

17

Water Management and Irrigation Scheduling

WILLIAM L. PEACOCK, LARRY E. WILLIAMS, AND L. PETER CHRISTENSEN

WATER MANAGEMENT

Seasonal evapotranspiration (ET) or water use of a mature raisin vineyard can vary from 19 to 26 inches (483 to 660 mm) in the San Joaquin Valley, depending on size of the leaf canopy. Evapotranspiration is the combined amounts of the water that evaporates (E) from the soil surface and the water that transpires (T) from the leaves to the surrounding air. Evaporative demand varies very little from season to season within the geographical boundary of the California raisin industry.

The total amount of irrigation water applied, however, is often more than vineyard ET. An additional 6 to 8 inches (152 to 203 mm) of water may be needed some years to leach salts and provide frost protection, and the efficiency of the irrigation system must be taken into account. Winter rainfall can offset irrigation requirements by 3 to 6 inches (76 to 152 mm) depending on the timing of the rainfall and the ability of the soil to store water. A typical raisin vineyard's seasonal irrigation ranges from 24 to 36 inches (610 to 914 mm) of water.

In developing an irrigation strategy for grapevines, you need to take canopy development and the timing of the vine's growth stages into consideration. Grapevine water use begins with budbreak. It gradually increases as the canopy develops and evaporative demand increases. The canopy is fully developed by early to mid-June, and peak water use occurs in June, July, and August. The best way to discuss the effect of irrigation on vine growth and fruit development is to divide the season into four stages (the irrigation stages described here should not be confused with the three stages of berry growth discussed in other chapters).

Irrigation stage one covers the period from shortly after budbreak to bloom (approximately April 1 to May 10). The water requirement during this period is low: only 2 to 2.5 inches (51 mm) of water is used during the 40-day period. Moisture stored in the soil from winter rains is usually sufficient to meet vineyard

water requirements during stage one. Even with no spring irrigations, grapevines rarely exhibit symptoms of water stress during this stage. The exceptions are vineyards on very sandy or shallow soils with limited soil water storage, or vineyards with cover crops. Irrigations during stage one are primarily for frost protection or augmentation of stored soil moisture. The danger of frost is high until mid-April, and then the probability of frost rapidly diminishes.

Irrigation stage two covers the period from bloom to veraison (approximately May 10 to July 1). Veraison is the point at which fruit begins to soften; it usually occurs in late June or early July in the San Joaquin Valley. Grapevines use 5.6 to 7.5 inches (142 to 191 mm) of water during stage two. Proper water management is critical during this time as cells divide and elongate in the fruit. Water stress at this time will reduce berry size and yield.

Irrigation stage three covers the period from veraison to harvest (approximately July 1 to September 1). 'Thompson Seedless' vineyards, when harvested in early September, use 8 to 10.7 inches (203 to 272 mm) during this stage of roughly 60 days. Raisin growers generally terminate irrigations 2 to 6 weeks prior to harvest (depending on soil type) to allow time for terrace preparation (drip irrigation of raisin vineyards may continue closer to harvest). Growers may cut irrigations back in order to impose moderate stress and reduce shoot growth between veraison and harvest in vigorous vineyards. Excessive vine growth during this period can delay fruit maturity, encourage bunch rot, and delay or reduce wood maturity.

Last is *irrigation stage four*, the postharvest period that concludes with leaf abscission in November. The length of this period depends on the harvest date. Water use during this period of roughly 60 days (for 'Thompson Seedless' vines harvested in early September) is 3.8 to 5.1 inches (97 to 130 mm). Irrigations at this time should be applied in amounts that maintain the canopy but do not encourage growth. Excessively vigorous

vines will continue to grow or start new growth after harvest and then fail to mature their wood if supplied with adequate water. Mild to moderate water stress will benefit such vines by stopping shoot growth and promoting wood maturity; however, vines should not be allowed to defoliate. In late October or early November, when temperatures are too low to encourage shoot growth, a heavy irrigation is recommended to replenish some of the soil water reservoir and satisfy the leaching requirement. Vines that are under extreme water stress during this period may exhibit delayed shoot growth the following spring.

The approximate ET of a 'Thompson Seedless' raisin vineyard during the four irrigation stages can be found in Table 17.1. Tables 17.2 and 17.3 give seasonal water use on a daily basis for a small canopy vineyard that shades 50 to 60 percent of the land surface (a vineyard using a single-wire trellis) and a large canopy vineyard that shades 75 percent of the land surface (a vineyard using a crossarm trellis). The seasonal water

Table 17.1 Approximate water use for a raisin vineyard during four seasonal irrigation stages*

Irrigation stage	Phenological events	Approximate dates	Days in irrigation stage	Vineyard water use during irrigation stage (inches/acre)†	
				Small canopy	Large canopy
Stage one‡	Budbreak to bloom	April 1 to May 10	40	2.0	2.5
Stage two§	Bloom to veraison	May 10 to July 1	51	5.6	7.5
Stage three¶	Veraison to harvest	July 1 to September 1	62	8.0	10.7
Stage four#	Harvest to leaf fall	September 1 to November 1	61	3.8	5.1
Total vineyard water use for season				19.4	25.8

*Based on the 'Thompson Seedless' variety

†To convert inches per acre to millimeters, multiply by 25.4.

‡Water requirement during irrigation stage one is supplied primarily by soil moisture stored from winter rains (except for vineyards on very sandy or shallow soils). It is difficult to stress vines during this stage. You may be able to help improve berry set by withholding irrigations.

§Do not stress vines during irrigation stage two: cell division and berry growth are occurring during this period and the fruit is very susceptible to sunburn.

¶Deficit irrigation during irrigation stage three (50 to 75% of ET) will have minimal or no effect on yield. Excessive irrigation can increase rot and delay fruit maturation.

#Apply enough water to maintain canopy during irrigation stage four. Avoid excessive growth or premature defoliation.

use for raisin vineyards in Tables 17.2 and 17.3 is based on historic reference ET (ET_o), and was developed through research in commercial raisin vineyards and using a weighing lysimeter at the UC Kearney Agricultural Center. Growers can base irrigation schedules on this water use information.

Table 17.2 SCHEDULING FURROW-IRRIGATED Vine water use (drip irrigation schedule) for a small canopy vineyard or one using a single-wire trellis system in the San Joaquin Valley*

Date	Gallons per acre per day [†]	Date	Gallons per acre per day [†]		
April	1-7	500	July	1-7	3,550
	8-14	750		8-14	3,700
	15-21	1,000		15-21	3,800
	22-30	1,200		22-31	3,750
May	1-7	1,550	August	1-7	3,650
	8-14	1,800		8-14	3,550
	15-21	2,050		15-21	3,400
	22-31	2,300		22-31	3,300
June	1-7	2,650	September	1-7	3,100
	8-14	2,900		8-14	2,850
	15-21	3,200		15-21	2,650
	22-30	3,350		22-30	2,400

*Vineyard canopy covers 50 to 60% of the land surface during summer months. When used to schedule drip irrigations, amounts must be increased according to the efficiency of the drip system.

†Divide values by number of vines per acre to determine gallons per vine per day. Divide values by 27,154 to calculate inches per day. Multiply values by 9.35 to calculate liters per hectare.

Table 17.3 Vine water use (drip irrigation schedule) for a large canopy vineyard or one using a trellis with a crossarm*

Date	Gallons per acre per day [†]	Date	Gallons per acre per day [†]		
April	1-7	700	July	1-7	4,700
	8-14	1,000		8-14	4,900
	15-21	1,300		15-21	5,050
	22-30	1,650		22-31	5,000
May	1-7	2,050	August	1-7	4,900
	8-14	2,400		8-14	4,800
	15-21	2,700		15-21	4,550
	22-31	3,100		22-31	4,400
June	1-7	3,550	September	1-7	4,100
	8-14	3,900		8-14	3,800
	15-21	4,250		15-21	3,500
	22-30	4,500		22-30	3,200

*Vineyard canopy covers 75% or more of the land surface during summer months. When used to schedule drip irrigations, amounts must be increased according to the efficiency of the drip system.

†Divide values by number of vines per acre to determine gallons per vine per day. Divide values by 27,154 to calculate inches per day. Multiply values by 9.35 to calculate liters per hectare.

VINEYARDS

The best way to discuss the principles of scheduling furrow irrigations is in terms of a water budget. The water budget balances vineyard water use with the size of the soil water reservoir. The grower should irrigate the vineyard when 30 to 50 percent of the soil water reservoir has been depleted by vine ET, and the irrigation should be sufficient to refill the reservoir. You can determine the soil water reservoir based on the soil's available water-holding capacity (which varies with soil texture), the depth of the root system, and allowable depletion.

Available soil water content, rooting depth, and allowable depletions for several different soil textures are given in Table 17.4. Available water is the difference in volumetric water content between field capacity (FC) and the permanent wilting point (PWP) of the

Table 17.4 Representative values for available water content, rooting depth, and allowable depletions for different soil types

Textural class	Available water (inches)*	Root zone depth (feet)†	Allowable depletion	
			Percentage‡	Inches§
Sandy	0.6	4.5	50	1.4
Loam	1.5	3.5	50	2.6
Clay	2.5	3.5	50	4.4

*Available water can be thought of as the difference in volumetric water content between field capacity and permanent wilting percentage. Values within textural classes should be considered rough estimates. To convert to millimeters per meter, multiply values by 7.74.

†To convert to meters, multiply values by 0.305.

‡The percentage allowable depletion represents the amount of available water that can be extracted before the next irrigation. To avoid stress, irrigation should occur when 30 to 50% of the available water is depleted throughout the root zone. 50% depletion is used in this example.

§Values obtained by multiplying available water × root zone depth × percentage allowable depletion. To avoid stress, irrigation must take place after the vineyard has used this amount of water. Inches × 27,154 = gallons per acre allowable depletion. To convert to millimeters, multiply values by 25.4.

soil. Allowable depletion is the amount of water that can readily be extracted by the grapevines before water stress begins. For a mature vineyard with a fully developed root system, the allowable depletion is about 1.4 inches (36 mm) for a sandy soil, 2.6 inches (66 mm) for a loam, and 4.4 inches (112 mm) for a clay soil.

The ET of a large canopy vineyard during July is about 0.18 inch (4.6 mm) per day (Table 17.3). Therefore, large canopy vines growing on sandy soil will require irrigation about once every 8 days to avoid water stress (1.4 inches [36 mm] allowable depletion for a sandy soil ÷ 0.18 inch [4.5 mm] per day). In contrast, a vineyard on loam soil can go 14 days between irrigations (2.6 inches [66 mm] allowable depletion for a fine sandy loam soil ÷ 0.18 inch [4.5 mm] per day).

The above examples illustrate an important point: the water use of vines with similar canopy types is the same regardless of soil type. It is much more difficult to furrow irrigate vineyards efficiently on sandy soil than on finer-textured soil: more water is lost below the root zone. This difference in irrigation efficiency gives the false impression that vines on sandy soil use more water than vines on finer-textured soils. Typical irrigation efficiency, allowable depletion, amount of water applied at each irrigation, number of irrigations per season, and total water applied for different soil texture classes are given in Table 17.5.

Irrigation Cutoff

Irrigations must be cut off long enough before harvest to allow the soil surface to be sufficiently dry for preparation of a dry terrace by harvest time. Irrigations should be cut off 2 to 4 weeks before harvest for sandy soils and 4 to 6 weeks before harvest for finer-textured soils (Table 17.6). Setting an early cutoff date to deliberately impose severe stress to the vine will not promote more total grape sugar or improve raisin grade.

Table 17.5 Comparison of irrigation amounts for varying soil types and corresponding irrigation efficiencies

Textural class	Irrigation efficiency (%)*	Allowable depletion (inches)-†‡	Irrigation amount (inches)‡§	Irrigation amount (gallons/acre)¶	Number of irrigations per year#	Total water applied for year (inches)‡
Sandy	40	1.4	3.5	94,500	14	49
Loam	70	2.6	3.7	99,900	7	26
Clay	80	4.4	5.5	148,500	4	22

*Irrigation efficiency is defined as the percentage of applied water that remains in the root zone and is available for crop uptake.

†Values were obtained from Table 17.4.

‡To convert to millimeters, multiply values by 25.4.

§Values were obtained by dividing allowable depletion by irrigation efficiency, and indicate how much water should be applied for each irrigation.

¶Values were obtained by multiplying acre-inches by 27,000 gallons per acre-inch to determine gallons. Working with gallons rather than inches is sometimes more useful. For example, it will take 277 minutes to apply 125,000 gallons per acre using a pump that discharges 450 gallons per minute. By keeping a record of the number of hours a pump is used on a block of grapes, you can easily determine application amount. To convert to liters per hectare, multiply values by 9.35.

#Values were obtained by dividing seasonal vine water use of 19.4 inches (Table 17.1) by allowable depletion.

A cutoff date that is too early will cause some leaf defoliation by harvest, and excessive defoliation by the time raisins are dry and boxed. This level of stress, if repeated yearly, can weaken the vineyard and reduce production, and should be avoided.

An earlier cutoff date is advisable where in past years vines have continued to grow vigorously at harvest time. Fruit maturity can be delayed when shoots continue to grow actively from veraison to harvest. Also, vines that continue to grow actively until late in the season may develop many poorly matured (not woody) canes. This can make it difficult in dormant season for a pruner to find enough mature, fruitful canes. Poor cane maturity can be a serious problem with young, excessively vigorous vineyards. To manage this problem, cut irrigations off early enough to ensure that most shoot growth is slowed or stopped by harvest.

Postharvest Irrigation

By mid-October, the vineyard is normally terraced back, disked, and prepared for a postharvest irrigation. In some vineyards the vines may have gone 2 months without an irrigation. Sixty percent or more of the available water in the root zone will have been depleted by October, and vineyards will exhibit symptoms of water stress in varying degrees. A postharvest irrigation in October is recommended to replenish soil moisture in the root zone and to leach salts.

Vineyards on sandy or shallow soils have a much smaller soil water reservoir; therefore, they may be stressed by the time raisin drying is complete. These vineyards should be irrigated as soon as possible after the raisins are removed from the field. In contrast, excessively vigorous vineyards on deep soils with high water-holding capacities should not receive postharvest irrigations until late October or early November. This will help reduce late-season growth and improve cane maturity. Postharvest irrigation can be delayed to prevent excessive late season growth on vineyards that have been defoliated by insects or mites.

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SCHEDULING DRIP IRRIGATIONS

There is much less soil water storage with drip irrigation (one-third to one-fourth as much as with furrow irrigation), and this makes frequent irrigations necessary to avoid water stress. By June, about 30 percent or less of the root system can be found in the wetted soil area directly beneath the emitter. Less than 15 percent of the root system may be wetted if the soil has slow-infiltration characteristics. Drip irrigations should be

Table 17.6 Suggested irrigation cutoff dates for raisin vineyards on varying soil types and with corresponding rooting depths in the San Joaquin Valley

Soil type	Rooting depth	Cutoff date*
Fine sandy loam	Deep	July 15 to 22
Sandy loam	Deep	July 22 to 31
Loamy sand or shallow	Hardpan	August 1 to 10

*NOTE: Irrigations must be cut off early enough to allow preparation of a dry terrace by harvest time (2 to 4 weeks for sandy soil and 4 to 6 weeks for fine-textured soil).

frequent (every 1 to 4 days during the summer months) and each irrigation should be sufficient to satisfy the vine's water use until the next irrigation.

Vine water use figures shown in Tables 17.2 and 17.3 are used to schedule drip irrigations and indicate how much water should be applied daily during the season. Table 17.2 provides daily water use figures for a vineyard with a 50 to 60 percent canopy, which is typical of most raisin vineyards using a single-wire trellis system. Table 17.3 gives daily water use for a vineyard with a 75 percent canopy, which is typical for vineyards using a crossarm trellis system.

It is easy and practical to use Table 17.2 or 17.3 to schedule drip irrigations for your vineyard. For example, to schedule irrigations during the first week of July for a small canopy vineyard, use Table 17.2. The schedule indicates that the vineyard's water use is 3,550 gallons per acre (33,193 L/ha) per day; therefore, irrigate with 3,550 gallons per acre every day (plus an efficiency adjustment: see below) to replenish the extracted soil water. For every-other-day irrigations, apply 7,100 gallons (66,385 L/ha) plus the efficiency adjustment (2 days × 3,550 gallons); to schedule irrigations every fourth day, apply 14,200 gallons (132,808 L/ha) plus the efficiency adjustment (4 days × 3,550 gallons). During summer months, drip irrigation intervals should not exceed 4 days because of restricted soil water storage and the potential for vine stress between irrigations. To calculate gallons per vine per day, divide the gallons per acre value by the number of vines per acre. For example, if the vineyard has a vine and row spacing of 8 × 12 ft. (2.4 × 3.6 m), divide 3,550 gallons per acre (33,202 L/ha) per day by 454 vines per acre (1,122 vines per hectare), for a result of 7.8 gallons (29.6 L) per vine per day.

Irrigation amounts shown in Tables 17.2 and 17.3 do not account for the irrigation efficiency of the drip system. Most drip systems have an emission uniformity or water application efficiency of 70 to 90 percent. The schedule amounts given in Tables 17.2 and 17.3 must be increased accordingly to compensate for the efficiency of the drip system. For example, the schedule indicates that 3,550 gallons per acre (33,202 L/ha)

per day should be applied the first week in July, and the emission uniformity of the drip system is 90 percent. Therefore you should apply 3,944 gallons per acre (36,891 L/ha) per day should be applied. This is calculated as follows: 3,550 gallons (33,202 L)/.90 = 3944 gallons (36,891 L).

Drip irrigations should be cut back to 50 to 75 percent of schedule amounts (Tables 17.2 and 17.3) beginning in late July or early August to slow shoot growth in vigorous vineyards. Drip irrigations are usually discontinued 1 or 2 weeks before harvest to allow the preparation of a dry terrace. Irrigation during harvest is risky since a rupture in the system could result in flooding and damage to the raisin crop, although some growers on very sandy soils will continue to irrigate during the sun-drying process.

After raisins are boxed, begin drip irrigation again by applying enough water to wet the soil to a depth of 3 or 4 feet (0.9 or 1.2 m) beneath the dripper. This may take 15,000 to 30,000 gallons per acre (140,290 to 280,581 L/ha) for sandy and loam soils, respectively. After wetting the root zone, continue drip irrigation using the amounts shown in Tables 17.2 and 17.3. Less water (50 percent of the schedule amounts) or no water should be applied until late October to vigorous vineyards that exhibit active shoot growth; later than that, low temperatures no longer encourage growth.

Irrigation Scheduling Based on Current Weather Information

Seasonal evaporative demand remains fairly constant from year to year in the San Joaquin Valley, so the data in Tables 17.2 and 17.3 should continue to serve as practical guides in scheduling irrigations. When you use these tables, increase the irrigation amounts during unseasonably hot weather and decrease them during unseasonably cool weather by 15 to 25 percent. Common sense should prevail, and tensiometers or other soil- or plant-based irrigation monitoring tools should be used to verify the accuracy of the irrigation schedule.

If you need to schedule irrigation more precisely, you can obtain real-time ETo data from the California Irrigation Management Information System (CIMIS). The information you will need to schedule irrigations throughout the current growing season are daily ETo values and reliable crop coefficients or regulated deficit irrigation (RDI) factors. The seasonal crop coefficients at full ET (K_c) and RDI factors for 'Thompson Seedless' grapevines were developed at the UC Kearney Agricultural Center (Figure 17.1). Daily vine ET equals ETo multiplied by K_c . The uppermost data set

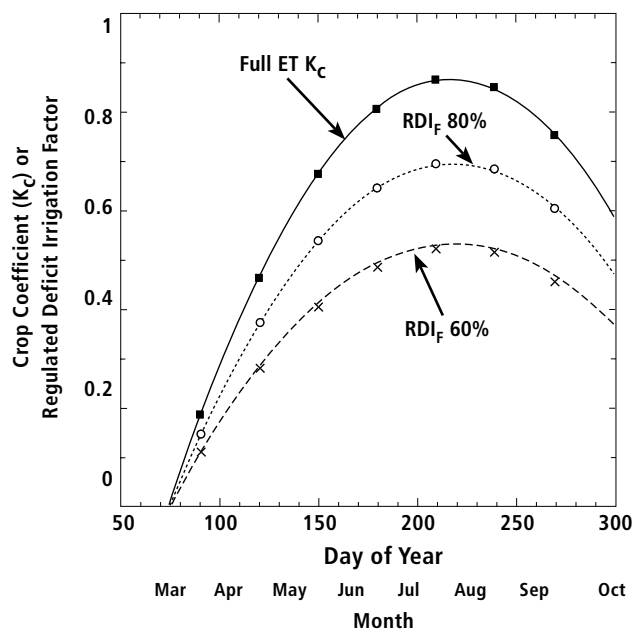


Figure 17.1 The seasonal crop coefficients for non-water-stressed 'Thompson Seedless' grapevines grown in a weighing lysimeter at the Kearney Agricultural Center (full ET K_c). The seasonal regulated deficit irrigation factors (RDI_F) were obtained by multiplying the seasonal K_c by either 60 or 80 percent. The following equations were obtained for each data set:

$$\text{Full ET } K_c = -1.11 + (0.0181 X) - (0.0000416 X^2)$$

$$RDI_F 80\% = -0.89 + (0.0145 X) - (0.0000333 X^2)$$

$$RDI_F 60\% = -0.67 + (0.0109 X) - (0.0000249 X^2)$$

where X equals the day of the year. Day of year 1 is the first of January.

in Figure 17.1 represents the K_c for vines growing in the weighing lysimeter (100 percent of ET). However, since yields were maximized with water application amounts at 80 percent of full vine water use, most raisin growers would use the seasonal 80 percent RDI_F . For vineyards that are weak or have vines that are smaller, the seasonal 60 percent RDI_F may be more appropriate. Therefore, the following equation can be used to schedule irrigations in raisin vineyards:

$$ET_c = ETo \cdot RDI_F$$

You can find the specific RDI_F to use in Figure 17.1. Using this method to determine vine water use, you can compensate with a fair degree of accuracy for changes in daily evaporative demand during the current growing season according to the canopy size or trellis type.

Water Use in Vineyards with Cover Crops

The irrigation schedules presented in Tables 17.2 and 17.3 and the crop coefficients and regulated deficit

irrigation factors presented above are for vineyards without cover crops. You will need to apply additional water if you have cover crops in order to avoid vine water stress, unless it is your objective to purposely slow the growth of an excessively vigorous vineyard.

Studies at the Kearney Agricultural Center have shown that the amount of additional water varies with the type of cover crop and its management. In one study, a continuous cover crop (bromegrass seeded during the winter, followed by resident vegetation in the summer) increased water use by 46 percent over the bare soil surface treatment. Bromegrass, killed after seed shattering (in May), increased water use by 19 percent over the no-vegetation treatment. A rye-vetch cover crop incorporated into the soil the second week of July required 35 percent more irrigation water.

Evaluation of Irrigation Scheduling and Amounts

There are several ways to validate irrigation schedules and amounts. Symptoms of water stress in vineyards usually are not visible in the San Joaquin Valley until mid-May to early June. The approximate date depends upon soil texture and rooting depth in the vineyard. The first visible sign of water stress is a decrease in the angle formed by the axis of the leaf petiole and the plane of the leaf blade. As water stress increases, shoot growth slows and internode growth is inhibited. As water stress becomes more acute, the shoot tips and tendrils die. Finally, under extreme water stress, leaves begin to abscise, starting with the most mature leaves and progressing toward the shoot tip. This level of stress is seldom observed in the San Joaquin Valley before late June or early July.

A tensiometer can be an important tool for monitoring the accuracy of your irrigation schedule. Tensiometers measure the soil's matrix potential. Shoot growth will slow when tensiometer readings average -40 centibars (kPa) in most of the root zone, and defoliation will begin when readings fall below -80 centibars (the limit of a tensiometer's range). Waterlogged con-

ditions are indicated when tensiometers read between 0 and -10 centibars. Place two tensiometers side by side with one monitoring the 18- to 24-inch (0.45 to 0.6 m) depth and the other monitoring the lower soil profile, the 36- to 48-inch (0.9 to 1.2 m) depth. Place the tensiometers in the vine row. One tensiometer site for every 20 acres (8 ha) is adequate.

When drip irrigations are correctly scheduled, the tensiometers will give you a constant reading of between -10 and -20 centibars (kPa) until irrigations are cut back or terminated prior to harvest; then the readings will become more negative. This is consistent with the principle of drip irrigation: frequent irrigations with steady-state soil moisture. With furrow irrigation, soil moisture levels and the soil matrix potential fluctuate considerably in the root zone, corresponding to the water budget principle of scheduling furrow irrigations. Typically, vines are furrow-irrigated when the soil matrix potential at the 2-foot (0.6 m) depth approaches -40 to -50 centibars. After a successful irrigation, the soil matrix potential will increase to -10 or -15 centibars, indicating the soil reservoir has been recharged. Tensiometers placed at depths of 2 and 4 feet (0.6 and 1.2 m) will indicate the depth of water penetration.

There are several other ways to validate and schedule irrigations in vineyards. You can monitor soil water content with a hydroprobe and apply the next irrigation when you measure a predetermined minimum soil water content. Plant-based measures of vine water stress, such as predawn or midday leaf water potential measurements, have been used for other crops. By this method, you would apply an irrigation when you had measured a predetermined value of leaf water potential. Grapevines generally are not considered to be stressed if midday values for leaf water potential are no lower than -10 bars (-1.0 MPa).

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