The California Microirrigation Pocket Guide

System Management & Maintenance

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The California Microirrigation Pocket Guide

Mike Morris
National Center for
Appropriate Technology

Larry Schwankl
University of California
Cooperative Extension

3040 Continental Drive
P.O. Box 3838
Butte, MT 59702-3838

1-800-ASK-NCAT
NCAT.ORG

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Introduction

A microirrigation system is a precision tool. Properly used and maintained, it can be more efficient, effective, environmentally friendly, and adaptable than most conventional surface or sprinkler irrigation systems. The tradeoff for all these benefits is that microirrigation systems require intensive management and maintenance.

The ***System Management & Maintenance*** half of this guidebook explains how to manage and maintain a microirrigation system. The glossary defines terms that are italicized in the main text.

The discussion covers all kinds of drip irrigation systems—above-ground and subsurface—as well as microsprinklers. The book also includes recommendations for meeting the stringent requirements of organic farming.

Wherever possible, we have followed the terminology and general recommendations of the NRCS **Irrigation Guide**. Readers looking for deeper and more technical discussions of the topics in this guidebook are encouraged to consult that comprehensive manual.

The exclamation mark **!** indicates safety hazards, potential equipment damage, or other situations calling for extra caution.

Please note that the reverse side of this book (***Pumps, Motors, & Engines***) covers the basics of pump, motor, and engine maintenance and energy efficiency.

This is not intended to be a complete microirrigation manual. It is generally assumed that you have a well-designed microirrigation system in place and water available at the field. There's little discussion of how to choose, design, or install a microirrigation system, and the discussion of injecting fertilizers and other chemicals is extremely limited. Excellent books are available on these complicated subjects and belong in your library; this book belongs in your hip pocket.

This new edition incorporates many improvements, including greater emphasis on the topic of ***soil health***.

Since the book first appeared 12 years ago, there have been major advances in soil biology and a nationwide soil health awareness campaign led by the USDA Natural Resources Conservation Service. When soils get healthier, they often catch and hold more water and become more drought resilient. Although often neglected in irrigation manuals, soil health needs to be a high priority for all irrigators.

Over the past two decades, California has experienced some of the most persistent and severe drought conditions in its history. We hope this book encourages some to convert to microirrigation—the most water-efficient of all irrigation methods—and enables others who already have drip and microsprinkler systems to run them more efficiently.

No guidebook can substitute for the judgment, observation, and local knowledge that good irrigators acquire through experience. So adjust, adapt, or reject any suggestion in this book that doesn't fit your situation or doesn't seem to be working. Use as much information as you can find about how your crops are responding, proceed cautiously, and test every recommended practice through direct field observations.

For Further Reading

- USDA Natural Resources Conservation Service. 1997. **Irrigation Guide**: Section 15 of the National Engineering Handbook. directives.sc.egov.usda.gov/OpenNonWebContent.aspx?content=17837.wba

1. Microirrigation Basics

This chapter explains:

- Advantages of microirrigation
- Disadvantages of microirrigation
- Typical microirrigation system layout
- Various kinds of emitters

In this book, the term ***microirrigation*** refers to any irrigation system that delivers water to trees, vines, or row crops through tubing or other low-flow devices such as drippers, drip tape, bubblers, or microsprinklers. Compared to most conventional surface or sprinkler irrigation methods, microirrigation delivers water more frequently, more slowly, and more uniformly.

Advantages of Microirrigation

- Frequent irrigation makes possible a high degree of control over the timing and amount of water applied.
- Well designed, installed, and maintained systems are highly efficient in their use of water, retaining as much as 85 to 95 percent of water in the root zone of plants.
- Delivering water precisely to the immediate vicinity of plant roots greatly reduces risks of erosion, surface runoff, deep percolation, and leaching nutrients or pesticides to groundwater.
- Distribution can be highly uniform, reducing the need to overwater some parts of the field in order to avoid underwatering other parts.
- Research has shown yield and quality improvements for many crops.
- Fertilizer can be injected in precise amounts, directly to the root zone and at the right times for optimal plant growth.
- Smaller pumping plants are often needed, using up to 50% less energy than conventional sprinkler systems.

- Fewer tractor trips across the field are needed, since chemicals can be injected through the irrigation system.
- The surface stays drier, reducing evaporation, weed growth, and muddy conditions that complicate using vehicles and machinery in the field. Note, however, that continually wet conditions near emitters may aggravate certain weed problems.
- Drip systems apply almost no water onto leaves, stems, or fruit—an advantage in avoiding certain plant diseases.
- Salinity problems are reduced, for three reasons:
    1. More continuously wet soil keeps salts diluted.
    2. Salts move to the outer edges of the wetted soil area, away from plant roots.
    3. Salts have little or no chance of being absorbed through the leaves.
- Microirrigation works well on irregularly shaped fields or soils with steep slopes—such as avocados on coastal hills in Southern California or wine grapes in Napa Valley. Microirrigation also works well on soils with low infiltration rates or low water-holding capacity.
- Microirrigation systems are easily automated, starting and stopping at pre-set intervals or responding directly to soil moisture measuring devices. They can be programmed to take advantage of lower off-peak electric rates, widely available in California.
- Professional microirrigation system design has reached a high level of sophistication. The Irrigation Association (*irrigation.org*) certifies irrigation designers who have taken courses and passed an exam, such as the courses offered by the Designer/Manager School of Irrigation at the Irrigation Training and Research Center (*itrc.org*) at Cal Poly, San Luis Obispo.

Disadvantages of Microirrigation

- Microirrigation systems require more intensive and technical management than conventional surface or sprinkler systems and also require new management skills and attitudes. For example, you may need to collect more field data, do mathematical calculations related to pressure, flow rates, and crop water use, and be willing to trust automated control systems.
- Microirrigation systems are among the most expensive to buy and install, costing $900 to $1,300 per acre or more.
- High-quality irrigation water is required to prevent clogging since water is delivered through small openings. Filtration and regular flushing are required, and chemical injection is usually needed to control biological and chemical sources of clogging.
- Animals, machinery, and foot traffic can cause leaks in above-ground tubing. Rodents, insects, and root intrusion can cause leaks in buried tubing.
- Plants often have restricted or shallow roots, limiting their ability to withstand dry periods without water.
- The irrigator's margin for error is reduced in hot, dry conditions since little or no "extra" water is stored in the soil. The water supply must be dependable. Regular inspections and troubleshooting are a must, and equipment problems must be repaired promptly.
- Although some salinity problems are reduced, salt accumulation can still be a problem since water applications are often inadequate to flush salts below the root zone. In severe cases, a sprinkler or surface irrigation system may be needed to leach salts below the root zone.
- Disposal of drip tape and tubing can be an issue. Some drip tape manufacturers have begun offering recycling programs in California.

Microirrigation System Layout

A ***mainline*** and a network of ***submains*** and ***manifolds***, usually made of PVC, carry water from the pump to one or more fields. Lengths of flexible drip tape or tubing, usually made of polyethylene and often called ***laterals*** or ***lateral lines***, carry water to ***emitters*** that discharge water to the plants.

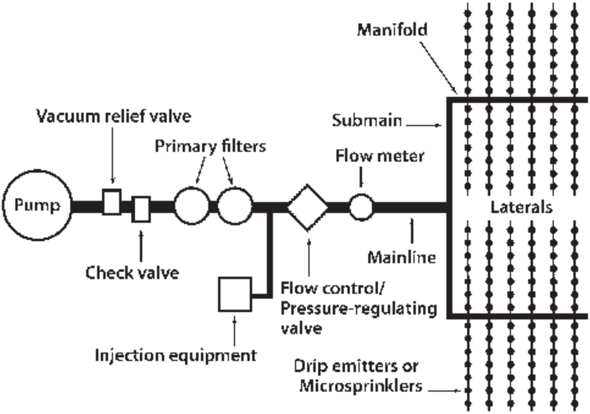


Figure 1. Typical System Layout

Types of Emitters

There are many kinds of emitters!

Drip emitters drip or trickle water from a single point or opening, usually between one-half and four gallons per hour. In California, above-ground drip emitters are used mainly for vines, trees, and shrubs. Multiple drip emitters may be grouped together to increase total flow or the area of wetted soil near plants.

Orifice emitters discharge water through a narrow passageway, making these emitters somewhat prone to clogging. ***Turbulent flow emitters,*** one of the most common types in California, direct water through a wider and "tortuous" (crooked or zigzagging) path that creates turbulence to reduce pressure with less clogging. ***Long-path emitters*** move water through a long, often spiraling path, dissipating pressure by means of wall friction.

Line-source emitters (also called ***drip tape, drip tubing, drip line, dripperline***, and many similar names) consist of flexible plastic tubing with uniformly spaced emitter points, typically 8 to 24 inches apart. Line source emitters used in agriculture typically include drip emitters (***in-line emitters***) within the tubing. The term ***drip tape*** usually refers to a thin-walled product that's sold flat, inflates when filled with water, and is operated at pressures of 8 to 12 pounds per square inch (psi). The term ***drip tubing*** usually refers to a thicker-walled product that's often sold in thousand-foot reels and can be used at pressures as high as 20 to 40 psi.

Figure 2. In-line turbulent flow emitter, removed from tubing, showing "tortuous" path

Discharge rates for drip tapes are often given in gallons per minute per 100 feet. Some products are designed for above-ground use while others are meant to be buried. Drip tapes often last just one season while drip tubing is generally expected to last multiple seasons. In California, drip tape and tubing are frequently used on strawberries and vegetable crops and sometimes on cotton, processing tomatoes, vines, and trees.

Microsprinklers (also called ***microspray*** or ***minisprinkler*** systems) discharge a mist or spray from small heads, generally at 10 to 20 gallons per hour. In California, these are most often used in orchards. Some microsprinklers have spinners while others contain no moving parts.

Compared to drip emitters, microsprinklers wet a wider area and are somewhat less prone to clogging since water moves through them at higher velocity. ***High-discharge*** microsprinklers, with their larger-diameter passageways, are especially resistant to clogging. Some growers also prefer microsprinklers to drip systems because they can easily see the water being discharged.

Pressure-compensating emitters contain a flexible orifice that gets smaller under pressure, allowing these emitters to deliver a near-constant flow of water over a wide range of operating pressures. Below a minimum pressure threshold, the pressure-compensating feature no longer works. Drip emitters, line source emitters, and microsprinklers are all available in pressure-compensating designs. They're more expensive than standard emitters and often installed in situations where they're unnecessary. Nonetheless, pressure-compensating emitters may be worth considering if you have long lines with substantial friction losses, varying source pressure, or significant elevation changes in your fields.

Basin bubblers discharge water in a small fountain, into a small basin or depression in the soil. Uncommon in California agriculture, basin bubblers are more frequently seen in urban and residential settings. They can soak a wider soil area than drip emitters, making it possible to use just one bubbler per plant or tree.

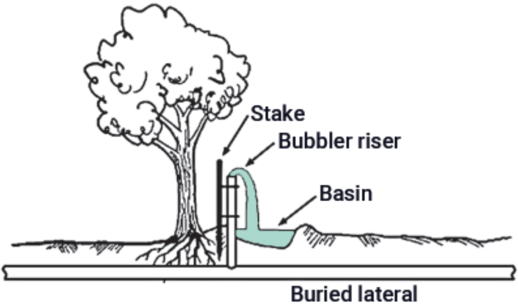


Figure 3. Basin Bubbler

2. Determining How Much Water to Apply

This chapter explains:

- The main idea of microirrigation management
- How to use historical average ET information
- How to use real-time ET information

Irrigation Scheduling in a Nutshell

The term ***irrigation scheduling*** refers to a plan for irrigating at the right times, and with the right amounts of water, for optimal plant growth and quality.

The short answer to the question of when to irrigate with a microirrigation system is ***often***. During peak water-use periods in California, drip systems are generally operated every one to three days, and microsprinkler systems are generally operated every two to four days. Because irrigation happens so often, your main management question is how long to run the system, not whether to run it.

The short answer to the question of how much water to apply is: ***Replace the water used by the crop since your last irrigation.***

This chapter explains several ways of determining how much water your crop has used since the last irrigation. Every approach has advantages and disadvantages, and it's often a good idea to use more than one method.

Crop water use is also known as ***evapotranspiration*** and abbreviated ***ET***. ET measures the combined effects of evaporation and transpiration. You can base your estimates of ET on historical averages or on real-time ("what happened yesterday") measurements.

Over and above your estimate of crop water use, you'll need to apply a little extra water to compensate for various losses and inefficiencies. As a ballpark, add 10 to 20% to your ET estimates or 10 to 15% extra for newer systems. If you have maintenance or design problems or an older system, you may need to add more.

On a daily and weekly basis, your key management question is this: ***How long do I need to run my system in order to replace the water used by my crop since the last irrigation?*** You can find the answer in three steps:

1. Determine how much water you need to apply, using the methods in this chapter.
2. Determine your system's application rate, using the methods in Chapter 3.
3. Divide the first number by the second number to decide how long you need to run the system.

Example:

1. You need to apply 0.4 inches to fully replace the water used by your crop since the last irrigation.
2. Your system's application rate is 0.08 inches per hour.
3. You need to run the system 5 hours (0.4 ÷ 0.08).

Using Historical ET Information

If a historical ET table is available for the crop you're growing, you can quickly estimate how much water you need to apply. Just look up your crop and date, add up the daily ET amounts since your last irrigation, and add 10 to 20% to compensate for inefficiencies. The tables on pages 12-21 show long-term historical ET averages for several tree and vine crops. Your local irrigation district or NRCS or Extension office may be able to provide historical ET information for other crops grown in your area.

These tables show total inches of water during a 15- to 16-day period. To find inches per day, divide this total by number of days in the period. (Note that some periods in the table are 15 days long while others are 16 days long.)

Example:

Almonds near Visalia, 3 days since last irrigation on May 4. System is 80% efficient, so 20% will be added for inefficiencies.

From Table 1 on the next page, almonds near Visalia historically use 2.30 inches during 15-day period from May 1 to May 15, or 0.15 inches per day. (2.30 ÷ 15 = 0.15)

3 days since last irrigation × 0.15 inches per day = 0.45 inches ET.

You need to apply: 0.45 + 0.09 (20% of 0.45) = 0.54 inches.

! California's weather can be unpredictable, and present and future conditions may be different from the past. The long-term averages in the following tables may need to be adjusted for your local climate, current weather conditions, and many other factors.

- **Make adjustments for any water that has been supplied by rainfall.**
- **The tables give values for mature trees and vines. Young trees will use less water. Make adjustments following the guidelines on page 22.**
- **The tables are based on crops grown without a cover crop. Orchards with a cover crop may use up to 30% more water.**
- **Proceed cautiously and watch carefully how your crops are responding. Soil moisture monitoring and plant tissue sampling are highly recommended, as ways to check the accuracy of ET estimates.**

Table 1. Long-term historical evapotranspiration averages (inches during period) for almonds

	Modesto	Williams	Parlier	Madera	Red Bluff	Visalia	Woodland	Bakersfield
Mar 16-31	1.04	0.95	1.12	1.04	0.96	1.12	1.21	1.21
Apr 1-15	1.26	1.26	1.53	1.26	1.80	1.44	1.62	1.53
Apr 16-30	1.78	1.68	1.88	1.78	2.40	1.98	1.98	1.98
May 1-15	2.08	2.08	2.41	2.19	2.70	2.30	2.52	2.63
May 16-31	2.91	2.65	3.03	2.78	2.80	2.91	3.03	3.29
June 1-15	3.28	2.90	3.28	3.15	2.85	3.28	3.53	3.40
June 16-30	3.35	3.35	3.48	3.48	3.00	3.48	3.74	3.61
July 1-15	3.63	3.91	3.77	3.91	3.30	3.77	4.05	3.91
July 16-31	3.91	4.21	3.76	4.21	3.68	4.06	4.06	4.36
Aug 1-15	3.38	3.53	3.38	3.67	3.45	3.53	3.67	3.95
Aug 16-31	3.01	3.31	3.31	3.31	3.52	3.31	3.61	3.76
Sept 1-15	2.68	2.68	2.68	2.82	2.85	2.96	2.96	2.96
Sept 16-30	2.05	2.18	2.05	2.18	2.25	2.32	2.46	2.46
Oct 1-15	1.66	1.66	1.66	1.66	1.80	1.79	2.04	1.91
Oct 16-31	1.14	1.14	1.14	1.14	1.28	1.26	1.52	1.64
Nov 1-15	0.74	0.63	0.74	0.74	0.75	0.84	0.95	0.84
Totals	**37.90**	**38.12**	**39.22**	**39.32**	**39.39**	**40.35**	**42.93**	**43.44**

Tables 1-10 are adapted from Larry Schwankl. 2007. **Understanding Your Orchard's Water Requirements**. Publication number 8212, University of California Division of Agriculture and Natural Resources.

Table 2. Long-term historical evapotranspiration averages (inches during period) for walnuts

	Red Bluff	Stockton	Chico	Modesto	Parlier	Visalia
Mar 16-31		0.23	0.23	0.23	0.25	0.25
Apr 1-15		1.25	1.27	1.11	1.35	1.27
Apr 16-30	1.35	1.87	1.73	1.84	1.94	2.04
May 1-15	1.50	2.45	2.49	2.25	2.61	2.49
May 16-31	2.40	2.97	3.03	3.16	3.30	3.16
June 1-15	2.55	3.39	3.49	3.63	3.63	3.63
June 16-30	3.00	3.85	3.90	3.90	4.05	4.05
July 1-15	3.45	4.50	4.62	4.45	4.62	4.62
July 16-31	4.32	4.39	4.56	4.74	4.56	4.92
Aug 1-15	4.20	4.05	4.10	4.10	4.10	4.28
Aug 16-31	4.48	3.65	3.83	3.65	4.01	4.01
Sept 1-15	3.60	2.97	2.62	3.08	3.08	3.40
Sept 16-30	2.85	2.18	2.33	2.18	2.18	2.47
Oct 1-15	2.25	1.63	1.72	1.72	1.72	1.85
Oct 16-31	0.96	0.71	0.57	0.73	0.73	0.82
Nov 1-15	0.30	0.27	0.25	0.29	0.29	0.34
Totals	**37.21**	**40.36**	**40.74**	**41.06**	**42.42**	**43.60**

Table 3. Long-term historical evapotranspiration averages (inches during period) for pistachios

	Madera	Visalia	Kern County
Apr 1-15	0.09	0.17	0.18
Apr 16-30	0.77	1.29	1.29
May 1-15	1.49	2.14	2.45
May 16-31	2.59	3.42	3.87
June 1-15	3.43	4.25	4.41
June 16-30	4.08	4.74	4.91
July 1-15	4.65	4.82	5.00
July 16-31	5.01	5.14	5.52
Aug 1-15	4.36	4.46	5.00
Aug 16-31	3.71	3.94	4.48
Sept 1-15	2.79	3.12	3.12
Sept 16-30	1.90	2.22	2.35
Oct 1-15	1.11	1.41	1.51
Oct 16-31	0.57	0.80	1.04
Nov 1-15	0.26	0.42	0.42
Totals	**36.81**	**42.34**	**45.55**

Table 4. Long-term historical evapotranspiration averages (inches during period) for stone fruit

	Stockton	Modesto	Yuba City	Merced	Madera	Parlier	Visalia
Mar 1-15	0.66	0.66	0.99	0.66	0.66	0.83	0.74
Mar 16-31	0.10	1.19	1.39	1.19	1.19	1.29	1.29
Apr 1-15	1.41	1.41	1.71	1.41	1.41	1.71	1.61
Apr 16-30	1.97	1.97	1.97	1.97	1.97	2.08	2.19
May 1-15	2.22	2.22	2.11	2.22	2.34	2.57	2.46
May 16-31	2.86	3.13	2.58	3.13	2.99	3.26	3.13
June 1-15	3.13	3.39	2.74	3.26	3.26	3.39	3.39
June 16-30	3.39	3.39	2.87	3.52	3.52	3.52	3.52
July 1-15	3.39	3.39	3.00	3.65	3.65	3.52	3.52
July 16-31	3.62	3.62	3.34	3.90	3.90	3.48	3.76
Aug 1-15	3.13	3.13	3.26	3.26	3.39	3.13	3.26
Aug 16-31	2.92	2.78	3.20	2.92	3.06	3.06	3.06
Sept 1-15	1.31	2.48	2.74	2.61	2.61	2.48	2.74
Sept 16-30	1.97	1.85	2.21	1.97	1.97	1.85	2.09
Oct 1-15	1.46	1.46	1.80	1.46	1.46	1.46	1.58
Oct 16-31	0.76	0.98	1.52	0.98	0.98	0.98	1.09
Totals	**34.30**	**37.05**	**37.43**	**38.11**	**38.36**	**38.61**	**39.43**

Table 5. Long-term historical evapotranspiration averages (inches during period) for prunes

	Yuba City	Red Bluff	Visalia
Apr 1-15	1.68	1.45	1.49
Apr 16-30	2.25	2.20	2.52
May 1-15	2.71	2.63	3.02
May 16-31	2.93	2.87	3.53
June 1-15	2.85	2.85	3.74
June 16-30	3.07	3.07	3.89
July 1-15	3.45	3.26	3.89
July 16-31	3.71	3.65	4.15
Aug 1-15	3.43	3.51	3.56
Aug 16-31	3.46	3.56	3.24
Sept 1-15	2.40	2.81	2.65
Sept 16-30	2.19	2.30	1.99
Oct 1-15	1.49	1.74	1.45
Oct 16-31	1.30	1.34	0.91
Totals	**36.92**	**37.24**	**40.03**

Table 6. Long-term historical evapotranspiration averages (inches during period) for table or canning olives

	Ukiah	Lakeport	Santa Rosa	Atascadero	Orland	Parlier
Mar 16-31	0.36		1.56	1.92	0.98	1.66
Apr 1-15	1.26	1.32	1.80	2.12	1.40	2.04
Apr 16-30	1.50	1.58	2.00	2.24	1.63	2.28
May 1-15	1.83	1.90	2.16	2.32	1.97	2.64
May 16-31	2.08	2.14	2.40	2.44	2.23	3.07
June 1-15	2.24	2.32	2.52	2.52	2.66	3.12
June 16-30	2.41	2.54	2.56	2.60	2.74	3.24
July 1-15	2.68	2.80	2.52	2.60	3.05	3.24
July 16-31	2.64	2.89	2.36	2.48	3.32	3.20
Aug 1-15	2.43	2.57	2.16	2.32	3.53	2.88
Aug 16-31	2.21	2.32	1.88	2.04	3.02	2.82
Sept 1-15	1.94	2.02	1.56	1.88	2.82	2.28
Sept 16-30	1.63	1.71	1.32	1.68	2.30	1.80
Oct 1-15	1.30	1.36	1.04	1.52	1.94	1.56
Oct 16-31	0.98	1.01	0.68	1.24	1.53	1.15
Totals	**27.49**	**28.48**	**28.52**	**31.92**	**35.12**	**36.98**

Table 7. Long-term historical evapotranspiration averages (inches during period) for citrus

	Orland	Lindcove	Orange Cove	Kern County	Santa Paula
Mar 16-31	0.80	0.83	1.04	1.07	0.98
Apr 1-15	1.14	1.14	1.17	1.37	1.40
Apr 16-30	1.32	1.56	1.46	1.66	1.63
May 1-15	1.60	1.77	1.66	1.98	1.97
May 16-31	1.81	2.18	2.29	2.28	2.23
June 1-15	2.16	2.39	2.34	2.50	2.66
June 16-30	2.23	2.50	2.44	2.60	2.74
July 1-15	2.48	2.60	2.63	2.67	3.05
July 16-31	2.70	2.81	2.91	2.80	3.32
Aug 1-15	2.87	2.81	2.83	2.80	3.53
Aug 16-31	2.45	2.70	2.71	2.70	3.02
Sept 1-15	2.29	2.39	2.44	2.37	2.82
Sept 16-30	1.87	1.98	2.05	2.05	2.30
Oct 1-15	1.58	1.66	1.66	1.69	1.94
Oct 16-31	1.24	1.35	1.46	1.46	1.53
Nov 1-15	0.67	0.94	1.07	1.14	1.30
Nov 16-30	0.40	0.62	0.68	0.81	0.90
Totals	**29.61**	**32.23**	**32.84**	**33.95**	**37.32**

Table 8. Long-term historical evapotranspiration averages (inches during period) for apples

	Ukiah	Lakeport	Stockton	Bakersfield
Apr 16-30	1.10	1.16	1.62	1.80
May 1-15	1.53	1.59	2.08	2.58
May 16-31	1.98	2.04	2.62	3.04
June 1-15	2.35	2.44	3.07	3.44
June 16-30	2.77	2.92	3.54	3.91
July 1-15	3.35	3.50	3.95	4.25
July 16-31	3.30	3.61	3.85	4.00
Aug 1-15	3.04	3.21	3.55	3.65
Aug 16-31	2.76	2.90	3.20	3.15
Sept 1-15	2.42	2.53	2.75	2.60
Sept 16-30	2.04	2.14	2.25	2.25
Oct 1-15	1.47	1.55	1.68	1.59
Oct 16-31	0.72	0.74	0.83	0.74
Totals	**28.83**	**30.33**	**34.99**	**37.00**

Table 9. Long-term historical evapotranspiration averages (inches during period) for pears

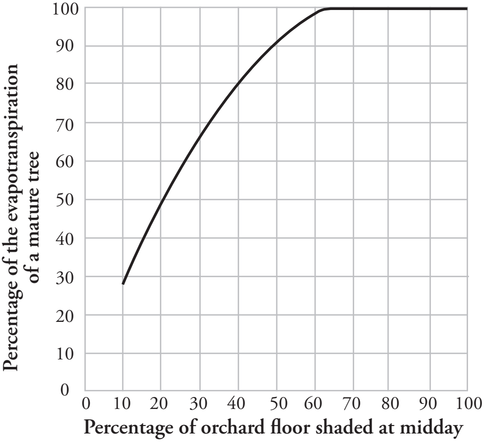
	Ukiah	Lakeport	Courtland
Mar 16-31	0.25		0.83
Apr 1-15	0.86	1.65	1.28
Apr 16-30	1.46	1.44	1.77
May 1-15	1.83	1.90	2.22
May 16-31	2.21	2.28	2.68
June 1-15	2.44	2.52	2.90
June 16-30	2.87	3.14	3.31
July 1-15	2.91	3.05	3.33
July 16-31	2.87	3.14	3.31
Aug 1-15	2.64	2.79	3.05
Aug 16-31	2.40	2.52	2.77
Sept 1-15	2.11	2.20	2.46
Sept 16-30	1.53	1.61	1.79
Oct 1-15	1.13	1.16	1.26
Oct. 16-31	0.79	0.82	0.88
Totals	**28.05**	**30.22**	**33.01**

Table 10. Long-term historical evapotranspiration averages (inches during period) for grapes

	Stockton	Modesto	Merced	Madera	Parlier	Visalia
Mar 16-31	0.00	0.64	0.64	0.64	0.64	0.64
Apr 1-15	0.90	0.90	0.90	0.90	1.05	1.05
Apr 16-30	1.35	1.35	1.35	1.35	1.50	1.50
May 1-15	1.65	1.65	1.65	1.80	1.95	1.80
May 16-31	2.24	2.56	2.56	2.40	2.72	2.56
June 1-15	2.85	3.00	3.00	3.00	3.00	3.00
June 16-30	3.15	3.15	3.30	3.30	3.30	3.30
July 1-15	3.15	3.15	3.45	3.45	3.30	3.30
July 16-31	3.36	3.36	3.68	3.68	3.36	3.52
Aug 1-15	3.00	3.00	3.15	3.15	3.00	3.15
Aug 16-31	2.56	2.40	2.56	2.72	2.72	2.72
Sept 1-15	0.60	1.95	1.95	1.95	1.95	2.10
Sept 16-30	1.35	1.20	1.35	1.35	1.20	1.35
Oct 1-15	0.90	0.90	0.90	0.90	0.90	0.90
Totals	**27.06**	**29.21**	**30.44**	**30.59**	**30.59**	**30.89**

Adjusting ET for Young Trees

Because of their smaller canopy, young trees have lower ET rates than mature trees. You can estimate the ET of young trees using the preceding tables and Figure 4 below. Mature tree ET levels are achieved when ground shading reaches 60 to 70 percent.



Source: Larry Schwankl. 2007. **Understanding Your Orchard's Water Requirements.** Publication number 8212, University of California Division of Agriculture and Natural Resources.

Figure 4. Evapotranspiration of young trees

Converting ET to Gallons per Day per Plant

To convert ET from Tables 1-10 (inches per day) to gallons per day per plant, use Table 11 (next page) or do a simple calculation with the following formula:

Water use (gal/day) =

crop spacing (ft^2) × ET (in/day) × 0.623

Example: ET is 0.25 inch per day.

Tree crop spacing 15 feet × 15 feet = 225 square feet.

Water use per tree = 225 × 0.25 × 0.623 = 35.0 gallons per day.

Table 11. Converting ET rates to gallons per day per plant

Crop Spacing (ft^2) = row spacing × plant spacing	Evapotranspiration (inches per day) 0.05	0.1	0.15	0.2	0.25	0.3	0.35	0.4
100	3	6	9	12	16	19	22	25
200	6	12	19	25	31	37	44	50
400	12	25	37	50	62	75	87	100
600	19	37	56	75	93	112	131	150
800	25	50	75	100	125	150	174	199
1000	31	62	93	125	156	187	218	249
1200	37	75	112	150	187	224	262	299
1400	44	87	131	174	218	262	305	349
1600	50	100	150	199	249	299	349	399
1800	56	112	168	224	280	336	392	449
2000	62	125	187	249	311	374	436	498
2200	69	137	206	274	343	411	480	548
2400	75	150	224	299	374	449	523	598

Source: Larry Schwankl, Blaine Hanson, and Terry Prichard. 1993. **Low-Volume Irrigation**. University of California, Davis.

Real-Time ET Information from Weather Stations and Satellites

Real-time ET estimates are generally more reliable than long-term historical averages, and California irrigators are fortunate to have access to **CIMIS**, the California Irrigation Management Information System. Managed by the California Department of Water Resources, CIMIS includes over 120 active weather stations and provides real-time ET estimates for much of the state, free of charge, at ***cimis.water.ca.gov***.

CIMIS estimates are based on complex calculations that include temperature, wind speed, relative humidity, solar radiation, and other factors. How closely these estimates match your actual ET will depend on your distance from the weather stations, your soils, planting dates, crop health, and micro-climate effects, among other things.

CIMIS gives ***reference ET*** values, abbreviated ET_0 and equivalent to the ET of well-watered pasture grass. To determine the ET for the crop you're growing, you'll need to multiply reference ET times a ***crop coefficient***, usually a number between 0.1 and 1.2. You can find crop coefficients on the CIMIS website, and your local Extension or NRCS office may also be able to help you locate and use the crop coefficients you need.

The main difficulties in using CIMIS relate to these crop coefficients. In some cases they're hard to find. They also depend on growth stage and vary through the growing season. Once you have the right crop coefficient, the calculation is as simple as the one below.

Example: oranges in July.

Today's reference ET: 0.25 inches per day.

Crop coefficient for oranges in July: 0.65.

Today's ET for oranges: 0.25 × 0.65 = 0.16 inches.

! Young crops always require special care, since their limited root zones and canopies make them especially vulnerable to heat and drought stress.

Also available in California are ***satellite-based*** ET estimates. Some private companies offer fee-based subscription services, and in 2021 **OpenET (*openetdata.org/*)** became available, providing free, publicly-available ET data. Developed by the USDA Agricultural Research Service and many partners, OpenET uses NASA satellite data (such as leaf temperature, leaf size, and solar radiation) along with meteorological, soil, and vegetation datasets, to calculate and provide user-friendly ET estimates for the entire western United States.

On OpenET maps, you can zoom down to field scale, looking at ET in your own fields or at the quarter-acre resolution of satellite data. You can also draw shapes on the map and see monthly and annual ET values within those boundaries. The ET values on the maps have already been adjusted for the crops growing in each field, so you generally don't need to use crop coefficients.

Do-It-Yourself Methods

Some areas in California, especially along the coast, have local micro-climates that differ considerably from the nearest CIMIS station. If no CIMIS information is available for your location, or if you want to check published estimates from CIMIS or OpenET, you might consider taking matters into your own hands.

Weather station prices start around $1,000 and go up to several thousand dollars. Software and a way to download information may cost extra. Weather stations also need to be maintained and calibrated periodically for accuracy.

Atmometers, also known as ***evaporimeters*** or ***ET gauges***, are flat, porous, ceramic disks that draw up water as evaporation dries their surface. They're generally cheaper than weather stations and provide reference ET only, so you'll need to use crop coefficient tables.

At the low-cost end of the scale, ***evaporation pans*** are open-top water containers, often standard metal washtubs. As water evaporates, the water level in the tub drops. Markings on the inside of the tub provide an estimate of available water remaining in the root zone. You can find guidelines and crop coefficient tables for evaporation pans on the Internet, or your local NRCS or Extension office may be able to assist you in making and using one of these devices.

Application Efficiency

As noted above, in order to fully replace the water your crops have used since the last irrigation you need to add a small amount of extra water, over and above ET, to compensate for inefficiencies and losses. ***Deep percolation*** is generally the main source of inefficiency, but runoff, evaporation, non-uniform application, and other factors may also come into play.

Efficiency can be defined and measured in various ways.

Application efficiency is defined as
water beneficially used by the crop ÷ water applied

"Water beneficially used by the crop" can include frost protection, salt flushing, and other factors besides evapotranspiration. But in the normal situation where your goal is simply to replace water used by crops since the last irrigation:

water you need to apply = ET (since last irrigation)
÷ application efficiency

Example:

ET is .65 inches since the last irrigation.

To replace this, you want to apply .65 inches to the root zone.

Application efficiency is 83 percent.

Water you need to apply = 0.65 ÷ .83 = 0.78 inches.

Finding your exact application efficiency is difficult. For practical purposes, though, you won't go far wrong adding 10 to 20% to ET. In the example above, the difference between adding 10% and 20% to 0.65 inches amounts to a mere 0.06 inches.

To estimate your application efficiency more precisely, and to monitor system performance over time, it's an excellent idea to check your system's uniformity. The next chapter (page 38) explains how to do this.

For Further Reading

- **California Irrigation Management Information System (CIMIS),** cimis.water.ca.gov *Real-time and historical ET information for most parts of California.*
- **Open ET,** openetdata.org *Free satellite-based ET estimates for the entire western United States.*
- **The Irrigation Training and Research Center at California Polytechnic State University, San Luis Obispo,** itrc.org *Publishes typical monthly ET rates for many California crops and climate zones.*
- **CropManage website,** cropmanage.ucanr.edu *UC Extension website offering real-time recommendations for efficient irrigation and fertilizer applications.*
- **University of California Fruit and Nut Research and Information Center,** fruitsandnuts.ucdavis.edu *Click on "Weather Models."*

A Note on Deficit Irrigation

Although irrigation is normally based on tracking ET, there are situations where you may want or need to use ***deficit irrigation***—the intentional underwatering of crops.

When irrigation water is limited, some crops can be stressed at times when their reproductive growth is low, resulting in little or no reduction in yield or quality.

Carefully timed deficit irrigation can also improve fruit quality and is often used for this purpose on wine grapes in California.

3. Determining Your Application Rate

This chapter explains:

- How to determine your system's application rate from flowmeter readings or direct measurements
- How to determine your system's emission uniformity

Anyone who operates a microirrigation system must know their system's application rate in inches per hour. If you don't know this number, you're guessing or blindly following instructions, not making informed decisions.

The application rate in your original design specifications may be fairly accurate, especially if you have a newer system. But all systems change over time because of wear, clogging, leaks, and other problems. This chapter explains how to check your actual application rate.

Chapter 2 explained how to determine the amount of water you need to apply. Once you know your application rate, your daily and weekly management decisions will largely boil down to dividing one number by another:

water you need to apply ÷ application rate = time you need to run the system

Having a Professional Evaluation

A professional evaluation, including your application rate, is strongly recommended if you have access to the services of a trained irrigation system auditing team. These teams, sometimes called ***Mobile Irrigation Labs*** or Eco-Labs, are often available through your Irrigation District or Resource Conservation District, or through private consultants. Inquire at your local NRCS or Cooperative Extension office.

Using Flowmeters to Find Your Application Rate

Every properly designed microirrigation system includes at least one flowmeter. Most often this is a propeller flowmeter installed at the head of the system, in the main supply line—after the filters and on a straight section of pipe. Small flowmeters may also be installed on individual lateral lines.

Photo: Larry Schwankl

Figure 5. Saddle-type propeller flowmeter

Flowmeter at the Head of the System

If your flowmeter gives instantaneous readings in gallons per minute (gpm) or cubic feet per second (cfs), simply convert these readings into inches per hour as follows:

_____ gpm ÷ _____ irrigated area (acres) × 0.0022 =
_____ application rate (inches per hour)

_____ cfs ÷ _____ irrigated area (acres) × 0.992 =
_____ application rate (inches per hour)

If there's no flowmeter on the system, you can still use the formulas above if you've recently had a pump test.

Instead of giving instantaneous readings, your flowmeter may record "totalized" flow in gallons, acre-feet, or acre-inches. To find your application rate, record the meter reading and time at the beginning and end of your irrigation set. Then follow the three-step process below:

Step 1: Divide total acre-inches by the number of hours, to determine acre-inches applied per hour.

If your flowmeter records gallons or acre-feet, use one of the following formulas:

______ gallons × 0.000037 ÷ _____ irrigation time (hours)
= ______ acre-inches per hour

______ acre-feet × 12 ÷ _____ irrigation time (hours)
= ______ acre-inches per hour

Step 2: Determine irrigated area in acres.

If you don't know your irrigated acreage, use your system dimensions and spacing:

____	×	____	×	____	÷	43,560 =	____
lateral length (feet)		lateral spacing (feet)		# laterals operating			irrigated area (acres)

Step 3: Divide applied water (Step 1) by irrigated area (Step 2) to find application rate.

_____ applied water (ac-in/hr)	÷	_____ irrigated area (acres)	=	_____	application rate (in/hr)

Example:

14,000 gallons applied during 4-hour set.

14,000 × 0.000037 ÷ 4 = .13 acre-inches per hour.

Irrigated area = 5 acres.

.13 acre-inches per hour ÷ 5 acres = 0.032 inches per hour.

Flowmeters on Lateral Lines

Your system may have small totalizing flowmeters installed on individual lateral lines throughout the system. While not very common in California, these flowmeters do have advantages. They normally cost less than $100 apiece and provide good information about emission uniformity. On the other hand, they may be less convenient to install and maintain than a single flowmeter at the head of the system.

To determine the application rate on the lateral line, record the meter reading and time at the beginning and end of your irrigation set. Then follow the three steps below to find your application rate in inches per hour:

Step 1: Divide acre-inches by the number of hours, to determine application rate in acre-inches per hour.

If meter readings are in gallons or acre-feet, use one of the conversion formulas on the previous page.

Step 2: Determine irrigated area of the lateral line in acres, using the following formula.

____ lateral length (feet) × ____ lateral spacing (feet) ÷ 43,560 = ____ irrigated area (acres)

Step 3: Divide applied water (Step 1) by irrigated area (Step 2) to find application rate.

____ applied water (ac-in/hr) ÷ ____ irrigated area (acres) = ____ application rate (in/hr)

Direct Measurement Method for Surface Drip and Microsprinklers

You can directly measure the application rate of any surface drip or microsprinkler system in the field, using the following three-step process:

Step 1: Sample the flow rates of individual emitters.
After the irrigation system reaches a steady pressure, take carefully timed 30-second flow measurements. A 100-ml graduated cylinder works well for drip systems, and a 1,000-ml graduated cylinder works well for microsprinkler systems.

Then calculate the flow rate for each emitter in gallons per hour (gph):

____ ml water collected in 30 seconds × 0.0317 = ____ discharge rate (gallons per hour)

See the center section of this guidebook for conversions. 1 fluid ounce = 29.5 ml and 1 pint = 472 ml.

If possible, check the flow rates of 30 to 50 emitters. By starting at one corner and moving diagonally through the field, you'll get samples from the head, middle, and ends of lateral lines. Pay special attention to the ends of laterals. Reduced flow rates here indicate plugging upstream.

Measurements will vary because of friction losses, elevation changes, and other factors. If you see a lot of variation, you have a problem with uniformity, most likely caused by poor system design or clogging.

Step 2: Find average flow rate per emitter in gallons per hour:

______	sum of all flow rates collected (gph)	÷	______	# of devices sampled	=	______	avg. flow rate (gph)

Step 3: Calculate system's application rate in inches per hour.

______	×	______	÷	______	× 1.6	=	______
avg. flow rate (gph)		# devices per plant		area per plant (ft^2)	(conversion factor)		application rate (in/hr)

Example: Trees on 16 ft × 22 ft spacing (352 ft^2).

4 drippers per tree.

Average flow rate per dripper = 0.97 gallons per hour.

0.97 gph × 4 drippers per tree ÷ 352 ft^2 plant area × 1.6
= 0.018 in/hr.

Pressure Measurement Method for Subsurface Systems

Directly measuring the application rate of subsurface (buried) microirrigation systems is difficult or impossible. Your best option is to take pressure measurements and then use tables provided by the manufacturer to convert these into flow rates. Compare your results to flowmeter readings.

Step 1: Measure pressure wherever you can.
Sometimes the head ends of lateral lines are exposed. Often, tail ends are exposed so they can be flushed. You may be able to adapt an end cap to fit a pressure gauge and temporarily slip it over the end of a lateral line. Or you may be able to fit a pressure gauge with a pitot tube and insert it into a hole punched in the tubing. After taking the reading, plug the hole with a goof plug.

Step 2: Use manufacturer's tables to convert pressure reading into flow rate.

The tables may give flow rates in gallons per minute per 100 feet (common for thin-walled drip tape) or in gallons per hour per emitter (common for thick-walled tubing).

Step 3: Calculate the system's application rate in inches per hour, using Tables 12 and 13 (following pages) or one of the following formulas.

____ emitter flow rate (gph) ÷ ____ emitter spacing (in) × 20 = ____ flow rate (gallons per minute per 100 feet)

Example:

Emitter flow rate 0.35 gph, emitter spacing 8 inches.

Flow rate = 0.35 ÷ 8 × 20 = 0.88 gals per minute per 100 feet.

____ flow rate (gpm/100 ft) ÷ ____ lateral spacing (in) × 11.55 = ____ application rate (in/hr)

Example:

Flow rate .54 gpm/100 ft, lateral spacing 30 inches.

Application rate = 0.54 ÷ 30 × 11.55 = 0.21 inches per hour.

____ emitter flow rate (gph) × ____ # devices per plant ÷ ____ area per plant (ft^2) × 1.6 = ____ application rate (in/hr)

Example:

Row crop, 5 foot × 1.5 foot plant spacing = 7.5 ft^2

2 emitters per plant, flow rate = 0.9 gallons per hour.

Application rate = 0.9 × 2 ÷ 7.5 × 1.6 = 0.38 inches per hour.

Table 12. Flow rate in gallons per minute per 100 feet, based on emitter flow rate and spacing.

Emitter flow rate (gallons per hour)	Emitter spacing (inches)					
	4	8	12	16	18	24
0.10	0.5	0.25	0.17	0.13	0.11	0.08
0.15	0.75	0.38	0.25	0.19	0.17	0.13
0.20	1.00	0.50	0.33	0.25	0.22	0.17
0.25	1.25	0.63	0.42	0.31	0.28	0.21
0.30	1.50	0.75	0.50	0.38	0.33	0.25
0.35	1.75	0.88	0.58	0.44	0.39	0.29
0.40	2.00	1.00	0.67	0.50	0.44	0.33
0.45	2.25	1.13	0.75	0.56	0.50	0.38
0.50	2.50	1.25	0.83	0.63	0.56	0.42
0.55	2.75	1.38	0.92	0.69	0.61	0.46
0.60	3.00	1.50	1.00	0.75	0.67	0.50
0.65	3.25	1.63	1.08	0.81	0.72	0.54
0.70	3.50	1.75	1.17	0.88	0.78	0.58
0.75	3.75	1.88	1.25	0.94	0.83	0.63
0.80	4.00	2.00	1.33	1.00	0.89	0.67
0.85	4.25	2.13	1.42	1.06	0.94	0.71
0.90	4.50	2.25	1.50	1.13	1.00	0.75
0.95	4.75	2.38	1.58	1.19	1.06	0.79
1.00	5.00	2.50	1.67	1.25	1.11	0.83

General formula:

____ emitter flow rate (gph) ÷ ____ emitter spacing (in) × 20 = ____ flow rate (gallons per minute per 100 feet)

Table 13. Application rate in inches per hour, based on lateral line flow rate and lateral spacing.

Lateral spacing (in)	**Flow rate (gallons per minute per 100 ft)**								
	0.1	**0.15**	**0.2**	**0.25**	**0.3**	**0.35**	**0.4**	**0.45**	**0.5**
12	0.10	0.14	0.19	0.24	0.29	0.34	0.39	0.43	0.48
14	0.08	0.12	0.17	0.21	0.25	0.29	0.33	0.37	0.41
16	0.07	0.11	0.14	0.18	0.22	0.25	0.29	0.32	0.36
18	0.06	0.10	0.13	0.16	0.19	0.22	0.26	0.29	0.32
20	0.06	0.09	0.12	0.14	0.17	0.20	0.23	0.26	0.29
22	0.05	0.08	0.11	0.13	0.16	0.18	0.21	0.24	0.26
24	0.05	0.07	0.10	0.12	0.14	0.17	0.19	0.22	0.24
26	0.04	0.07	0.09	0.11	0.13	0.16	0.18	0.20	0.22
28	0.04	0.06	0.08	0.10	0.12	0.14	0.17	0.19	0.21
30	0.04	0.06	0.08	0.10	0.12	0.13	0.15	0.17	0.19
32	0.04	0.05	0.07	0.09	0.11	0.13	0.14	0.16	0.18
34	0.04	0.05	0.07	0.08	0.10	0.12	0.14	0.15	0.17
36	0.03	0.05	0.06	0.08	0.10	0.11	0.13	0.14	0.16
38	0.03	0.05	0.06	0.08	0.09	0.11	0.12	0.14	0.15
40	0.03	0.04	0.06	0.07	0.09	0.10	0.12	0.13	0.14
42	0.03	0.04	0.06	0.07	0.08	0.10	0.11	0.12	0.14
44	0.03	0.04	0.05	0.07	0.08	0.09	0.11	0.12	0.13
46	0.03	0.04	0.05	0.06	0.08	0.09	0.10	0.11	0.13
48	0.02	0.04	0.05	0.06	0.07	0.08	0.10	0.11	0.12
50	0.02	0.03	0.05	0.06	0.07	0.08	0.09	0.10	0.12
52	0.02	0.03	0.04	0.06	0.07	0.08	0.09	0.10	0.12
54	0.02	0.03	0.04	0.05	0.06	0.07	0.09	0.10	0.11
56	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09	0.10
58	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09	0.10
60	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09	0.10

General formula:

____ flow rate (gpm/100 ft) ÷ ____ lateral spacing (in) × 11.55 = ____ application rate (in/hr)

Uniformity

Poor uniformity and overwatering are the main causes of poor application efficiency in microirrigation systems. Poor uniformity forces you to overwater some parts of the field in order to avoid underwatering other parts.

There are many ways to define and measure uniformity. ***Emission uniformity*** (EU) measures the variation in flow rates among emitters—differences caused by friction losses, elevation changes, clogging, intermingling emission devices when making repairs, or manufacturing inconsistencies. Emission uniformity can be calculated as:

$$\begin{array}{c}\text{Average flow of}\\\text{lowest 25\% of}\\\text{emitters measured}\end{array} \div \begin{array}{c}\text{Average flow}\\\text{of all emitters}\\\text{measured}\end{array}$$

Example: Avg flow of lowest 25% of emitters measured: 0.92 gallons per hour.

Avg flow of all emitters measured: 1.04 gallons per hour.

Emission uniformity = 0.92 ÷ 1.04 = .885 (or 88.5%).

EU is a reasonably accurate indication of application efficiency (pages 25-26) and has the great advantage that it can be calculated from the same flow-sampling measurements described on pages 33-34.

Well-designed and well-maintained microirrigation systems should have an EU in the range of .85 to .90 for orchards and .80 to .90 for row crops.

In any system, EU tends to decrease over time. Calculate EU shortly after your system is installed to check the quality of the design and installation. Also check EU periodically as part of routine maintenance. A sudden drop indicates serious maintenance and repair problems.

4. Determining How Long to Run Your System

This chapter explains how to calculate the time needed to apply:

- A desired depth of water in inches
- A desired number of gallons per day per plant

Applying a Desired Depth of Water

Chapter 3 explained how to determine the application rate in inches per hour for any kind of microirrigation system, and also explained how to calculate emission uniformity, a good approximation to application efficiency.

The amount you need to apply, in order to fully replace the water your crops have used, is ET since your last irrigation divided by your system's application efficiency. (Or, for a quick approximation, ET plus 10 to 20%.)

And the basic equation for determining how long to run your irrigation system is:

_____ amount needed (inches) ÷ _____ application rate (inches per hour) = _____ Irrigation time needed (hours)

Example: ET is 0.55 inches since last irrigation.
Application rate is 0.09 inches per hour.
Application efficiency is .88.

So the amount needed is 0.55 ÷ 0.88 or 0.63 inches.

Irrigation time needed is 0.63 ÷ 0.09 = 7.0 hours.

Because irrigations are so frequent and systems are often automated, microirrigation usually involves planning ahead a week or two at a time based on expected ET. The CIMIS and OpenET systems do not include ET predictions based on weather forecasting, but you can use historical ET information or recent real-time estimates to make your own estimates.

Example: Expected ET for the next 15 days is 3.48 inches or 0.23 inches per day.

Application rate is 0.09 inches per hour.

Application efficiency is 0.88.

So amount needed per day is 0.23 ÷ 0.88 or 0.26 inches.

Irrigation time needed per day is 0.26 ÷ 0.09 = 2.9 hours.

Applying Desired Gallons per Day per Plant

If you know the application rate for each emitter in gallons per hour, you can easily calculate the required irrigation time using the following three-step process:

Step 1: Convert ET rates to gallons per day per plant.

Use Table 11 on page 23 or do a simple calculation with the following formula:

$$\text{Water use (gals/day)} = \text{crop spacing (ft}^2) \times \text{ET (in/day)} \times 0.623$$

Example: ET is 0.25 inch per day.

Tree crop spacing 15 feet × 15 feet = 225 square feet.

Water use per tree = 225 × 0.25 × 0.623 = 35.0 gallons per day.

Step 2. Calculate the number of gallons per day that you need to apply to each plant.

Amount you need to apply per day = ET (gallons per day) ÷ application efficiency

Example: ET for each tree is 35.0 gallons per day.

Application efficiency is 0.82.

You need to apply 42.7 gallons per day per tree (35.0 ÷ 0.82).

Step 3: Determine the application rate of your irrigation system in gallons per hour per plant.

Application rate (gal/hr) = number of emission devices × discharge rate per emission device (gal/hr/emitter)

Example: Four drip emitters per tree.

Discharge rate per emitter 1 gallon per hour.

Application rate = 4 gallons per hour per tree.

Step 4: Determine required irrigation time in hours per day.

Use the following formula:

_____ amount you need to apply (gals/day) ÷ _____ application rate (gals/ hr) = _____ irrigation time needed (hrs/day)

Example: You need to apply 42.7 gallons per day per tree.

Application rate is 4 gallons per hour per tree.

42.7 gallons per day ÷ 4 gallons per hour = 10.7 hours per day.

5. Monitoring Soil Moisture

This chapter explains:

- How soils are classified (USDA classification system)
- How soils hold water
- Why healthy soils hold more water
- Several ways to monitor soil moisture

Even if you're managing your microirrigation system mainly through estimates of crop water use (ET), soil moisture monitoring is a useful way to check the accuracy of ET estimates from historical averages, weather stations, or satellites. Soil moisture monitoring is also an excellent method for young trees and vines or other crops (including many row crops) whose ET rates are hard to estimate.

Soil Textures and Types

Soils are commonly classified into ***textures*** or ***texture classes,*** based on the proportion of sand, silt, and clay particles. Sand particles are larger than clay particles, with silt particles falling in between. For example, a soil that's 20% clay, 60% silt, and 20% sand (by weight) would be classified as silt loam. Other texture classes are sand, loamy sand, sandy loam, loam, silt, sandy clay loam, clay loam, silty clay loam, sandy clay, silty clay, and clay. ***Coarse-textured*** soils have a high percentage of sand and ***fine-textured*** soils have a high percentage of clay.

Soils are also given names and classified into ***soil types*** or ***soil series***, based mainly on soil-development factors such as geology, chemistry, age, and location. There are over 20,000 named soils in the U.S., with names often referring to a town or landmark near where the soil was first recognized. For example, Yolo Silt Loam is a deep alluvial soil with a high water-holding capacity, found in and around Yolo County. Hesperia is a sandy loam with a low infiltration rate, found southeast of Fresno.

The full description of a soil series includes a number of layers or ***horizons***, starting at the surface and moving downward. To identify the soil types or series in your fields, refer to a soil survey. Soil surveys may be available from your local NRCS or Cooperative Extension office, from your local resource conservation district, or from sources on the Internet such as the NRCS Web Soil Survey: ***websoilsurvey.nrcs.usda.gov/app***

How Soils Hold Water

Soil holds water in small pores, just like a sponge. A soil's ability to hold water depends heavily on its texture, with fine-textured soils usually (but not always) holding more water than coarse-textured soils.

During rainfall or irrigation, pore spaces largely created by soil life (i.e., plant roots, earthworms, bacteria, and fungi) fill with water. After the pores are saturated, water keeps draining while evaporation at the surface pulls water upward through ***capillary forces,*** like water climbing up a paper towel. Capillary forces also hold water in films around the soil particles.

After a few hours (in sandy soils) or days or even weeks (in clay soils), a balance is achieved between gravitational and capillary forces. Water stops draining, and soil reaches a condition known as ***field capacity***.

The remaining water, ***capillary water,*** is the water that matters most to growing crops. However, only a fraction of capillary water—often less than half—is ***plant available***. As soils dry out, the films of water around the soil particles eventually get so thin that plants can no longer overcome the capillary forces holding water to soil particles. The plants start to wilt.

Available water-holding capacity (AWC) is the amount of water a soil can make available to plants, defined as the difference between the volume of water stored at field capacity and the volume of water stored at the permanent wilting point.

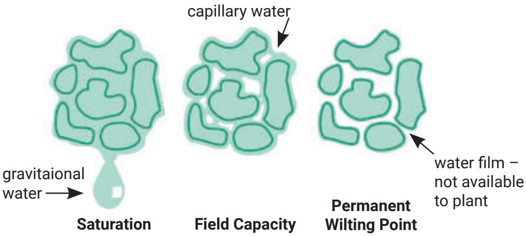


Figure 6. Saturation, Field Capacity, and Permanent Wilting Point

Measuring Moisture: Volume vs. Soil Water Tension

Some soil moisture monitoring devices give ***volumetric*** measurements, such as inches of water per foot of soil depth, while other devices measure ***soil water tension***, defined as the amount of energy holding water in soil. Think of soil water tension as a measure of how tightly water is bound to soil surfaces or how hard the plant needs to work to extract water. (You may see it called soil water ***potential***, ***matric potential***, or other names.) Soil water tension is usually measured in ***centibars*** (cb), where a centibar is 1/100th of a bar, and a bar is roughly one atmosphere of pressure or 14.5 pounds per square inch. However, you may also see soil water tension measured in ***kilopascals*** (kPa).

Soil texture strongly influences soil water tension. For example, clay soils have small pores and hold water more tightly than silt soils, with their larger pores. Coarse soils (such as sands and sandy clay loams) have released 50 percent of their water by the time soils have dried out to 40 to 50 cb. On the other hand, many clay and silty soils retain over 50 percent of water at 80 cb.

What Method Is Right for You?

Choose a tool you can trust on your soils and crops. Some devices work better in coarse soils than in fine soils, some devices work better with annual crops than with perennial crops, and so on. High-value crops may justify a more expensive monitoring system than low-value crops.

Consider what's convenient for you. Some devices are portable while others are hard-wired in place. Some devices give "raw" data while others do the calculations for you or display readings in a graph. Some devices require cables that may interfere with tillage while others use radio signals or other remote data collection methods.

Be realistic in your expectations. Soil moisture measurement, even with the advent of ever-more-accurate devices, doesn't eliminate all guesswork. Soil measuring devices can't substitute for the powers of judgment and observation that good irrigators acquire over time.

The methods that follow are arranged roughly in order of cost, from least expensive to more expensive. All work reliably and are useful if used properly and diligently.

Direct Inspection

The least expensive methods rely on digging up soil samples in the field and then inspecting and feeling them.

Feel and Appearance Method

With practice and diligence, the feel and appearance method can be accurate enough for most irrigation management decisions.

Take walnut-sized soil samples from various locations and depths in the field, appropriate to your crop's root zone. Then use Table 14 on the following page to estimate the soil water content of your samples.

Table 14. Determining Soil Water Content by Feel and Appearance

Coarse Texture	Moderately Coarse Texture	Medium Texture	Moderately Fine and Fine Texture	% of Available Water Capacity (AWC)
Free water appears when soil is bounced in hand.	Free water is released with kneading.	Free water can be squeezed out.	Puddles and free water forms on surface.	Exceeds field capacity – runoff and deep percolation.
Upon squeezing, no free water appears on soil, but wet outline of ball is left on hand.				100% – At field capacity
Tends to stick together, forms a weak crumbly ball under pressure.	Forms weak ball that breaks easily; does not stick.	Forms a ball and is very pliable; sticks readily if relatively high in clay.	Ribbons out between thumb and finger; has a slick feeling.	70 – 80% of AWC
Tends to stick together. May form a very weak ball under pressure.	Tends to ball under pressure, but seldom holds together.	Forms a ball, somewhat plastic; sticks slightly under pressure.	Forms a ball; ribbons out as above, but ribbons may fracture and break as they form	50 – 70% of AWC
For most crops, irrigation should begin at 40 to 60% of AWC.				
Appears to be dry; does not form a ball under pressure.	Appears to be dry; does not form a ball under pressure.	Somewhat crumbly but holds together under pressure.	Somewhat pliable; balls up under pressure.	25 – 50% of AWC
Dry, loose, single-grained flow through fingers.	Dry, loose, flows through fingers.	Powdery dry, sometimes slightly crusted but easily breaks down into powder.	Hard, baked, cracked; sometimes has loose crumbs on surface.	0 – 25% of AWC

Source: Natural Resources Conservation Service. 1997. **Irrigation Guide.**

The NRCS brochure "Estimating Soil Moisture by Feel and Appearance" includes color photographs of various soils and soil moisture conditions: ***wcc.nrcs.usda.gov/ftpref/wntsc/waterMgt/irrigation/EstimatingSoilMoisture.pdf***

Hand-Push Probe

You can use a ***hand-push probe*** to determine the depth of wetted soil, as well as to retrieve soil samples. These extremely handy tools cost under $100 and are one of easiest ways to check moisture anywhere in your fields.

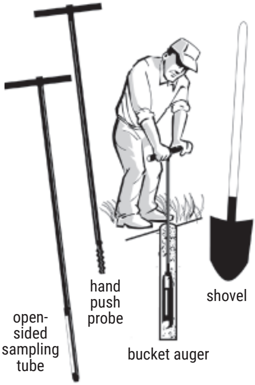


Figure 7. Soil sampling tools

Push the probe vigorously into the soil by putting your weight on the handle without turning. The probe will stop abruptly when it reaches dry soil. Check the mark on the shaft to determine the depth of the wetted soil.

Most hand-push probes have an auger on the tip, allowing you to retrieve a soil sample by twisting the probe and pulling it out of the soil.

Meters and Sensors

Tensiometers

A ***tensiometer*** is an airtight, water-filled tube with a porous ceramic tip and a vacuum gauge near the top. As the name implies, tensiometers measure soil water tension. Water flows into or out of the ceramic tip, changing vacuum pressure inside the tube. When water stops moving and reaches equilibrium with its surrounding soil, the vacuum pressure indicates soil moisture tension and can be read from the gauge.

Tensiometers are easy to use, last years with good care, and are not affected by soil temperature or salinity. While not as accurate as some electronic devices, they're plenty accurate for most farming situations. They cost $80 to $150 apiece but you can find instructions on the Internet on making your own for less.

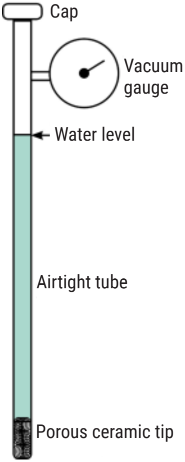


Figure 8. Tensiometer

Because they're easy to install and remove, tensiometers are well-suited to cultivated fields, annual crops, orchards, and other situations where buried blocks or cables would be awkward. They work best from 0 to 80 cb, making them better suited to coarse soils. (A fine-textured soil can retain more than half of its available water capacity at 80 cb.)

Electrical Resistance Sensors

Electrical resistance sensors take advantage of the familiar idea that wet soil conducts electricity better than dry soil. They work by absorbing water from the surrounding soil. A meter runs an electric current through two electrodes implanted in the sensor, measuring electrical resistance, which is then translated into a soil moisture tension reading by either a portable hand-held meter or a data logger.

The two most common types of electrical resistance blocks are ***gypsum blocks*** (with a short life of as little as only one year but a low cost of $12 to $25 apiece) and ***granular matrix sensors*** (lasting three to seven years or more and costing $45 to $60 apiece). Freezing will usually not hurt granular matrix sensors, whereas it can cause cracking and premature aging in gypsum blocks.

Electrical resistance sensors are more strongly affected by salinity than tensiometers. To give accurate readings, they need to be buried carefully, with good soil contact and no air pockets—something that's not always easy to do in coarse or gravelly soils. When burying any soil moisture sensing device, your goal is to install each sensor in surroundings that are representative of the field. So be careful to minimize soil compaction and disturbance to the surrounding soil and canopy cover.

Table 15. Irrigation Guidelines Based on Centibar Readings

Reading	Interpretation
0-10 cb	Saturated soil
10-20 cb	Most soils are at field capacity, no irrigation needed
30-40 cb	Typical range requiring irrigation in coarse soils
40-60 cb	Typical range requiring irrigation in medium soils
70-80 cb	Typical range requiring irrigation in heavy clay soils
> 85 cb	Crop water stress likely for most crops and soils

Dielectric Sensors

Dielectric sensors measure the charge-storing capacity of soil: its tendency to become electrically polarized when exposed to an electric field, acting like a capacitor. Unlike tensiometers or electrical resistance blocks, dielectric sensors give ***volumetric*** measurements: the volume of water per volume of soil.

The two main types of dielectric sensors are ***capacitance*** sensors—also known as ***frequency domain reflectometry (FDR)*** sensors—and ***time domain reflectometry (TDR)*** sensors. Once extremely expensive, TDR devices have become available that are close in price to high-quality FDR devices, making TDR an option worth considering for irrigators who need a high degree of accuracy.

Table 16. Available Water-Holding Capacity and Intake Rates

Soil Texture	AWC Range (inches per foot depth)	Typical AWC (inches per foot depth)
Coarse Sand, Sand	0.1–0.4	0.25
Fine Sand, Very Fine Sand	0.6–0.8	0.75
Loamy Coarse Sand, Loamy Sand	0.7–1.0	0.85
Loamy Fine Sand, Loamy Very Fine Sand	1.0–1.4	1.25
Coarse Sandy Loam	1.2–1.4	1.3
Sandy Loam	1.3–1.6	1.45
Fine Sandy Loam	1.6–1.8	1.7
Sandy Clay Loam, Clay	1.7–1.9	1.8
Very Fine Sandy Loam, Sandy Clay, Silty Clay	1.8–2.0	1.9
Loam, Silt	1.9–2.2	2.0
Silt Loam, Clay Loam, Silty Clay Loam	2.3–2.5	2.4

	Intake Rate (inches per hour)		
Soil Texture	Sprinkler	Furrow	Border and Basin
Clay, Silty Clay	0.1–0.2	0.1–0.5	0.1–0.3
Sandy Clay, Silty Clay Loam	0.1–0.4	0.2–0.8	0.25–0.75
Clay Loam, Sandy Clay Loam	0.1–0.5	0.2–1.0	0.3–1.0
Silt Loam, Loam	0.5–0.7	0.3–1.2	0.5–1.5
Fine or Very Fine Sandy Loam	0.3–1.0	0.4–1.9	1.0–3.0
Sandy Loam, Loamy Very Fine Sand	0.3–01.25	0.5–2.4	1.5–4.0
Loamy Fine Sand, Loamy Sand	0.4-1.5	0.6–3.0	2.0–4.0
Fine Sand, Sand	0.5+	1.0+	3.0+
Coarse Sand, Sand	1.0+	4.0+	4.0+

Source: Natural Resources Conservation Service. 1997. **Irrigation Guide.**

AWC and intake rate are affected by salinity, rock fragments, compaction, restrictive layers, vegetative cover, and other factors, and can often be increased over time by good soil management that improves soil health.

Data Loggers

A ***data logger*** is an electronic device, usually powered by batteries or a solar panel, that records data at regular intervals. Electrical resistance blocks, tensiometers, and dielectric sensors can all be connected to data loggers.

Soil moisture data loggers are typically mounted on a post and connected by cable to one or more sensors. At regular intervals (from every few minutes to every few hours), the data logger sends a weak electric current to the sensors, taking measurements and storing them in memory.

Data loggers store months or years of data that can be downloaded at your convenience or sent via Internet to your phone or laptop. They can send alerts if soil moisture gets above or below desired levels and can function as controllers that automatically modify your irrigation schedule based on soil moisture and weather conditions.

As a ballpark, you're going to spend $150 to $600 for a hand-held meter or a data logger. Total cost of a system will depend on the number and type of sensors you install. A wireless system with a single dielectric sensor can be set up for as little as $1,200, including annual fees for a data plan. On the other hand, a system with multiple sensors and a weather station that monitors multiple locations and depths could easily cost tens of thousands of dollars.

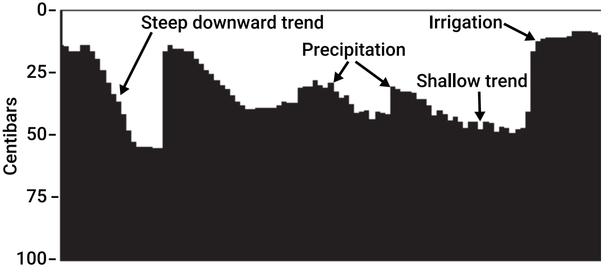


Figure 9. Data Logger Graphical Display, 5 Weeks of Readings

Neutron Probes

Neutron probes are highly accurate devices that are often used by crop consultants. They're expensive ($3,500 to $4,500) and require special training and licensing because of the radiation safety hazard.

Tips on Placing Moisture Sensors and Interpreting Readings

- It's generally not practical to monitor every part of the field, so install sensors in areas with typical soils and growing conditions. Avoid unusually wet or dry areas.
- In drip irrigation, the ideal sensor placement is at the ***edge of the wetted soil***. Sensors placed too close to an emitter will show continuously wet soil while sensors placed too far from an emitter will show continuously dry soil.

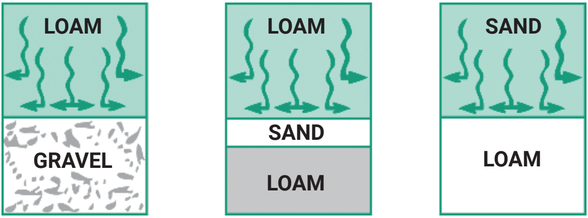
! Drip emitters wet only a small volume of soil, especially in sandy soils. Misplacing a buried moisture sensing device by even a few inches may yield highly inaccurate readings.

- Take the exact moisture readings you're seeing with a grain of salt and pay more attention to trends. Soil moisture under microirrigation should remain fairly constant, with soils drying slightly following irrigation and being re-wetted by the next irrigation. A steady increase in soil moisture or continually wet soil means you're over-irrigating. Steadily decreasing soil moisture or continually dry soil means you're under-irrigating.
- For a better idea of what sensor readings mean, use a soil probe or auger to sample, feel, and inspect soil from the root zone—taking care not to disturb the soil moisture sensors when you do this.
- When monitoring young trees and vines, place sensors close to the plant, among the active roots.

- For deep-rooted crops, you may want to place sensors at one-foot depth increments in the rooted volume.
- Another common strategy is to place one sensor in the top one-third and another in the bottom one-third of the root volume, as "on-off" indicators. Start irrigating when the shallow sensor begins to get dry. Stop irrigating when the deep sensor begins to get wet.

! Sensors may have to be relocated in orchard and vine crops as the crop and its root system develop from seedlings to mature trees and vines.

Changes in soil texture act as a temporary barrier to water movement



Source: Natural Resources Conservation Service. 1997. **Irrigation Guide**.

Generally, a drip emitter wets a smaller area in sandy (coarse) soil than it would in finer soils. But coarse soil overlying fine soil, or vice versa, may hold up to three times as much water as it would in more uniform soils, causing water to move laterally. If you have distinct layers of soil, you may want to monitor soil moisture in each layer separately.

For Further Reading

Morris, Mike. 2022. **Soil Moisture Monitoring: Low-Cost Tools and Methods**. ATTRA publication IP 277. attra.ncat.org/publication/soil-moisture-monitoring-low-cost-tools-and-methods

6. Catch More Water in Your Soil

This chapter explains several ways to improve soil health, water-holding capacity, and intake rates.

Improve Soil Health

The NRCS defines ***soil health*** as "the continued capacity of soil to function as a vital living ecosystem that sustains plants, animals, and humans." Healthy soil carries out functions including regulating water, sustaining plant and animal life, filtering and buffering pollutants, cycling nutrients, and providing physical stability and support. The NRCS calls four main principles key to soil health:

1. Maximizing presence of living roots
2. Minimizing disturbance
3. Maximizing soil cover
4. Maximizing biodiversity

These practices feed microorganisms, protect soil from excessive heat and pounding raindrops, and create soil aggregates and water-holding channels and pores. Many agricultural soils are far below their biological potential. Through good soil health management, you may be able to improve your water-holding capacity and infiltration rates, even dramatically.

Table 17. Organic Matter Increases Water-Holding Capacity

	Typical inches of water per foot of soil		
% organic matter	Sand	Silt loam	Silty clay loam
1%	1.0	1.9	1.4
2%	1.4	2.4	1.8
3%	1.7	2.9	2.2
4%	2.1	3.5	2.6
5%	2.5	4.0	3.0

Source: Hudson, Berman. 1994. **Soil Organic Matter and Available Water Capacity**. Journal of Soil and Water Conservation 49 (2) 189-194.

Why Healthy Soil Holds More Water

In healthy soil, many of the pores are created by soil organisms: digging, tunneling, digesting, excreting, dying, and secreting various glues (such as glomalin) that make soil particles stick together in small clumps called ***aggregates*** that help maintain stability when soil is wet.

As soils get healthier, more numerous and diverse organisms create water-holding channels, pores, and aggregates, often greatly increasing infiltration rates and water-holding capacity.

Although you can't change your soil's texture class, you may very well be able to improve its health. That's why maintaining and improving soil health is "Job One" for irrigators. Everything about irrigation gets easier when you're working with healthy soil.

Ways of Improving Soil Health

✓ Reduce tillage.
✓ Keep plant residues and tall stubbles in the field.
✓ Grow diverse cover crops and incorporate into soil.
✓ Add organic materials: manure, biochar, mulch, compost, etc.
✓ Use diverse crop rotations to increase biodiversity.
✓ Inoculate with mycorrhizal fungi.
✓ Encourage earthworms.
✓ Regularly test your soils, including health indicators such as organic matter, respiration, and aggregate stability.

Other Ways of Catching More Water

Keep the soil covered and protected from heat and wind to ***reduce evaporation***.

✓ Grow cover crops to keep the soil covered year-round.
✓ Establish rows of trees, shrubs, or grass as windbreaks.

Reduce compaction to decrease runoff and flooding, improve aeration, and allow plant roots to go deeper.

- ✓ Minimize wheel traffic and hoof impact on wet fields.
- ✓ Grow deep-rooted cover crops like oats, cereal rye, or radishes.

Checking Infiltration Rates with a Ring Test

For a rough idea of your soil's intake rate, see Table 16 or look up values for your soils in the Web Soil Survey. You can get a better idea by doing a *ring test*. Pound a ring made of metal or PVC into the soil, pour a carefully measured amount of water into the ring, and record the time it takes for all the water to sink in.

Don't expect too much precision from ring tests and be careful about comparing different dates or times of year. Differences in soil moisture, temperature, and vegetation will greatly skew results. Here are some ways to make ring tests more accurate:

- Line the inside of the ring with plastic wrap. After adding water, carefully pull the plastic wrap out, releasing the water exactly when you start timing.
- Add exactly one inch of water, so you can calculate your infiltration rate in inches per hour. (If you use a 6-inch diameter ring, this amount will be 444 mL.)
- Use a double-ring infiltrometer ($200 to $700), whose "ring within a ring" design forces water in the inner ring to infiltrate vertically and reduces error due to lateral spread of water.
- After the water is completely infiltrated, repeat the test. The second application (in wet soil) will give a more meaningful estimate of your infiltration rate.
- Use distilled water.

For Further Reading

NRCS Soil Health page: nrcs.usda.gov/conservation-basics/natural-resource-concerns/soils/soil-health

Soil for Water website: soilforwater.org
Peer-to-peer learning network and story collection managed by NCAT, devoted to finding and sharing better ways of catching and storing water in soil.

Bellows, Barbara et. al. 2020. **Soil Health Indicators and Tests.** ATTRA publication IP603. attra.ncat.org/publication/soil-health-indicators-and-tests

Guerena, Martin and Rex Dufour. 2019. **Managing Soils for Water.** ATTRA publication IP594. attra.ncat.org/publication/manage-soil-for-water *discusses using the principles of soil health to improve water infiltration and storage.*

Infiltration Ring with Ray Archuleta. ATTRA video. attra.ncat.org/infiltration-ring-with-ray-archuleta

LandPKS: landpotential.org
Free mobile phone app developed by the USDA Agricultural Research Service. *Includes tools for soil health monitoring and allows you to check your soil's texture and classification using your phone's camera.*

Managing Soil and Irrigation for Drought. ATTRA video. **attra.ncat.org/managing-soil-and-irrigation-for-drought**

Stika, John. 2016. **A Soil Owner's Manual: How to Restore and Maintain Soil Health.** CreateSpace Independent Publishing. *Practical, no-nonsense guide to restoring the full potential and functional capacity of your soil.*

Strickler, Dale. 2018. **The Drought Resilient Farm.** Storey Publishing. *Comprehensive guide to getting water into soil, keeping it in soil, and helping plants and livestock access it.*

Web Soil Survey: websoilsurvey.nrcs.usda.gov/app
Maintained by NRCS as the authoritative source of U.S. soil survey information, with soil maps and data for over 95 percent of the nation's counties.

7. Measuring Water in Plant Tissues

This chapter explains:

- How to measure stem water potential with a pressure chamber
- Tentative guidelines for interpreting these readings

Instead of using historical or real-time ET and monitoring soil moisture, you can measure water tension in plant tissues. This approach is rapidly gaining popularity in California, especially in orchard crops.

How a Pressure Chamber Works

Water in a plant moves through small cells called ***xylem***—essentially a network of pipes carrying water from the roots to the leaves. Water in xylem is under ***tension***, a stretching or pulling force. As soil dries, the roots can no longer keep pace with evaporation from the leaves and tension increases. The plant works harder to move water from its roots to its leaves,

A pressure chamber (also known as a *pressure bomb*) is an airtight chamber with adjustable pressure. A leaf or small shoot is placed inside the chamber, with a small part of the stem (the petiole) extending outside through a seal. Pressure is increased until water just begins to appear at the cut surface of the petiole. High pressure means the leaf is experiencing a high level of tension and water stress. ***Stem water tension*** is commonly expressed in bars.

Prices for pressure chambers range from $1,400 for “manual pump-up” models to $4,400 for “gas-pressured console” models. Table 18 on the following pages gives guidelines for interpreting pressure chamber readings from walnuts, almonds, and prunes.

! The guidelines in Table 18 are tentative and subject to change as research continues.

Table 18. Tentative Guidelines for Interpreting Pressure Chamber Readings - Mid-day Stem Water Potential

Reading (bars)[†]	Walnut	Almond	Prunes
0 to 2	Not commonly observed	Not commonly observed.	Not commonly observed.
2 to 4	Fully irrigated, low stress, commonly observed when orchards are irrigated carefully according to real-time ET estimates. Long-term root and tree health may be a concern, especially on California Black rootstock.		
4 to 6	Low to mild stress, high rate of shoot growth visible. Suggested level from leaf-out until mid June when nut sizing is completed.		
6 to 8	Mild to moderate stress, shoot growth in non-bearing and bearing trees has been observed to decline. These levels do not appear to affect kernel development.	Low stress, indicator of fully irrigated conditions, ideal conditions for shoot growth. Suggest maintaining these levels from leaf-out through mid June.	Low stress, common from March to mid April under fully irrigated conditions. Ideal for maximum shoot growth.
8 to 10	Moderate to high stress, shoot growth in non-bearing trees may stop. Nut sizing may be reduced in bearing trees and bud development for next season may be negatively affected.		Suggested levels in late April through mid June. Low stress levels enabling shoot growth and fruit sizing.

[†] Stem water tension values are often expressed in negative numbers. Positive number are used here.

Reading (bars)	Walnut	Almond	Prunes
10 to 12	High stress, temporary wilting of leaves observed. New shoot growth may be sparse or absent with some defoliation. Nut size likely to be reduced.	Mild to moderate stress. These levels of stress may be appropriate during the phase of growth just before the onset of hull split (late June).	Suggested mild levels of stress during late June and July. Shoot growth slowed but fruit sizing unaffected.
12 to 14	Relatively high levels of stress, moderate to severe defoliation, should be avoided.		Mild to moderate stress suggested for August to achieve desirable sugar content in fruit and to reduce “dry-away” (drying costs).
14 to 18	Severe defoliation, trees are likely dying.	Moderate stress. Suggested stress level during hull split to help control diseases such as hull rot and alternaria, if diseases are present. Hull split occurs more rapidly.	Moderate stress acceptable in September.
18 to 20	Crop stress levels in English walnut not observed at these levels.	Transitioning from moderate to higher crop stress levels.	Moderate to high stress levels. Most commonly observed after harvest. Generally undesirable during any stage of tree or fruit growth. Most appropriately managed with post-harvest irrigation.
20 to 30		High stress, wilting observed, some defoliation.	
Higher than 30		Extensive defoliation has been observed.	High stress, extensive defoliation.

From Allan Fulton, et. al., 2007. **Tentative Guidelines for Interpreting Pressure Chamber Readings** (**Midday Stem Water Potential-SWP**) **in Walnut, Almond, and Dried Plum**. University of California, Davis.

For Further Reading

Fulton, Allan and Richard Buchner. 2014. **Using the Pressure Chamber for Irrigation Management in Walnut, Almond, and Prune.** Publication 8503. University of California Division of Agriculture and Natural Resources.
ucanr.edu/datastoreFiles/391-761.pdf

Sacramento Valley Orchard Source. **Stem Water Potential Series.**
sacvalleyorchards.com/manuals/stem-water-potential
A website offering a series of publications and videos on stem water potential measurement and interpretation.

8. Maintaining Your System

This chapter explains:

- Routine maintenance procedures
- How to prevent and solve clogging problems
- Special precautions related to chlorine and acids

Microirrigation systems require more diligent maintenance than conventional surface or sprinkler systems, and emitter clogging is the greatest problem you face. This chapter covers general maintenance first and then discusses clogging problems in more detail.

Checking for Leaks

You should be able to spot leaks easily in surface drip and microsprinkler systems. These may be caused by loose fittings, water hammer, stretched hoses, accidental damage by workers or equipment, or chewing by animals or insects. Look for leaks often, ideally every time you operate the system.

In subsurface drip systems, the first indication of a leak is often a wet spot on the ground. But leaks may be hard to see. Watch flowmeters closely, since leaks will cause an increase in flow rate. Strategically placing pressure gauges in the system may also help, since a significant leak will cause a pressure drop.

Flowmeters and Pressure Gauges: Your First Line of Defense

Your flowmeters and pressure gauges are simple yet powerful diagnostic tools. Check them frequently.

Leaks cause increased flow and decreased pressure.

Clogging causes decreased flow downstream from clogs and increased pressure upstream.

Cleaning Filters

Filters need to be cleaned regularly. Dirty filters allow clogging, reduce system pressure, and lower application rates.

Good-quality (preferably liquid-filled) pressure gauges should be installed on upstream and downstream sides of filters. A dirty filter will cause an increased pressure differential. Follow the manufacturer's guidelines for an acceptable pressure drop.

Screen and ***disc*** filters are well suited to removing inorganic materials from groundwater, including sand. Sand ***media filters***, typically more expensive, can be used in almost all situations because of their three-dimensional filtering capability. They always include at least two tanks and are suited to removing organic material and biological contaminants commonly found in surface water, such as algae, moss, and bacterial slimes.

Filters are available in various mesh or media sizes. Consult the emitter manufacturer for particle size filtering requirements. Note that filtering particles smaller than required by the emitters will cause higher pressure losses across filters without adding any benefit.

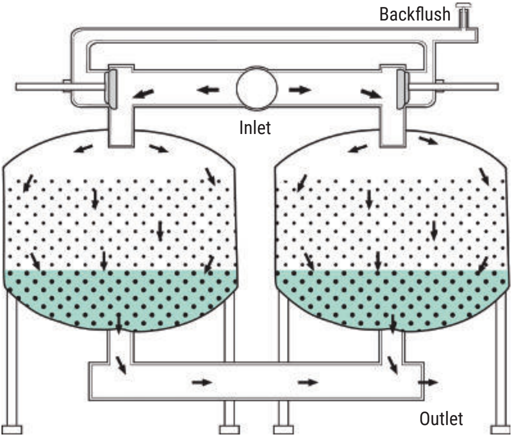


Figure 11. Media filter

Backwashing reverses the flow of water through filters in order to clean them. Screen, disc, and sand media filter systems are all available with automatic backwash capability—cleaning filters on a regular schedule or whenever the pressure drop across the filter reaches a certain level. Automatic backwash systems cost more initially but save maintenance time.

You'll need to design a means to dispose of backwash water. Usually a small-diameter PVC pipeline extending from an outlet below the filters returns backflush water to the canal or holding pond, or conveys it to the field for disposal. Some growers use this water to irrigate windbreaks.

On sand media filters, a throttle valve is usually installed on the flush line to optimize flow. A sock can be used to determine how much media (sand) is leaving during a flush cycle. This should be adjusted so the media just starts to discharge.

Replace filter media when it begins to cake together. Also add media periodically to replace any lost during backwashing.

Flushing Lines

Many small contaminants will pass through filters or precipitate out. Periodically flush lines to remove silt, clay, and other small particles that can join together and clog emitters.

First flush mainlines and submains. Then open the lateral lines and allow them to flush clean. For most tree and vine crop systems, lateral line flushing is done by hand, a few lines at a time. Row crop systems often have their ends plumbed together in flushing manifolds to save time.

Most systems should be flushed about every two weeks. If the lines seem clear, you can probably flush less often. If it takes more than a minute or two to flush the lines clean, you may need to flush more often. Notice what is coming out of the lines. Organic matter may indicate a need for better water treatment. Large amounts of debris can indicate filter failure.

Automatic flush valves may be installed on the ends of your laterals. These are designed to stay open until pressure gets high enough to close them. They work well in some systems but don't always provide a long enough flushing period to completely clear the laterals.

Inspecting Emitters

Microsprinklers are easy to inspect, since even slight clogging will be obvious in the spray pattern. Partly clogged drip emitters are hard to identify without catching and measuring flows to determine discharge rates. (See Chapter 3.) Completely clogged drip emitters should be cleaned or replaced. Most are sealed, however, and can't be taken apart for cleaning.

Preventing and Solving Clogging Problems

! Before injecting any chemical, make sure your system has appropriate check valves, low pressure drain, vacuum relief valve, pressure switch, and interlocking system controls, as well as solenoid valves on chemical injection lines, to prevent backflow and contamination of water supplies. Check with your County Agricultural Commissioner's office to make sure you're in compliance with all federal and state laws. For equipment diagrams and a directory of offices, visit *cdpr.ca.gov.*

Lime Precipitates

Various dissolved minerals in irrigation water precipitate when they're exposed to air and can clog emitters. Groundwater generally causes more precipitation problems than surface water.

Lime (calcium carbonate) is a crusty white precipitate. A drop of muriatic (hydrochloric) acid will cause lime to fizz. To check the hazard of lime clogging, test your water for pH, calcium, and bicarbonate. If calcium and bicarbonate are present at 2.0 milliequivalents per liter (approximately

100 ppm), and pH is 7.5 or more, there's a danger of precipitation. Higher levels of calcium and bicarbonate mean higher risk of precipitation and clogging.

Lime clogging can be prevented, and often remediated, by injecting acid to lower pH to 6 to 6.5. (Measure with pH strips or a pool/spa test kit.) Sulfuric acid is most commonly used. For water with moderate lime risk, injecting acid every two to four weeks may solve the problem. The injection should last through most of the irrigation application.

Many organic growers use vinegar to prevent and remediate lime clogging. See the caution on page 71.

For water with high lime hazard, you may need to inject acid for a couple hours during each irrigation cycle, or even continuously. Drip emitters that are completely clogged with lime require strong treatment. Try injecting enough acid to lower the pH to 5.0. Wait 24 hours and then thoroughly flush the system.

Iron Precipitates

Iron appears as reddish staining. Iron levels of 0.5 ppm or higher pose a risk of iron precipitate clogging. Iron levels of 1 ppm or higher are a particular risk.

Iron precipitate clogging is a more serious problem than lime, and acid injections will not solve it. The accepted prevention is to aerate water by pumping it into a reservoir where the iron is allowed to settle out. Note, however, that holding water in a reservoir increases the chance of biological clogging from algae, slimes, fungi, and aquatic weed seeds and plant parts.

Root Intrusions

Root hairs can grow into orifices, clogging emitters and even growing into tubing. Root clogging is most likely to happen with permanent crops such as trees and vines, and especially in the spring and fall when the irrigation system is not being used. During the irrigation season, daily irrigation creates saturated conditions that discourage root growth. (Celery poses a special risk, however, since its roots thrive in saturated conditions.)

To diagnose possible root intrusions, watch flowmeters closely for a drop in flow rate that signals clogging. To cope with root intrusion, try frequently flushing the laterals with water injected with chlorine (100 ppm). Copper, which binds tightly to soil particles, can be injected through subsurface drip systems in tree crops, forming a copper-impregnated zone surrounding the emitters that's inhospitable to root growth. Drip irrigation products are also available with an herbicide, trifluralin, impregnated in the emitters to prevent root intrusion.

Biological Contaminants

Surface waters often contain algae, bacterial slimes, protozoa, fungi, and many other exotic creatures. Wells may also be contaminated by iron bacteria. All can clog emitters or (worse) grow in pipelines and laterals.

Good filtration, especially with sand media filters, will remove most biological contamination. You may also need to treat your system with a biocide, however—most commonly chlorine. Some trial and error may be required until you find the right treatment. You want to use the smallest possible amount of chemical that will keep your system clean.

> Many organic growers use hydrogen peroxide as a biocide. See the caution on page 71.

Water with moderate biological contamination may require monthly or more frequent treatment with 10-20 ppm free chlorine, measured at the most distant point from the pump. (Use a pool/spa test kit to measure chlorine levels, and make sure the indicator chemicals are fresh.) The injection should last four to six hours or more. A good time to inject is at the end of the irrigation set. Allow the chlorinated water to sit in the system until the start of your next irrigation.

The Microsprinkler Advantage

In some cases, biological contaminants that clog drip emitters may easily pass through microsprinklers because the water moves through orifices at a higher velocity.

Severe biological contamination may require continual low-level chlorine injection: 1-2 ppm chlorine, measured at the point in the system farthest from the pump. Drip emitters that are completely clogged with biological contaminants require strong treatment. Try injecting 50-100 ppm chlorine. Wait 24 hours, then thoroughly flush the system.

Liquid chlorine (sodium hypochlorite) is most commonly used—either household bleach (5.25% available chlorine) or pool chlorine (up to 15% available chlorine). Granular chlorine (calcium hypochlorite), with up to 70% available chlorine, is easier to store than liquids but takes longer to mix. Gas chlorine is 100% available chlorine but poses serious health hazards.

To calculate the correct amount of liquid chlorine, use the following formula:

$$\text{chlorine injection rate (gal/hr)} = \text{system flow rate (gpm)} \times \text{desired chlorine concentration (ppm)} \times 0.006 \div \text{strength of chlorine solution (\%)}$$

Example: System flow rate is 275 gallons per minute.

You want a concentration of 10 ppm free chlorine.

You're using pool chlorine with 15% available chlorine.

275 gpm × 10 ppm × 0.006 ÷ 15 = 1.1 gallons per hour

You need to inject chlorine at 1.1 gallons per hour.

For use in the formula above, 12.8 pounds of calcium hypochlorite mixed in 100 gallons of water will make a one-percent available chlorine solution.

Safety and Common Sense around Chemicals

Mixing and Handling

! It is your responsibility to know and follow the laws and codes governing the use of agricultural chemicals, which may include licensing, fencing, notification and posting, first-aid equipment, leak detectors, alarms, and containment structures. Maintain detailed records of all chemical applications.

! Any failure on the part of your injection system or water-pumping system can cause chemicals to contaminate your water source or spill onto the ground. Your system must include appropriate check valves, low pressure drain, vacuum relief valve, pressure switch, and interlocking system controls, as well as solenoid valves on chemical injection lines, to prevent backflow. See Chapter 9, ***Chemigation***.

! Be especially careful when mixing chemicals. Wear eye protection and gloves. Follow label instructions. Pay special attention to the correct order of mixing. Any carelessness on your part could cause an explosion of caustic chemicals, a release of toxic gases, or a chemical reaction that will clog emitters. See the special precautions for chlorine and acids below.

! Have proper emergency and safety equipment on-site and available, and train all workers in its proper use.

! Use a separate injector for each chemical and each tank. Keep hose connections very clean and avoid disconnecting hoses unless absolutely necessary.

! Discontinue all use of chemicals for a period of time before you backflush the filters. Likewise, do not inject chemicals while backflushing.

! Keep your area neat. A messy workplace encourages sloppy work and makes it difficult to spot leaks.

Protecting Crops and Equipment

! Before injecting any chemical, make sure *all* your system components can handle it.

! To avoid clumping and harmful concentrations, make sure injected chemicals are completely mixed. Generally, injection rates should not exceed 0.1% of the system's flow rate.

! Don't leave fertilizer or chemicals, except chlorine, in the system between irrigations. (An exception, noted above, is leaving acid in the system for 24 hours to treat emitters severely clogged with lime.) Run clean water through the system before and especially after injecting any chemical.

! Know the travel time for chemicals from the injection point until they reach the most distant part of your irrigation system. You can detect the arrival of most fertilizers (although not urea) using a salinity monitor. You can detect the arrival of chlorine using a pool/spa test kit.

Special Precautions for Chlorine

! Chlorine gas is extremely dangerous, and can cause eye and skin burns, lung damage, and even death. Always store chlorine compounds separately in fiberglass or epoxy-coated plastic tanks.

! Hire only qualified professionals to fill chlorine supply tanks, adjust injectors, and fix leaks.

! **Organic growers are not allowed to have residual chlorine levels exceeding the maximum residual disinfectant limit under the Safe Drinking Water Act. This limit is currently 4.0 mg/L (equivalent to 4.0 ppm) for chlorine. Allowed alternatives to chlorine include hydrogen peroxide, alcohols, and soap-based algicide/demisters. Check with your certifying agent for further clarification.**

! Always add chlorine to water, never vice versa.

! Never mix chlorine and acids together, or store them in the same room, since they will form chlorine gas.

! Chlorine may destroy the effectiveness of fertilizers, herbicides, or insectides. Never inject chlorine at the same time as you are injecting these other chemicals.

Special Precautions Related to Acids

! Inject acids downstream from the primary filters. Use a separate small filter if needed. Some authorities recommend injecting acid upstream of the filters, but this increases the risk of damaging the filters or introducing toxic chemicals into filter flush water.

! Acid can damage emitters and other irrigation components, with the greatest corrosion risk at pH below 5.5. The flexible orifice in some pressure-compensating emitters is especially susceptible to damage by acid.

! Organic growers are generally not allowed to use synthetic acids. Many organic growers use vinegar, which contains acetic acid and is allowed if it is from a natural source. Check with your certifying agent for further clarification.

! A nitrogen fertilizer/sulfuric acid mix is safer to handle than straight acid, but over time can change soil pH.

! Before injecting any acid, always test for compatibility—with your irrigation water and with any other chemical being introduced. Mix a small batch in a jar and watch one to two hours for any cloudiness that would indicate precipitation.

! Never use anhydrous ammonia or aqua ammonia in a drip irrigation system or mix them with any kind of acid, as this combination may cause a violent explosion.

! Urea sulfuric acid is incompatible with many substances and should generally not be mixed with anything. Mixing acidified fertilizer with chlorine will produce toxic chlorine gas.

! Always add acid to water, never vice versa.

Some Incompatibilities Related to Chlorine and Acids

Chlorine with acids	Produces toxic chlorine gas. Never store chlorine and acids in the same room.
Chlorine with acidified fertilizer	Produces toxic chlorine gas.
Chlorine with water	Produces toxic chlorine gas. Always add chlorine to water and never vice versa.
Chlorine with water containing iron or manganese	Causes precipitation and clogging.
Chlorine with fertilizers, insecticides, or herbicides	May destroy effectiveness of fertilizers, insecticides, or herbicides.
Anhydrous ammonia or aqua ammonia with any acid	Causes a violent explosion and release of toxic gases.
Acids with irrigation water	Precipitation and clogging. Always add acid to water and never vice versa.
Urea sulfuric acid with anything	Generally should not be mixed with anything; risk of precipitation or toxic gas.
Phosphoric acid with calcium nitrate	Causes severe clogging.

! **The list above is not complete. Many other combinations are incompatible or dangerous.**

Summary of Maintenance Tasks

Check for leaks.	Daily or weekly
Check flowmeters and pressure gauges.	Daily or weekly
Inspect emitters for clogging.	Daily or weekly
Backflush filters.	As needed; variable; can be automated
Inspect media filter; replace sand if caked.	As needed; variable
Flush lateral lines.	About every 2 weeks
Inject acid (moderate lime risk).	Every 2-4 weeks
Inject acid (high lime risk).	During every irrigation
Inject chlorine or other biocide (moderate biological contamination).	Monthly
Inject chlorine or other biocide (severe biological contamination).	During every irrigation
Measure application rate and emission uniformity.	Once or twice per year
Inspect and adjust pressure-regulating valves.	Once or twice per year
Inspect and replace pressure gauges.	Once or twice per year

For Further Reading

Schwankl, L., B. Hanson, and T. Prichard. 2008. **Maintaining Microirrigation Systems**. Publication 21637, University of California Division of Agriculture and Natural Resources.

9. Chemigation

This chapter explains guidelines and precautions for:
- Injecting fertilizer
- Injecting pesticides

Rules and Regulations

The term ***chemigation*** means applying any chemical through an irrigation system. This includes fertilizers, fungicides, herbicides, insecticides, and soil amendments, as well as acids, chlorine, or other chemicals used to prevent clogging. The term ***fertigation*** refers to one kind of chemigation, namely applying fertilizer through an irrigation system.

Pesticides are regulated by the U.S. Environmental Protection Agency and are currently subject to stricter legal requirements than fertilizers or chemicals used to prevent clogging. As a general rule, though, you should take the same basic precautions and use the same backflow prevention equipment regardless of what kind of chemical you're injecting. From a practical, legal, and safety standpoint, it makes no sense to cut corners.

Before injecting any chemical, check with your County Agricultural Commissioner's office to make sure you're in compliance with all federal and state laws. For a directory of offices, visit ***cdpr.ca.gov.***

Note that special restrictions and requirements apply if your irrigation system is connected to a public water supply. Some irrigation districts and other local agencies also have their own regulations, which may be stricter than state or federal law.

Fertigation Guidelines and Precautions

Fertigation is a rapidly-evolving subject, and California's irrigators are at the cutting edge.

Compared to other methods, applying fertilizer through a microirrigation system gives you a great deal of control over soil nutrient levels, opening up new possibilities for precise management. Applications can be lighter and more frequent, fine-tuned to the day-to-day conditions and needs of your crop. You can achieve highly uniform distribution. You generally use less labor and make fewer tractor trips across the field. You use less fertilizer, reducing costs as well as the risk of leaching fertilizer to groundwater.

As you explore these possibilities, expect a learning curve and a continuous process of trial and error. Close monitoring and excellent recordkeeping are a must.

You'll want to have your soils tested at least annually by a commercial laboratory if you're growing row crops. You may also want to have a lab test plant tissue samples several times per year as well as trying the various in-field "quick tests" that have become available for soils and plant sap. (For permanent crops, many horticulturalists and viticulturalists prefer tissue testing over soil testing.) Some sophisticated growers in California conduct a complete fertility analysis weekly or even more often.

Producers who are new to microirrigation often over-apply fertilizer. In general, "spoonfeeding" is recommended for best crop growth. Use frequent light applications instead of occasional heavy applications. Besides promoting best crop growth, low concentrations of fertilizer will also reduce many clogging problems.

Mixing and Handling

The main challenges you'll face have to do with solubility and incompatibility. Incompletely dissolved ingredients will cause clumping, uneven applications, and clogged emitters. Mixing incompatible ingredients can cause dangerous reactions or create insoluble products that will clog your system.

! **Treat all fertilizers with respect as potentially hazardous chemicals. Follow all precautions on pages 70 to 73.**

! **Many fertilizers will damage irrigation equipment or cause clogging. Flush your system thoroughly before and after applying fertilizers, and never leave fertilizer in the system between irrigations. Some authorities recommend injecting fertilizer upstream of the filters to reduce clogging, but this increases the risk of introducing fertilizer into flush water.**

! **Before injecting any fertilizer into your system, perform a jar test. Mix a small batch and watch one to two hours for any cloudiness that would indicate precipitation.**

! **Always fill your mixing container with half to three-quarters of the water you need, before adding dry soluble fertilizer. Add dry ingredients slowly, stirring constantly to prevent lumps.**

! **Most dry nitrogen fertilizers make water cold, reducing solubility. It may take several hours, with constant recirculation, until a solution warms up enough to allow the fertilizer to dissolve completely. Add liquid fertilizer to water (creating some heat) before adding dry, soluble fertilizer.**

Incompatibilities Related to Fertilizers

Urea sulfuric acid with anything	Many incompatibility problems.
Acid or acidified fertilizer with chlorine	Produces toxic chlorine gas.
Phosphate fertilizers with anything	May cause precipitates and clogging.
Two concentrated fertilizer solutions with each other	May cause precipitates and clogging.
A compound containing sulfate with one containing calcium.	Causes gypsum precipitates and clogging
Solution gypsum with irrigation water high in bicarbonate/carbonate	May cause precipitates and clogging.
Fertilizer containing phosphorus (e.g., phosphoric acid) with fertilizer containing calcium (e.g. calcium nitrate)	Causes severe and immediate precipitation and clogging.
Chlorine with fertilizers, insecticides, or herbicides	May destroy the effectiveness of fertilizers, insecticides, or herbicides.
Hard irrigation water with phosphate, neutral polyphosphate, or sulfate compounds	May cause precipitates and clogging.

The list above is not complete. Many other combinations are incompatible or dangerous.

Injecting Pesticides

Insecticides, herbicides, and fungicides have all been applied through microirrigation systems. While nowhere near as common as fertigation in California, these practices are becoming more common, and they have advantages. For example, chemical concentrations are much lower when applied through irrigation water than when applied through aerial applications or ground spraying, and the dangers of overspray and wind drift are greatly reduced. Chemicals can also be applied in smaller doses throughout the season, instead of one heavy dose at the beginning of the season.

! Always follow label instructions. Never use a pesticide unless the label says it can be chemigated. When labels disagree with state codes, follow whichever is more strict.

Precise application, timing, equipment calibration, and safe handling are critical with these chemicals, and any mistake can put your crop at risk – not to mention your health and that of your workers.

The California Department of Pesticide Regulation is responsible for enforcing federal and state laws governing the use of pesticides, with field enforcement carried out by County Agricultural Commissioners and their staffs. For chemigation regulations, reporting and licensing requirements, diagrams of safety devices, and a wide variety of educational materials, visit ***cdpr.ca.gov/docs/emon/grndwtr/chem.htm.***

For Further Reading

Burt, Charles. **Fertigation and Chemigation Basics for California.** 2003. Irrigation Training and Research Center. San Luis Obispo, CA. itrc.org/reports/chemigation/basics.pdf

Burt, C., K. O'Connor, and T. Ruehr. 1995. **Fertigation**. Irrigation Training and Research Center. San Luis Obispo, CA.

Schwankl, L. and T. Prichard. 2001. **Chemigation in Tree and Vine Micro Irrigation Systems.** Publication 21599. University of California Division of Agriculture and Natural Resources.

Zoldoske, D., T. Jacobsen, and E. Norum. 2004. **Grower Training Manual for Backflow Prevention in Chemigation of Pesticides.** Center for Irrigation Technology. Fresno, CA. cdpr.ca.gov/docs/emon/grndwtr/chem.grower-manual.pdf

10. Salinity

This chapter explains:

- Causes of salinity
- How drip irrigation affects salinity patterns
- Salinity coping strategies

Microirrigation generally causes less salinity problems than conventional sprinkler and surface irrigation, for three main reasons: (1) More continuously wet soil keeps salts diluted; (2) Salts move to the outer edges of the wetted soil area, away from the roots; (3) Salts have little or no chance of being absorbed through the leaves.

However, salt accumulation can still be a problem, mainly since light water applications typical of microirrigation are often inadequate to flush salts below the root zone.

Salinity Basics

When exposed to water, salts break down into negative ions (such as chloride, boron, nitrate, and sulfate) and positive ions (such as calcium, magnesium, and sodium).

Sodium, chloride, and boron are essential nutrients at low concentrations but can be toxic to plants at higher concentrations. Soils high in sodium, magnesium, carbonate, or bicarbonate often have poor tilth and slow water intake rates.

Salt buildup often begins with dissolving of salts from fertilizers, manure decomposition, or weathering of soils that are naturally high in salts. Under arid conditions, high temperatures and wind evaporate water from the soil surface. Capillary forces draw water up through the soil, and plants take up water through their roots, leaving behind dissolved salts in the soil. Shallow saline groundwater can also move upward, and salt is also often imported with water supplies.

Salt accumulation decreases yields by interfering with the ability of plants to take up water. Plants differ a great deal in their sensitivity to salts, but most are vulnerable during germination or emergence and most seedlings are highly sensitive. Salinity levels that reduce bean yields 50 percent will leave wheat, barley, and sugar beet yields unaffected. Avocados are highly sensitive to salt.

Salinity Patterns under Drip Irrigation

Salt is carried by water and deposited in areas where water stops moving, such as the edges of wetted areas. Over time, salt concentrations at the edges of the wetted area around an emitter can become extremely high.

In surface drip systems, salinity is generally lowest directly beneath each emitter, since water leaches excess salts downward. As you move horizontally away from the emitter, salinity increases, often reaching its highest point halfway between emitters. Little or no salt leaching takes place in these areas.

In salt-affected soils, the placement of emitters in relation to plants can be critical. In general, placing emitters closer to plants reduces salinity problems since the wetted area extends further away from the plant.

For buried drip systems, the situation is different. Salinity is generally low beneath and around the emitters, but there's little leaching above the emitters, causing salinity levels to be high near the surface. Rainfall can cause high concentrations of salt to leach downward into the root zone. Lack of rainfall can also leave salts in the seed bed for subsequent row crops.

Coping Strategies

To address salinity issues you first need to identify the cause of the problem. If a high water table is moving salts upwards into the root zone, you may be able to install soil drainage that lowers the water table. If high temperatures are evaporating salt-laden irrigation water from a bare soil surface, you can try mulching or leaving crop residues on the soil surface to reduce evaporation.

Generally, though, the only solution is to apply water in excess of field capacity, leaching salts downward through the soil profile and below the root zone. For this to work, the soil must have good internal drainage, and you'll very likely need to repeat the process on a regular basis.

The percentage of applied water that drains below the root zone is known as the ***leaching fraction***. Charts and tables are available to assist you in calculating the leaching fraction needed to keep salinity within acceptable levels for your crop.

Microirrigation systems often can't apply enough water for effective leaching. You may need to use an alternative sprinkler or surface irrigation system (such as hand move sprinklers in vegetables and row crops) for leaching. Alternative irrigation systems used to germinate crops can serve the dual purpose of salinity management.

Other Coping Techniques

- Space emitters close together and install laterals in each row to reduce salt accumulation and damage.
- Light, frequent irrigations sometimes reduce the upward movement of saline groundwater into the root zone.
- Keep soils wetter than usual to reduce competition between plant roots and salts for available water.
- If you're depending on rainfall for leaching, run your drip system during rainfall for greater effectiveness. Running a buried drip system during rainfall can also dilute salt that's leaching down into the root zone.

- Plant seeds on the ***edges*** of raised beds to reduce their exposure to salt, which tends to accumulate in the slightly lower center of a raised bed.
- Alternatively, build up the bed and run your irrigation system just before planting, to move salts to the top and center of the bed. Then remove or knock down the top of the bed, along with accumulated salts.
- Plant crops that are less sensitive to salinity. You may also be able to grow plants that will take up and accumulate negative ions such as chloride and boron.
- Monitor salinity to know when you're approaching salinity thresholds for your crops.
- If high sodium, carbonate, or bicarbonate levels are reducing permeability and intake rates, acidify water to reduce carbonate and bicarbonate levels, while at the same time injecting gypsum to increase calcium levels.

! Gypsum can plug emitters and can also cause abrasion and damage to microsprinkler nozzles. Use very pure and finely ground gypsum and always perform a jar test to check for solubility before injecting gypsum.

For Further Reading

Burt, Charles and Stuart Styles. 2007. **Drip and Micro Irrigation Design and Management for Trees, Vines, and Field Crops**. Irrigation Training and Research Center. San Luis Obispo, CA. See Chapter 5, "Salinity for Drip/Micro."

Rodriguez, Omar and Rex Dufour. 2020. **Saline and Sodic Soils: Identification, Mitigation, and Management Considerations**. ATTRA publication IP 602. attra.ncat.org/publication/saline-and-sodic-soils-identification-mitigation-and-management-considerations

11. Resources for California Irrigators

Federal Agencies

USDA/Natural Resources Conservation Service (NRCS)

Within the U.S. Department of Agriculture (USDA), NRCS works with private landowners to help them protect their natural resources, offering conservation programs, technical, and financial assistance through over 60 USDA offices in California.

California NRCS offers:

- Technical assistance with designing and improving irrigation systems
- Conservation measures to reduce runoff and sediment and protect water quality
- Soil survey information
- Soil salinity prevention and drainage reduction
- Nutrient water management planning and technical assistance
- Financial and technical assistance through a wide variety of programs aimed at protecting environmental quality, wetlands, wildlife habitat, and watersheds

Check the phone book for the USDA/NRCS Field Office closest to you. Or visit **ca.nrcs.usda.gov**.

The U.S. Bureau of Reclamation (Reclamation)

Reclamation's **Central Valley Project** includes 20 dams and reservoirs, 11 power plants, and 500 miles of major canals. These deliver about 5 million acre-feet of water to irrigation and water districts for agricultural use, supplying the water for approximately one-third of the agricultural land in California.

Reclamation has the responsibility, in partnership with water users, states, and other interested parties, to help improve water resource management and water use efficiency in the western United States. Reclamation's water conservation office can assist growers through the grower's irrigation district.

Reclamation administers several water conservation grant and technical assistance programs that provide funding to irrigation and water districts or universities for water management improvements and education/training. Of special interest to irrigators is the WaterSMART grant program: **usbr.gov/watersmart**

Reclamation's projects in northern California generally fall within the **Mid-Pacific Region,** which has Area Offices at Folsom (near Sacramento), Fresno, Willows, and Shasta Lake. There are also Area Offices at Klamath Falls, Oregon, and Carson City, Nevada.

Reclamation's Mid-Pacific Water Conservation Program is headquartered in the Regional Office in Sacramento.
Phone: **(916) 978-5200** Website: **usbr.gov/mp**

Reclamation's **Lower Colorado Region** covers much of southern California, including Imperial, Coachella Valley, and Palo Verde Irrigation Districts. There's a Southern California Area Office in Temecula, as well as Area Offices in Nevada and Arizona.

The Lower Colorado Water Conservation Program is headquartered in the Regional Office in Boulder City, Nevada.
Phone: **(702) 293-8186** Website: **usbr.gov/lc**

The USDA Agricultural Research Service (ARS)
ARS has a Water Management Research Laboratory in Parlier, southeast of Fresno, and an Experimental Station in Shafter, Kern County. ARS research helped advance the use of subsurface drip irrigation in California: reducing the application of fertilizers and increasing yield and quality in several row crops and vegetables.
Phone: **(559) 596-2999**
Website: **ars.usda.gov/main/site_main.htm?modecode=53-02-00-00**

State Agencies

The Department of Water Resources (DWR) operates the State Water Project (SWP), delivering water to the East Bay, Southern San Joaquin Valley, San Luis Obispo and Santa Barbara Counties, as well as Southern California. DWR promotes water use efficiency, including water recycling, water conservation, groundwater recharge/water banking, water transfers, and water marketing.
Phone: **(916) 653-6192** Website: **water.ca.gov**

Two (among many) programs of special interest to irrigators:

- DWR's **California Irrigation Management Information System (CIMIS)** provides ET data to agricultural and landscape water users. Website: **cimis.water.ca.gov**
- DWR offers many tools and services in support of California's Sustainable Groundwater Management Act (SGMA), including a **Sustainable Groundwater Planning Grant Program**. **water.ca.gov/programs/groundwater-management/sgma-groundwater-management**

The State Water Resources Control Board and nine Regional Boards regulate water quality in California and ensure its proper allocation and efficient use. The State Water Board has four major programs: Water Quality, Financial Assistance, Water Rights, and Enforcement. The Financial Assistance Program administers loans and grants including:

- The Agricultural Drainage Loan Program
- The Agricultural Drainage Management Loan Program
- The Agricultural Water Quality Grant Program

Phone: **(916) 341-5700** Website: **waterboards.ca.gov**

The **California Department of Food and Agriculture** offers a variety of services and funding programs for irrigators through its **Office of Environmental Farming & Innovation**, including a **Healthy Soils Program** that provides financial assistance for implementing practices that improve soil health and a **State Water Efficiency & Enhancement Program (SWEEP)** that provides grants to "implement irrigation systems that reduce greenhouse gases and save water on California agricultural operations." Website: **cdfa.ca.gov/oefi**

Nonprofit Organizations

California Association of Resource Conservation Districts
Each Resource Conservation District (RCD) has a board of directors made up of landowners in that district. RCDs address a wide variety of conservation issues, such as forest management, water and air quality, wildlife habitat, and soil erosion control. The California Department of Conservation and NRCS provide training and support, as well as a watershed grant program for districts.
Phone: **(916) 457-7904** Website: **carcd.org**

Several RCDs conduct **Irrigation Mobile Laboratory** programs. Professional Mobile Lab staff conduct intensive evaluations that give you detailed feedback on your irrigation system efficiency and management practices. NRCS provides technical assistance and other support to the Mobile Labs in Tehama, Yolo, and Kern counties. In the Central California Coast and in Southern California, Mobile Lab programs are run by the Cachuma RCD (in Santa Maria), the Riverside-Corona RCD (in Riverside), and the Coachella Valley RCD (in Indio).

Universities

University of California Cooperative Extension
The outreach arm of the University of California's **Division of Agriculture and Natural Resources (ANR)**, UC Cooperative Extension conducts irrigation research and education and coordinates a network of farm advisors in more than 50 county offices. Call your local farm advisor for irrigation information and help solving specific problems.

For information about UC programs related to agriculture and natural resources, and a directory of county offices, visit **ucanr.edu**.

You can purchase UC Extension publications cited in this book, and many others, from **anrcatalog.ucanr.edu** or by calling **(800) 994-8849**.

Of special interest to irrigators:

- The UC Extension **CropManage website** provides real-time recommendations for efficient irrigation and fertilizer applications. **cropmanage.ucanr.edu**
- A **Drought Management site** offers irrigation strategies for many crops: **ucmanagedrought.ucdavis.edu/Agriculture/Crop_Irrigation_Strategies**

The Irrigation Training and Research Center (ITRC) at the California Polytechnic State University in San Luis Obispo conducts research, manages a state-of-the-art hydraulic/irrigation laboratory, and provides technical assistance to producers, under contract with local organizations.

ITRC also provides training through dozens of short courses each year on irrigation system design, evaluation, and management. ITRC's website offers a complete list of classes offered, as well as books, videos, software programs, and an extensive collection of papers, databases, and evaluation tools.
Phone: **(805) 756-2434** Website: **itrc.org**

The Center for Irrigation Technology (CIT), within California State University, Fresno, offers equipment testing, seminars, workshops, publications, software, news announcements, and more.
Phone: **(559) 278-2066** Website: **jcast.fresnostate.edu/cit**

CIT manages the **Advanced Pumping Efficiency Program,** using the Public Purpose Programs Fund under the auspices of the California Public Utilities Commission. This program provides education, technical assistance, pump efficiency tests, rebates for pump repairs, and incentives for system retrofits.
Phone: **(800) 845-6038**
Website: **jcast.fresnostate.edu/pumpefficiency**

CIT also manages the **Wateright** website, a "multi-function, educational resource for irrigation water management" that includes a wide variety of publications, tutorials, references, news, and events. Website: **wateright.org**

Utilities

Many California utilities and rural electric cooperatives offer excellent programs to their irrigation customers. For example:

Pacific Gas and Electric Company offers pump testing through the Advanced Pumping Efficiency Program (described above), as well as a wide variety of rebates and incentives. Phone PG&E's Agricultural Customer Service Center: **(877) 311-3276**. Or visit: **pge.com/ag**

Southern California Edison offers incentives, free pump testing, and fee-based predictive maintenance services to its irrigation customers, along with many other technical services.
Phone: **(800) 655-4555**
Website: **sce.com/business/ems/agriculture**

Irrigation Consultants

Irrigation consultants can be an excellent source of irrigation scheduling services, system evaluations, pump testing, and other technical services. For a list of irrigation consultants, visit **cimis.water.ca.gov/Resources.aspx**

Glossary

Acidification: Adding acid to a microirrigation system to lower water pH and prevent or remediate clogging caused by chemical precipitation.

Acre-foot: The volume of water required to cover one acre of land to a depth of one foot (325,851 gallons).

Acre-inch: The volume of water required to cover one acre of land to a depth of one inch (27,154 gallons).

Application efficiency: The amount of water **beneficially used** by the crop divided by the total amount of water applied. Also sometimes called **irrigation efficiency**.

Atmometer: A simple tool for estimating evapotranspiration, using a flat, porous ceramic disk that draws up water as evaporation dries the surface of the disk. Also known as an **evaporimeter** or **ET gauge**.

Available water capacity (sometimes called **plant-available water** and similar names): The amount of water a soil can make available to plants, the difference between the amount of water stored at **field capacity** and the amount stored at the **permanent wilting point**.

Backwashing: Cleaning filters by reversing the flow of water or discharging water over the filter screen.

Basin bubbler: An emitter that discharges water in a small fountain.

Beneficial uses of water: Uses of water necessary for the survival and well being of humans, plants, and wildlife. In California water law, these include not just irrigation but also using water to flush salts or protect plants from freezing.

Capacitance sensor: A type of dielectric sensor, also known as a **frequency domain reflectometry (FDR)** sensor.

Capillary water: Water held in soil by capillary forces—the molecular attraction between water and soil particles.

Centibar: Measure of pressure equal to 1/100th of a bar, where a bar is roughly one atmosphere of pressure or 14.5 pounds per square inch.

Chemigation: Applying chemicals through an irrigation system, such as fertilizers, fungicides, herbicides, insecticides, or soil amendments.

Chemigation valve: A mechanical device designed to prevent backflow of contaminated water into source water.

Chlorination: Adding chlorine to an irrigation system to prevent or remediate clogging by biological organisms.

CIMIS: The California Irrigation Management Information System, a state program that includes a computerized network of over 200 automated weather stations.

Coarse-textured soil: Soil with a high percentage of sand.

Coefficient of variation: A measure of manufacturing inconsistencies among emitters.

Crop coefficient: A number that's multiplied by a **reference ET** to give ET for a particular crop and stage.

Data logger: A device used for automatically recording and/or transmitting data from one or more sensors.

Deep percolation: The draining of irrigation water below the root zone where it is no longer available to the crop.

Deficit irrigation: Intentional underwatering: irrigating with amounts of water that do not fully replace ET. Also known as **RDI**: **regulated deficit irrigation.**

Dielectric sensor: A soil moisture sensor that measures the charge-storing capacity of soil: its tendency to become electrically polarized when exposed to an electric field.

Drip emitter: An emitter that drips water from a single point at a low rate, generally one-half to four gallons per hour.

Drip tape: A thin-walled type of line-source emitter that's sold flat on a reel and inflates when filled with water.

Drip tubing: A thicker-walled type of line-source emitter, with a round profile.

Electrical resistance sensor: A soil moisture sensor that works by running an electric current through electrodes implanted in the sensor, measuring electrical resistance.

Emission uniformity: A measure of how uniformly water is applied over a field, often defined as the average flow of the lowest 25 percent of all emitters measured divided by the average flow of all emitters measured. A related term, **distribution uniformity (DU)**, is sometimes preferred.

Field capacity: The soil moisture condition where gravitational water has fully drained and only capillary water remains—generally the upper limit of good irrigation management since additional water will drain away and be unavailable to plants.

Fine-textured soil: Soil with a high percentage of clay.

Freqency domain reflectometry (FDR) sensor: A type of dielectric sensor that measures charge-storing capacity by pulsing electromagnetic waves into soil and measuring the difference in frequency between output and return waves.

Granular matrix sensor: A common type of electrical resistance sensor.

Gypsum block: A common type of electrical resistance sensor.

Hand-push probe: A simple, low-cost tool that is used to determine the approximate depth of wetted soil.

Iron precipitate: A common cause of microirrigation system clogging which appears as reddish staining.

Lateral lines (or **laterals**): The lengths of tubing or tape that supply water to emitters from mainlines and submains.

Leaching: Applying irrigation water in excess of plant requirements and soil water-holding capacity in order to remove salts from the root zone through deep percolation.

Leaching fraction: The fraction or percentage of applied irrigation water that percolates below the root zone. Leaching fraction recommendations specify how much "extra" water is needed to maintain acceptable levels of salt in the soil.

Lime precipitate: A common cause of microirrigation system clogging (calcium carbonate) which appears as a crusty white precipitate.

Line-source emitter: A type of emitter consisting of drip tape or tubing with emission points at regular intervals. Also called **dripline**, **dripperline**, and many other names.

Long-path emitter: Emitter that forces water through long, circuitous passageways, using wall friction to reduce pressure.

Mainlines and submains: The water delivery pipelines that supply water from the control head to the lateral lines.

Manifolds: The pipelines farthest from pump, to which the laterals are attached.

Media filter: A filter that passes water through sand to remove suspended solids.

Microirrigation system: An irrigation system that delivers water through a system of tubing and low-volume devices such as drippers, bubblers, drip tapes, or microsprinklers. Also called **drip, trickle,** or **low-volume irrigation**.

Microsprinkler (also called **minisprinkler, mini-spray, micro-spray, jet, spinner,** and similar names): An emitter that discharges a mist or spray from a small head.

Mobile Irrigation Lab: a free service offering on-site evaluations of irrigation systems to improve their efficiency.

Neutron probe: A device for measuring soil moisture using a radioactive source.

OpenET: A satellite-based service offering free evapotranspiration estimates for the western United States.

Orifice emitter: A type of emitter that discharges water through a narrow passageway or orifice.

Pan coefficient: A number that's multiplied times the amount of evaporation from a pan to yield a reference ET.

Permanent wilting point: The soil moisture condition where plants can no longer extract the tightly held films of capillary water from soil at a rate fast enough to recover from wilting.

pH: A measure of acidity or alkalinity. A pH of 7.0 is neutral, less than 7.0 is acidic, and greater than 7.0 is alkaline.

Pitot tube: A device for measuring the velocity of flowing water, inserted directly into a pipeline.

Point-source emitter: An emitter that discharges water from a single point, as opposed to tapes or tubing that discharge water from multiple points.

Pressure chamber: An airtight chamber with adjustable pressure, used for measuring **stem water potential**.

Pressure-compensating emitter: An emitter that delivers a near-constant flow of water over a range of operating pressures. Drip emitters, line source emitters, and micro-sprinklers are available in pressure-compensating designs.

Propeller flowmeter: A device for measuring flow rates in pipelines, consisting of a propeller linked to a flow indicator.

Reference ET: The ET of a standardized and well-studied reference crop, used as a basis for calculating the ET for other crops. In California's CIMIS program, the reference ET is the ET of "well-watered, actively growing, closely clipped grass that's completely shading the soil."

Resistance block: A device made of gypsum or granular material that measures the electrical resistance (conductivity) of current between two electrodes as an indication of soil moisture.

Saline soils: Soils in which salt concentration in the crop root zone is too high for optimum plant growth.

Saturation: The soil moisture condition where pore spaces between soil particles are completely filled with water. Saturated soil is generally too wet for good plant growth, starving plant roots and soil microorganisms of oxygen.

SDI: A common abbreviation for *subsurface drip irrigation*.

Sodic soils: Soils with a high concentration of sodium.

Soil aggregate: Small clump of soil particles held together by biological secretions and glues (such as glomalin) that helps soil maintain stability and resist erosion. Aggregate stability is an excellent indicator of **soil health**.

Soil health: The continued capacity of soil to function as a vital living ecosystem that sustains plants, animals, and humans. Preserving and improving soil health should be a high priority for all irrigators.

Soil texture: A soil description or classification based on the percentages of clay, silt, and sand.

Soil type (or **soil series**): A soil classification based mainly on soil-building factors such as geology, chemistry, and location.

Soil water tension (sometimes called soil-water **potential**, **matric** potential, or similar names): The amount of energy holding water to soil particles, which can also be viewed as the work plants need to do to extract water and transport it through soil.

Stem water tension (sometimes called stem water **potential**): The stretching or pulling force exerted on water as it moves upwards from the roots through plant tissues.

Surface runoff: Water flowing off the surface of irrigated fields, most commonly at the low end of the field.

Tension: A stretching or pulling force.

Tensiometer: A device for measuring soil water tension consisting of an airtight water-filled tube with a porous ceramic tip and a vacuum gauge.

Time domain reflectometry (TDR) sensor: A type of dielectric sensor that that measures the charge-storing capacity of soil by measuring the travel time of a reflected electrical wave sent along two parallel rods or stiff wires.

Turbulent flow emitter: An emitter that forces water through a crooked or "tortuous" path, creating turbulence that reduces pressure.

Xylem: Cells in plant stems that function as pipes carrying water from the roots to the leaves. Water in xylem is under **stem water tension**.