12 Irrigation Scheduling and Tree Stress

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Introduction

Prune trees, like all other crop plants, require substantial amounts of water each season to grow and to produce a crop. Most of the water used by a prune tree is lost by evaporation from the leaves to the atmosphere; hence, the demand for water is largely determined by weather conditions such as sunlight intensity, air temperature, humidity, and wind speed. Essentially all of the water used by a prune tree is supplied by water stored in the soil following irrigation or rainfall. The quantity of water that is available to the tree is determined by the depth of soil occupied by the root system and soil physical properties such as sand, silt, and clay content, soil compaction, and so on. The atmospheric demand and the soil water supply determine what is called the water balance of the tree. One approach to irrigation management in prune orchards is to use this water balance to determine the frequency and amount of irrigation over the season. In this approach, the atmospheric water demand for the orchard as a whole is referred to as crop evapotranspiration (ET_c).

This chapter is divided into three sections. The first section is devoted to an explanation of ET_c and how it is used for irrigation management in prune orchards. The second section describes the soil factors that are important in determining the supply side of the water balance approach and how these factors may impact irrigation management. The third section describes the physiology of water stress in prune trees and how water stress is measured with the pressure chamber technique. This technique is important for the practice known as regulated deficit irrigation (RDI), in which mild to moderate tree water stress is used as a management tool to reduce fruit moisture content and increase fruit soluble solids, both of which are economically beneficial to prune production.

Using Evapotranspiration Estimates to Schedule Irrigations

Knowing the pattern of water use of a prune orchard over the season is important in developing a successful irrigation schedule. The water use of orchard crops can be estimated by combining evapotranspiration reference values (ET_o) derived from climatic data with a site-specific measure of crop development called the crop coefficient (K_c). Historical ET_o averages for an area can be used to predict crop water use over the season. Real-time ET_o (current season) daily values can be used to refine the historical ET_o estimates and determine current-year water requirements.

Evapotranspiration (ET)

Evapotranspiration consists of two components: evaporation and transpiration. Evaporation is water evaporated from the soil surface. Transpiration is water evaporated from plant leaves. The two terms are combined into one term because it is difficult to measure the two components separately. In the spring, as leaves expand and the area shaded by the tree canopy increases, evaporation from the soil surface decreases and transpiration from leaf surfaces increases. During and after an irrigation event, evaporation is higher until the soil surface dries over a few days time.

Transpiration is water evaporating from plant leaves mainly through pores in the leaf called stomata. The rate of transpiration depends on the solar energy available for evaporating the leaf water, the movement of the air around the plant, and the relative dryness of the air. About 95% of the water taken up by plants is transpired. Transpiration is a necessary consequence of the need for plants to take up carbon dioxide in photosynthesis, but transpiration also cools the leaves, and the flow of transpiration water facilitates the transport of many nutrients from the roots to the leaf.

Solar radiation is the primary source of energy for evapotranspiration. Increased solar radiation increases the potential evapotranspiration. The amount of solar radiation depends on the time of day, time of year, latitude, and cloud cover. Maximum radiation in California occurs in June. Although solar radiation provides the energy needed for evapotranspiration, the evaporated water or water vapor must also flow away from the leaf and soil surface for evapotranspiration to occur. The rate at which water vapor flows away from a leaf depends on the water vapor content of the surrounding air and the air turbulence. The water vapor content of the surrounding air depends on temperature and humidity. High temperatures mean increased potential for transpiration. High humidity means that the potential for transpiration is less. The rate at which water vapor flows is also affected by turbulence caused by eddies and wind. Turbulent air transports water away from the leaves into the atmosphere. This is the reason leaves on even well-watered trees can show some wilting on very hot, dry, windy days, as the evaporated water is being pulled away from the leaves very rapidly. Day length and canopy size (measured as orchard floor shading at noon) also determine the water use. Maximum day length occurs in late June. Maximum crop water use is achieved when 60 to 70% of the orchard floor is shaded, measured at midday.

Estimating crop water use from climate data

Climate data such as net solar radiation, temperature, humidity, and wind speed are commonly used to calculate a reference crop evapotranspiration (ET_o). The reference crop evapotranspiration is that of an adequately irrigated grass crop clipped to 3 to 6 inches, completely covering the soil and not water deficient. The reference crop provides a standard measure of evapotranspiration that can be determined easily at various locations using climate data. The evapotranspiration for a particular crop is then calculated from:

$$ET_c = K_c \times ET_o$$

where
ET_c = crop evapotranspiration
K_c = crop coefficient
ET_o = evapotranspiration of the reference crop

Crop coefficients relate crop evapotranspiration to the reference crop evapotranspiration. The value of the crop coefficient depends on crop type, and stage of growth. Crop coefficients are simply the ratio of actual measured crop ET_c to ET_o. Crop coefficients

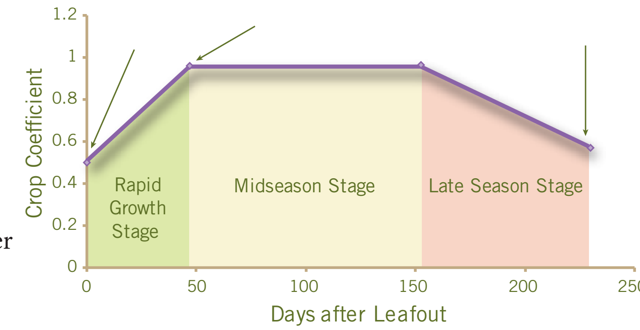

Figure 12.1 Crop coefficients for a mature prune orchard over the growing season, from leaf-out to leaf drop.

for a mature prune orchard over one growing season are shown in figure 12.1.

Prune water use begins at leafout and rapidly increases as the canopy develops until approximately 62% of ground shading. The maximum canopy coincides with an increase in evaporative demand as days lengthen and air temperatures increase. The canopy in mature orchards is fully developed by mid April. Peak water use occurs in June and July. As the leaves become less functional the K_c declines toward leaf drop, where K_c for the orchard becomes 0 if there is no cover crop. Water use may be 20% greater (not to exceed K_c = 1.15) with an actively growing cover crop or if substantial weed cover is present. Table 12.1 contains numerical K_c values for prunes in 2-week time periods over the season.

Table 12.1. Numerical crop coefficients (K_c) for prunes in 2-week periods

Period	K_c
Mar 16–31	0.45
Apr 1–15	0.62
Apr 16–30	0.84
May 1–15	0.96
May 16–31	0.96
June 1–15	0.96
June 16–30	0.96
July 1–15	0.96
July 16–31	0.96
Aug 1–15	0.95
Aug 16–31	0.92
Sep 1–15	0.84
Sep 16–30	0.78
Oct 1–15	0.69
Oct 16–31	0.57

Availability of ET_o information

Evapotranspiration information is often available in two forms: historical ET information and real-time weather data. Historical ET_o information is the crop water use estimated from long-term averages. For any particular day, the actual ET_o may vary from the historical average, but it has been found that the actual variability of weekly May to September reference crop evapotranspiration from year to year is small. Thus, differences between historical (average) ET_o values based on many years of data and actual values for any given year are small. Table 12.2 shows historical ET_o from three prune-growing areas of the state assembled from more than 20 years of individual CIMIS station data. The sample irrigation worksheet in table 12.3 combines the ET_o and K_c for a 2-week period for prunes each month in Tehama County, California. The product of ET_o and K_c is the ETc for each period, totaling 41.83 inches of total water requirement.

Real-time ET estimates are available to most growers in California. Real-time ET_o is determined by collecting weather data and estimating ET_o. California uses the CIMIS (California Irrigation Management Information System) network of more than 100 active weather stations to collect the data and then estimate the ET_o almost anywhere in the state. This information is readily available from a number of sources. Two good Web-based sources are the UC Statewide Integrated Pest Management Web site, http://www.ipm.ucdavis.edu, and the California Department of Water Resources' CIMIS Web site, http://www.cimis.water.ca.gov. The pasture grass ET_o must then be converted to the ET_c of the crop by using a crop coefficient.

Scheduling irrigations using crop water use estimates, rainfall, and soil moisture use

Full-potential water use (ET_c) represents water demand, and this demand must be met by the water supply:

Total water supply = Effective rainfall + Soil moisture contribution + Net irrigation

For water supply, the stored soil moisture and effective rainfall are important factors in addition to irrigation, and each must be considered to construct an effective and efficient irrigation schedule.

The amount of soil moisture can be quantitatively determined using soil moisture measuring devices, as discussed later in this chapter. The two times when measurement is most critical to an irrigation schedule are at leafout and at the driest point (usually after harvest and just before postharvest irrigation). Failure to irrigate prune trees after harvest can yield small

Table 12.2. Historical biweekly ET_o during prune season

Period	Gerber CIMIS Station 8, Tehama County	Nicolaus CIMIS Station 30, Sutter County	Clovis CIMIS Station 39, Fresno County
3/16–31	2.15	2.03	2.05
4/1–15	2.38	2.28	2.45
4/16–30	2.69	2.64	2.82
5/1–15	3.22	3.01	3.32
5/16–31	3.77	3.51	3.91
6/1–15	4.05	3.65	4.05
6/16–30	4.20	3.93	4.23
7/1–15	4.28	3.95	4.32
7/16–31	4.26	3.96	4.42
8/1–15	3.80	3.53	3.93
8/16–31	3.70	3.43	3.82
9/1–15	3.06	2.81	3.10
9/16–30	2.72	2.33	2.50
10/1–15	2.30	1.95	2.07
10/16–31	1.75	1.53	1.57
Total	48.33	44.54	48.56

Table 12.3 Sample irrigation scheduling worksheet showing potential water use

Prune ET_o Historical from Gerber CIMIS Station # 8, Tehama County
Assumptions:
1. Leaf-out 3/15
2. Leaf-drop 10/15

Date	A = Historical ET_o (in/period)	B = Crop coefficient* (K_c)	C = A × B: Potential water use (in)
3/16–31	2.15	0.45	0.97
4/1–15	2.38	0.62	1.48
4/16–30	2.69	0.84	2.26
5/1–15	3.22	0.96	3.09
5/16–31	3.77	0.96	3.62
6/1–15	4.05	0.96	3.89
6/16–30	4.20	0.96	4.03
7/1–15	4.28	0.96	4.11
7/16–31	4.26	0.96	4.09
8/1–15	3.80	0.95	3.61
8/16–31	3.70	0.92	3.40
9/1–15	3.06	0.84	2.57
9/16–30	2.72	0.78	2.12
10/1–15	2.30	0.69	1.59
10/16–31	1.75	0.57	1.00
Total			41.83

Note: *Crop coefficient is based on a midsummer minimum of 62% land surface shaded at midday.

fruit buds for the following year. The amount of stored water for a given soil is calculated as the available water-holding capacity (AWHC) times the depth of rooting, or more simply as the root zone available water. Nonstressed ET_c equals the effective rainfall plus stored soil water depletion until about 50% of the root zone available water is extracted. Scheduling should begin at leafout. If effective rainfall exceeds ET_c during the spring, the appropriate time to measure root zone moisture would be when the effective rainfall does not exceed ET_c. Irrigation should be scheduled to begin at that point. The sample irrigation scheduling worksheet in table 12.4 shows a water balance that slowly uses the stored soil water over the season. This schedule minimizes the leaching of nitrogen fertilizers, avoids stress on the tree, and leaves a drier root zone at the end of the season that can efficiently store winter rain water.

It is difficult at best to determine the effective rainfall portion of the total rainfall. During spring rains, about 50 to 70% of the total rainfall enters the soil to become effectively used by the orchard. Another rule of thumb is to sum the rainfall for a single event, however long that may be, subtract 0.25 inches (a common amount that just evaporates from wet soil), then take 80% of the remainder as effective rainfall.

In accounting for crop use of soil moisture when no irrigation or effective rainfall takes place during an irrigation period, the moisture extracted would equal the ET_c. Likewise, effective rainfall would decrease the soil moisture extraction. Examples of both these instances are shown in table 12.4, which uses the calculated ET_c from table 12.3 and adds the soil contribution and effective rainfall to yield the net irrigation requirement.

The net irrigation requirement is the amount that all portions of the field must receive to sustain full potential water use. Unfortunately, no irrigation system is 100% efficient, even microirrigation systems (see chapter 11, “Irrigation Systems”). The sample irrigation worksheet in table 12.5\ uses a double-line drip system that has a distribution uniformity of 92%. Since the system is operated with no runoff and no deep percolation losses and evaporation is at a minimum, the distribution uniformity equals the irrigation efficiency. The gross irrigation volume must be increased to account for the remaining 8% nonuniformity, to ensure that even the driest parts of the field receive the minimum amount of water to supply ET_c (the net requirement calculated in table 12.4). This final total is the gross irrigation requirement.

Table 12.4. Sample irrigation scheduling worksheet showing water balance over a season
Prune ET_o Historical from Gerber CIMIS Station # 8 Tehama County
Assumptions:
1. Leaf-out 3/15
2. Leaf-drop 10/15
3. Harvest 9/1–9/15
4. Root zone extracted soil moisture from 4/15 to leaf drop = 4.8 in

Date	C = A ´ B: Potential water use (in)	E = Soil contribution (in)	F = Effective rainfall* (in)	G = (C–E–F): Net irrigation requirement (in)
3/16–31	0.97	0	1	–0.03
4/1–15	1.48	0	1.75	–0.27
4/16–30	2.26	1.0	1.5	0.26
5/1–15	3.09	1.4	0.0	1.19
5/16–31	3.62	0.3	0.5	2.82
6/1–15	3.89	0.3	0	3.59
6/16–30	4.03	0.3	0	3.73
7/1–15	4.11	0.3	0	3.81
7/16–31	4.09	0.3	0	3.79
8/1–15	3.61	0.3	0	3.31
8/16–31	3.40	0.3	0	3.10
9/1–15	2.57	0.3	0	2.27
9/16–30	2.12	0.0	0	2.12
10/1–15	1.59	0.0	0	1.59
10/16–31	1.00	0.0	0	1.00
Total	41.83	4.80	4.75	32.28

Note: *Effective rainfall is calculated from actual rainfall.

Table 12.5 continues with a simple calculation that yields the duration of operation to meet the gross irrigation for the period. Required inputs include the tree spacing and irrigation application per tree.

Using real-time evapotranspiration to schedule irrigations

It is possible to more accurately estimate tree crop evapotranspiration using real-time evapotranspiration data provided by systems such as CIMIS. All that is necessary is to substitute real time ET_o data into the ET_o column in table 12.3 when the data are available. Using this method, one can schedule forward in time using historical ET_o, then enter the real-time data to refine the irrigation schedule. If the historical ET_o underestimated real time ET_o, the irrigation time on the next irrigation can be increased to match the difference. If the historical ET_o was an overestimate, irrigation can be reduced accordingly.

Soil-Based Irrigation Scheduling

Soil-based methods of irrigation scheduling assume that the soil moisture content largely determines the moisture status of the plant. If there is less water in the soil and the water is held at a greater tension, it will be more difficult for the plant's roots to take up water. The result is that the plant will be under greater stress. Thus, irrigation scheduling is done by monitoring the soil moisture and maintaining it within acceptable limits that do not adversely affect plant growth.

The use of soil moisture monitoring devices such as tensiometers, gypsum blocks, neutron probes, or other devices is an excellent way to manage irrigation scheduling. Soil moisture monitoring in microirrigated orchards is complicated by the importance of monitoring device placement. Monitoring devices should be placed so that they reflect the average changes in the emitters' wetted volume. A shrinking wetted volume or slowly drying root zone during the season indicates underirrigation. Overirrigation would increase the wetted volume during the season and cause loss of water to deep percolation. In flood- or sprinkler-irrigated orchards, monitoring the soil moisture before and after irrigation provides additional information on selecting the duration of irrigation as well as the depth to which irrigation water will penetrate.

The most basic method of monitoring soil moisture is to collect soil samples from various depths (e.g., 1-foot increments) within the root zone and either estimate soil moisture using the "feel method" (see the USDA NRCS Estimating Soil Moisture by Feel and Appearance Web site, http://www.mt.nrcs.usda.gov), or to measure it directly by weighing, oven drying, and reweighing. Using a soil auger, sampling tube, or even a shovel requires significant time and effort to sample throughout the root zone. If weight data are used to calculate a volumetric soil moisture value (e.g., in/ft of soil moisture), an undisturbed soil sample must be collected, a difficult task. In order to make monitoring of soil moisture easier and quicker than collecting soil samples, a number of soil moisture monitoring tools are available. Some of these soil moisture monitoring tools are described below.

Tensiometers

A tensiometer is a device for measuring soil water tension, a measure of the surface tension force holding water in the soil. A tensiometer (fig. 12.2) consists of a cylindrical pipe about 1 inch in diameter with a porous ceramic cup attached to one end and a vacuum gauge attached to the other.

Table 12.5. Sample irrigation scheduling worksheet for a double-line drip system with a distribution uniformity of 92%

Prune ETo Historical from Gerber CIMIS Station # 8 Tehama County
Assumptions
1. Leaf-out 3/15
2. Leaf-drop 10/15
3. Tree Spacing 20 ´ 20 Feet

Date	G = (C - E - F): Net irrigation requirement (in)	H = Emission uniform* (%)	I = G/H: Gross irrigation amount (in)	J = Tree spacing (ft2)	K = (I ´ J ´ .623): Gallons per tree/ period (gal/period)	L = Average application rate (gph/tree)	M = (K/L): Hours of predicted irrigation time (hr/period)
3/16–31	–0.03	92	–0.04	400	–9.0	8	–1.1
4/1–15	–0.27	92	–0.30	400	–74.4	8	–9.3
4/16–30	0.26	92	0.29	400	71.0	8	8.9
5/1–15	1.19	92	1.30	400	322.9	8	40.4
5/16–31	2.82	92	3.07	400	764.3	8	95.5
6/1–15	3.59	92	3.90	400	972.2	8	121.5
6/16–30	3.73	92	4.05	400	1,009.8	8	126.2
7/1–15	3.81	92	4.14	400	1,032.9	8	129.1
7/16–31	3.79	92	4.12	400	1,027.3	8	128.4
8/1–15	3.31	92	3.60	400	895.9	8	112.0
8/16–31	3.10	92	3.37	400	839.9	8	105.0
9/1–15	2.27	92	2.47	400	615.6	8	76.9
9/16–30	2.12	92	2.31	400	574.5	8	71.8
10/1–15	1.59	92	1.73	400	430.2	8	53.8
10/16–31	1.00	92	1.09	400	270.9	8	33.9
Total	32.28		35.09		8,744		1,093

Note: *Irrigation efficiency is assumed to be equal to the distribution uniformity of the drip system.

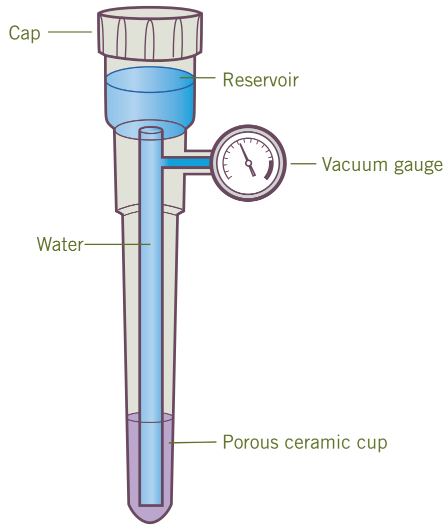

Figure 12.2 Tensiometer.

Tensiometers indirectly measure soil moisture. They are installed for the entire season or longer and provide readings at the same location over an extended period of time. Tensiometer readings are easily interpreted and indicate the soil water conditions experienced by the trees' roots. Soil salinity does not affect the readings.

In an unsaturated soil, soil water tension (frequently referred to as a suction or matric potential) falls below atmospheric pressure. As wet soil dries, this soil water suction increases, causing water to flow out of the tensiometer through the porous cup. The small pores in the cup prevent air from entering the tensiometer if the tension is within the range of the vacuum gage. This outflow of water creates a vacuum inside the tensiometer and increases the reading on the vacuum gauge. If the soil is rewetted by irrigation, water will be drawn back into the tensiometer, reducing the vacuum inside, and the reading on the tensiometer gauge will decrease.

The vacuum gauge measures the suction in centibars (cb: 100 cb = 1 Bar = 1 Atm), with a range of 0 to 100. A reading of 0 cb indicates a saturated soil in which plant roots will probably suffer from poor aeration. A reading of 10 to 25 cb reflects a soil at field capacity. The lower reading is for sandy soils at field capacity, and the higher reading is for finer-textured soils. Readings of 70 to 80 cb indicate a dry soil. Tensiometers do not read above about 85 cb, as this is about the point at which air begins to enter the porous tip and the vacuum is lost.

Tensiometers do not provide information on the amount of water depleted from the soil unless they have been calibrated for the particular soil type. They therefore indicate when to irrigate, but not how much to irrigate.

Although tensiometers are used most frequently for monitoring soil moisture, they can also be incorporated into automated irrigation systems. Tensiometers with solenoids can be used to control an irrigation system, and tensiometers equipped with transducers can be used with computerized irrigation systems.

Installation

To measure soil water tension, insert the porous cup end of the tensiometer at the depth desired through a pilot hole, made with a soil probe, in the soil. The porous cup should be soaked in water for several hours before installation, filled with water, and then allowed to dry temporarily to confirm that the tensiometer can develop a vacuum. Water should be placed in the bottom of the pilot hole and allowed to soak in. The tensiometer's porous tip can then be pushed into the wet soil in the bottom of the pilot hole, ensuring good contact between the porous tip and the soil. After installation, fill the tensiometer with water and allow it to equilibrate with the soil water for about 24 hours. A tensiometer should be installed in the zone of greatest root density, at about one-quarter to one-third of the maximum root depth. A tensiometer at this depth can be used to schedule irrigations. For sprinkler- or flood-irrigated orchards, a tensiometer reading of approximately 60 cb indicates a need for irrigation in the near future. For microirrigated orchards, the frequent irrigations should keep the soil in the emitter's wetted volume near field capacity, and the tensiometer should read near the 15 to 35 cb range. Refinements based on soil sampling will be required to adjust for site-specific conditions.

A second tensiometer should also be installed in the bottom one-third of the root depth to assure that the moisture is maintained to an adequate depth. Usually, the shallower tensiometer will begin to show an increased reading (indicating drier soil) before the deeper tensiometer begins to change. Trees tend to take up water from the shallower depths first. Some water managers using tensiometers in flood- or sprinkler-irrigated orchards use the beginning of moisture extraction from the deeper depths, indicated by a change in the lower tensiometer's readings, as an indicator of when to irrigate. This practice seems to work well as long as irrigation water can penetrate to the lower depths to replace the soil moisture used. If the tensiometer reading at the lower root depth remains unchanged following an irrigation or continues to rise during the growing season, irrigation applications may be insufficient, and frequency or duration of irrigation should be increased.

Tensiometers should be placed in the tree row to minimize damage by equipment. In addition, placement of tensiometers relative to microirrigation emitters, especially drippers, is critical to their use. If the tensiometer is too close to the drip emitter, it will constantly read wet; if it is too far from the emitter, the tensiometer will dry out and not be rewetted. The tensiometer should be placed near the edge of the emitter's wetted volume so that changes in the wetted area, reflecting over- or underirrigation, can be detected (see chapter 11, "Irrigation Systems").

The number of tensiometer stations required depends on the irrigation system and on soil uniformity and management. For areas up to 40 acres, at least two stations should be established. Stations should be located in areas representative of overall moisture status, with separate stations for problem areas or for areas with different soil conditions. In sprinkler irrigation, tensiometers should not be placed in areas in which the sprinkler pattern is "shaded" by a tree.

Maintenance

Tensiometers must be properly maintained. This requires periodically refilling the pipe with water and replacing porous cups that have cracked or become clogged with salts. If the soil becomes too dry (tensiometer readings greater than 85cb), the porous cup will break tension and air will enter the tensiometer. A cracked cup or a leaking vacuum gauge also prevents a vacuum from developing in the tensiometer and causes the instrument to always read zero. In locations where temperatures fall below freezing, tensiometers should be protected or removed from the field during cold periods. Finally, other than testing before installation, the porous cup of a tensiometer filled with water should not be exposed to the atmosphere for long periods of time. Such exposure causes evaporation of water from the cup's surface, which in turn may cause salt buildup and clogging of the cup.

Electrical Resistance Blocks

Electrical resistance blocks, commonly referred to as gypsum blocks, are an inexpensive and simple soil moisture measurement tool. They are useful for timing irrigations but do not provide information regarding the amount of irrigation water required. Electrical resistance blocks are installed permanently at a site and have the advantages of allowing their user to quickly monitor soil moisture at the same location throughout the season. Resistance blocks monitor soil moisture indirectly by measuring the electrical resistance between two electrodes attached to a small cast block of gypsum buried in the soil. Some electrical resistance blocks have electrodes mounted in fiberglass or in plastic or metal-encased blocks containing a sand-gypsum mixture. Wires, available in various lengths, lead from the blocks to the soil surface. The electrical resistance is read with a portable conductance meter. Measuring conductance (1 ÷ resistance) requires alternating current (AC), which the resistance block meter produces from its direct current (DC) battery. Using a simple resistance or ohmmeter to read the electrical resistance blocks will not give stable or reliable readings. Electrical resistance blocks and meters vary in cost by manufacturer, with blocks costing from $6 to $25 each and meters costing approximately $250. Since the meter is portable, only a single meter is required to monitor all the installation sites. At a normal site, a block may last 2 to 3 years, but it may require annual replacement in areas that have frequent irrigation or a high water table.

One manufacturer produces a block and meter that read soil water tension directly in centibars, while most other manufacturers provide charts or tables to correlate the meter readings to centibar values. Soil water tension information indicates the timing of irrigation but does not indicate the amount of irrigation water required. Indirectly, the irrigation amount can be arrived at through a trial-and-error procedure of monitoring the resistance blocks before and after irrigations. Blocks whose readings indicate wetter conditions following irrigation reflect irrigation water reaching their depth. If a block does not reflect wetter soil conditions after irrigation, the irrigation was insufficient to reach the block's depth. Observing the changes in resistance block readings after a number of irrigations allows an irrigator to gauge the irrigation to match the soil moisture deficit.

Data loggers, which can be used with soil moisture blocks, are available to record moisture block readings on a frequent and automated schedule. This "continuous" measurement of soil moisture can help the irrigator improve irrigation water management while minimizing the labor associated with reading the moisture blocks.

Installation

Gypsum blocks should be placed at several soil depths. At a minimum, blocks should be placed in the top one-third and bottom one-third of the root zone. Consultants who install soil moisture

monitoring sites using resistance blocks often place blocks at 1-foot intervals throughout the root zone. Soil moisture conditions are monitored only in the soil closely surrounding a resistance block. Wires from the blocks are brought to the soil surface to facilitate periodic connection to the portable meter for soil moisture measurements. The matric potential of the blocks is assumed to be in equilibrium with the surrounding soil, so the blocks act much like the surrounding soil, taking up and releasing water as the soil wets and dries. The electrical conductance between the electrodes varies according to the water content of the block. The higher the water content, the higher the conductance and the lower the electrical resistance.

The placement of resistance block stations in an orchard depends primarily on the soils. Generally, monitoring stations should be chosen to be representative of what is happening in the surrounding area. At a minimum, two stations per 40 acres are recommended, with additional stations in problem areas or in areas with different soil conditions. Since gypsum is soluble, gypsum blocks slowly dissolve. The life of a block can be extended 1 or 2 years by adding a small quantity of gypsum to the back-fill soil at the time of installation. A small quantity of lime (CaCO3) may likewise be useful in an acid soil to prolong the life of a block.

Most electrical resistance blocks monitor soil moisture more effectively in the drier range of soil water tensions (in excess of 33 cb). Consequently, blocks are more useful in the medium- to heavy-textured soils (loams and clays), which retain more available water in the higher soil water tension range. Sands and coarse-textured soils tend to release much of their water at low tensions, where the blocks are not as accurate or responsive. Blocks are also affected by highly saline-alkali soil conditions and may therefore not be appropriate for this use.

In prunes, moisture resistance blocks can often be installed in the tree row to protect them from traffic or cultivation damage. They should be installed within the drip line of a tree. When sprinkler irrigation is used, avoid placing the resistance blocks in the drier "shadow" area caused by the tree blocking the sprinkler's spray.

At a station, resistance blocks to be placed at various depths can either be sequentially stacked in the same hole or placed in separate holes. Placing blocks in separate holes has the advantage of locating the block in the soil environment closest to an undisturbed condition, but it has the disadvantage of requiring more work. Both techniques have been used successfully.

Prior to installation, test each block by soaking it in water and connecting it to its companion conductance meter. The meter should indicate a wet moisture block. The installation hole should be only slightly larger than the block and can be made using a soil probe or small auger. The hole should be to the depth at which the block will be installed. Before inserting the block, add about 2 ounces of water to the hole and allow it to soak into the bottom of the hole.

To place the block in the hole, run the wire lead through an appropriate length of ½-inch-diameter PVC pipe and put tension on the wire to hold the block on the end of the pipe. One manufacturer's block has a special collar that fits into the end of ½-inch PVC pipe to facilitate installation. Lower the block into the hole and push it firmly into the moist soil in the bottom of the hole. Remove the PVC pipe and fill the hole for several inches with the removed soil. Pack the soil firmly, preferably using a wooden rod such as a broom handle so as to avoid damaging the blocks or wires. Continue refilling the hole in stages, making sure that the soil is firmly packed at each stage in an effort to simulate undisturbed conditions. Refilling the hole properly is important to ensure that water and roots do not penetrate the hole more easily than the surrounding soil.

When installing blocks in trafficked or cultivated areas, trench or bury the lead wires to prevent damage. Identify the blocks by knotting the wire, color coding, or tagging. If possible, protect the bare ends of the wire leads since they tend to become corroded. Scraping the wire leads with a knife blade or fingernail file prior to attaching the meter will provide a better connection.

How to use the information from the blocks

Resistance block information is best used by evaluating changes in block readings. In flood- or sprinkler-irrigated orchards, a block that shows surrounding soil becoming drier between irrigations is a good indicator that water uptake by roots is occurring at that depth. Most frequently, trees preferentially take up water from the shallower depths, drying shallow soil before taking up water from deeper soil. Resistance blocks placed in shallower soil therefore show a change first. Some block users use this transition of water uptake from drier shallow soil to the deeper soil, along with a particular meter reading of the shallow block, as a signal to irrigate. These "signals" to irrigate are often arrived at over time by watching and comparing the tree response with block readings.

As with tensiometers, placement of moisture blocks relative to microirrigation emitters, especially drippers, is critical to their use. If a moisture block is too close to the drip emitter, it will constantly read wet, while if placed too far from the emitter, it will dry out and not be rewetted. Moisture blocks should be placed on the edge of the emitter's wetted volume so that changes in the wetted area, reflecting over- or underirrigation, can be detected.

As mentioned earlier, the blocks do not provide information on how much to irrigate, only on when to irrigate. Irrigation rates can be estimated through a process of trial and error. Reading the blocks just prior to irrigation and then reading them 2 to 3 days after irrigation (when drainage has nearly stopped) can provide information on the depths to which irrigation water penetrated. If a block's readings remained unchanged (assuming it is not already reading completely wet), the water did not reach that depth. To wet the soil to that depth, a longer irrigation would be needed.

If the block(s) in the deeper soils never change readings, the period between irrigations may be lengthened; another possibility is that there is no root activity at that soil depth. A lack of root activity can be due to saturated soil conditions (caused by overirrigation or a high water table), disease, or nematodes. In addition, if the deeper blocks continually read wet, it is impossible to tell whether the soil is being overirrigated and is losing water to deep percolation.

If the accuracy of the readings may be in question, often indicated by readings remaining unchanged when they should be changing, checking a nearby location's soil moisture using a soil auger and the "feel" method is an excellent first check.

Neutron Soil Moisture Meters

A neutron soil moisture meter (neutron probe) is a device for measuring soil moisture consisting of an electronic gauge, a connecting cable, and a probe cylinder containing a nuclear source and a detector tube (fig. 12.3).

The nuclear source is an Americium 241/Beryllium capsule that emits high-energy neutrons. When lowered down an access tube into the soil, the high-speed neutrons collide with surrounding soil particles and lose energy, creating low-energy, or thermal, neutrons. Some of these neutrons are reflected back to the probe cylinder and are counted by the thermal neutron detector tube. These counts are transmitted through the cable back to the gauge and displayed to the user. The neutron probe is therefore a sophisticated hydrogen counter. Since water is the primary source of hydrogen atoms in the soil, the neutron probe indirectly measures the soil moisture level.

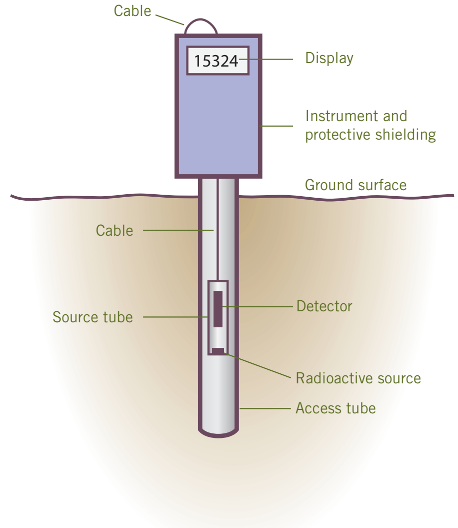

Figure 12.3 Neutron soil moisture gauge.

Neutron probe measurements are taken by lowering the probe cylinder into the access tube to the desired depth. The neutron probe measures a large (volleyball-size) sample. This is a larger sample than most other soil moisture sensors measure, an advantage of using the neutron probe. The probe cylinder can be lowered to the same depth each time, allowing repeated measurements at the same location. The neutron probe allows the user to obtain very accurate soil moisture measurements in a matter of minutes.

The neutron probe has some disadvantages, however. Soil moisture measurements at shallow depths (6 inches or less) are often unreliable because neutrons escape through the soil surface. Initial calibration of the neutron probe at a site can be time-consuming. Since the neutron probe uses a nuclear source, the operator must be trained in its handling, storage, and use. A license to operate the gauge is required, as are periodic inspections. The initial cost of the neutron probe is also quite high, approximately $4,000.

Installation

Establishing a neutron probe monitoring site entails installing an access tube to the desired depth. Access tubing can be aluminum pipe, PVC pipe, or electrical metal tubing (EMT). Since the probe readings are affected by the access tubing material, the material used for the tubing should be consistent throughout the orchard. Aluminum has the least effect on the readings, while PVC pipe will cause lower readings because the chlorine in the PVC absorbs "slow" neutrons.

Access tubing should be approximately two

inches in diameter. The inside diameter of the access tube should be nearly the same diameter as the probe cylinder. In areas with a high water table, the bottom of the access tubing should be sealed.

A hole the same diameter as the outside diameter of the access tubing should be augered into the soil to a depth slightly greater than the maximum measurement depth. The installed access tubing should fit snugly into the augered hole. The top of the access tube should be covered when not in use to prevent water or other foreign material from entering.

Placement of monitoring sites

The number of required monitoring sites depends on soil uniformity and management. For areas up to 40 acres, at least two sites should be established. Stations should be in areas representative of overall moisture conditions, with separate sites established for problem areas or for areas with different soil or management conditions.

The maximum depth at which the access tube is installed should be at least the depth of the active root zone. For established prune trees with no restricting soil layers or high water table, measuring to a depth of 5 feet will monitor most water usage by the tree. Installing to a depth slightly greater is recommended for monitoring deep percolation losses below the root zone.

The access tube should be placed in the tree row. In flood- or sprinkler-irrigated orchards, the access tube should be installed within the drip line of the tree, but not directly next to the trunk. In sprinkler irrigated-orchards, the access tube should not be placed in locations where trees "shade" the sprinkler distribution pattern. In microirrigated orchards, access tubes should be placed near the edge of the emitters' wetted soil volume. This allows monitoring changes in soil wetted volume caused by over- or underirrigation.

What do the readings mean?

Neutron probe readings are simply counts of returning neutrons, so a calibration must be done to translate the readings to soil moisture measurements. For timing irrigations, it may be sufficient to simply define the neutron probe reading at which the soil is "full" (approximately at field capacity) and to identify the reading at which irrigation should begin (refill point). A more thorough calibration, in which neutron probe readings are compared with actual soil moisture as determined by volumetric soil sampling, allow the user to determine not only the timing of irrigations but also the required irrigation amounts. The latter calibration technique is time-consuming but need be done only once for a given monitoring site. Sites with different soil types must be calibrated separately. Once calibrated, the neutron probe is very accurate.

Calibrations should relate soil water content to a relative count, which is the actual gauge count divided by a standard count. This procedure is recommended because the actual count can change with time due to deterioration of the radioactive source and because of electronic drift. The standard count is made by placing the probe at least 2 feet above the soil and 2 feet away from any source of hydrogen ions, such as a human body. The count is made with the source tube locked in the gauge.

Maintenance

Neutron probes require little maintenance beyond checking to ensure that the probe is operating properly and that the access tubes are free of water or foreign material. If repairs are required, they can be quite costly and must be done by the gauge manufacturer.

Dielectric Constant Soil Measuring Devices

A relatively new technology for soil moisture measurement makes use of the dielectric constant, a physical property of materials. The dielectric constant of a material impacts the travel time of a high-frequency electromagnetic pulse passing through the material. The dielectric constant of soil and water are significantly different (soil = 3 to 7; water = 80). Two soil moisture measurement techniques take advantage of these differences in dielectric constant. Time domain reflectometry (TDR) measures the travel time of an electromagnetic wave along two or more waveguides of known length; frequency domain reflectometry (FDR), also known as capacitance measurements, measures the soil capacitance of a high-frequency radio wave pulsed through the instrument and soil. These devices generally require that sensors be permanently installed in the soil.

The most common soil-installed TDR sensor has been a pair of parallel stainless steel rods spaced a known distance apart, usually about 5 cm. The length of the rods determines the monitored soil volume: the device measures a cylinder the length of the probes with a diameter slightly greater than the spacing of the rods. Monitoring various depths thus requires installation of a number of pairs of parallel rods, each pair of different lengths. One manufacturer of TDR sensors has combined the parallel rods with remote diode shorting into a single segmented probe that can measure various depths.

A number of FDR sensors are currently available. They either require the permanent installation of a sensor or sensors, or installation of a PVC access tube down which a probe is lowered; in one case, a portable sensor can be "pushed" into the soil as a soil probe and allow a measurement to be taken.

If TDR or FDR devices are to be used, growers should work closely with a consultant or other professional familiar with their use. There are numerous stages, ranging from installation to interpretation of the data, where their expertise may prove valuable.

Advantages of dielectric constant devices

A major advantage of most TDR and FDR devices is that they can be automated to take continuous measurements. This allows the user to have an accurate picture of how soil moisture is changing with time, such as how soil moisture changes during soil moisture uptake by the tree or as a result of an irrigation. The electromagnetic wave generating component of TDR and FDR devices can monitor and store information from multiple sensors using a multiplexing system and a data logger. These capabilities are unique to TDR and FDR devices. TDR and FDR devices can also be accurate once calibrated to the site.

Disadvantages of dielectric constant devices

TDR and FDR devices have significant disadvantages when used for field applications. First, both types monitor a relatively small volume of soil, measuring only a slight distance from the sensors. For TDR devices using pairs of parallel metal rods, pairs of different lengths must be installed if soil moisture readings for various depths are desired. Excellent contact between the soil and the TDR or FDR sensor must be maintained. Some of the greatest difficulties in using the devices have been caused by poor contact following installation; it is often difficult to attain good contact, particularly in gravely or heavy soils. The devices are also difficult to calibrate to achieve the desired accuracy. Finally, the cost of TDR and FDR devices is high. The systems, including the wave generators, multiplexer, and data storage units, often cost $7,000 or more. A portable FDR probe costs approximately $600.

Placement of monitoring sites

A minimum of two sites per 40 acres is recommended; however, as with other soil moisture measurement devices, soil, irrigation, tree, and management variability often determine the number of sites necessary in an orchard. The multiple-station monitoring capability of TDR and FDR devices, with their necessary wiring connections, limits the distance between monitoring sites. At each site, it is useful to take measurements at 1-foot depth intervals to monitor root uptake and irrigation refill and penetration.

Monitoring sites should be obtain the information desired. If the information is to be used for scheduling irrigations for the orchard, a location typical of the surrounding area should be chosen. Choosing a site in the tree row within the drip line of the tree and a few feet from the trunk is preferred. If a problem area of the orchard is to be investigated, siting should be chosen accordingly.

In microirrigated orchards, as with the other soil moisture monitoring devices, dielectric constant devices should be installed near the edge of the wetted soil volume to monitor any changes in it. These changes often reflect over- or underirrigation.

Plant-Based Irrigation Scheduling, Water Stress, and Regulated Deficit Irrigation

The water that is lost by each leaf of a prune tree (transpiration, the "T" of "ET," fig. 12.4A) is continuously being replaced by water that the leaf

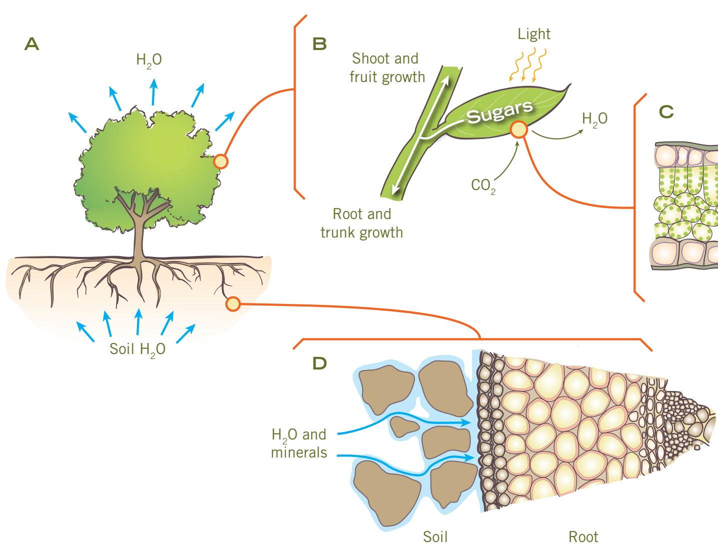

Figure 12.4 Water flow through the soil-plant-atmosphere continuum (SPAC). Water evaporates through the same stomatal pores in the leaf (C) that allow the uptake of atmospheric CO_2 for the production of sugars in the process of photosynthesis (B). The water leaving the tree canopy (A) must be continuously replaced by water uptake from the soil (D).

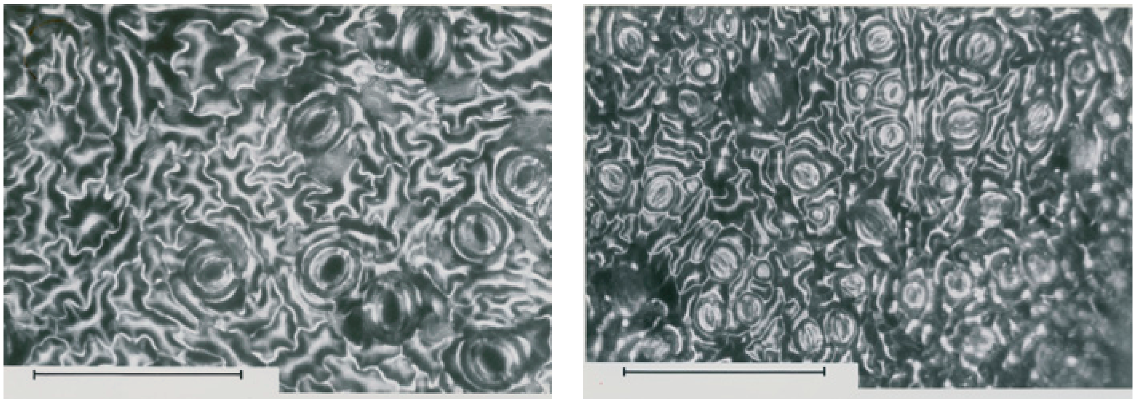

Figure 12.5 Apple leaf surfaces observed under the microscope, showing open (A) and closed (B) stomatal pores. The bar on both micrographs equals 100 μm.

pulls from its stem, much like a wick or a siphon pulls water from a reservoir. The stem, in turn, pulls water from the branch, and so on through the plant to the roots, which ultimately pull water from the soil (fig. 12.4D). The need for water is driven by the need to convert atmospheric carbon dioxide into sugars by the process of photosynthesis (fig. 12.4B). All the sugars that build the prune fruit during its development and are present in the fruit at harvest are obtained by photosynthesis. In order to allow carbon dioxide into the leaf, specialized cells on the leaf surface called stomatal guard cells (fig. 12.5) must press open a gap called the stomatal pore. This gap allows carbon dioxide uptake, but it also allows water loss (see fig. 12.4C), initiating the transpiration process. The stomatal pore can be thought of as a main door to the photosynthetic factory in the leaf, and this door must remain open for the factory to receive its most important raw material (carbon dioxide). When prune trees are under water stress, stomata close (fig. 12.5B), and photosynthesis is reduced.

Water Stress

Most of the transport of water within a plant is through the xylem, the woody tissue composed of long, hollow cells. These cells have very strong walls and are designed to withstand the tension that develops as water is being pulled from the soil. As the soil dries, it becomes harder for the plant to extract water from the soil, and the tension within the plant increases. As the tension increases, the degree of water stress within all parts of the plant increases. We can measure this stress using a pressure chamber, commonly called a pressure bomb. A leaf must first be covered to prevent moisture loss, and, depending on the type of measurement desired, either removed from the plant immediately or after a period of time (see below) and placed in a chamber with a small part of the leaf stem (the petiole) sticking out of the chamber through a seal (fig. 12.6). The chamber is slowly pressurized until the water begins to flow (upwell) out of the petiole xylem. This pressure is called the endpoint pressure (see fig. 12.6). The endpoint pressure equals the tension on the water in the leaf; a high pressure value means a high tension value in the leaf and a high degree of water stress in the tree. The units of pressure most commonly used are the bar (1 bar = 14.5 psi) and the megapascal (1 MPa = 10 bars). Because tension is the opposite of pressure, and pressure is expressed as a positive value, tensions are expressed as negative values (e.g., –1 MPa or –10 bar). An easy way to remember this is to think of water stress as a deficit: the more the stress, the more the plant is experiencing a

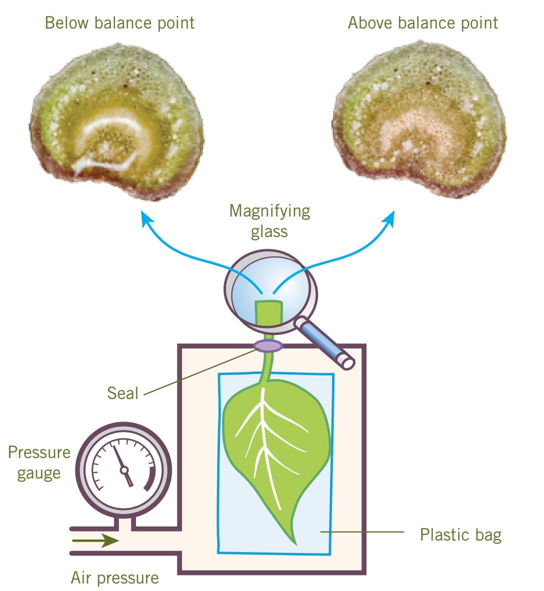

Figure 12.6 Schematic of a leaf inside a pressure chamber and photos of the appearance of the cut end of the petiole when it is dry (left, below the balance point, no water upwelling), and wet (right, above the balance point, water upwelling from the tissue).

deficit of water. The scientific name given to this deficit is the water potential of the plant.

Stem Water Potential

For prune trees, many growers and researchers have adopted the use of midday stem water potential (SWP) as a measure of water stress. In this method a plastic or foil envelope is used to cover a fully expanded (mature) lower canopy shaded leaf that is close to the trunk or a main scaffold. The recommended minimum time between covering and measuring in the pressure chamber is 10 minutes, but longer times (hours or days) are acceptable as long as the leaf remains dry and undamaged. The leaf must be dry, in shade at the time of covering, and should remain in shade until the time of sampling. Choice of leaf (spur, shoot, nitrogen status, proximity to fruit, etc.) is not important, as long as the leaf is reasonably healthy and small enough to fit comfortably in the bag (flat is best, but folding is acceptable as long as the leaf does not break), and the petiole is a good size for sealing in the pressure chamber. Leaves that are slightly damaged mechanically or by insect feeding may be more difficult to read in the pressure chamber because of bubbling, but they can still give valid readings.

The correct sampling time is midday, when stress is at its peak, usually during a few hours after solar noon, between 1:00 pm and 3:00 p.m. (daylight savings time). Leaves should remain covered during the entire sampling and measurement procedure. Although the envelope will prevent leaf water loss after picking, the time between picking the leaf and completing the measurement should be minimized. It should be possible to complete the measurement in less than 1 minute. It is most convenient to pick the leaf from the plant by gently snapping the leaf off at its connection to the spur or shoot, then recutting the leaf petiole with a sharp razor. A dull razor or ordinary knife will usually give a rough-cut surface, which makes the endpoint (see fig. 12.6) more difficult to observe. The leaf petiole is inserted through the seal and the seal tightened. It is important to minimize the length of petiole that extends beyond the top of the seal to a few millimeters. The amount of petiole removed during recutting has no influence on the measurement, nor does the degree of seal tightening, as long as the petiole remains intact and the endpoint can be clearly observed.

With the leaf inside the chamber, the measurement is made by increasing the pressure in the chamber until water begins to come out of the petiole's cut surface. Usually, the pressure at which water appears is very definite, so it does not make much difference in the pressure reading to wait a little too long for a lot of water or stop a little short if there is evidence that water is just beginning to come to the surface. When using a good-quality hand lens (7×), the water coming out of the petiole cut surface looks like an upwelling of water from a porous surface (see fig. 12.6). The best endpoint is one where a small increase in pressure (such as 0.2 bar) causes a noticeable increase in the quantity of water at the cut end, and where a small decrease in pressure causes the water to disappear quickly back into the petiole. The rate of pressure increase itself does not influence the measurement, unless it is so fast that the endpoint is not noticed until after the pressure has passed the true balancing pressure (overshoot). The best method is to increase the pressure slowly, especially when close to the endpoint pressure. Two or more leaves on the same tree should give almost identical readings (i.e., within about 0.2 bar), so for beginners it is good practice to sample more than one leaf per tree to check for reproducibility of measurement. With experience, only 1 leaf per tree is necessary. Remeasuring the same leaf should get nearly the same value. This is done at the first endpoint by reducing the pressure enough that water disappears into the petiole, then increasing the pressure slowly until the endpoint appears again. Different trees can give different readings, however, and these reflect real differences in tree water potential, so it may be important to keep track of each tree separately.

For fully irrigated prune trees (i.e., no limitation in soil water), regardless of tree age, midday stem

Table 12.6. Midday stem water potential (bars) to expect for fully irrigated prune trees under different conditions of air temperature and relative humidity

Temperature (°F)	Air relative humidity (RH, %)						
	10	20	30	40	50	60	70
70	–6.8	–6.5	–6.2	–5.9	–5.6	–5.3	–5.0
75	–7.3	–7.0	–6.6	–6.2	–5.9	–5.5	–5.2
80	–7.9	–7.5	–7.0	–6.6	–6.2	–5.8	–5.4
85	–8.5	–8.1	–7.6	–7.1	–6.6	–6.1	–5.6
90	–9.3	–8.7	–8.2	–7.6	–7.0	–6.4	–5.8
95	–10.2	–9.5	–8.8	–8.2	–7.5	–6.8	–6.1
100	–11.2	–10.4	–9.6	–8.8	–8.0	–7.2	–6.5
105	–12.3	–11.4	–10.5	–9.6	–8.7	–7.8	–6.8
110	–13.6	–12.6	–11.5	–10.4	–9.4	–8.3	–7.3
115	–15.1	–13.9	–12.6	–11.4	–10.2	–9.0	–7.8

water potential will depend on the local weather conditions, as shown in table 12.6. For young prune trees, where maximum vegetative growth may be desirable, the average midday stem water potential value should be close to the baseline. If the average is more negative than the baseline value at the temperature and relative humidity conditions when the measurements are made, the trees are under water stress, and vegetative growth will probably be reduced. If trees remain more negative than the baseline even though the soil is wet, this may indicate either that the roots are not healthy and root water uptake is being impaired or that water movement through the xylem is being blocked.

Regulated Deficit Irrigation

For mature prune trees, a moderate level of water stress during the growing season has been shown to be beneficial in that it reduces fruit drying ratio, excessive shoot growth, and, in some cases, the need for irrigation by 50% or more. The purposeful withholding of irrigation for a horticultural benefit is called regulated deficit irrigation (RDI). For prune trees, the current best estimate for the desired level of water stress at different times in the season, regardless of weather conditions, is given in table 12.7.

For full-coverage irrigation systems such as flood or sprinkler, RDI values can be used as irrigation thresholds: wait until the average of the monitored trees reaches these values before irrigating. For higher-frequency irrigation systems such as drip or microsprinkler, irrigation should be started once the trees reach the target, but the frequency or duration (or both) should be adjusted during the season to keep the trees close to the target value for that time of year. For either full-coverage or higher-frequency irrigation, allowing the trees to reach a stress of –15 bars or more during late June and early July can be dangerous because fruit cracking can occur when tree water stress is suddenly reduced by irrigation. Early irrigation cutoff has not been associated with increased preharvest fruit drop, although sudden increases in tree water stress near harvest, which may occur after irrigation cutoff in shallow soil, have been associated with increased levels of preharvest fruit drop.

Since each orchard is unique, only experience will tell the grower what it takes to achieve these targets. The pressure chamber should be used to manage irrigation by fine-tuning current irrigation practices. For instance, if trees show no stress immediately after a flood irrigation and show only slight stress just before the next, it should be possible to lengthen the irrigation interval, assuming that poor water penetration does not prevent adequate refilling of the soil profile. In addition to having horticultural benefits on fruit quality, reducing the amount of applied irrigation water conserves water and reduces the flow of nutrients and other pollutants into the groundwater.

Experimental results using RDI in prunes

Three irrigation treatments were applied to drip-irrigated prune trees in Butte County, California, during 1994–1996 in an 18-year-old commercial French prune (*Prunus domestic* L. cv. 'French') orchard near Gridley (Lampinen et al. 2001). The soil was classified as a Gridley clay loam, and trees were planted at an 18-by-18-foot spacing on Marianna 2624 rootstock. The control irrigation treatment applied approximately 100% of crop ET (ET_c), and two RDI levels were adjusted as necessary to achieve target SWP levels of –15 bars (moderate stress, as in table 12.8) or –20 bars (severe stress) by the end of September. Figure 12.7 shows the monthly average SWP for all years combined.

It is clear that for this orchard, application of 100% ET_c (based on the crop coefficients given in table 12.3 and real-time ET_o) did not maintain the control treatment trees at baseline values during

Table 12.7. Suggested target levels of midday stem water potential (bars) during the growing season in prunes

Period in season	Month						
	Mar	Apr	May	June	July	Aug	Sep
Early	–6	–8	–9	–10	–12	–13	–14
Mid	–7	–8	–9	–11	–12	–13	–15
Late	–7	–9	–10	–11	–12	–14	–15

Table 12.8. Three-year average production data for prunes under full irrigation (control) and at moderate and severe levels of RDI, with least significant difference (LSD) at the 5% level of significance

Irrigation treatment	Applied water (%ETc)	Spring bloom (flowers/cm branch)	Total number fruit dropped/ac (´ 1,000)	Fresh fruit yield (t/ac)	Dry fruit yield (t/ac)	Number fruit/ac at harvest (´ 1,000)	Dry fruit count/ pound	Number of undersize fruit (%)	Fruit hydration ratio	Side cracks (%)	End cracks (%)	Growth in trunk cross sectional area (cm²)	Fresh pruning mass (lb/tree)
control	108%	0.161	700	18.1	6.07	5,020	61	7.04	2.99	1.17	1.37	10.53	27
moderate RDI	57%	0.166	560	17.5	6.03	5,090	62	6.80	2.90	0.78	0.93	9.68	24
severe RDI	38%	0.161	490	16.2	5.73	4,940	68	8.32	2.83	0.75	1.67	8.86	23
LSD (5%)		0.023	100	1.77	0.54	680	3	2.49	0.07	0.38	0.67	1.30	4.5

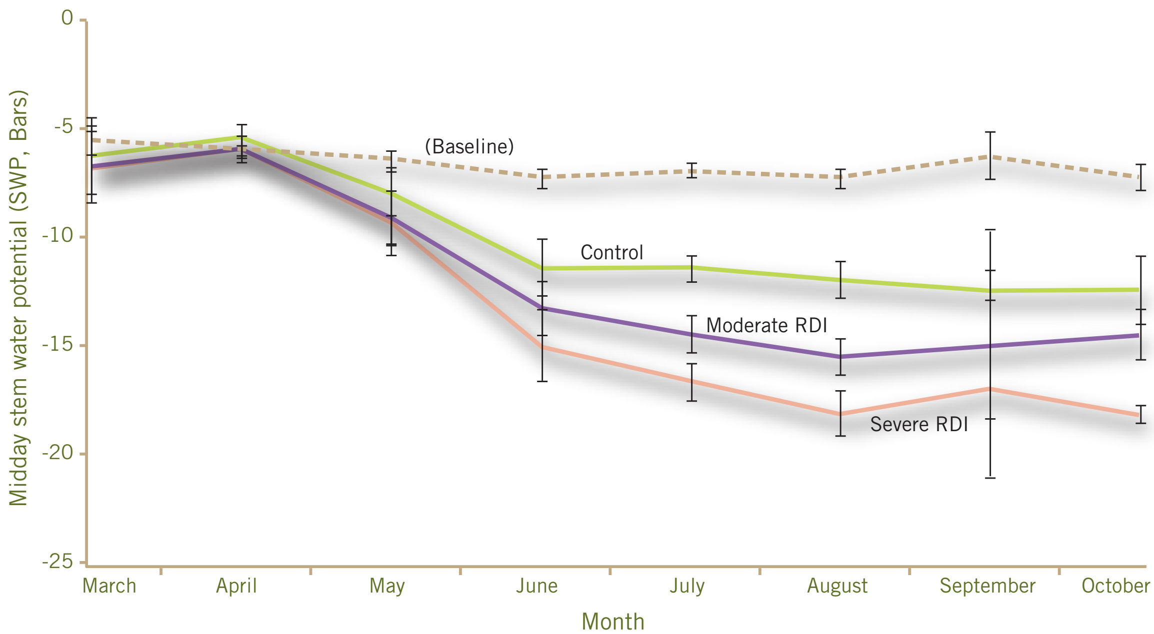

Figure 12.7 Monthly average values of stem water potential for 3 years of an irrigation experiment in prunes. Values for the three treatments (control, moderate, and severe RDI), as well as the baseline SWP (see table 12.6) expected under fully irrigated (nonstressed) conditions.

most of the summer. There are many possible reasons for this: for instance, the drip irrigation system did not wet the entire soil volume occupied by roots, and hence there were roots in soil that became progressively drier as the season progressed. However, comparing the three treatments, the control had the highest SWP, the moderate RDI achieved the target value of –15 bars by mid-September (table 12.7), and the more severe RDI produced the lowest values of SWP from June to October (fig. 12.7).

Over the 3 years of the study, there was no indication that RDI was having a long-term detrimental effect on the trees; table 12.8 shows the combined year's water application and prune production data. The only statistically significant effects of the moderate RDI compared with the control treatment were decreases in fruit drop and fruit hydration ratio, both of which are economically beneficial. Long periods of irrigation deprivation followed by flood irrigation have been associated with fruit cracking in prunes, but cracking was not found to be a problem in this RDI study. The average reduction in applied water was also substantial (about 50%), which may be economically significant, depending on water and pumping costs. These data show that prune production is relatively tolerant of stress, and that moderate levels of stress may be economically beneficial.

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