

## 16

## Grapevine Water Relations

LARRY E. WILLIAMS

Water is important to all living organisms. It is an essential constituent of cells: 80 to 90 percent of the fresh weight of living cells is water. It is a solvent in which gases, salts, and other solutes are able to move in and out of cells and from organ to organ. Water is a reagent in photosynthesis and in a number of other biochemical or biophysical processes. Lastly, water is essential for the maintenance of turgor (a certain degree of turgor is required for cell growth, the operation of stomata, and the maintenance of form of non-lignified structures).

Water movement occurs along gradients of decreasing free energy or molecular activity, often described as *differences in water potential*. If some external agent produces the difference in water potential, the movement of water is called *mass flow*. One example of mass flow in a plant is the upward movement of water in the vine (in the xylem tissue) caused by evaporation from the leaves. If the movement of water results from the random motion of molecules, as in evaporation, the process is called *diffusion*. Osmosis is an example of diffusion caused by a difference in water potential on two sides of a membrane, usually caused by differences in the concentration of solutes.

### Water Movement in the Soil-Vine-Atmosphere Continuum

Stomata are microscopic pores on the lower surface of grape leaves where water vapor is lost and carbon dioxide (CO<sub>2</sub>) is taken into the leaf. Stomata are closed in darkness, so little water is lost from the vine once the sun sets in the evening. When the sun comes up in the morning, stomata will gradually open. They are fully open at approximately one-third of full sunlight. The opening of stomata results in the loss of water vapor from the leaf due to the large gradient in water potential between the atmosphere and inside the leaf (which is considered to be at 100 percent relative humidity). As the leaf loses water vapor, water moves from the

cells surrounding the substomatal cavity into that cavity, continuing the process.

The movement of water out of a cell lowers its water potential (a decrease in free energy), so water will move into that cell from another cell with a higher water potential. More and more cells will continue to lose water until water is lost from cells located next to the leaf's vascular tissue. The vascular tissue contains specialized cells (*vessels*) that transport water from the roots to the leaves. The loss of water from these cells in the leaf creates a tension within the xylem, which is transmitted down the length of the vascular tissue in the vine. This tension effectively pulls water up through the vine as a result of the strong cohesive properties of water molecules in these small water-conducting cells, which are analogous to microscopic water pipes. Once water begins to move upward within the xylem of the root system, more water will move from the cortical cells in the roots to the xylem. As within the leaf, water movement out of a root cortical cell lowers its water potential and induces more water to move into that cell. Finally, this process initiates water uptake into the root from the soil profile.

*Field capacity* (FC) is the amount of water retained in the soil after gravitational water has drained from the soil. The water that remains is held in soil pores by capillary action and as a thin film surrounding individual soil particles. Soil pores up to about 10  $\mu\text{m}$  in diameter will hold water by capillary action, whereas larger pores (over 60  $\mu\text{m}$ ) will allow water to rapidly pass through. The component of the soil water potential that is of major importance here is the matric potential; capillary action and adsorption hold the water to colloids such as clay and organic matter.

As the soil dries out, the water in the larger soil pores is depleted first, so that only the smaller pores retain water. At a certain point, soil water is no longer available to the plant due to the strong capillary action of the finer pores. This is the *permanent wilting point* (PWP). When you subtract the PWP from the FC, the difference is the *available water content* (AWC). One-

half of the AWC is readily available to a plant; below this point, water is harder and harder to extract from the soil. As with water movement within the vine, the movement of water in the soil depends upon the existence of gradients of decreasing free energy or decreasing water potential. Water will move in the soil from areas of higher water potential to areas of lower water potential.

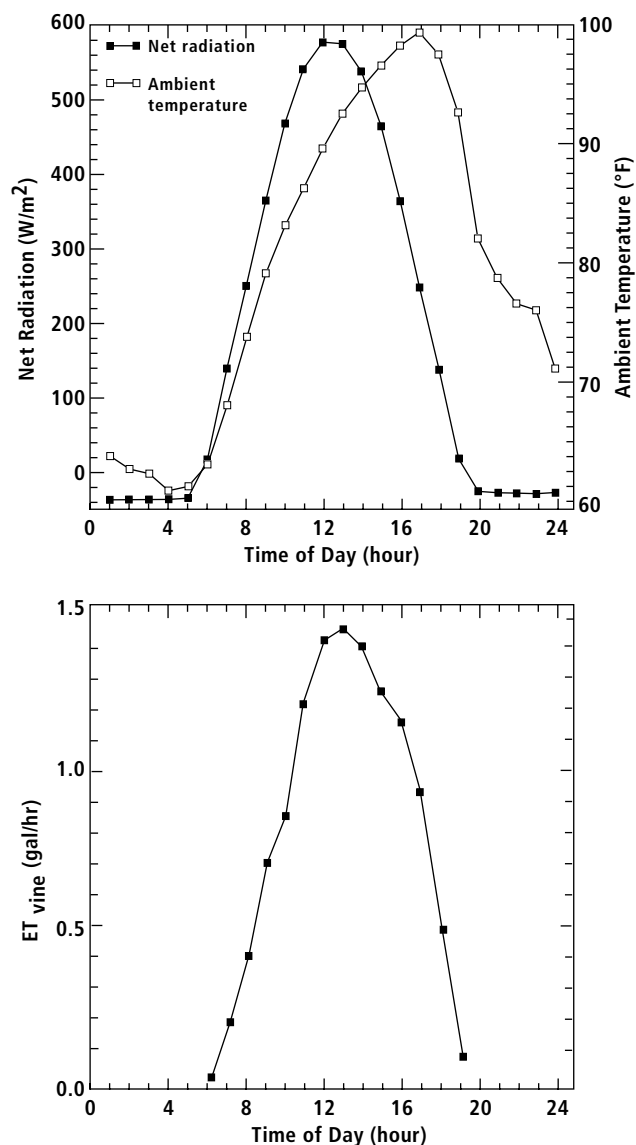
.....

### DAILY AND SEASONAL VINE WATER RELATIONS AND WATER USE

Pure water has a water potential of 0 megapascals (MPa). The introduction of any solute into water will decrease its water potential. The predawn leaf water potential of a grapevine is high (i.e., it can approach 0 MPa). This may be due in part to root pressures that develop in grapevines. Root pressures as great as 0.4 MPa (4 bars) have been reported. The sap exudate from cut surfaces of the vine prior to budbreak is probably a result of root pressure. The leaf water potential of grapevines undergoes daily fluctuations, with the lowest value of the day measured sometime between 1:00 PM and 3:00 PM daily. Increasing evaporative demand and decreasing availability of soil water generally cause midday values for leaf water potential to decline as the season progresses.

Midday leaf water potential for 'Thompson Seedless' grapevines, however, generally does not fall lower (i.e., more negative) than  $-0.8$  to  $-1.0$  MPa ( $-8$  to  $-10$  bars) throughout the growing season if the vines are well watered and not water stressed. Both predawn and midday values of leaf water potential are more negative for water-stressed vines than for those that are not stressed. Late in the season, midday leaf water potential of non-irrigated vines in the San Joaquin Valley may fall as low as  $-1.4$  MPa ( $-14$  bars). The leaf water potential of all vines rebounds in the afternoon and well into the evening, with the highest (least negative) value recorded before dawn. Seasonal values for midday leaf water potentials of 'Thompson Seedless' grapevines are linearly related to soil water content: as the soil dries out, leaf water potential decreases.

The main driving force for vineyard water use (or evapotranspiration [ET]) is net radiation. Net radiation provides the energy to convert water in the liquid state (inside the leaf) to the vapor state (lost via the stomatal pore) outside the leaf. As you can see in Figure 16.1, vine water use is more highly correlated with net radiation than with ambient temperature. Other environmental factors influencing ET include wind speed and vapor pressure deficit (as the relative humidity decreases, vapor pressure deficit increases).



**Figure 16.1** The diurnal time course of vine water use, net radiation, and ambient temperature on June 2, 1996. Vine water use was obtained from 'Thompson Seedless' grapevines grown in a weighing lysimeter at the UC Kearney Agricultural Center. The trellis system for the vines was a 2-foot crossarm at the top of a 7-foot stake, with fruiting wires at either end of the crossarm. Vines within the lysimeter were irrigated whenever 2 mm (approximately 2.11 gallons) of water had been used, so the vines were not stressed for water at any time. Net radiation and ambient temperatures were obtained from a CIMIS (California Irrigation Management Information System) weather station located approximately 1 km (0.6 mile) from the lysimeter. For a complete description of the weighing lysimeter, see Phene et al., *Automated Lysimeter for Irrigation and Drainage Con-*

Vapor pressure deficit is highly dependent upon ambient temperature. Therefore, the increase in water use at higher temperatures is due generally to higher net radiation and lower relative humidity during those periods. In addition to providing the energy to drive

ET, light influences the degree to which the stomata open. Wind and vapor pressure deficit also influence the degree of grapevine stomatal opening. In this way, the vine is able to regulate the amount of water it uses via changes in stomatal conductance.

The level of vineyard water use depends upon a number of factors. During establishment a vineyard uses less water than a mature vineyard (Table 16.1). Results from a study at the UC Kearney Agricultural Center that used a weighing lysimeter (a very sensitive device to measure plant water use) indicate that during the first two years of growth vines only use approximately 50 percent as much water as a mature vine. During the first year, much of the water went to evaporation from the soil surface. Mature vines used an average of 1,650 gallons from budbreak to the end of October from 1990 to 1996. Mature vines at full canopy covered approximately 60 to 65 percent of the surface area allotted to each vine, with approximately 9 m<sup>2</sup> of total canopy surface area per vine. Third-leaf vines used approximately 70 percent of the water used by mature vines. Other studies have demonstrated that trellis type and vine size have a significant effect on vine water use. Vines grown on trellis systems that spread the canopy and vines with more leaf area will

use more water. The pruning pattern you use may or may not have an effect on vine water use (Table 16.1).

Vine water use also varies throughout the growing season. Water use is low early in the season, from budbreak until one month later, as the vine has little leaf area during that time (Figure 16.2). Once there is appreciable leaf area and evaporative demand increases, vine water use increases in an almost linear fashion. Vine water use becomes constant at full canopy. Maximum water use in 1996 was about 13.5 gallons of water per day for a period of approximately 60 days. The decrease in vine water use from day 150 to day 175 (approximately 1 June to 27 June) reflects a decrease in evaporative demand during that period. Vine water use decreases as the season progresses because leaves start to senesce and fall off the vine. During the course of the Kearney Agricultural Center study, researchers found that leaf damage from variegated leafhoppers (*Erythroneura variabilis* Beamer) significantly reduced vine water use late in the season as compared to water use in years when leafhopper populations had been controlled with pesticides.

**Table 16.1** Water use of 'Thompson Seedless' grapevines during and after vineyard establishment, determined with a weighing lysimeter (vine water use [ETc] or potential ET [ETo] amounts obtained by summing data from date of budbreak [or the day vines were planted, in 1987] until the end of October each year)

Year	ETc (inches)	ETc (gal per vine)	ETo (inches)*	Cultural/pruning practice†-
1987‡	14	700	46	Planted April 9
1988	16	800	45	Trained up the stake
1989	23	1,160	47	Two 12-bud canes
1990	29	1,400	47	Four 15-bud canes
1991	34	1,720	47	Six 15-bud canes
1992	32	1,590	47	Six 15-bud canes
1993	34	1,704	44	Eight 15-bud canes
1994§	33	1,678	44	Eight 15-bud canes
1995§	29	1,430	42	Eight 15-bud canes
1996	34	1,717	45	Eight 15-bud canes

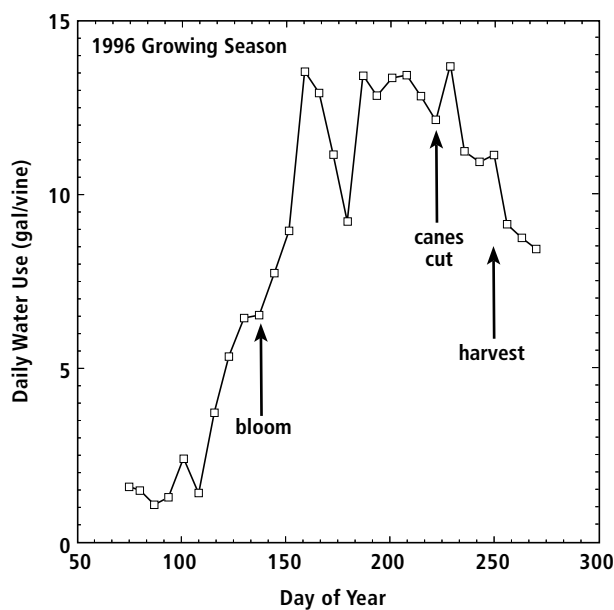
\*Potential ET (ETo) data were obtained from a CIMIS weather station at the Kearney Agricultural Center. ETo is the amount of water used by a short, green crop completely shading the ground. It is a measure of the evaporative demand of a particular region throughout the year.

†The number of canes to be left on the vines from 1991 to 1996 was determined by dissecting buds the previous winter to determine bud fruitfulness and subsequently devising a pruning pattern.

‡Vines in the lysimeter were furrow irrigated the first growing season. From 1988 to 1996, vines within the lysimeter were drip irrigated. Daily irrigations took place whenever vines used 2 mm (2.11 gallons) of water. Thus the vines in the lysimeter may have been irrigated five to six times a day during the portion of the season with the greatest evaporative demand. The irrigation system generally commenced the first week of May and continued until the end of October.

§The vines in the lysimeter were trunk girdled in 1994 and 1995 as the vines were used to produce table grapes. The vines were not girdled in 1996.

.....  
**EFFECTS OF IRRIGATION**



**Figure 16.2** Seasonal water use of 'Thompson Seedless' grapevines growing in a weighing lysimeter at the Kearney Agricultural Center during 1996. Budbreak, bloom, and harvest occurred on March 10, May 12, and September 2, respectively. To calculate daily water use, we summed weekly water use and divided that number by 7. Canes of vines growing within the lysimeter were manually cut approximately 18 inches from the ground on August 5 to simulate the mechanical cane cutting performed on vines surrounding the lysimeter. Other information as described in Figure 16.1 and Table 16.1.

## ON VINE GROWTH

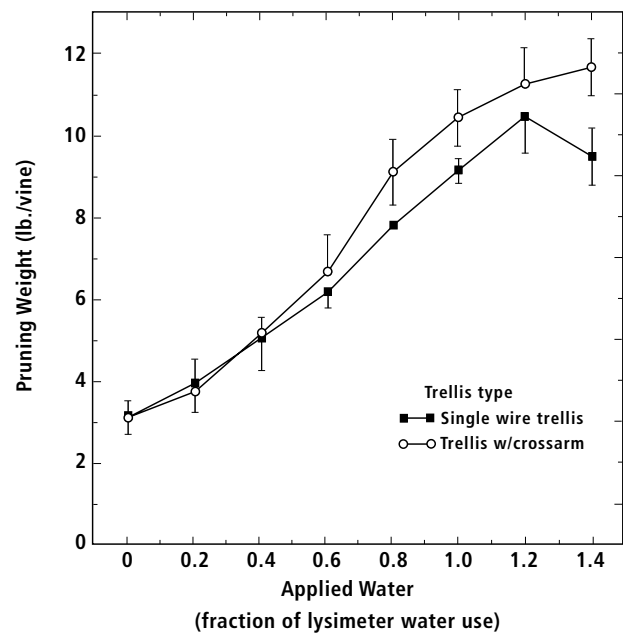
## Vegetative Growth

Most studies on grapevine irrigation have demonstrated that water deficits affect vegetative growth to a greater degree than they affect reproductive growth. A reduction in shoot growth is one of the first visible symptoms of vine water stress. When water stress is severe or when its onset is too rapid, the stress can kill the shoot tip. Moderate water deficits will decrease the rate of shoot elongation, along with internode length and radial expansion. Leaf area per vine is less under water deficit conditions due to reduced shoot length and smaller leaves. The growth of lateral shoots is reduced more by water stress than that of primary shoots. This may be because soil water deficits do not develop until later in the growing season, after the primary shoots have had considerable growth and before most lateral shoots initiate their growth. The weight of pruned canes taken during the dormant portion of the growing season is used as a measure of the previous season's shoot growth. There is an almost linear increase in pruning weights of 'Thompson Seedless' grapevines using a single-wire trellis as the amount of applied water increases from 0 to 120 percent of the water used by vines growing in a weighing lysimeter (Figure 16.3). A further increase in water application amount (to 140 percent) decreased pruning weights for that trellis treatment. Vines using the crossarm trellis system exhibited a sigmoidal increase in pruning weights with an increase in applied water, leveling off at the higher level of applied water.

Few studies have examined the effects of water deficits on the growth of the grapevine's permanent structures (root system, trunk, and cordons, if any). Potted vine studies indicate that root growth is less sensitive to water deficits than is shoot growth. Trunk biomass and diameter are both reduced by water deficits. It should be pointed out that the concentration of storage sugars in the root system and trunk are not affected by water deficits, but since biomass is reduced, total sugars are less in water-stressed vines than in non-stressed vines.

## Reproductive Growth

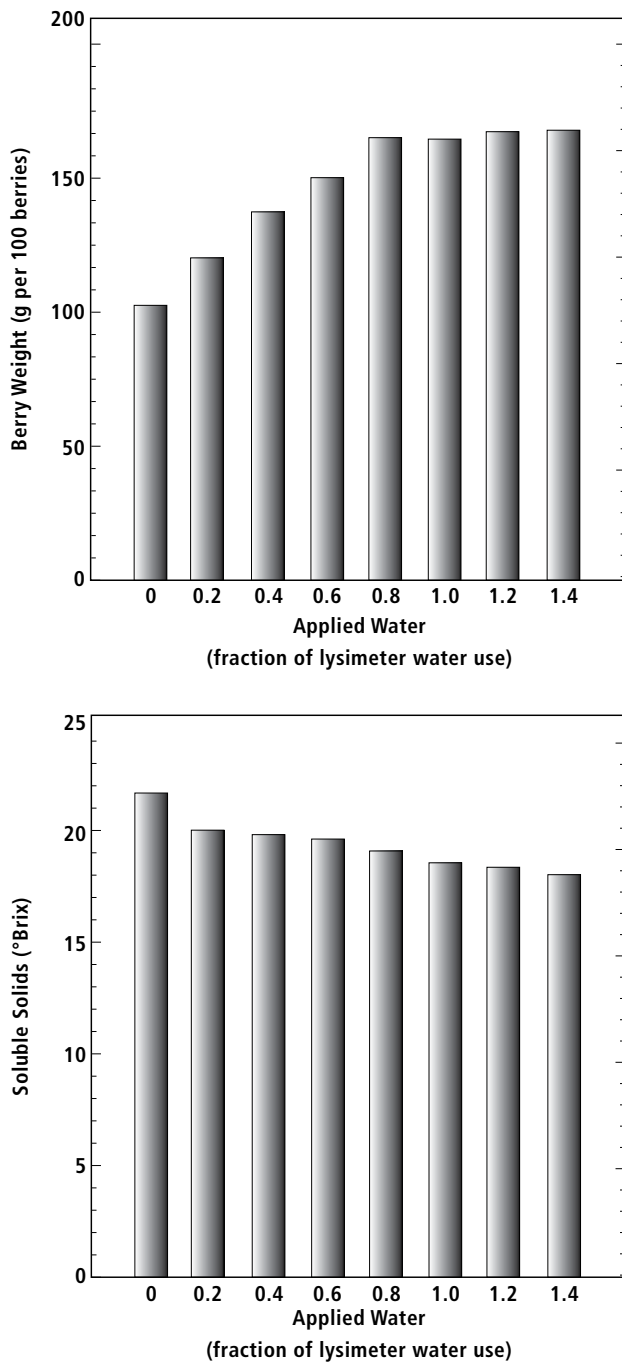
Reproductive growth of grapevines is generally less sensitive to water stress than vegetative growth. However, the stage at which berry growth is most sensitive to water deficits is stage I (see chapter 5, Grape Berry Growth and Development, for definitions of the stages of berry growth). Water deficits during stage I decrease both the division and the elongation of the cells in the berry. Berry growth is reduced more by a water stress episode during stage I than by a similar episode during



**Figure 16.3** Pruning weights of 'Thompson Seedless' grapevines irrigated at various fractions of full vine ET (as determined with a weighing lysimeter). Whenever vines in the lysimeter were irrigated daily and throughout the growing season, vines in the eight irrigation treatments were also irrigated at the fraction indicated on the x-axis of the graph. Each irrigation treatment was replicated eight times. The data are the means of four growing seasons (1990 to 1993). The single-wire trellis system consisted of a wire run atop a 7-foot stake. The crossarm trellis consisted of a 2-foot crossarm atop a 7-foot stake, with fruiting wires at either end of the crossarm. Bars represent one standard error.

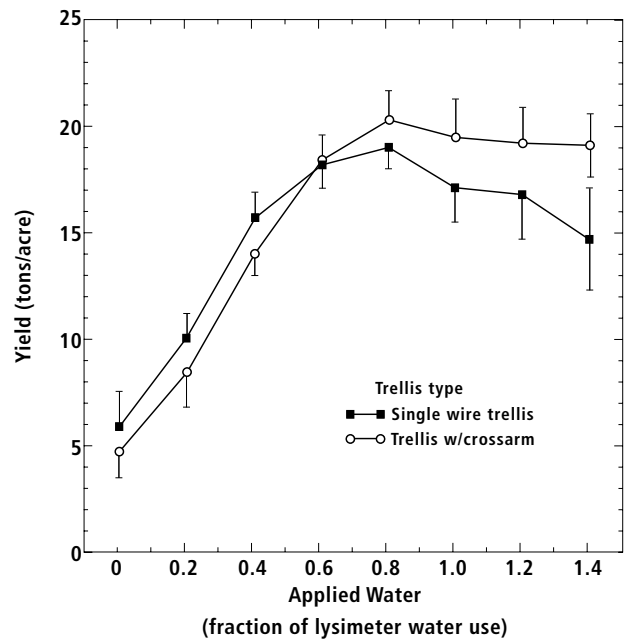
stage II or III. In addition, reductions in berry growth caused by stage I water stress cannot be reversed by supplemental irrigation during stages II or III. An irrigation study at the Kearney Agricultural Center demonstrated a linear increase in berry weights correlating to applied water levels of 0 to 80 percent of full ET, when irrigating was maintained at the same level for the full growing season (Figure 16.4). This study also showed that applying water in excess of 80 percent of full ET all season long did not result in larger berries. Maximum berry size for 'Thompson Seedless' can therefore be obtained under mild water deficits. More recent studies have also demonstrated that deficit-irrigation (50 percent of full ET) after veraison has no detrimental effect on berry size: cutting off water to raise vineyards in order to prepare the soil for fruit drying does not adversely affect berry size.

Vine water status will affect the solute concentration (mainly sugars) throughout berry development. The accumulation of sugar in the fruit appears to be less affected by water deficits than is berry growth. Many vines that are water stressed have fruit with a higher concentration of sugar than on vines that are given more water (Figure 16.4). This may be due to at least three factors. First, berries may lose water under



**Figure 16.4** Berry weight and soluble solids of 'Thompson Seedless' grapevines irrigated at various fractions of full vine ET. Data represent the means of data collected in 1990, 1991, and 1992, and are averaged across the two trellis treatments. The legends for figures 16.1 through 16.3 explain how irrigations for each treatment were scheduled.

water deficit conditions such that the sugar in the fruit becomes more concentrated. Second, vines that are water stressed generally have lower yields whereas vines given more water have more sinks (higher yield) competing for carbohydrates. And third, it has been demonstrated that fruit growing in the shade, as they



**Figure 16.5** Yield (fresh weight) of 'Thompson Seedless' grapevines irrigated at various fractions of full vine ET. Data points represent the means of five growing seasons (1990 to 1993 and 1996). Other information as described in the legend for Figure 16.3.

might be on irrigated vines with excessive vegetative growth, have lower rates of sugar accumulation.

The yield of 'Thompson Seedless' grapevines as a function of applied water and trellis type is shown in Figure 16.5. There is an almost linear increase in yield for vines grown with a crossarm trellis as water applications increase from 0 to 80 percent of full ET. Beyond 80 percent of ET, yield decreases slightly before leveling off. The optimum water application amount for a single-wire trellis is 60 to 80 percent of full ET, with reductions in yield on either side of those levels. It would appear that under severe soil water deficits the single-wire trellis would be an advantage, whereas it would be a disadvantage under conditions of too much water. The optimization of yield for 'Thompson Seedless' vines in this study at water applications of 60 to 80 percent of full ET indicates that the smaller canopy that develops under mild water deficits (see Figure 16.3 for pruning weight data) does not hinder berry size or final yield.

From the data in Figures 16.3, 16.4, and 16.5, one can draw some useful conclusions regarding an irrigation strategy for 'Thompson Seedless' grapevines grown for raisins. The major yield component determining final yield for 'Thompson Seedless' grapevines is the number of clusters per vine. One reason yield is maximized at water applications of 60 to 80 percent of full ET is that those treatments have the greatest bud fruitfulness year after year (see chapter 4, Bud Development and Fruitfulness of Grapevines). Overirriga-

tion results in fewer clusters per vine due to lower bud fruitfulness and increased bud necrosis. The reduction in yield under greater water deficits is mostly the result of decreased berry growth and fruit dehydration, especially for vines irrigated at 0 and 20 percent of full ET. Another important consideration when producing raisins is to ensure that the berries mature (accumulate sugar) early enough to allow time for them to be laid out to dry. Even though yields were highest for 60 and 80 percent of full ET across all treatments, the sugar accumulation rate in those fruit was not the lowest. Therefore, you may be able to maximize yields without significantly delaying the harvest date.

The data presented here support numerous studies that indicate beneficial effects from *regulated deficit irrigation* (RDI) for woody perennial crops. Following this practice, growers irrigate plants at a deficit during specific phenological stages of growth. In *sustained deficit irrigation*, as is describe above for 'Thompson Seedless' grapevines, growers irrigate at a fraction of full ET throughout the growing season. This is clearly a useful way to save water while maximizing production.

.....

## R E F E R E N C E S

- Grimes D. W., and L. E. Williams. 1990. Irrigation effects on plant water relations and productivity of 'Thompson Seedless' grapevines. *Crop Sci.* 30:255-60.
- Phene, C. J., G. J. Hoffman, T. A. Howell, D. A. Clark, R. M. Mead, R. S. Johnson, and L. E. Williams. 1991. Automated lysimeter for irrigation and drainage control. In *Proceedings of lysimeters for evapotranspiration and environmental measurements*. St. Joseph, MO: ASCE. 28-36
- Williams, L. E. 1996. Grape. In E. Zamski and A. A. Schaffer, eds., *Photoassimilate distribution in plants and crops. Source-sink relationships*. New York: Marcel Dekker, Inc. 851-81.
- Williams, L. E., N. K. Dokoozlian, and R. Wample. 1994. Grape. In B. Shaffer and P. C. Anderson, eds., *Handbook of environmental physiology of fruit crops*. Orlando: CRC Press. 83-133.
- Williams, L. E., and M. A. Matthews. 1990. Grapevine. In B. A. Stewart and D. R. Nielsen, eds. *Irrigation of agricultural crops*. Agronomy monograph No. 30. Madison: ASA-CSSA-SSSA. 1,019-55.
- Williams, L. E., D. W. Williams, and C. J. Phene. 1993. Modeling grapevine water use. In C. S. Stockley, R. S. Johnstone, P. A. Leske, and T. H. Lee. *Proc. eighth Australian wine ind. tech. conf. Adelaide: Winetitles.* 29-33.