bank account, irrigation "deposits" must be made throughout the growing season to maintain available water in the account. Maintaining available water in the root zone provides the orchard with a cushion in case of under-irrigation due to management miscalculations, equipment failure or other factors that affect the availability of water.

ADVANTAGES AND DISADVANTAGES OF USING SOIL MOISTURE MONITORING DEVICES

ADVANTAGES

Soil moisture assessment is much quicker with a permanently installed device, and it is much easier than hand soil moisture sampling.

The soil moisture measurement using an installed soil moisture device is taken in the same location throughout the season versus hand sampling a new location each time. This provides a better picture of soil moisture changes.

Most soil moisture monitoring devices can be read with a portable readout device but many are also capable of being monitored with a logging device that stores the readings for later download and review. This continual logging of soil moisture readings provides an even better picture of what is happening with soil moisture over time. In "Soil Moisture" *Level 3.0*, this logging of soil moisture information will be discussed in greater detail.

Most of the soil moisture monitoring devices are low maintenance with the exception of tensiometers, which must be periodically refilled with water, purged of air bubbles, and protected from freezing. Remember, though, that electronic devices that are exposed to a harsh environment in the orchard will need regular maintenance.

DISADVANTAGES

The major disadvantage of soil moisture monitoring devices is their cost, ranging from a few hundred dollars to a few thousand dollars for each monitoring location in the orchard. Greater capability such as logging the soil moisture readings and the capability to remotely access the information increases the cost.

2.0 Practice:

Use manually operated soil moisture sensors to at least 3 to 5 feet and monitor on a biweekly time step. Use information to ensure calculated water is not over- or under-irrigating trees.

What's New in "Soil Moisture" Level 2.0?

In "Soil Moisture" *Level 1.0*, Feel and Appearance soil moisture determination techniques were used to assess soil moisture. They should remain in your water management tool box, but more advanced soil moisture measurement approaches are available that can be more accurate and allow you to monitor the soil moisture at the same location throughout the season.

At "Soil Moisture" *Level 2.0*, soil moisture measurement devices will be used, at least on a biweekly basis, to assess soil moisture. When used in conjunction with evapotranspiration irrigation scheduling and plant water status measurement, they can provide excellent guidance to irrigation practices.

All soil moisture devices must be properly installed so there is good contact between the device and the soil. Device manufacturers frequently provide information on proper installation techniques, or service providers do this as part of their service. For almonds, we want to monitor down to the 3- to 5-foot depth, so find out how the soil moisture monitoring device is installed at such deeper depths. No matter how accurate the device is, if it is not installed correctly, it will not provide good information.

Figure 2. Watermark® soil moisture block and hand reading unit.

SOIL MOISTURE MONITORING DEVICES

SOIL WATER POTENTIAL DEVICES

Figure 1. Tensiometer. (Photo by T. Prichard)

These soil moisture monitoring devices include tensiometers (Fig. 1) and granular soil moisture devices such as gypsum blocks and Watermark® blocks (Fig. 2). These devices measure soil moisture tension or how "tightly" the water is held by the soil; as the soil dries out it holds the water more tightly, making it more difficult for the tree to extract water from the soil. These devices have been around longer than a new generation of dielectric constant devices (discussed next), and they provide valuable soil moisture information at a relatively low cost. Hardware is available to "log" the information as well as to remotely access the soil moisture information. The relationship between soil moisture and soil moisture tension, however, depends on soil texture or the relative amounts of sand, silt and clay in the soil. For this reason, these sensors need to be calibrated for the specific location they are installed. As an example, for a given soil moisture tension, soil moisture content of a sandy loam soil will be less than that of a clay loam. Additionally, tensiometers have an upper measurement limit of about 80 centibars while Watermark blocks and gypsum blocks do not read under high moisture conditions.

A general rule of thumb for interpretation: Soil moisture is nearing a level that can result in tree stress when soil tension (indicated by the centibar meter reading) reaches a level that corresponds to more than 50% depletion of the plant-available water at a specific soil depth. The soil tension

GUIDELINES FOR INTERPRETING SOIL MOISTURE TENSIONS (CENTIBARS) MEASURED WITH RESISTANCE BLOCKS AND TENSIOMETERS.

Soil Tension	Sand/Loamy Sand	Sandy Loam	Loam/Silt Loam	Clay Loam/Clay
(centibars)	Depletion of the Plant-Available Water (%)			
10	0	0	Not fully drained	Not fully drained
30	**40**	25	0	0
50	65	**55**	10	10
70	75	60	25	20
90	80	65	35	25
110	85	68	40	32
130	87	70	**47**	38
150	90	73	52	43
170	95	76	55	46
190	98	79	58	**49**

Table adapted by Allan Fulton from Scheduling Irrigations: When and How Much Water to Apply. Division of Agriculture and Natural Resources Publication 3396. University of California, Oakland. p.106.

level that corresponds with 50% depletion levels will vary depending upon soil type because of different soil porosity characteristics. For example, a soil tension reading of 35 centibars may indicate that a very sandy soil will approach 50% depletion of plant-available soil moisture but for a loam/silt loam soil, 50% depletion may not be approached until tension readings approach 110 to 130 centibars (see http://cetehama.ucanr.edu/files/20515.pdf).

Figure 3. Dielectric constant soil moisture device.

DIELECTRIC CONSTANT DEVICES

The dielectric constant is the ability of a substance to store electrical energy in an electrical field. In the case of measuring soil moisture the moist soil is the substrate. The dielectric constant of water is greatly different than dry soil, so dielectric constant soil moisture devices can measure the water content of soil. Among the dielectric constant devices (Fig. 3) are capacitance probes, time domain reflectometry (TDR) sensors, and frequency domain probes. These devices vary in their sensitivity to salinity and their volume of soil measured, but they all must be calibrated to provide accurate quantitative soil moisture assessment. A good question to ask a device manufacturer or a service provider is if their device has been calibrated for the soil types in your orchard. If they have not been calibrated for your soil, they will still provide information on changes in soil moisture but they won't provide accurate information on the amount of water in the soil (Fig. 4).

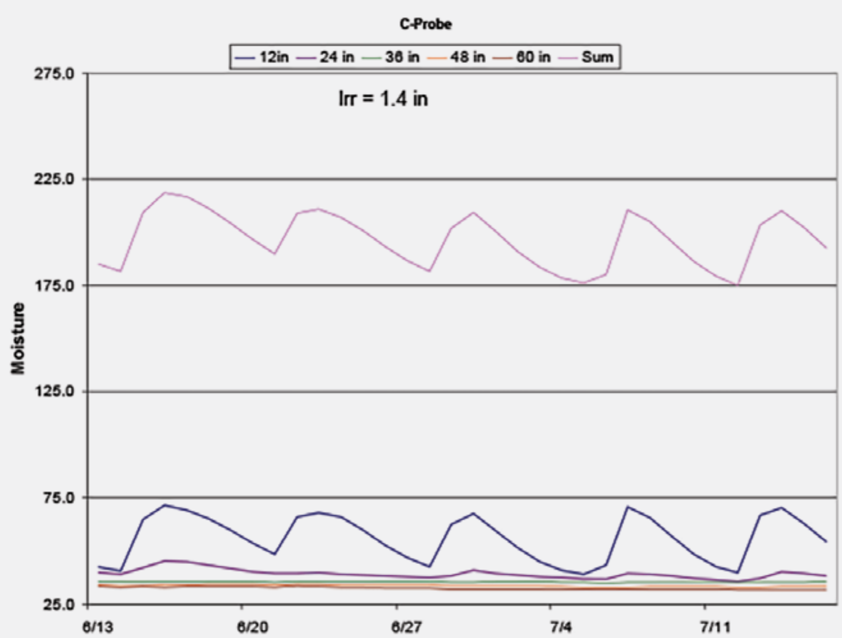
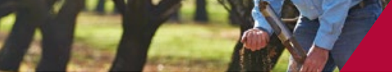


Figure 4. Dielectric probe readings as individual depth and summation of depths indicating soil moisture trend over time. Each increase is a result of a 1.4-inch irrigation.



NEUTRON PROBES

The neutron probe (Fig. 5) is a radioactive device that has been used to monitor soil water content for several decades. Due to its radioactivity, the device must be operated by a licensed operator and, therefore, is most often available through professional agricultural consultants.

Figure 5. Neutron probe soil moisture meter. (Photo by L. Schwankl)

DOING SOIL MOISTURE MONITORING YOURSELF VS. HIRING IT OUT

Do you want to do the soil moisture monitoring yourself or hire it out? Doing it yourself may at first seem less expensive, but your time (or your employees time) used for soil moisture monitoring certainly is an expense. The soil moisture monitoring devices need to be read regularly — it is suggested at a minimum every other week — so this task is an ongoing time commitment. In addition, you must assess the information, decide what it means, and most importantly, incorporate it into your irrigation water management.

A soil moisture monitoring consultant will take over much of the work of soil moisture monitoring. It is important to ask them what services they provide. Do they provide and install the devices? Do they monitor the devices for you? Do they provide an interpretation of the information? Do they provide the information to you on a schedule that allows you to incorporate it into your irrigation water management decision making? Of course, the cost of their service is a critical question to ask. Discuss with the consultant how the soil moisture information will be provided to you — tabular or graphical forms are both common. Look at a sample of the information they provide and make sure it makes sense to you.

Remember that monitoring soil moisture is not an end in itself. Your goal is getting soil moisture information that you understand and can incorporate into your irrigation water management strategy. If you feel a consultant is important to reaching that goal, their cost may well be worth it. If you feel you can reach that goal on your own, then you may not need a consultant's services.

ALMOND TREE ROOT ZONE

What is the root zone of an almond tree? This would seem like an easy question to answer, but it is not. An almond tree's root zone depends on the soil conditions the roots are growing in and the area to which irrigation water is applied. In areas of the almond-growing region where winter rainfall is adequate to fill the root zone, the entire area that the tree roots can explore may be the root zone. Later in the season, after the soil moisture has been depleted, only the area where irrigation water is supplied is considered to be the root zone.

In terms of root zone depth, measurements have shown that almond trees withdraw water from as deep as 6 to 7 feet if the soil conditions allow root penetration.[1] More often, almond tree root depth is limited by soil conditions. In general, the majority of almond roots are in the top 3 feet of soil. Layers such as hardpans may restrict root growth, as can rapid changes in soil texture between soil layers. Further complicating the issue is that orchard soil is by no means uniform. Some areas of an orchard may have breaks in restricting layers, and the soil texture may vary widely within an orchard.

Water is not taken up evenly throughout a tree's root zone, primarily because roots are not distributed evenly throughout the rooting volume (the soil volume explored by the roots). Greater concentrations of roots generally occur at shallower depths and closer to the tree's trunk, but this pattern may be modified by water availability resulting from irrigation practices.

[1] Shackel, K. 2010. Drought Survival Strategies for Almond Orchards. University of California, Davis, Department of Plant Sciences. University of California Cooperative Extension Solano County website, http://cesolano.ucanr.edu/files/60415.pdf.

Figure 6. Root concentration around a subsurface drip line. (Photo by L. Schwankl)

Soil moisture uptake under localized irrigation techniques such as drip irrigation can differ significantly from that observed in full-coverage surface and sprinkler irrigation systems. In addition, by mid-to-late season, the rooting volume will be concentrated (Fig. 6) where water is applied, as the roots proliferate where water is available and die or are dormant in dry areas.

PLACEMENT OF SOIL MOISTURE SENSORS

Cost of the soil moisture monitoring sites will likely determine how many monitoring sites are practical in an orchard. A site or two in an orchard is common, but if you have significant soil textural differences in an orchard, additional sites may be important. If you know you have soil textural differences in an orchard, consider placing a soil moisture monitoring site in each major soil type.

Placement of the monitoring site relative to the tree and your irrigation system is often a difficult decision. Especially with microirrigation systems, soil moisture will vary greatly within the tree's root zone. Your objective is to have the soil moisture sensors in a location that reflects average soil moisture that the tree is experiencing. The following guidance may help.

First and foremost, place the sensors where they won't be disturbed by equipment, cultural practices or people in the orchard. This usually means placing the site in the tree row.

The monitoring site should receive soil moisture recharge by the irrigation system, but it shouldn't be in the wettest spot around the tree. If you are using sprinklers or microsprinklers, the tree's trunk or canopy may provide "shadows" where irrigation water does not reach due to interference with the water application. Avoid placing sensors in such a water shadow. Water availability and uptake will vary across the season. Winter rains will refill much of the soil profile and the trees will use this water, but by midsummer the active water uptake areas will be those recharged by the irrigation system. You want to have your monitoring site in the area recharged by irrigation. Consider using your feel and appearance hand sampling skills to investigate potential soil sensor locations following an irrigation, see http://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs144p2_051845.pdf. You are looking for a location that receives irrigation water and has active roots taking up water.

Choose a monitoring site with healthy trees surrounding it. The tree growth should be typical of the orchard.

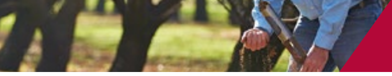
Choose a site that is easily accessible. You will be going back to the site frequently to read the devices. If the soil moisture monitoring system is remotely accessed (discussed in detail in "Soil Moisture" *Level 3.0*), this may not be as important a consideration.

INSTALLATION OF SOIL MOISTURE SENSORS

Proper installation of soil moisture sensors is critical to getting good soil moisture information. There are many sensors on the market, but they all have a common requirement that they be installed in good contact with the surrounding soil so they reflect what is happening as soil moisture changes. Most manufacturers provide guidance, written and sometimes video guidance, on proper installation. A valuable service many of the consultants/service providers offer is their installation expertise. Some installation requires customized tools. If you are unsure about the proper installation, strongly consider having it done by an expert. Improper installation of expensive sensors is a waste of money.

USING SOIL MOISTURE INFORMATION

Most soil moisture monitoring device users track trends in soil moisture. These soil moisture trends provide useful information on depletion and



replacement of soil moisture. Unless carefully calibrated for the installation location, the soil moisture devices do not provide information on the exact amount of soil moisture so it is difficult to determine the tree water use or the required irrigation amount from the soil moisture device readings. Tree water use and irrigation requirements are best determined by evapotranspiration (ET) techniques with the soil moisture data providing valuable information about whether the ET scheduling is on track.

Keep good records each time you read the soil moisture devices, recording the date, site location and depth of each reading. Additional information, such as monitoring date relative to the last irrigation and the next irrigation, is valuable.

A soil moisture monitoring site should monitor the soil moisture at each foot to a maximum depth of 3 to 5 feet. Each sensor will provide different soil moisture readings. Generally the shallower depths will be the most active with water uptake and refill being evident. Sensors at deeper depths usually show less change but they provide important information on when the tree is tapping the soil moisture at deeper depths (usually because the soil moisture has been depleted at the shallower depths) and information on how deep applied irrigation water is penetrating. It is difficult to keep moisture at lower depths as the season progresses, and it is normal for soils to dry below 3 to 4 feet later in the summer. Attempting to keep these lower zones moist later in the summer may result in tree health problems.

Use of soil moisture will vary depending on the irrigation system used. The following are typical strategies for using soil moisture information.

SPRINKLER SYSTEMS

Use orchard water requirement (evapotranspiration or ET) information to estimate the water used since the last irrigation. See “Orchard Water Requirements” *Levels 1.0* and *2.0* for guidance on doing this. Monitor the soil moisture devices one to three days following the irrigation and record the information. A day or two prior to your next estimated irrigation date, read the soil moisture devices again and record the information. The change between these values and the previous, post-irrigation values will provide you information on which depths have experienced water depletion. The values will also provide you guidance on whether it is time to irrigate.

Remember that the soil moisture data is limited to only providing you information at the site location in the orchard. Use your experience, and preferably tree water status information (see “Plant Water Status” *Levels 1.0* and *2.0*), to supplement the soil moisture information when you are making irrigation water management decisions.

MICROIRRIGATION (DRIP AND MICROSPRINKLER) SYSTEMS

Soil moisture information is used differently with high irrigation frequency microirrigation systems. Especially with drip systems, irrigation may be nearly daily during midsummer. Again, use Orchard Water Requirement (evapotranspiration or ET) information to estimate how much water to apply (see “Orchard Water Requirements” *Levels 1.0* and *2.0*). When using microirrigation, the soil moisture data provides valuable information on whether you are meeting the tree water needs. If the soil moisture data indicates that the soil moisture at the deeper depths shows a drying trend, it is likely that you are under-irrigating. Over-irrigating will be indicated by the deeper depth sensors showing that the soil is getting wetter over time.

Again, remember that the soil moisture information is only telling you what is happening at the sensor site. Don’t rely entirely on it to make your irrigation decisions. Use your experience, preferably bolstered by tree water status information (see “Plant Water Status” *Levels 1.0* and *2.0*), to supplement the soil moisture information when evaluating your irrigation water management.

SOIL MOISTURE MONITORING IN YOUNG ORCHARDS

Soil moisture monitoring is particularly well-suited to young tree irrigation scheduling. Due to the limited root zone and the small and variable young tree canopy, evapotranspiration (ET) estimation for young trees is difficult to do accurately. Therefore, for the first two to three years of a young almond orchard, experience has shown soil moisture monitoring to be a successful strategy to schedule irrigations. During young orchard development, the objective should be to supply all the tree water needs and avoid tree water stress.

A soil moisture sensor site should be installed in the active root zone of a selected young tree. The young tree should be healthy and typical of surrounding trees. The site should be in soil conditions typical for the orchard. If the orchard soil conditions are highly variable, more monitoring sites may be appropriate.

When placing the soil moisture monitoring instruments near the young tree, be aware that the young tree's root zone may be very limited at first. There must be root water uptake around the soil moisture instruments for their readings to be of value. Just as the canopy will develop rapidly for a young tree, so will the root zone. Also make sure the monitoring site is placed so that the irrigation system will re-wet the area around the sensors.

Monitoring instruments should be installed each foot to a depth of 4 to 5 feet. While a first leaf tree may not withdraw water from that depth, a second leaf or older tree may utilize the deeper stored water. The deeper sensors also provide valuable information on the depth of irrigation water penetration and the soil moisture status at the beginning of the season.

Soil moisture readings should be done at least on a weekly basis due the limited root zone of the young tree. When the shallower soil depths show signs of moisture depletion, irrigate to replace the depleted water. Young trees require frequent, small amounts of irrigation. This is most efficiently done with drip irrigation since the applied water can be targeted to the young trees' root zone. At the young orchard stage, flood, sprinkler, and to some degree microsprinklers, end up applying water to orchard areas outside the young trees' rooting volume. This makes it difficult to use ET irrigation scheduling for determining irrigation needs in young trees.

Determining the required amount of applied water should be done based on experience. Monitor the soil moisture just before and then a couple of days after an irrigation. The change in soil moisture readings will help you determine if enough or too much water was applied. Fine tune your irrigations using this procedure. Remember that as the tree canopy develops, which can happen quickly in the young trees, the tree water use increases. Adapt your irrigation practices accordingly.

NEXT STEPS

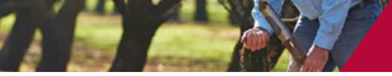
Determining soil moisture is not an end in itself. Use the information to adjust your irrigation practices. When using evapotranspiration (ET) scheduling, soil moisture sampling is an excellent check to make sure the recommended irrigation amounts are correct. For example, following an irrigation, if you expect the soil profile to be full of water, check the soil moisture to confirm this. Even better would be to have also checked the soil moisture just prior to the irrigation. This would provide you valuable information on where and how deep the irrigation water penetrated.

You will find that taking periodic readings of the soil moisture devices (at a minimum biweekly under "Soil Moisture" *Level 2.0*) will leave you wondering what happened with soil moisture between your readings. In "Soil Moisture" *Level 3.0*, logging of daily (or more frequent) soil moisture readings will provide a better picture of what is happening with soil moisture content.

MOVING UP THE CONTINUUM

In "Soil Moisture" *Level 3.0*, use of soil moisture data logging and various methods of accessing the soil moisture data will be discussed. These approaches to obtaining "continual" soil moisture readings will provide you better information that you can incorporate into your irrigation water management practices.

Further information and guidance on this approach can be found in the "Soil Moisture" *Level 3.0* section of the *Almond Irrigation Improvement Continuum*.



SOIL MOISTURE

> **3.0 Practice:**
>
> Use automated moisture sensors that store data over time. Review weekly to ensure calculated water is not over- or under-irrigating trees.

INTRODUCTION

Determining the soil moisture status in the trees' root zone is important information for good irrigation water management. Measurements can act as an indicator of over- or under-irrigation when using other scheduling methods, or they can be used as a stand-alone indicator of when to irrigate. Stored soil moisture serves as a bank account of water available for the orchard. As the trees "withdraw" water from the stored soil moisture bank account, irrigation "deposits" must be made throughout the growing season to maintain available water in the account. Maintaining available water in the root zone provides the orchard with a cushion in case of under-irrigation due to management miscalculations, equipment failure, or other factors that affect the availability of water.

At "Soil Moisture" *Level 2.0*, soil moisture measurement devices are used, at least on a biweekly basis, to assess soil moisture. When used in conjunction with evapotranspiration irrigation scheduling and plant water status measurement, they can provide excellent guidance to irrigation practices.

At "Soil Moisture" *Level 3.0*, the use of soil moisture monitoring devices will be supplemented by using equipment to store soil moisture readings providing continual soil moisture information. These systems are often available with telemetry capabilities so they can be remotely read, minimizing the need for a person to go to the site to gather soil moisture data.

ADVANTAGES AND DISADVANTAGES OF USING SOIL MOISTURE MONITORING DEVICES

ADVANTAGES

Soil moisture assessment is much quicker with a permanently installed device, and it is much easier than hand soil moisture sampling.

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Figure 2. Watermark® soil moisture block and hand reading unit.

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130	87	70	**47**	38
150	90	73	52	43
170	95	76	55	46
190	98	79	58	**49**

Table adapted by Allan Fulton from Scheduling Irrigations: When and How Much Water to Apply. Division of Agriculture and Natural Resources Publication 3396. University of California, Oakland. p.106.

DIELECTRIC CONSTANT DEVICES

The dielectric constant is the ability of a substance to store electrical energy in an electrical field. In the case of measuring soil moisture, the moist soil is the substrate. The dielectric constant of water is greatly different than dry soil, so dielectric constant soil moisture devices can measure the water content of soil. Among the dielectric constant devices are capacitance probes, time domain reflectometry (TDR) sensors, and frequency domain probes. These devices vary in their sensitivity to salinity and their volume of soil measured, but they all must be calibrated to provide accurate quantitative soil moisture assessment. A good question to ask a device manufacturer or a service provider is if their device has been calibrated for the soil types in your orchard. If they have not been calibrated for your soil, they will still provide information on changes in soil moisture, but they won't provide accurate information on the amount of water in the soil.

The most commonly used dielectric constant device is the capacitance probe. They are commonly seen either as a single point sensor (one sensor) or as a profile probe (Fig. 3) (multiple sensors stacked on top of each other with sensors at different depths).

NEUTRON PROBES

The neutron probe (Fig. 4) is a radioactive device that has been used to monitor soil water content for several decades. Due to its radioactivity, the device must be operated by a licensed operator and, therefore, is most often available through professional agricultural consultants.

Figure 3. Dielectric constant soil moisture device.

Figure 4. Neutron probe soil moisture meter. (Photo by L. Schwankl)

DOING SOIL MOISTURE MONITORING YOURSELF VS. HIRING IT OUT

Do you want to do the soil moisture monitoring yourself or hire it out? Doing it yourself may at first seem less expensive, but your time (or your employees' time) used for soil moisture monitoring certainly is an expense. The soil moisture monitoring device systems need to be downloaded regularly — it is suggested at a minimum every week — so this task is an ongoing time commitment. In addition, you must assess the information, decide what it means, and most importantly, incorporate it into your irrigation water management.

A soil moisture monitoring consultant will take over much of the work of soil moisture monitoring. It is important to ask them what services they provide. Many of today's consultants are using the same sensors but offer unique differences in their software packages and customer support. Do they provide and install the devices? Do they monitor the devices for you? Do they provide an interpretation of the information? Do they provide the information to you on a schedule that allows you to incorporate it into your irrigation water management decision making? Of course, the cost of their service is a critical question to ask. Discuss with the consultant how the soil moisture information will be provided to you — tabular or graphical forms are both common. Look at a sample of the information they provide and make sure it makes sense to you.

Remember that monitoring soil moisture is not an end in itself. Your goal is getting soil moisture information that you understand and can incorporate into your irrigation water management strategy. If you feel a consultant is important to reaching that goal, their cost may well be worth it. If you feel you can reach that goal on your own, then you may not need a consultant's services.

Figure 5. Root concentration around a subsurface drip line. (Photo by L. Schwankl)

ALMOND TREE ROOT ZONE

What is the root zone of an almond tree? This would seem like an easy question to answer, but it is not. An almond tree's root zone depends on the soil conditions the roots are growing in and the area to which irrigation water is applied. In areas of the almond-growing region where winter rainfall is adequate to fill the root zone, the entire area that the tree roots can explore may be the root zone. Later in the season, after the soil moisture has been depleted, only the area where irrigation water is supplied is considered to be the root zone.

In terms of root zone depth, measurements have shown that almond trees withdraw water from as deep as 6 to 7 feet if the soil conditions allow root penetration.[1] More often, almond tree root depth is limited by soil conditions. Layers such as hardpans may restrict root growth, as can rapid changes in soil texture between soil layers. Further complicating the issue is that orchard soil is by no means uniform. Some areas of an orchard may have breaks in restricting layers, and the soil texture may vary widely within an orchard.

Water is not taken up evenly throughout a tree's root zone, primarily because roots are not distributed evenly throughout the rooting volume (the soil volume explored by the roots). Greater concentrations of roots generally occur at shallower depths and closer to the tree's trunk, but this pattern may be modified by water availability resulting from irrigation practices.

Soil moisture uptake under localized irrigation techniques such as drip irrigation can differ significantly from that observed in full-coverage surface and sprinkler irrigation systems. In addition, by mid-to-late season, the rooting volume will be concentrated (Fig. 5) where water is applied, as the roots proliferate where water is available and die or are dormant in dry areas.

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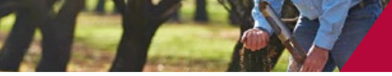
[1] Shackel, K. 2010. Drought Survival Strategies for Almond Orchards. University of California, Davis, Department of Plant Sciences. University of California Cooperative Extension Solano County website, http://cesolano.ucanr.edu/files/60415.pdf.



PLACEMENT OF SOIL MOISTURE SENSORS

Cost of the soil moisture monitoring sites will likely determine how many monitoring sites are practical in an orchard. A site or two in an orchard is common, but if you have significant soil textural differences in an orchard, additional sites may be important. If you know you have soil textural differences in an orchard, consider placing a soil moisture monitoring site in each major soil type.

Placement of the monitoring site relative to the tree and your irrigation system is often a difficult decision. Especially with microirrigation systems, soil moisture will vary greatly within the tree's root zone. Your objective is to have the soil moisture sensors in a location that reflects average soil moisture that the tree is experiencing. The following guidance may help.

First and foremost, place the sensors where they won't be disturbed by equipment, cultural practices or people in the orchard. This usually means placing the site in the tree row.

The monitoring site should receive soil moisture recharge by the irrigation system, but it shouldn't be in the wettest spot around the tree. If you are using sprinklers or microsprinklers, the tree's trunk or canopy may provide "shadows" where irrigation water does not reach due to interference with the water application. Avoid placing sensors in such a water shadow. Water availability and uptake will vary across the season. Winter rains will refill much of the soil profile and the trees will use this water, but by midsummer the active water uptake areas will be those recharged by the irrigation system. You want to have your monitoring site in the area recharged by irrigation. Consider using your feel and appearance hand sampling skills to investigate potential soil sensor locations following an irrigation, see http://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs144p2_051845.pdf. You are looking for a location that receives irrigation water and has active roots taking up water.

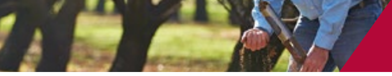
Choose a monitoring site with healthy trees surrounding it. The tree growth should be typical of the orchard.

Choose a site that is easily accessible. You will be going back to the site frequently to read the devices. If the soil moisture monitoring system is remotely accessed, this may not be as important a consideration.

A soil moisture monitoring site should monitor the soil moisture at each foot to a maximum depth of 3 to 5 feet. Each sensor will provide different soil moisture readings. Generally the shallower depths will be the most active with water uptake and refill being evident. Sensors at deeper depths usually show less change, but they provide important information on when the tree is tapping the soil moisture at deeper depths (usually because the soil moisture has been depleted at the shallower depths), and information on how deep applied irrigation water is penetrating. It is difficult to keep moisture at lower depths as the season progresses, and it is normal for soils to dry below 3 to 4 feet later in the summer. Attempting to keep these lower zones moist later in the summer may result in tree health problems.

INSTALLATION OF SOIL MOISTURE SENSORS

Proper installation of soil moisture sensors is critical to getting good soil moisture information. There are many sensors on the market, but they all have a common requirement that they be installed in good contact with the surrounding soil so they reflect what is happening as soil moisture changes. Most manufacturers provide guidance, written and sometimes video guidance, on proper installation. A valuable service many of the consultants/service providers offer is their installation expertise. Some installation requires customized tools. If you are unsure about the proper installation, strongly consider having it done by an expert. Improper installation of expensive sensors is a waste of money.



CONTINUAL READ SOIL MOISTURE MONITORING

As mentioned previously, nearly all soil moisture devices can be connected to data loggers that query the soil moisture devices periodically and then save the information for later download or transmittal to the user. This provides “continual” or “real-time” soil moisture information rather than simply snapshots of soil moisture content obtained by manually reading the devices. This continual monitoring is a powerful tool for determining soil moisture changes resulting from tree water uptake and irrigation applications. Manual soil moisture reading often misses significant soil moisture changes occurring between monitoring, especially for high frequency irrigation systems like microirrigation. While continual-read soil moisture systems are more expensive than manual-read systems, the additional information is often well worth the expense.

There are a variety of options available with continual-read soil moisture monitoring systems. They include:

1. The user periodically downloads the soil moisture data themselves and using their own computer tools, such as Microsoft Excel, or software provided by the soil moisture equipment supplier, analyzes the data.

2. The soil moisture monitoring consultant periodically downloads the soil moisture data. The consultant can provide this raw data to the client or they can analyze it, often translating it into graphical form, for the client. The consultant may also make recommendations on irrigation water practices based on the soil moisture data.

3. The soil moisture monitoring system uses a telemetry system (cell phone, radio, etc.) to read the soil moisture sensor data logger and make the information available to the user. Depending on the system, the information may be sent to the user’s computer or be made available on a website. Again, receiving the raw data or having the data analyzed into a more quickly reviewed form (e.g., graphical) is often available. Most users find that having the information in a graphical form is much more useful than simply looking at raw numbers. If you are going to have the service provider analyze the raw soil moisture information and provide it to you in a graphical form, evaluate their graphical format and make sure you understand it and that it suits your needs. It should be noted that services such as having the information available on a secure website come with a monthly fee, so be sure to ask your service provider about those costs. A major advantage of a web-based system is that you can access the information from anywhere using a computer, tablet or smartphone.

The bottom line on these soil moisture monitoring options is that often the more services you choose (e.g., analysis of data, display and storage on a website), the more it costs. Be aware of all the costs prior to choosing a system.

INTERPRETING CONTINUAL SOIL MOISTURE INFORMATION

As mentioned previously, two of the common soil moisture device types are soil water potential devices and dielectric constant devices. The following are typical examples of the information from each of these devices. For each example, observations will be made to help you interpret the information. As is typical, the information is presented in a graphical format.

SOIL WATER POTENTIAL DEVICE

A commonly used soil water potential device is the Watermark® block. The Watermark® block readout is in the same units as the tensiometer — kPa of soil moisture tension. The greater the instrument reading, the higher the soil moisture tension and the drier the soil. What you need to remember is for the Watermark® block, the higher the reading, the drier the soil. Depending on the soil type, a value of between 10 and 30 kPa indicates a soil at field capacity.

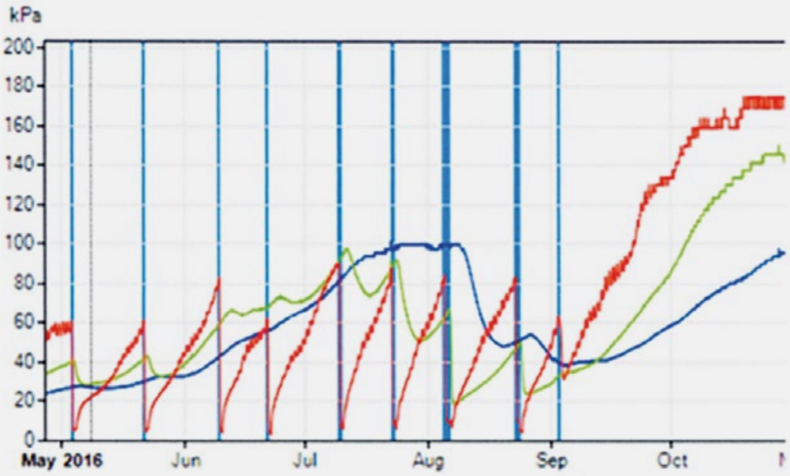


Figure 6. Typical soil moisture graph for a Watermark® block installation.

OBSERVATIONS

There are three lines on the graph in Figure 6, the orange line is the soil moisture sensor at the 1-foot depth, the green line is the 2-foot sensor, and the blue line is the 3-foot sensor. The solid, vertical blue lines are irrigation events.

With each irrigation event, the 1-foot sensor indicates that the soil was fully re-wetted (readings went below 20 in value).

While the 2-foot sensor responded to each irrigation, it indicates that the 2-foot soil depth was not re-wetted to field capacity (approximately 30 kPa in value) until a large irrigation at the beginning of August. Prior to that, the 2-foot sensor showed a drying trend from the beginning of the season until the first part of July. This would indicate that the irrigations were not adequate to keep up with tree water use during this period.

The 3-foot sensor indicates a drying soil moisture trend until the large irrigation event in the first part of August. This drying trend indicates that the tree was using water from the 3-foot depth, but it wasn't being replaced by irrigations. The large irrigation the first part of August and the next irrigation in the latter part of August refilled much of the soil moisture at the 1-foot, 2-foot and 3-foot depths.

DIELECTRIC CONSTANT DEVICES

A commonly used type of dielectric constant device is the capacitance probe. Figure 7 below is the graphical summary of a continuous read capacitance probe. There are four graphs in Figure 7. The top graph is the total soil moisture in the top 36 inches of soil. This information (blue line) is developed by summing the values from the sensors at the 1-foot, 2-foot and 3-foot depths. The greater the value, the more the soil moisture. The blue-shaded zone at the top of the graph is the target for an irrigation that refills the soil moisture in the top 3 feet of soil.

The second graph in the figure would display any rain that occurred. During the June and July period of this monitoring, there was no rainfall.

The third graph of the figure is the daily reference ET, known as ETo. This is not the same as tree ET, but is useful in showing the pattern of tree water use. For more information on this topic, see “Orchard Water Requirements” *Levels 2.0* and *3.0*.

The bottom graph is a record of a pressure switch installed in the irrigation system. It shows when, and for how long, the irrigation system was operating.

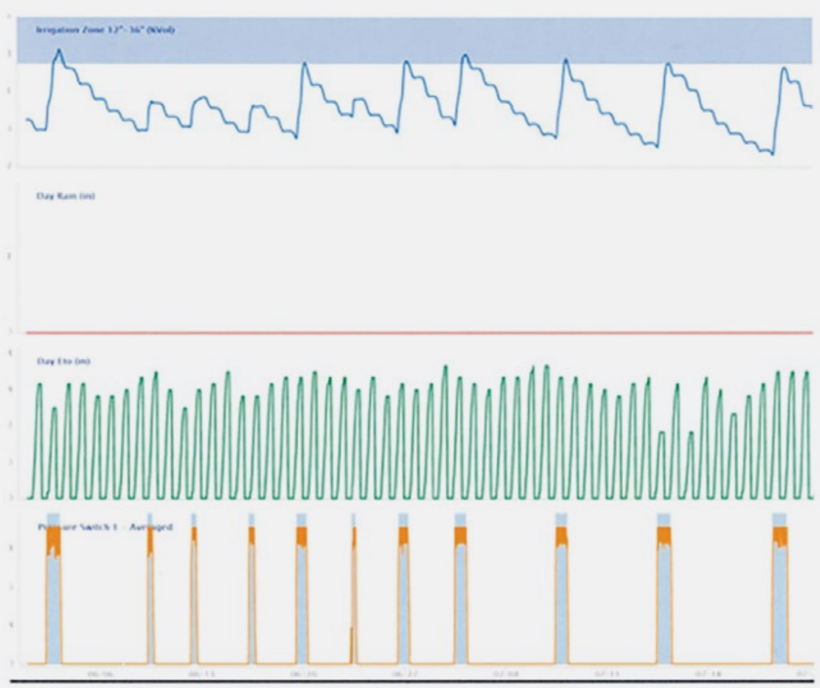
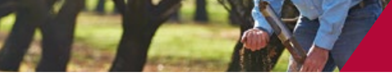


Figure 7. Sample soil moisture graph for a capacitance probe installation.



OBSERVATIONS

The stair-step, downward pattern of the soil moisture in the top graph is the result of the tree water use. Tree water use only occurs during the day, hence the stair-step pattern. A telltale sign that some use for initiation of irrigation is when the "step" becomes shallower under constant ET conditions. This is considered a sign that soil moisture is not sufficient at that depth to satisfy the tree demands and it is time to irrigate.

Significant soil moisture increases in the first 3 feet is a result of irrigation. Irrigation events are shown in the bottom graph.

The irrigation events that refilled the first 3 feet of soil up to the "blue zone" refilled the soil profile without over-irrigating. The irrigations on 6/10, 6/13, 6/16 and 6/24 did not completely refill the soil moisture in the first 3 feet of soil.

The daily ETo graph shows how consistent ET is during June and July. While there is some variability, the ET is surprisingly consistent. Note that there were a few days in the middle of July when ET was significantly lower — these were likely cloudy days during which ET was lower.

The soil moisture record indicates that the orchard was well-irrigated. Irrigations kept up with tree water use, replacing the used soil moisture.

USING SOIL MOISTURE INFORMATION

Most soil moisture monitoring device users track trends in soil moisture. These soil moisture trends provide useful information on depletion and replacement of soil moisture. Unless carefully calibrated for the installation location, the soil moisture devices do not provide information on the exact amount of soil moisture, so it is difficult to determine the tree water use or the required irrigation amount from the soil moisture device readings. Tree water use and irrigation requirements are best determined by evapotranspiration (ET) techniques, with the soil moisture data providing valuable information about whether the ET scheduling is on track.

Continual soil moisture monitoring information allows the user to compare the soil moisture level in relation to irrigation practices. Under sprinkler irrigation, the soil moisture levels may "trigger" irrigations while orchard water requirement (evapotranspiration, ET) information can provide the amount of irrigation. See "Orchard Water Requirements" *Levels 2.0* and *3.0* for guidance on doing this. The continual soil moisture data will also provide valuable information on the fate of the irrigation water. It can tell you how deep the water penetrated and if the irrigation fully recharged the root zone.

Under microirrigation where irrigations may be daily during peak water use periods, the trends in soil moisture levels can provide information on whether irrigations are matching the orchard water use. If the soil moisture levels are decreasing as the season progresses, it indicates that the irrigations are not keeping pace with orchard water use. If the soil moisture appears to be increasing as the season progresses, you are over-irrigating. As with sprinkler irrigation, the amount of irrigation can be determined from the orchard evapotranspiration (ET). See "Orchard Water Requirements" *Levels 2.0* and *3.0* for guidance on doing this.

Remember that the soil moisture data is limited to only providing you information at the specific site location in the orchard. Use your experience, and preferably tree water status information (see "Plant Water Status" *Levels 2.0* and *3.0*) to supplement the soil moisture information when you are making irrigation water management decisions.

SOIL MOISTURE MONITORING IN YOUNG ORCHARDS

Soil moisture monitoring is particularly well-suited to young tree irrigation scheduling. Due to the limited root zone and the small and variable young tree canopy, evapotranspiration (ET) estimation for young trees is difficult to do accurately. Therefore, for the first two to three years of a young almond orchard, experience has shown soil moisture monitoring to be a successful strategy to schedule irrigations. During young orchard development, the objective should be to supply all the tree water needs and minimize tree water stress.

A soil moisture sensor site should be installed in the active root zone of a selected young tree. The young tree should be healthy and typical of surrounding trees. The site should be in soil conditions typical for the orchard. If the orchard soil conditions are highly variable, more monitoring sites may be appropriate.

When placing the soil moisture monitoring instruments near the young tree, be aware that the young tree's root zone may be very limited at first. There must be root water uptake around the soil moisture instruments for their readings to be of value. Just as the canopy will develop rapidly for a young tree, so will the root zone. Also make sure the monitoring site is placed so that the irrigation system will re-wet the area around the sensors.

Monitoring instruments should be installed at 1-foot intervals to a depth of 4 to 5 feet. While a first leaf tree may not withdraw water from that depth, a second leaf or older tree may utilize the deeper stored water. The deeper sensors also provide valuable information on the depth of irrigation water penetration and the soil moisture status at the beginning of the season.

Young tree continual soil moisture monitoring is extremely useful, and information should be analyzed on a weekly basis due to the limited root zone of the young tree. When the shallower soil depths show signs of moisture depletion, irrigate to replace the depleted water. Young trees require frequent, small amounts of irrigation. This is most efficiently done with drip irrigation since the applied water can be targeted to the young tree's root zone. At the young orchard stage, flood, sprinkler, and to some degree microsprinklers, end up applying water to orchard areas outside the young tree's rooting volume. This makes it difficult to use ET irrigation scheduling for determining irrigation needs in young trees.

Determining the required amount of applied water should be done based on experience. Monitor the soil moisture, looking for the "sweet spot" where soil moisture levels stay relatively constant across the season. This indicates that the irrigations are replacing the soil water used by the tree. Remember that as the tree canopy develops, which can happen quickly in the young trees, the tree water use increases. Adapt your irrigation practices accordingly.

NEXT STEPS

Determining soil moisture is not an end in itself. Use the information to adjust your irrigation practices. When using evapotranspiration (ET) scheduling, soil moisture sampling is an excellent check to make sure the recommended irrigation amounts are correct. Soil moisture sensors should help you determine if you are replacing the soil moisture used by the trees between irrigations. Unless part of an intentional deficit irrigation strategy, soil moisture should stay relatively constant across the season. It may be depleted between irrigation events, but each irrigation should refill the soil water "bank account."

MOVING UP THE CONTINUUM

Soil moisture monitoring in *Level 3.0* is operating at the advanced level. You have all the tools in place to make the best use of soil moisture monitoring. Learning to make the best use of those tools to improve your irrigation water management is a long-term challenge.

Plant Water Status

PLANT WATER STATUS

The most basic observations of plant water status that growers can use in managing irrigation are visual cues. Although monitoring plant water status using visual cues is a poor substitute for quantifiable measurements through stem water potential, they can be valuable in indicating relatively large deviations from the optimal level of irrigation, which would indicate over- and under-irrigation (Fig. 1). Using this approach, growers should evaluate visual cues as described below just prior to irrigation or on a biweekly basis.

1.0 Practice:

Evaluate orchard water status using visual plant cues just prior to irrigation or on a biweekly basis.

INFORMATION TO GATHER

Growers should try to spot the early symptoms of plant water stress and respond before more severe symptoms appear. Often, by the time the more severe symptoms are seen, the damage to yield and quality are irreversible.

Early-season symptoms of under-irrigation water stress that growers should watch for are the lack of new shoots and short shoots or early cessation of growth.

Visual symptoms of under-irrigation during the growing season begin as a change in leaf color from bright green to green with a bluish tint. More severe stress symptoms include leaf droop. If significant water stress due to under-irrigation is experienced prior to hullsplit, delayed or poor hullsplit will result.[1] Symptoms of more severe water stress also include premature leaf drop and shriveled kernels. Although relying on visual symptoms may not be the best method to manage irrigation, recognizing under-watering and taking action is reasonable at this level of management and technology. The early symptoms, if acted upon, can prevent the more severe symptoms.

Often associated with water stress due to under-irrigation is the increased incidence of spider mites,[2] as well as potassium deficiency symptoms (Fig. 2), such as reduced leaf and shoot growth followed by leaf margins becoming necrotic with a folded leaf and curled tip.

Visual symptoms of over-irrigation during the growing season are poor tree vigor, evidence of standing water on the soil surface, and the shift of weed species toward water-preferring weeds. Nutsedge and other sedges, as well as common purslane and spurges, tend to prosper in wetter areas. According to UC weed specialists, a sign of overwatering is the reduced longevity of herbicide performance rather than a shift to a specific suite of weeds. In these cases, summer annual species (pigweeds, lambsquarter, junglerice, spurge, purslane and similar weeds) are the most common because they are

Figure 1. Tree water stress in late June expressed through visible defoliation. (Photo by K. Shackel)

[1] Prichard, T., W. Asai, P. Verdegaal, W. Micke, and B. Teviotdale. 1994. Effects of Water Supply and Irrigation Strategies on Almonds. Modesto: Almond Board of California. Comprehensive Project Report 1993-94.

[2] Youngman, R., and M. Barnes. 1986. Interaction of Spider Mites (Acari: Tetranychidae) and Water Stress on Gas Exchange Rates and Water Potential of Almond Leaves. Environmental Entomology 15:594-600.

Figure 2. Almond potassium deficiency symptoms are similar to those that can be observed as visual signs of water stress. (Photo by IPNI)

primed to germinate in the late spring and summer. For assistance in visually identifying weed species, visit the UC IPM weed photo gallery.

However, it should be noted that in an orchard with poor water infiltration, standing water may not be an indication of overwatering. Over-irrigation should be confirmed by soil augering to evaluate soil moisture, as described in the *Continuum 1.0* section "Soil Moisture."

WHEN TO MAKE OBSERVATIONS

Visual evaluation of the orchard should be done during the growing season, just prior to a planned irrigation. This is when water stress is at its highest level for that irrigation period.

OTHER CONSIDERATIONS

During the first years of the orchard, canopy expansion is the most important process that leads to high productivity. As the orchard reaches maturity, the significance of water deficits that affect vegetative growth are reduced. Vegetative growth in almonds is very sensitive to water deficits. Avoiding water deficits throughout the season in young trees is critical to reaching full production in the shortest time.

In mature orchards, responses to water deficits depend on the timing of the stress. Since most almond-growing regions typically start the season with adequate soil moisture from rainfall or irrigation, vegetative growth in mature almond orchards is rarely impacted. However, this is not the case during drought and deficient water supply in the soil profile during the spring growth phase. For more information on the impact of water stress from under-irrigation due to inadequate water supplies, see UC ANR Publication 8515, Drought Management for California Almonds.[3]

NEXT STEPS

Use these visual cues just prior to irrigation to verify the irrigation schedule based on the orchard water requirement determined in the *Continuum Level 1.0* sections "Orchard Water Requirements" and "Integrating Irrigation Water Management Practices."

MOVING UP THE CONTINUUM

The *Almond Irrigation Improvement Continuum Level 2.0* section "Plant Water Status," recommends using a pressure chamber to measure stem water potential (SWP) just prior to irrigation or on a monthly time basis to ensure calculated water applications are not over- or under-irrigating trees.

SWP measurements taken just before irrigation indicate the orchard water status when soil moisture levels are the driest and orchard stress is potentially the highest. SWP measured at this time can be used to confirm the accuracy of other scheduling methodologies: orchard water demand estimation or soil moisture monitoring.

[3] Doll, D., and K. Shackel. 2015. Drought Tips: Drought Management for California Almonds. Oakland: University of California Agriculture and Natural Resources Publication 8515. ANR CS website, http://anrcatalog.ucanr.edu/Details.aspx?itemNo=8515.

PLANT WATER STATUS

INTRODUCTION

The most basic observations of plant water status that growers can use in managing irrigation are visual cues (Fig. 1).

However, these visual cues can be somewhat subjective and are often expressed after plant stress is higher than desired. Measuring stem water potential (SWP) using a pressure chamber is a more quantitative method for measuring plant water status, and relationships have been established between pressure chamber measurements and tree growth and productivity. From these relationships, guidelines have been developed to assist growers in making irrigation scheduling decisions.

SWP measurements can be used to confirm the accuracy of other irrigation scheduling methods such as ET estimation or soil moisture monitoring methods, or as a stand-alone scheduling aid.

The following discussion of pressure chamber operation and interpretation of measurements was excerpted from UC ANR Publication 8503, Using the Pressure Chamber for Irrigation Management in Walnut, Almond, and Prune (2014).

2.0 Practice:

Evaluate orchard water status using the pressure chamber just prior to irrigation or on a monthly basis. Compare readings to established guidelines to make irrigation scheduling decisions or confirm soil or ET estimation scheduling methods.

Figure 1. Tree water stress in late June. (Photo by K. Shackel)

INFORMATION TO BE GATHERED

PLANT WATER STATUS

During plant transpiration, water moves from the soil into fine roots, up through the vascular system, and out into the atmosphere (Fig. 2).

Water flows through the tree from high potential in the soil (about –0.1 bar) to low potential in the atmosphere (less than –40 bars). Low potential is created at the leaf surface through small openings called stomata that open and close to regulate photosynthesis, gas exchange, and plant water loss. Simultaneously, water held in the soil enters root tissue and begins its journey to the leaves. This creates a vacuum, or tension, within the water-conducting system of the tree. The amount of tension depends on the balance between available soil moisture and the rate at which water is transpired from leaves.

A pressure chamber measures plant water tension by applying pressure to a severed leaf and stem enclosed in an airtight chamber. The pressure required to force water out of the petiole of a severed leaf equals the water potential and is measured by an external pressure gauge (Fig. 3).

As soil moisture is depleted, more tension develops in the plant, requiring more pressure to force water out of the cut surface of the leaf petiole.

Stem water potential (SWP) is a direct measure of water tension (negative pressure) within the plant and is given in metric units of pressure, such as bars (1 bar is about 1 atmosphere of pressure, or 14.7 psi). Even under fully irrigated conditions, the July SWP in almond trees at midday can be as low as –10 bars simply because this much tension is required to pull water out of the soil and through the tree. Technically, SWP should always be shown as a negative value (e.g., –10 bars), but in conversation we often omit mentioning "negative" before the value. More information about the operation of the pressure chamber can be found in Using the Pressure Chamber for Irrigation Management in Walnut, Almond, and Prune.[1] The following pressure chamber measurement topics are a summary of those in this publication.

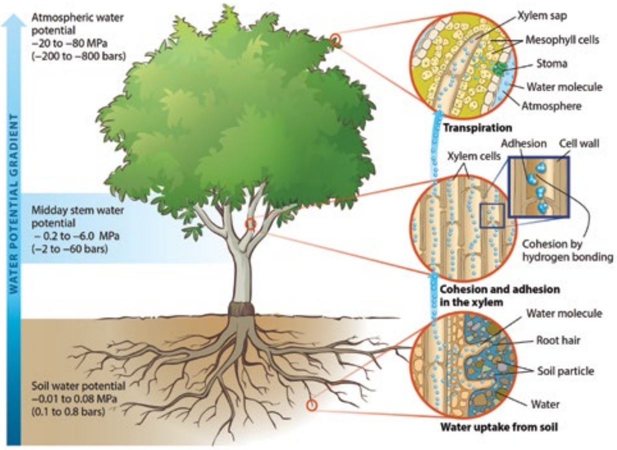


Figure 2. Illustration of how water moves from the soil through an irrigated tree and into the atmosphere, from both a whole-tree and cellular perspective. SWP measures the water potential gradient that drives this movement of water through the tree. (Source: Adapted from Pearson 2008. Pearson. 2008. Upper Saddle River, NJ: Pearson Education Inc.)

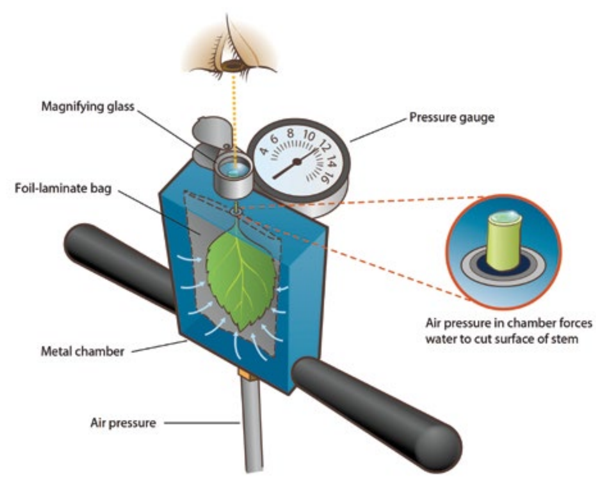


Figure 3. Schematic showing how water potential is measured in a severed leaf and stem (petiole) using a hand-held, pump-up pressure chamber. (Source: Adapted from Plant Moisture Stress (PMS) Instrument Company)

[1] A. Fulton, R. Buchner, J. Grant, and J. Connell. 2014. Using the Pressure Chamber for Irrigation. Management in Walnut, Almond, and Prune. Oakland: University of California Agriculture and Natural Resources Publication 8503. ANR CS website, http://anrcatalog.ucanr.edu/Details.aspx?itemNo=8503.

MAKING SWP OBSERVATIONS

TIME OF DAY

Stem water potential (SWP) is best measured midday from noon to 4 p.m. The idea is to make measurements when the tree is experiencing relatively constant and maximum water demand. Thus, the guidelines for interpreting SWP measurements have been made by using midday measurements.

To measure SWP, a leaf from the lower shaded canopy is placed inside a foil bag ("bagged") for at least 10 minutes before it is cut from the tree and placed into the pressure chamber (keeping it in the bag). Bagging the leaf for longer periods for convenience will not affect the midday measurement. Bagging the leaf eliminates water loss so the leaf reaches equilibrium with the water-conducting system of the adjacent branches and trunk.[2]

TIME OF SEASON

SWP measurements should begin during the spring and continue through the summer and fall. Measurements in early spring can be extremely helpful in deciding when to initiate irrigation. This approach will show how orchard water status responds to seasonal weather changes, irrigation decisions, and how irrigation scheduling might be improved. Postponing SWP measurements until early summer will miss the progressive changes in orchard water status leading up to the summer season (when water demand is highest).

TIME BETWEEN IRRIGATIONS

How often measurements are taken depends on practical considerations. Orchard acreage, time availability, coordination with other tasks, and specific interests may influence measurement frequency. Most irrigation managers have found that measuring SWP just prior to irrigation and one or two days after irrigation provides the best information about the ongoing water status of the orchard. SWP measurements taken just before irrigation will indicate the orchard water status when soil moisture levels are the driest and orchard stress is potentially the highest. Monitoring SWP one or two days after irrigation will indicate how well the tree water status recovered after irrigation.

Larger changes in SWP may be observed before and after irrigation when irrigation frequency is stretched out more with a flood system that applies more water in a single irrigation compared with a drip or microirrigation system that applies smaller volumes of water more frequently.

HOW MANY MEASUREMENTS TO MAKE IN A BLOCK

Determining how many trees to monitor must balance having enough trees to reliably represent the orchard and being able to cover the desired total acreage in a timely and efficient manner. Sampling fewer trees and accepting the possibility of less-representative measurements is better than not using SWP at all because it is perceived as too labor intensive. The number of trees to monitor in an orchard also depends on soil variability and irrigation uniformity. Fewer trees are needed if the orchard is growing on one predominant soil type with uniform irrigation. More trees are needed if there is more than one soil type and nonuniform irrigation. A sampling strategy that can be completed in about 30 to 60 minutes per orchard is ideal, especially if several orchards must be monitored on the same afternoon. Understanding of orchard water status will improve as the number of trees monitored is increased. A sample size ranging from 5 to 10 trees per orchard is probably a good compromise between achieving representative measurements and covering acreage efficiently.

SELECTING TREES FOR MEASUREMENT

Trees selected for SWP monitoring should be representative of the orchard. Good measurement trees would be of the same variety and rootstock and similar in age, degree of pruning, and canopy size. Measurement trees should be irrigated in the same manner as the rest of the orchard and should be healthy. The trees selected for SWP measurement should be at least 100 feet inside the orchard and have other healthy trees growing

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[2] H. McCutchan and K. A. Shackel. 1992. SWP as a Sensitive Indicator of Water Stress in Prune Trees (Prunus domestica L.cv French). Journal of the American Society of Horticultural Science 117:607-611.

around them for competition to avoid anomalies such as may occur by selecting trees along the edge of an orchard or near a missing tree in the interior of the orchards. The same trees should be used to measure SWP each time to reduce variation from one reading time to the next. The sample trees should be marked with flagging or spray paint or possibly identified using a handheld GPS device so they are easily relocated each time SWP measurements are made.

HOW MANY LEAVES PER TREE

Little variability in SWP is found between leaves on a tree when the leaves are chosen low on the canopy in shaded locations and the operator doesn't compromise the sample leaf by mechanical damage or not following a consistent protocol. Random error is about 0.5 and 1.0 bar for a single sample measurement. The most efficient method is to measure more trees at one sample per tree vs. more leaves on a single tree. If an outlier is measured and it is expected an error occurred in measurement, skip the measurement or re-bag a leaf and return to measure after 10 minutes.

SELECTING THE LEAF FOR MEASUREMENT

Bags should be placed on leaves located in the interior shaded canopy as close to the trunk as possible (Fig. 4). Leaves should be healthy, fully expanded, and without apparent nutritional deficiencies, yellowing from excessive shading or older age, or physical damage from wind or hail. Lower interior leaves are selected as near to the trunk as possible, where the bagged leaf equilibrates readily with the tree's main water-conducting system. Reflective, water-impervious mylar foil bags are commonly used for bagging leaves. Bags are available from some pressure chamber manufacturers and retail distributors of food storage bags, and they are reusable. Leaves higher in the canopy or farther out on a limb can have significantly lower levels of SWP due to more resistance to water flow through the vascular system.

BAGGING THE SAMPLE LEAVES

The importance of bagging or covering the sample leaves on large perennial trees can't be emphasized enough. Ideally, the sample leaves need to be bagged for at least 10 minutes prior to excising the leaf from the tree. The bag should remain on the leaf after it is cut from the tree and while the SWP is being measured on the leaf. Removing the leaf from the bag at any point during the excising and measurement of SWP will result in an error in measurement. Resist the temptation to remove the leaf from the foil bag even if it makes inserting the sample leaf into the chamber easier and more convenient. Placing the bag and leaf in the chamber can be made easier by selecting leaves with long petioles. Depending on the chamber size, selecting or redesigning the bag for easy inserting can help.

Figure 4. Lower interior leaves are selected on almond trees to measure SWP. (Photo by A. Fulton)

PRESSURE CHAMBER SELECTION AND OPERATION

SELECTION

A number of companies produce durable, portable and relatively inexpensive pressure chambers for measuring stem water potential (SWP). The choice of a pressure chamber depends largely on preferences. The cost may range from about $1,000 to about $7,000, depending on the style, design and whether the unit is new or used. Compressed nitrogen gas is a convenient, relatively inexpensive, and inert (non-reactive) gas to use as a source of pressure. Air pressure requires a special pump to provide sufficient pressure. Most small, affordable air compressors cannot provide enough pressure. Approximately 300 to 400 psi or perhaps higher may be needed to measure stem water potential in almonds. Carbon dioxide gas is also used to supply pressure with some pressure chambers.

Several pressure chamber styles and designs are available, ranging from simple manual pump-ups to consoles with more advanced features (Fig. 5).

Figure 5. Four examples of commercially available pressure chambers. Example A is a pump-up style by PMS Instruments in which a foot pump creates air pressure in the rectangular chamber. Example B, by Specialty Engineering, also has a rectangular chamber, employs a tripod to hold the pressure chamber, and uses compressed carbon dioxide (CO2) gas to supply the pressure. Example C is a suitcase-style pressure chamber. It has a cylindrical chamber that uses an external source of nitrogen gas, stored in a metal cylinder, to pressurize the chamber. Both PMS Instruments and Soilmoisture Equipment Corp. offer this style of pressure chamber. Example D is a console- or bench-style pressure chamber by Soilmoisture Equipment Corp. that also uses an external bottle of nitrogen gas to pressurize the chamber. Photos: Courtesy of Plant Moisture Stress (PMS) Instrument Company, Albany, OR (A, C); Specialty Engineering, Waterford, CA (B); and Soilmoisture Equipment Corp., Santa Barbara, CA (D).

All have the same basic components and operate on the same concept. Basic components of a pressure chamber include an airtight chamber and locking lid to hold the sample leaf; a source of compressed air, nitrogen or carbon dioxide to provide pressure in the chamber; a control valve to pressurize and exhaust the chamber; a regulating valve or manual pump to control the rate at which the chamber is pressurized; and a gauge to display the pressure inside the chamber. Pressure chamber gauges vary in style. Both mechanical dial and electronic digital-style gauges are available. Though many of the components are readily available, and homemade pressure chambers have been constructed, this is not recommended. Commercially available pressure chambers have been tested for quality, safety and accuracy, whereas homemade chambers are not.

OPERATION

Using a consistent technique helps improve the accuracy of SWP measurements. In almonds, as much as a plus or minus 2 bar discrepancy has been documented with different operators. Such errors can be due to differences in speed and method of handling the sample from the time the leaf is excised until the measurement is completed, or they can be due to differences among operators in recognizing the endpoint.[3] Relying on one operator to monitor the same orchards over the season, using the same

[3] D. Goldhamer and E. Fereres. 2001. Simplified Tree Water Status Measurements Can Aid Almond Irrigation. California Agriculture 55(3): 32-37.

pressure chamber and consistent technique, is recommended to minimize variability. SWP measurements should be completed as rapidly as possible after bagged leaves are excised. It usually takes an experienced operator 15 to 30 seconds to take a measurement. To minimize variability, readings should be made immediately after the leaf is cut off the tree. The endpoint occurs when pressure inside the chamber has equalized with water tension in the leaf. The endpoint reading should be taken just as the lighter colored xylem in the center of the cut petiole begins to darken as water begins to appear (Fig. 6). Bubbling or fizzing at the cut surface indicates that the endpoint has been exceeded. If the endpoint is accidentally exceeded or is in doubt, it can be double-checked by simply reducing the pressure inside the chamber enough so that the water recedes from the surface of the cut stem. Once the water disappears, chamber pressure is again increased, perhaps at a slower rate of pressure increase and the measurement is retaken to confirm accuracy. There is a slight decrease in the water potential measurement with each succeeding repressurization, but it should be minimal if the water has not been allowed to exude from the petiole for very long. Good measurement technique also involves carefully bagging and excising bagged leaves to prevent damaging leaf blades or stems. To avoid strangling or pinching off the stem, be careful to not overtighten the rubber grommet (Fig. 6B and 6C). Strangling the stem can be a problem, especially with small almond leaves and stems. If a leaf is torn or the stem is broken, the SWP will not be accurate as previously described because the water-conducting system of the stem will have been compromised. Most pressure chambers (excluding hand-held, pump-up models) incorporate an adjustable metering valve to regulate how fast pressure builds inside the chamber. Metering valves should be set to increase pressure slowly to lessen the chance of missing the endpoint. Experienced operators will set how fast the chamber pressurizes so that it is possible to both watch for the endpoint and read the pressure gauge at the same time. This ability provides a better feel for the measurement and improves confidence and accuracy in observing the endpoint. Experience suggests that a pressure increase of 0.2 to 0.4 bars per second is about right near the endpoint. In addition, less error occurs when pressure entering the chamber is quickly stopped at the endpoint by using the shut-off valve and not the regulator valve.[4] The pressure regulator valve is a needle type that can be easily damaged from overtightening to stop pressure into the chamber.

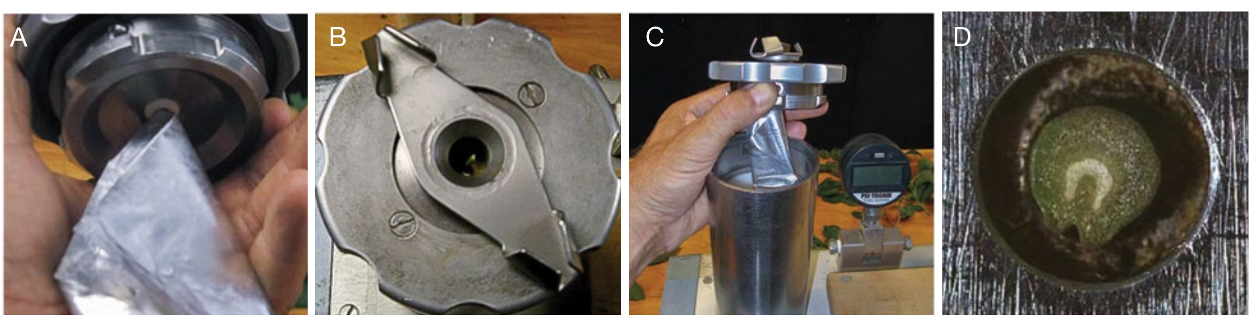


Figure 6. Measuring SWP after the bagged leaf is excised from a tree involves first inserting the stem of a bagged leaf upward through the top of the pressure chamber (A). In photo (B), a longer stem is shown protruding out of the top of the chamber. Some researchers emphasize that the stem should not be protruding out this much for the most accurate measurement of SWP. Other researchers and experienced practitioners have more difficulty seeing the endpoint without the longer stem, which can also introduce error in seeing the endpoint. Securely tighten the grommet holding the protruding stem of the bagged stem in the pressure chamber cap (B). Place a bagged leaf in the pressure chamber. After the leaf has been inserted securely tighten the pressure chamber cap around the petiole (C). Determine the endpoint for a SWP measurement (D). Close to the endpoint, water will begin to appear at the surface and the horseshoe shaped xylem in the middle will begin to darken. This is when the endpoint reading should be taken. (Photos by A. Fulton)

[4] A. Naor and M. Peres. 2001. Pressure Increase Rate Affects the Accuracy of Stem Water Potential Measurements in Deciduous Trees Using the Pressure Chamber Technique. Journal of Horticultural Science and Biotechnology 76(6): 661-663.

USING SWP IN ALMOND IRRIGATION

Suggested guidelines for interpreting SWP measurements in almonds are shown in Table 1.

SWP in almonds has been observed to range from -6 to -60 bars. Tree and crop responses also change over the season. Low levels of tree water stress (-6 to -10 bars SWP) in almonds are usually observed in the spring, shortly after leafing, when the days are shorter, weather is cooler, and rainfall is more abundant. As the season progresses, temperature and day length increase while relative humidity tends to decrease, resulting in SWP levels in the minimal to mild range (-10 to -14 bars SWP) for fully irrigated, mature trees. Excellent yields (over 4,000 pounds per acre) are possible in the southern San Joaquin Valley when irrigation is managed to maintain tree water status in the low to mild SWP range for the entire season. Almond production regions with good weather during pollination (i.e., with warmer temperatures and less rainfall) and receiving more intensive fertility management appear to be more responsive to low tree stress. However, concerns exist about potentially higher incidence of disease, lower limb dieback, and shorter orchard life under this management regime. Irrigation managers also need to avoid saturated soils and poor aeration, which compromise root health and tree performance. The decision to adopt intensive irrigation management to sustain low to mild stress involves an economic decision weighing the pros and cons of higher-yielding orchards with potentially shorter life spans, versus lower-yielding (but still competitive) orchards with longer lives.

For locations where a low tree stress management approach may not be the best management strategy, the use of SWP to impose timely and controlled levels of tree stress in almond may be the better choice. Controlled tree stress is referred to as "regulated deficit irrigation" or RDI. RDI involves withholding water at crop development stages where controlled levels of tree stress do not adversely affect crop yield or kernel quality and might improve tree performance. For more information on deficit irrigation refer to UC ANR Publication 8515, Drought Management for California Almonds,[5] and California Agriculture article "Regulated deficit irrigation reduces water use of almonds without affecting yield."[6]

Pressure chamber reading or SWP (bars)	Stress level	Extent of crop and types of crop responses associated with different SWP levels in almond
0 to -6	None	No stress. Not commonly observed in almond. Only observed in early spring.
-6 to -12	Minimal	Fully irrigated conditions. Stimulates shoot growth, especially in developing orchards. Higher yield potential may be possible if these levels of crop stress are sustained over a season, barring other limitations related to frost, pollination, diseases, or nutrition. Sustaining these levels may result in higher incidence of disease and reduced life span. Typical of mature trees from leaf-out through mid-June.
-12 to -14	Mild	Reduced growth in young trees and shoot extension in mature trees. Suitable from mid-June until the onset of hullsplit (July). Still able to produce competitively. Recommended crop stress level after harvest. May reduce energy costs or help cope with drought conditions.
-14 to -18	Moderate	Stops shoot growth in young orchards. Mature almonds can tolerate this level of crop stress during hullsplit (July/August) and still yield competitively. May help control diseases such as hull rot and alternaria, if present. May expedite hullsplit and lead to more uniform nut maturity. Also may help reduce energy costs and cope with drought conditions.
-18 to -22	Very High	Wilting observed. Widespread defoliation. Stomatal conductance of CO_2 and photosynthesis declines as much as 50% and impacts yield potential due to reduced leaf activity. Some limb dieback.
-30 to -60	Severe	Extensive or complete defoliation is common. Trees may survive despite severe defoliation and may be rejuvenated. Some limb dieback. Much less or no bloom and very low yield potential can be expected the following season until trees are rejuvenated.
Less than -60	Extreme	Complete defoliation, no flowering in the subsequent year. Dieback likely.

Table 1. Guidelines for interpreting SWP measurements in almonds.

[5] D. Doll and K. Shackel. 2015. Drought Tips: Drought Management for California Almonds. Oakland: University of California Agriculture and Natural Resources Publication 8515. ANR CS website, http://anrcatalog.ucanr.edu/Details.aspx?itemNo=8515.

[6] W. C. Stewart, A. Fulton, W. H. Krueger, B. D. Lampinen, and K. A. Shackel. 2011. Regulated Deficit Irrigation Reduces Water Use of Almonds Without Affecting Almond Yield. California Agriculture 65(2): 90-95. http://calag.ucanr.edu/Archive/?article=ca.v065n02p90.

SWP: A STAND-ALONE OR COMPLEMENTARY IRRIGATION MANAGEMENT TOOL?

As a direct measure of tree response to irrigation management and the soil, climate and orchard environment, SWP is unique compared with other methods that assess tree water status indirectly. As such, through trial and error, SWP can be used — and has been successfully adopted by many growers — as a stand-alone technique for irrigation scheduling in almonds. Using SWP alone, along with the interpretive guidelines presented in this publication, gives a relatively straightforward answer to the question of when to irrigate.

However, trial and error may not suffice in some situations, and SWP measurements alone may not provide enough information. For example, pressure chamber measurements can show low crop stress in April, May and early June in orchards even though irrigation has been postponed or reduced. The trees consume water stored in the root zone from winter rainfall or winter irrigation during this period to satisfy their water requirements. Without some monitoring of soil moisture or tracking of ET, it is possible to experience a sudden and rapid increase in tree water stress starting in midsummer when evaporative demand is high and stored soil moisture is depleted. Meanwhile, a drip or microsprinkler irrigation system will not have the capacity to apply enough water to recharge the soil moisture depletion and sufficiently relieve tree stress. This can be a problem particularly in orchards where soils have a low water infiltration rate. Irrigation should be initiated before the stored water is depleted excessively. Irrigation set times should be selected to replace most of the extracted water while avoiding long run times that result in waterlogged soils and increased risk of injury to the root system.

Using SWP in conjunction with soil moisture monitoring or a water budget (or both) can also help overcome some common limitations of soil moisture monitoring and irrigating according to ET. SWP readings that indicate low tree stress, even though soil moisture sensors indicate dry soil, might suggest that trees are getting water from greater depths in the root zone that are not being monitored by soil moisture sensors. This situation could indicate a need for deeper soil moisture monitoring. Similarly, SWP readings that indicate desirable levels of tree stress, even when a water budget indicates under-irrigation, suggest the need to re-examine assumptions about ET rates, rooting depth, and available moisture reserves. In a different situation, SWP measurements might indicate moderate to high tree stress even when soil moisture sensors placed within the wetted pattern of the drip emitter show high soil moisture content. In this case, additional investigation is necessary to determine if soil moisture sensors accurately represent the root zone and predominant soil types or if the sensors are defective. It may be possible that roots extend beyond the areas wetted by drip emitters or microspinklers. Some of these situations are more likely to occur where rainfall plays a more prominent role in supplying orchard water needs. If the entire soil profile is recharged with rainfall, roots are not confined to the drip zone and can extract moisture from a much larger area.

OTHER CONSIDERATIONS

YOUNG ORCHARDS

During the first years of the orchard, canopy expansion is the most important process that leads to high productivity. As the orchard reaches maturity, the significance of water deficits that affect vegetative growth are reduced. Vegetative growth in almonds is very sensitive to water deficits. Avoiding water deficits throughout the season in young trees is critical to reaching full production in the shortest time. The use of SWP measurements in young orchards can be very useful to overcome the difficulties in estimating ET with changing canopy size.

When sampling small trees, particularly during the first year, excessive leaf removal may be an issue, especially if the trees are not growing well. One solution is to identify three or four side-by-side rows of uniformly growing trees in representative areas of an orchard. Each row will have three or four trees identified for SWP measurement. Then, using a rotational schedule, measure SWP in a different row each day, returning to the first row after trees have had time to grow additional leaves suitable for measurement (usually two or three weeks after the previous measurement in the first row). Typically, second-year and older trees should have sufficient canopy that rotating between rows of sample trees is no longer necessary.

MATURE ORCHARDS

Responses to water deficits depend on the timing of the stress. Since most almond-growing regions typically start the season with adequate soil moisture from rainfall or irrigation, vegetative growth in mature almond orchards is rarely impacted. However, this is not the case during drought and deficient water supply in the soil profile during the spring growth phase. For more information on the impact of water stress from under-irrigation due to inadequate water supplies, see UC ANR Publication 8515, Drought Management for California Almonds.[7]

NEXT STEPS

Measurements of SWP can be used for a stand-alone irrigation scheduling method or to verify an irrigation scheduling program based on ET estimation or soil moisture monitoring. Measurements are made just prior to irrigation to verify the irrigation schedule based on the orchard water requirement determined in the *Continuum Level 2.0* sections "Orchard Water Requirements" and "Integrating Irrigation Water Management Practices."

MOVING UP THE CONTINUUM

The *Almond Irrigation Improvement Continuum Level 3.0* section "Plant Water Status" recommends using a pressure chamber to measure stem water potential (SWP) just prior to irrigation or on a weekly basis, comparing readings to baseline values to ensure calculated water applications are not over- or under-irrigating trees.

SWP measurements which are taken just before irrigation indicate the orchard water status when soil moisture levels are the driest and orchard stress is potentially the highest. SWP measured at this time can be used to confirm the accuracy of other scheduling methodologies: orchard water demand estimation or soil moisture monitoring. SWP baseline readings are discussed and guidelines presented for interpreting the measured distance from the baseline.

[7] Doll, D., and K. Shackel. 2015. Drought Tips: Drought Management for California Almonds. Oakland: University of California Agriculture and Natural Resources Publication 8515. ANR CS website, http://anrcatalog.ucanr.edu/Details.aspx?itemNo=8515.

PLANT WATER STATUS

"Plant Water Status" *Level 3.0* relies on the same *2.0* process for using pressure chambers to evaluate orchard water status. Please refer to "Plant Water Status" *Level 2.0* for a detailed explanation of that process. In "Plant Water Status" *Level 3.0*, the "baseline concept" can be used to interpret readings to make irrigation scheduling decisions or confirm soil or ET estimation scheduling methods. The baseline concept and alternative methods to assess orchard water status are outlined in this section.

3.0 Practice:

Evaluate orchard water status using the pressure chamber just prior to irrigation or on a weekly basis. Compare readings to established guidelines or use the baseline concept to interpret readings to make irrigation scheduling decisions, or confirm soil or ET estimation scheduling methods.

USING BASELINE PREDICTIONS TO INTERPRET ALMOND ORCHARD SWP VALUES

Because SWP is affected by weather conditions at the time measurements are made, readings can vary from one day to the next as the weather changes, even if irrigation management and soil moisture are relatively stable. SWP measurements should not be done under cloudy conditions because the measurements will not be representative of a maximum ET condition and will change after the cloudy conditions pass. This has caused irrigation managers to question the use of the standard guidelines (*Level 2.0*, Table 1) since they are unsure whether conditions exist that make them valid. These issues have led to the development of a refinement of the SWP method called the **baseline concept** for irrigation managers who want to account for additional perspective when interpreting SWP readings for irrigation scheduling.

The baseline SWP for any given day and time is defined as the SWP that is expected if soil moisture is abundant and not limiting transpiration under the prevailing temperature and humidity conditions. Because these numbers were developed under non-cloudy conditions, readings should only be taken under clear skies.

Baseline values are derived from mathematical models and have been validated in field experiments on almonds. Estimates of baseline SWP for almonds over a range of air temperatures and relative humidity are provided in Table 2.

An online calculator of baseline SWP is also available at the Fruit and Nut Research and Information Center website, http://informatics.plantsciences.ucdavis.edu/Brooke_Jacobs/index.php.

Estimating the baseline will require access to public or private weather databases (e.g., CIMIS) that provide hourly temperature and relative humidity data, or an inexpensive simple handheld psychrometer (Fig. 7) that can measure temperature and relative humidity in the orchard at the same time that SWP measurements are taken. The baseline is based on CIMIS, which should be equivalent to the temperature and relative humidity **above** the orchard, rather than **in** the orchard (presumably under the canopy). This may not be a big deal, but has been reported to be as much as a bar or so difference.

Figure 7. Field temperature and humidity sensor.

	Air relative humidity (RH,%)						
Temp. (°F)	**10**	**20**	**30**	**40**	**50**	**60**	**70**
75	-7.3	-7.0	-6.6	-6.2	-5.9	-5.5	-5.2
80	-7.9	-7.5	-7.0	-6.6	-6.2	-5.8	-5.4
85	-8.5	-8.1	-7.6	-7.1	-6.6	-6.1	-5.6
90	-9.3	-8.7	-8.2	-7.6	-7.0	-6.4	-5.8
95	-10.2	-9.5	-8.8	-8.2	-7.5	-6.8	-6.1
100	-11.2	-10.4	-9.6	-8.8	-8.0	-7.2	-6.5
105	-12.3	-11.4	-10.5	-9.6	-8.7	-7.8	-6.8
110	-13.6	-12.6	-11.5	-10.4	-9.4	-8.3	-7.3
115	-15.1	-13.9	-12.6	-11.4	-10.2	-9.0	-7.8

Table 2. Baseline SWP (bars) to expect for fully irrigated almond trees under different conditions of air temperature and relative humidity.

INTERPRETING BASELINE SWP IN ALMONDS

The baseline SWP values for almonds will change with weather conditions (Table 2). During cool weather, estimates of baseline SWP may be -5 to -7 bars. However, under hot and dry weather conditions, baseline SWP for almonds may be as low as -11 to -12 bars.

Irrigation timing — minimal stress. An example of when the use of baseline SWP helps distinguish tree water stress would be a day when an almond orchard baseline is -10 bars SWP and the mature orchard SWP measurements are -14 bars SWP, or 4 bars below baseline. This would clearly suggest that tree water stress is occurring and that the need for irrigation is approaching. On a very hot, windy day, when the baseline is -13 bars SWP and the orchard measurement is -15 bars SWP, it would suggest that tree stress is occurring. However, these readings are more associated with the hot, dry weather conditions than with irrigation management. Under such conditions, mild tree stress can occur even when irrigation management is on track and soil moisture is not limiting. Once the hot, dry weather passes, both the estimate of baseline SWP and the orchard SWP measurements will recover to levels indicating lower tree stress.

Irrigation timing — moderate stress. If targeting moderate water stress conditions to promote hullsplit or to discourage hull rot, then irrigate when measured SWP values are 5 to 6 bars below baseline.

Young orchards. For 1- or 2-year-old trees, irrigation should occur when trees are 2 bars lower than baseline.

Over-irrigation. An example of over-irrigation would be if the baseline is -5 to -6 bars SWP and pressure chamber measurements are consistently within the range of -4 to -5 bars SWP. In this scenario, trees may be over-irrigated and root zones may be too wet.

Higher irrigation frequency and orchards with smaller size of the wetted root zone will experience more rapid swings in SWP as the temperature and humidity change. When these conditions exist more frequent measurements of SWP are recommended.

USING ALTERNATIVE METHODS TO ASSESS ORCHARD WATER STATUS

Measurements of plant water status using a pressure chamber are the standard for measuring water stress in almonds. However, measurements can be time consuming and labor intensive, which is a constraint in obtaining the number of samples necessary to develop efficient irrigation scheduling techniques. A number of alternative plant-based methods have been developed for measuring water stress, some of which are automated and being sold commercially for the purpose of automated or semi-automated irrigation scheduling. These methods hold promise for reducing the effort of measuring plant water stress, but it should be noted that these methods often do not have a good correlation with stem water potential and therefore should be used with caution. Bruce Lampinen, integrated orchard management walnut and almond specialist with the University of California Cooperative Extension, stated at the Almond Production Research Conference in 2016 in the presentation “Plant Water Status — A Review of Existing Tools” that “whichever of these techniques you use, be sure to calibrate it against stem water potential.”

These alternative methods are based on measuring changes in plant characteristics due to water stress. As an almond tree becomes stressed from a lack of water, changes can be observed in:

- Stem water potential: becomes more negative
- Leaf temperature: increases
- Leaf characteristics: change
- Trunk diameter or radius dawn to midday fluctuation: decreases

These characteristics can potentially be used to estimate plant water status.

CROP IMAGING AND ANALYSIS TO ESTIMATE ALMOND WATER STRESS

When a plant is under no water stress, the stomata are open and the water vapor diffusing from the leaf tends to cool the leaf. If the plant is experiencing water stress, the stomata tend to close and the leaf temperature may increase, depending on the ambient conditions. Therefore, leaf temperature can be a good water stress indicator for plants.[1] In recent studies, aerial thermal imaging has been used to measure canopy temperature to predict plant water status.[2]

FIELD-BASED MEASUREMENTS

Canopy temperature can be measured continuously using an infrared thermometer at the field level, and the information can be relayed via the cell phone network for data analysis and interpretation to estimate plant water stress. Many of these service providers use a combination of canopy temperature and soil moisture data and other key variables to assist in making recommendations.

AERIAL IMAGES

Images of the orchard obtained via flight or satellites are processed to visualize plant water stress or indications of crop vigor. Generally, thermal imagery is used to measure the ambient temperature and the canopy temperature. From these measurements estimates are made of crop ETc. Images are available on a set flight schedule or when satellite paths provide data. The various services provide access to data via the internet on handheld devices. Another spectral method uses a calculation of normalized difference vegetation index (NDVI), which uses measured reflectance in the near-infrared and red light spectra to estimate plant biomass and general vigor.

NDVI values range from (–1) to (+1) based on red and infrared radiance, where positive values indicate low concentrations of dead biomass surfaces, and high concentrations of living biomass surfaces. NDVI can potentially be used to estimate ground cover and adjust the crop coefficient (Kc). This method can be useful when estimating Kc for orchard crops, which can vary widely with plant spacing, tree pruning and age.

MEASUREMENTS OF TRUNK DIAMETER OR RADIUS CHANGE (SHRINK/SWELL) USING DENDROMETERS

The dendrometer is an electronic sensor mounted on the trunk of a tree to provide continuous monitoring of changes in the trunk radius. Diurnal changes (shrink and swell) and seasonal change can be monitored. Tree growth and water balance affect the trunk shrink/swell and the amplitude is proportional to water deficit. The value of midday shrinkage (MDS) has been suggested as an accurate plant-based measure of stress in trees. This measure was found to have a clear response to irrigation events, but relating this to stress requires a fully watered tree as a reference.

NEXT STEPS

Although measurements of SWP can be used for a stand-alone irrigation scheduling, it is more useful combined with an irrigation scheduling program based on ET estimation or soil moisture monitoring. Measurements are made just prior to and several days after irrigation to verify the irrigation schedule based on the orchard water requirement determined in *Continuum Level 3.0* sections “Orchard Water Requirements” and “Integrating Irrigation Water Management Practices.”

[1] T. N. Carlson, R.R. Gillies, and E.M. Perry. 1994. A Method to Make Use of Thermal Infrared Temperature and NDVI Measurements to Infer Surface Soil Water Content and Fractional Vegetation Cover. Remote Sensing Reviews 9(1–2):161–173.

[2] M. Moller, V. Alchanatis, Y. Cohen, et al. 2007. Use of Thermal and Visible Imagery for Estimating Crop Water Status of Irrigated Grapevine. Journal of Experimental Botany 58(4):827-838.

Integrating Irrigation Water Management Practices

INTEGRATING IRRIGATION WATER MANAGEMENT PRACTICES

The goal of irrigation scheduling is to determine how to supply the orchard with the correct amount of water at the appropriate time. Most growers make irrigation decisions based on their experience and the practical limitations of their systems. However, research has developed good irrigation water management practices to optimize orchard water management that should be included in grower decision making.

There are compelling reasons to adopt technical water management procedures. First, more precise water management can increase revenues. Conserving water reduces grower inputs, which increases revenue by a magnitude dependent on the water cost. Second, reducing the amount of water applied also conserves a natural resource vital to all Californians. Demonstrating good stewardship of water resources will serve growers well in the ever-increasing competition for limited water supplies.

1.0 Practice:

Combine irrigation system performance data with "normal year" regional crop evapotranspiration estimates to determine the orchard-specific water requirements and schedule irrigations. Check soil moisture with an auger and/or visually monitor plant water status to verify scheduling.

INTEGRATING 1.0 PRACTICES

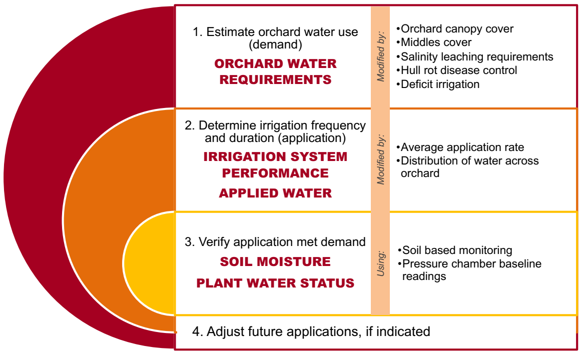
Supplying irrigation in the correct amount and at the correct time to meet the trees' needs is the goal of irrigation scheduling. This goal is best served by using estimates of crop water use (evapotranspiration, or ETc) considering the specific orchard water requirements and irrigation water conditions. These site-specific factors, such as canopy size, the presence of middles cover (cover crops/weeds), soil and water salt levels, and the use of deficit irrigation, are discussed in the *Level 1.0* section "Orchard Water Requirements." Additionally, delivering the correct amount of water to the majority of the orchard requires knowledge of application rate and the distribution of water across the orchard as discussed in the *Level 1.0* section "Irrigation System Performance." Verifying the appropriate amount of applied water is described in the *Level 1.0* section "Applied Water."

Although the above method of estimating orchard water requirements and ultimately system operating or set time are good, they are only a best estimate. The adequacy of the irrigation schedule generated using the approach above should be verified by soil- and/or plant-based monitoring methods as discussed in the *Level 1.0* sections "Soil Moisture" and "Plant Water Status."

To help address the errors inherent in the estimation of the orchard water requirements, growers rely on the soil to act as a buffer to small amounts of over- or under-irrigation by virtue of its water-holding capacity. However, if errors are large, either over-irrigation, causing soil saturation, or under-irrigation, causing water deficits,

can occur. Both can be detrimental to the orchard and the crop. If monitoring indicates the existence of either condition, adjustments in the schedule should be made.

Almond irrigation scheduling, water application, and verifying the effectiveness of the process is a four-step process. The following graphic illustrates how the *Level 1.0* measures work together to shape overall good irrigation scheduling and management of California almonds.



1.0 IRRIGATION SCHEDULING SAMPLE CALCULATION

GOOD IRRIGATION WATER MANAGEMENT PRACTICES FOR CALIFORNIA ALMONDS

Four steps for good irrigation water management practices should be employed to schedule almond irrigations. They are:

1. Meet the orchard's estimated orchard requirement by developing an irrigation schedule using ETc estimates based on specific orchard conditions.
2. Determine the irrigation system operation time using the average application rate determined by evaluating the irrigation system performance.
3. After the schedule has been implemented, monitor soil water status and/or plant water status to verify the schedule.
4. If soil- or plant-based monitoring indicate too much or too little irrigation, adjust the schedule for the next irrigation period.

The steps above indicate practices and considerations that should be made for any good irrigation water management system. The sample calculation below uses that as a guide and provides an example of how to tie together the measurements derived from the *Level 1.0* sections of the *Continuum*. Together they provide the pieces to develop a good irrigation water management strategy for your operation.

In this example we will first estimate the orchard water use (ETc) with the given orchard conditions, then determine the orchard water requirements needed at each irrigation and time of irrigation by adding the salt leaching requirements to determine irrigation volumes; confirming the applied water volume through water measurement; and using soil monitoring and/or visual plant cues of water status to verify the estimates of crop water use and irrigation delivery. If monitoring suggests the schedule is in error, corrections to the schedule should be made.

Given orchard conditions:

- Orchard maturity: Mature orchard, canopy shaded area greater than 70%
- Middles cover: None
- Location: Fresno, ET Zone 15
- Scheduling period: June 1–30
- Irrigation water salinity: 1.0 dS/m
- Irrigation system type: Sprinkler irrigation

1. Determine the orchard water requirement.
   - Data collected via instruction from *Level 1.0* section “Orchard Water Requirements”:
     - – ETc estimate for Zone 15 in June: 8.51 inches
     - – Leaching requirement (LR) = 15% or 0.15
   - Calculations:

     $$\text{Orchard water requirement (OWR)} = \text{ETc} \div 1 - \text{leaching requirement}$$

     $$\text{OWR} = 8.51 \div (1 - 0.15) = 10.0 \text{ in}$$

2. Determine the irrigation system application rate and set run time.
   - Data collected via instruction from *Level 1.0* section “Irrigation System Performance”:
     - – Average application rate: 0.10 inches per hour
   - Calculations:

     $$\text{Irrigation system run time} = \text{OWR} \div \text{application rate}$$

     $$\text{Irrigation system run time} = 10.0 \div 0.10 = 100 \text{ hrs}$$

3. Verify schedule prior to the next calculation period.
   - Data collected via instruction from “Soil Moisture” *Level 1.0* and/or “Plant Water Status” *Level 1.0*:
     - – Use visual plant water status cues or soil moisture evaluation to confirm the schedule is adequate

4. Adjust future irrigations if the verification described above in Step 3 indicates over- or under-irrigation.

MOVING UP THE CONTINUUM

“Integrating Irrigation Water Management Practices” in *Almond Irrigation Improvement Continuum Level 2.0* provides for more frequent estimates of water use to align water applications with the seasonally changing orchard water requirements. Improved irrigation system performance procedures and water measurement devices are used. Additionally, soil and plant water status is more accurately measured, providing better information to verify irrigation scheduling.

INTEGRATING IRRIGATION WATER MANAGEMENT PRACTICES

INTRODUCTION

The goal of irrigation scheduling is to determine how to supply the orchard with the correct amount of water at the appropriate time. Most growers make irrigation decisions based on their experience and the practical limitations of their systems. However, research has developed good irrigation water management practices to optimize orchard water management that should be included in grower decision making.

There are compelling reasons to adopt technical water management techniques. First, more precise water management can increase revenues, particularly if an orchard is over- or under-irrigated. If under-irrigated, increasing water application can result in more efficient production per amount of water used. If over-irrigated, conserving water increases revenue by a magnitude dependent on the water cost. Second, applying appropriate amounts of water assures good stewardship of a natural resource vital to all Californians. Demonstrating good stewardship of water resources will serve growers well in the ever-increasing competition for limited water supplies.

2.0 Practice:

Use irrigation system performance data with "normal year" regional crop evapotranspiration estimates to determine the orchard-specific water requirements and schedule irrigations. Use soil moisture and or plant water status monitoring to verify scheduling and adjust as necessary. Alternately, use soil monitoring devices and plant water status monitoring as a stand-alone scheduling tool.

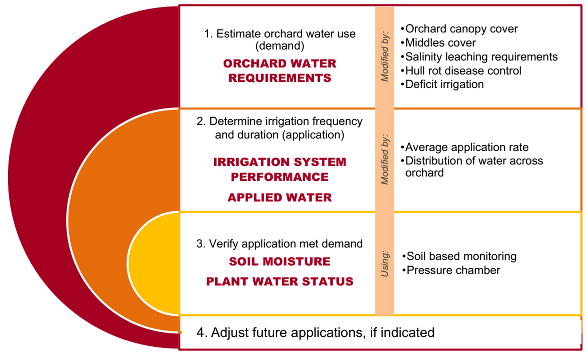
INTEGRATING 2.0 PRACTICES

Supplying irrigation in the correct amount and at the correct time to meet the trees' needs is the goal of irrigation scheduling. This goal is best served by using estimates of crop water use (evapotranspiration or ETc) considering the specific orchard water requirements and irrigation water conditions. These site-specific factors, such as canopy size, the presence of middles cover (cover crops/weeds), soil and water salt levels, and the use of deficit irrigation, are discussed in "Orchard Water Requirements" *Curriculum Level 2.0*. Additionally, delivering the correct amount of water to the majority of the orchard requires knowledge of application rate and the distribution of water across the orchard as discussed in "Irrigation System Performance" *Level 2.0*. Verifying the appropriate amount of applied water is described in "Applied Water" *Level 2.0*.

Although the above method of estimating orchard water requirements and ultimately system operating or set time are good, they are only a best estimate. The adequacy of the irrigation schedule generated using the approach above should be verified by soil- and/or plant-based monitoring methods as discussed in "Soil Moisture" and "Plant Water Status" in *Level 2.0*.

To help address the errors inherent in the estimation of the orchard water requirements, growers rely on the soil to act as a buffer to small amounts of over- or under-irrigation by virtue of its water-holding capacity. However, if errors are large, either over-irrigation, causing soil saturation, or under-irrigation, causing water deficits, can occur. Both can be detrimental to the orchard and the crop. If monitoring indicates the existence of either condition, adjustments in the schedule should be made.

Almond irrigation scheduling, water application and verifying the effectiveness of the process is a four-step process. The following graphic illustrates how the *Level 2.0* measures work together to shape overall good irrigation scheduling and management of California almonds.



DETERMINE IRRIGATION APPLICATION FREQUENCY AND DURATION

GOOD IRRIGATION WATER MANAGEMENT PRACTICES FOR CALIFORNIA ALMONDS

Four steps for good irrigation water management practices should be employed to schedule almond irrigations.

1. Meet the orchard's estimated orchard requirement by developing an irrigation schedule using ETc estimates based on specific orchard conditions.

2. Determine the irrigation system frequency and duration using the average application rate determined by evaluating the irrigation system performance. Measure irrigation system uniformity (Distribution Uniformity or DU) and make irrigation system improvements if required.

3. After the schedule has been implemented, monitor soil water status and/or plant water status to verify the schedule.

4. If soil- or plant-based monitoring indicates too much or too little irrigation, adjust the schedule for the next irrigation period.

The steps above indicate practices and considerations that should be made for any good irrigation water management system. The sample calculation below uses that as a guide and provides an example of how to tie together the measurements derived from the *Level 2.0* sections of the *Continuum*. Together they provide the pieces to develop a good irrigation water management strategy for your operation.

In this example we will first estimate the orchard water use (ETc) with the given orchard conditions, then determine the orchard water requirements needed at each irrigation and time of irrigation by adding the salt leaching requirements to determine irrigation volumes; confirming the applied water volume through water measurement; and using soil monitoring and/or plant water status verify the estimates of crop water use and irrigation delivery. If monitoring suggests the schedule is in error, corrections to the schedule should be made.

Given orchard conditions:

- Orchard maturity: Mature orchard, canopy shaded area greater than 70%
- Ground cover: None
- Location: Fresno, ET Zone 15
- Scheduling period: June 1–15
- Irrigation water salinity: 1.0 dS/m (since the water salinity in this example is near the crop tolerance level, leaching water will be included in each irrigation period)
- Irrigation system type: Sprinkler irrigation
- Soil: Sandy clay loam with an available water content of 2 inches per foot with a root zone of 5 feet. The result is a total available water holding capacity of 10 inches. At 50% allowable depletion the refill capacity is estimated at 5 inches. Soil has a water infiltration problem after about 20 hours of irrigation.

1. Determine the orchard water requirement.
   - Data collected via instruction from “Orchard Water Requirements” *Level 2.0*:
     – ETc estimate for Zone 15 for June 1-15: 4.10 inches
     – Leaching requirement: 15% or 0.15
   - Calculations:

     Orchard water requirement (OWR) = ETc ÷ (1 – leaching requirement)

     OWR = 4.10 ÷ (1 – 0.15) = 4.82 in

2a. Determine the irrigation system application rate and set run time.
   - Data collected via instruction from ”Irrigation System Performance” *Level 2.0*:
     – Average application rate: 0.10 inches per hour
   - Calculations:

     Irrigation system run time = OWR ÷ application rate

     Irrigation system run time = 4.82 ÷ 0.10 = 48 hrs

2b. Consider rooting, soil water holding capacity, and infiltration characteristics.
   - Using the above soil root zone depth and available water holding capacity along with the assumed 50% depletion between irrigations, the refill estimate is 5 inches of water.
   - Since the soil has an infiltration problem after about 20 hours of irrigation, apply two, 24-hour irrigations seven days apart.

3. Verify schedule prior to the next calculation period.
   - Data collected via instruction from “Soil Moisture” *Level 2.0* and/or ”Plant Water Status” *Level 2.0*:
     – Use soil moisture and or plant water status data to confirm the schedule is adequate

4. Adjust future irrigations if the verification described above in Step 3 indicates over- or under-irrigation.

MOVING UP THE CONTINUUM

“Integrating Irrigation Water Management Practices” from *Almond Irrigation Improvement Continuum Level 3.0* provides for more frequent estimates of water use to align water applications with the seasonally changing orchard water requirements. Improved irrigation system performance procedures and water measurement devices are used. Additionally, soil monitoring devices are automated and plant water status is determined using the difference for a fully watered baseline condition, providing better information to verify irrigation scheduling.

INTEGRATING IRRIGATION WATER MANAGEMENT PRACTICES

3.0 Practice:

Use irrigation system performance data with "normal year" regional crop evapotranspiration estimates to determine orchard-specific water requirements and schedule irrigations. Adjust the next irrigation scheduling period using real-time ETc to determine the actual orchard water requirement, then adjust the next scheduling period as the season progresses. Monitor orchard water status using soil- and plant-based methods to assess the adequacy of the irrigation schedule. Alternately, use soil monitoring devices and plant water status monitoring baseline techniques as a stand-alone scheduling tool.

INTRODUCTION

The goal of irrigation scheduling is to determine how to supply the orchard with the correct amount of water at the appropriate time. Most growers make irrigation decisions based on their experience and the practical limitations of their systems. However, research has developed good irrigation water management practices to optimize orchard water management that should be included in grower decision making.

There are compelling reasons to adopt technical water management techniques. First, more precise water management can increase revenues, particularly if an orchard is over or under-irrigated. If under-irrigated, increasing water application can result in more efficient production per amount of water used. If over-irrigated, conserving water increases revenue by a magnitude dependent on the water cost. Second, applying appropriate amounts of water assures good stewardship of a natural resource vital to all Californians. Demonstrating good stewardship of water resources will serve growers well in the ever-increasing competition for limited water supplies.

INTEGRATING 3.0 PRACTICES

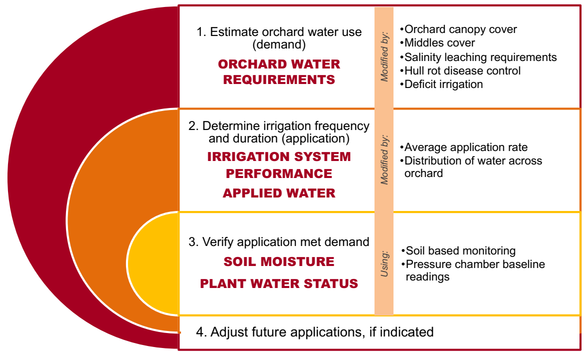
Supplying irrigation in the correct amount and at the correct time to meet the trees' needs is the goal of irrigation scheduling. This goal is best served by using estimates of crop water use (evapotranspiration or ETc) considering the specific orchard water requirements and irrigation water conditions. These site-specific factors, such as canopy size, the presence of middles cover (cover crops/weeds), soil and water salt levels, and the use of deficit irrigation, are discussed in "Orchard Water Requirements" *Curriculum Level 3.0*. Additionally, delivering the correct amount of water to the majority of the orchard requires knowledge of application rate and the distribution of water across the orchard as discussed in "Irrigation System Performance" *Level 3.0*. Verifying the appropriate amount of applied water is described in "Applied Water" *Level 3.0*.

Although the above method of estimating orchard water requirements and ultimately system operating or set time are good, they are only a best estimate. The adequacy of the irrigation schedule generated using the approach above should be verified by soil- and/or plant-based monitoring methods as discussed in "Soil Moisture" and "Plant Water Status" in *Level 3.0*.

To help address the errors inherent in the estimation of the orchard water requirements, growers rely on the soil to act as a buffer to small amounts of over- or under-irrigation by virtue of its water-holding

capacity. However, if errors are large, either over-irrigation, causing soil saturation, or under-irrigation, causing water deficits, can occur. Both can be detrimental to the orchard and the crop. If monitoring indicates the existence of either condition, adjustments in the schedule should be made.

Almond irrigation scheduling, water application and verifying the effectiveness of the process is a four-step process. The following graphic illustrates how the *Level 3.0* measures work together to shape overall good irrigation scheduling and management of California almonds.



DETERMINE IRRIGATION APPLICATION FREQUENCY AND DURATION

GOOD IRRIGATION WATER MANAGEMENT PRACTICES FOR CALIFORNIA ALMONDS

Five steps for good irrigation water management practices should be employed to schedule almond irrigations.

1. Meet the orchard's estimated orchard requirement by developing an irrigation schedule using ETc estimates based on specific orchard conditions.
2. Determine the irrigation system frequency and duration using the average application rate determined by evaluating the irrigation system performance. Measure irrigation system uniformity (Distribution Uniformity or DU) and make irrigation system improvements if required.
3. Verify the schedule using the current season's ETo to assess the over- or under-irrigation during the previous irrigation period. In scheduling the next irrigation period, the difference is used to adjust the next scheduled irrigation amount.
4. After the schedule has been implemented, monitor soil water status and/or plant water status to verify the schedule.
5. If soil- or plant-based monitoring indicates too much or too little irrigation, adjust the schedule for the next irrigation period.

The steps above indicate practices and considerations that should be made for any good irrigation water management system. The sample calculation below uses that as a guide and provides an example of how to tie together the measurements derived from the *Level 2.0* sections of the *Continuum*. Together they provide the pieces to develop a good irrigation water management strategy for your operation.

In this example we will first estimate the orchard water use (ETc) with the given orchard conditions, then determine the orchard water requirements needed at each irrigation and time of irrigation by adding the salt leaching requirements to determine irrigation volumes; confirming the applied water volume through water measurement; and using soil monitoring and/or plant water status verify the estimates of crop water use and irrigation delivery. If monitoring suggests the schedule is in error, corrections to the schedule should be made.

Given orchard conditions:

- Orchard maturity: Mature orchard, canopy shaded area greater than 70%
- Ground cover: None
- Location: Hanford, ET Zone 16
- Scheduling period: Past period July 16–31, next period Aug 1–15
- Irrigation water salinity: 1.0 dS/m (since the water salinity in this example is near the crop tolerance level, leaching water will be included in each irrigation period)
- Irrigation system type: Sprinkler irrigation
- Soil: Sandy clay loam with an available water content of 2 inches per foot with a root zone of 5 feet. The result is a total available water holding capacity of 10 inches. At 50% allowable depletion the refill capacity is estimated at 5 inches. Soil has a water infiltration problem after about 20 hours of irrigation.

1. Determine the orchard water requirement.
   - Data collected via instruction from "Orchard Water Requirements" *Level 3.0*:
     - ETc estimate for Zone 16 for:

       July 16–31 = 5.38 inches

       Aug 1–15 = 4.81 inches
   - Leaching requirement: 15% or 0.15
   - Calculations:

     Orchard water requirement (OWR) = ETc ÷ (1 – leaching requirement)

     $\text{OWR} = \text{July 16-31} = 5.38 \div (1 - 0.15) = 6.33 \text{ in.}$

     $\text{OWR} = \text{Aug 1-15} = 4.81 \div (1 - 0.15) = 5.66 \text{ in.}$

2a. Determine the irrigation system application rate and set run time.
   - Data collected via instruction from "Irrigation System Performance" *Level 3.0*:
     - Average application rate: 0.10 inches per hour
   - Calculations:

     Irrigation system run time = OWR ÷ application rate

     $\text{Irrigation system run time} = 6.33 \div 0.10 = 63.3 \text{ hrs}$

2b. Consider rooting, soil water holding capacity, and infiltration characteristics.
   - Using the above soil root zone depth and available water holding capacity along with the assumed 50% depletion between irrigations, the refill estimate is 5 inches of water.
   - Since the soil has an infiltration problem after about 20 hours of irrigation, apply three, 21-hour irrigations five days apart.

3. Verify schedule prior to the next calculation period.
   - Assess the real-time ETc and calculate the OWR, then adjust the next irrigation to account for the over- or under-application
     - Applied irrigation (July 16–30) 6.33 in
     - Actual ETc (July 16–31) 4.7 in

       $\text{Actual OWR July 16-31} = 4.7 \text{ in} \div (1 - 0.15) = 5.53 \text{ in}$
     - Difference between the two amounts 6.33 in and 5.53 in = 0.8 excess applied
     - Estimated ETc Aug 1–15 = 4.81in

       OWR Aug 1–15 = 5.66 in
     - Applied irrigation Aug 1–15 = 5.66 – 0.8 = 4.86 in
   - Data collected via instruction from "Soil Moisture" *Level 3.0* and/or "Plant Water Status" *Level 3.0*:
     - Use real-time soil moisture and or plant water status data to confirm the schedule is adequate

4. If soil- or plant-based monitoring indicates too much or too little irrigation, adjust the schedule for the next irrigation period. Adjust future irrigations if the verification described above in Step 3 or 4 indicates over- or under-irrigation.

GLOSSARY

acre foot – the volume of water required to cover 1 acre of land to a depth of 1 foot (43,560 cubic feet or 325,851 gallons)

agricultural water use efficiency – the ratio of applied water to the amount of water required to sustain agricultural productivity. Efficiency is increased through the application of less water to achieve the same beneficial productivity or by achieving more productivity while applying the same amount of water.

applied water – the amount of water applied to the orchard during the growing season

available soil moisture – the amount of water held in the soil that can be extracted by a crop; often expressed in inches per foot of soil depth. It is the amount of water released between in situ field capacity and the permanent wilting point.

available water – water that is available for a plant to uptake

California Irrigation Management Information System (CIMIS) – a network of automated weather stations that are owned and operated cooperatively between the DWR and local agencies. The stations are installed in most of the agricultural and urban areas in the state and provide farm and large landscape irrigation managers and researchers with "real-time" weather data to estimate crop and landscape ET rates, and make irrigation management decisions.

distribution uniformity – the evenness of water applied across a field

electrical conductivity (EC) – the measure of the ability of water to conduct an electrical current, the magnitude of which depends on the dissolved mineral content of the water

evapotranspiration (ET) – the sum of water use through transpiration and water lost through evaporation from the soil surface

ETc (evapotranspiration under optimal conditions) – the sum of the orchard water use through transpiration and water lost through evaporation from the soil surface

ETo (reference evapotranspiration) – the evapotranspiration rate from an extended surface of 3- to 6-inch (8 to 15 cm) tall green grass cover of uniform height, actively growing, completely shading the ground, and not short on water

irrigation efficiency (IE) – the efficiency of water application and use, calculated by dividing a portion of applied water that is beneficially used by the total applied water, expressed as a percentage. The two main beneficial uses are crop water use (evapotranspiration, ETc) and leaching to maintain a salt balance.

Kc – crop coefficient

leaching fraction – the fraction or percentage of water applied to the orchard that drains below the root zone

leaching requirement – the minimum leaching to prevent yield loss

soil texture – refers to the percentage of sand, silt and clay particles in a soil. Sand, silt and clay particles are defined by their size. Soil texture has important effects on soil properties. Water-holding capacity, drainage class, consistency and chemical properties are just a few examples of properties that are affected by soil texture.

telemetry – the process of recording and transmitting the readings of an instrument

tensiometer – a device used to measure matric water potential

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Handy conversions

1 cubic foot = 7.48 gallons

1 gallon = 3.785 liters

1 cubic meter = 264 gallons

1 acre foot = 325,851 gallons = 43,560 cubic feet

1 acre inch = 27,158 gallons = 3,360 cubic feet

1 acre = 0.4 hectare = 43,560 square feet

1 cubic foot per second (cfs) = 449 gallons per minute (gpm)

450 gpm for 1 hour = 1 acre inch per hour