D. **Vine Water Deficits Caused by Reduced Soil Water Availability**

Winegrape Water Use

Winegrape water use is driven by a vine's canopy exposure to the energy of the sun. The vine encounters this energy as direct radiation from the sun and indirect radiation sources such as heated low humidity air, and wind. The combined effect of these energy sources on the vine canopy determines vine water use when soil moisture is not limited.

The intensity of these atmospheric factors varies over the day as well as over the season and can be measured and used as input to an empirical model to calculate relative water demand. The result, termed the reference evapotranspiration (ETo), most closely approximates a full coverage grass crop and will vary over the season. Normal or average years ETo data is shown for Lodi California in *Figure D-1*. Water use is also influenced by vine canopy growth from bud break to full canopy expansion. Together these factors contribute to a water use pattern that begins at a low rate in spring, peaks in mid-summer and then declines as leaf drop approaches (*Figure D-2*). For this discussion, we will assume the canopy is at a full practical midday land surface shading of 50 percent at maximum canopy expansion. This level of land surface coverage is a large wine grape canopy but still allows for standard vineyard cultural operations Land surface shading can be measured mid-day as the percent of shade on the vineyard floor. Shading is predominately influenced by row spacing and vine vigor; however, canopy management practices (such as hedging or canopy disruption by machine harvesting) can further modify this pattern by reducing the energy intercepted by the vine.

Vine water use is reduced below full potential when soil moisture is limited and irrigation is not supplied. *Figure D-3* illustrates both the full potential water use and the water use of a deficit irrigation regime on a weekly basis. Early season water use is similar between the two regimes since adequate moisture is available in the soil. When soil moisture becomes limited in mid-season, differences in water use can be seen. Irrigation can be applied to significantly influence the differences shown in water use. *Figure D-4* illustrates seasonal cumulative water use of the same vineyard in the Lodi area with adequate soil moisture for the entire season and one of a deficit irrigation regime. Notice the near 30 percent seasonal difference in water use between full potential water use and a deficit irrigation regime over the season.

Figure D-1. Lodi Eto, 1984 - 2003 Average Stations # 42 and # 166

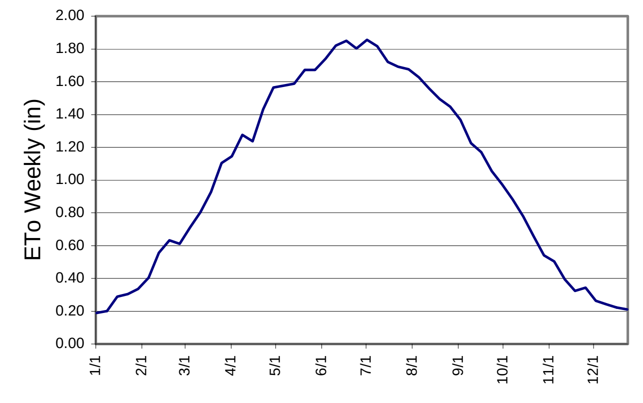


Figure D-2. Seasonal Vine Full Potential Water Use, Lodi Average ETo

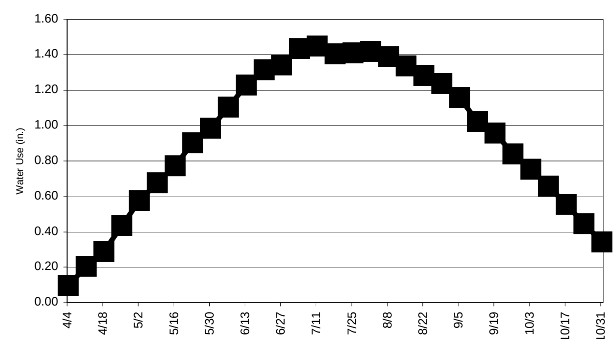


Figure D-3. Water Use Of Full Potential and Deficit Regime (-13/60%) Lodi Average Eto

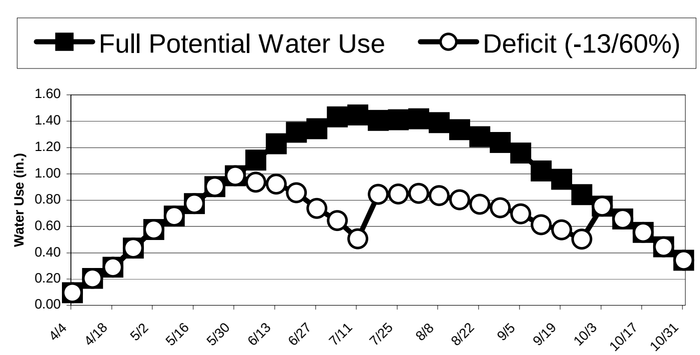
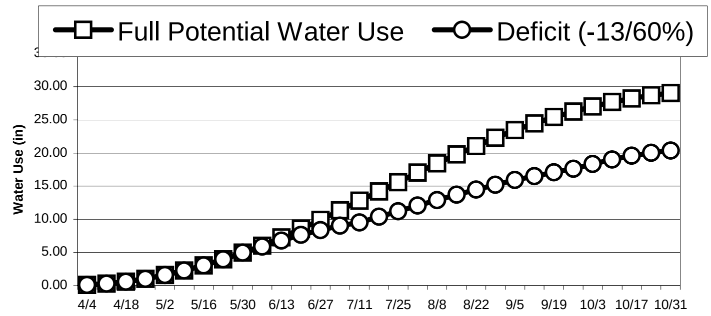


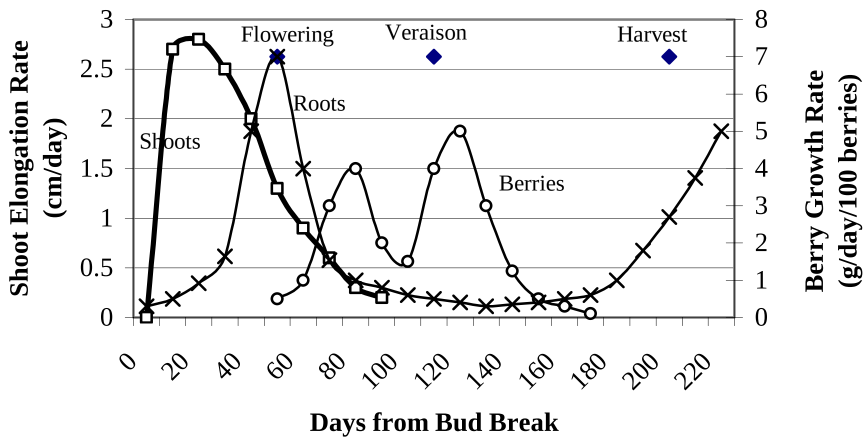
Figure D-4. Cumulative Water Use of Full Potential and Deficit Strategy (-13/60%), Lodi Average ETo



Vine/Fruit Growth and Development

The growth of shoots and leaves begins shortly after bud break. Growth proceeds at a high rate then declines to near zero as veraison is approached (*Figure D-5*). Nearly one-half the shoot length is attained by flowering. Berry growth rate increases after flowering in an initial rapid period of growth (Stage I). In the next stage (II), growth rate is much slower followed by another rapid growth period (Stage III) near veraison. Vegetative growth rate of the shoot continues to decline in berry Stage I and is virtually none existent during Stage III. Root growth, measured as the number of actively growing root tips per square meter of soil, has two distinct high growth rate periods—one at flowering and another near and post harvest. Recent research has shown a continual turnover in root numbers for the entire season.

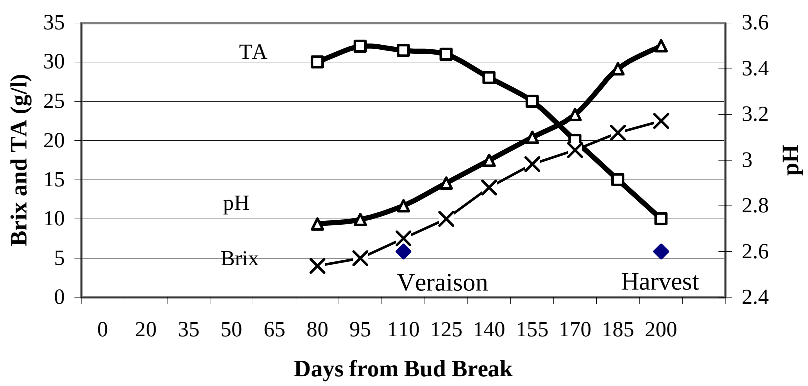
Figure D-5. Growth rate of various organs of Colombar grapevines, after Van Zyl (1984)



Berry ripening begins at veraison. The berries begin to soften, change color and begin to accelerate in growth during this third and last stage of growth (Stage III, *Figure D-6*). Berries decrease in titratable acidity (TA) and increase in pH and soluble solids (brix) as harvest is approached. If water is abundant, lateral shoot growth can continue during this period.

Most soils can provide adequate water for basic shoot growth, root growth, and berry cell division up to a month before veraison (Stage I). During berry development (Stage II), for a 3-week period leading up to veraison, water deficits can reduce main and lateral shoot growth. Limiting main shoot growth to near one meter in length provides adequate leaf area to mature the crop. Limiting growth of the main shoot and laterals provides more light to the fruit, increasing anthocyanins and phenolics for increased wine color and character. Another way to access adequate shoot growth is to determine the leaf area per weight of fruit. Between 0.8 – 1.2 m2/kg fruit for a single canopy and 0.5 -0.8 m2/kg for divided is considered optimal (Dokoozlian 1996).

Figure D-6. Titratable acidity (TA), pH and Brix change during Stage III



Effects of Vine Water Supply on Vine and Fruit

Vine Response to Water Deficits

The effects of vine water deficits can be both beneficial and harmful to the crop, depending on their timing and severity. When water deficits occur, the vine responds by closing pores in the leaf, called stomata to limit water loss. This closing of stomata reduces water loss, creating a better balance between water demand and moisture extracted by the roots. This strategy of moderating the severity of water deficits works well initially, generally limiting the effects of water deficits to a reduction in vegetative growth. As water deficits increase in severity and duration, the stomata are closed for longer periods of time. Since the stomata are the entry points for carbon used in photosynthesis, severe water deficits limit the time the stomata are open which limits photosynthesis and the production of sugar.

Water Deficit Severity

In areas of moderate climatic water demand or adequate soil water increases, deficits can be mild and expressed by a reduction of vegetative growth.

In areas of higher climatic water demand or in soils of limited water storage, deficits can occur sooner and be severe enough to cause reduced photosynthesis and partial or complete defoliation.

Water deficits can be moderated by irrigation.

Vegetative Growth

Water deficits occurring early season (bud break to fruit set) are not usually possible in most viticultural regions as previously discussed. Midseason (fruit set to veraison) water deficits are possible in soils that are shallow or coarse textured with limited (soil) water holding capacity. In low rainfall areas and during drought years, midseason deficits are possible even in deep soils. During this period, shoot development (both main shoot length and the number and length of lateral shoots) can be restricted by water deficits. Reduced canopy development can result in reduced leaf area, which may be insufficient to develop and mature fruit in low vigor situations. In years with low amounts of stored water at bud break irrigation may needed to attain adequate shoot growth. However, when vine vigor provides adequate to more than adequate canopy to support the crop load, restricting or controlling additional canopy (leaf area) may be desirable.

More severe water deficits, occurring in the period between veraison and harvest, can result in senescence of lower and interior canopy leaves providing more light to the fruit. Some loss of leaves in the fruit zone may occur without significantly reducing sugar accumulation. Moderate amounts of irrigation water during this period can successfully moderate water deficits, causing the desired effect of inhibiting further shoot growth with out reducing photosynthesis or causing defoliation. Excessive water deficits can cause defoliation, which can lead to sunburn, “raisining” or increased berry temperature, all causing reduced fruit quality.

Irrigation volumes should be adjusted to moderate, not eliminate, the deficit. Excessive irrigation during this period may cause lateral shoot growth to resume, creating a competitive sink for photosynthate, which can increase shading, cause bunch rot in susceptible varieties, delay fruit maturation and harvest. Effects on the wine are poor color/character and veggie flavors.

Timing of Water Deficits

Midseason, moderate water deficits can cause reduced vegetative canopy growth, allowing increased fruit exposure to light without limiting photosynthesis. Later season water deficits can reduce leaf cover in the fruiting zone.

Severity of Water Deficits

It is apparent that moderate, midseason vine water deficits can have a beneficial effect by reducing vegetative growth and limiting lateral growth. If too severe, deficits in mid to late season can restrict sugar accumulation or cause excessive fruit exposure.

A continued or increasing water deficit following harvest provides little or no benefit to vine and next year's crop. Root growth, which increases after harvest, can be restricted and can result in early season nutrient deficiencies the following spring. In colder areas, low temperature injury of permanent wood fruiting structures can also result if too little or excessive water is applied post harvest.

Berry Growth

Berry growth begins after flowering and pollination. Growth progresses at a rapid rate for 40-60 days. In this period, called Stage I, a berry diameter may double in size. Stage II follows for approximately 14-40 days where the growth rate slows or stops, often call the "lag" phase. The onset of Stage III is marked by veraison lasting until harvest (typically a 35-55 day period) in which berry growth resumes. Berry growth is less sensitive to water deficits than vegetative growth. However, depending on the timing and severity of water deficits, berry size can be reduced.

Water deficits during Stage I of fruit growth are thought to reduce potential berry size by reducing the number of cells per berry. The reduction in cell number causes smaller berries and almost always causes a reduced yield. However as previously mentioned, water deficits at this time are unusual in most winegrape regions of California. In years with low amounts of stored water at bud break irrigation may needed to prevent significant berry size and therefore yield reduction. Water deficits occurring during Stage II (lag phase) or III (cell enlargement) can only affect cell size. The common effect of moderate water deficits during these later periods is to slightly reduce berry (cell) size. Severe water deficits can cause reduced berry size at harvest by dehydration.

Yield

Reports on the effect of water deficits on yield are varied. Results from both California and Australia indicate white varieties (Chenin blanc, Thompson Seedless and Chardonnay) maximize yield at near 60-70 percent of full potential seasonal vine water use. With the remainder of the consumed water supporting increased vegetative growth. In red varieties, water deficits at the same level have been shown to slightly decrease yield (3 to 19%) from that of full potential water use. It is important to note the 4 year average yield reduction of 19% was from a 10 to an 8 ton per acre Cabernet Sauvignon yield. The quality of the 10-ton crop was very poor. Additionally, t yield reductions generally require moderate deficits to be repeated for one to two years before the yield reduction occur. Berry size is the most common cause of yield reductions in yield however fruit load, reported as the berries per vine, can also be responsible. Severe water deficits can reduce yield in the subsequent season as a result of reduced fruit load measured as cluster number and berries per cluster (and therefore, berry numbers). Yield reductions in red varieties have been associated with increased fruit quality while full potential water use results in reduced fruit quality expressed as reduced wine color and character.

Symptoms of Water Deficits

- Decrease in the angle formed by the axis of the leaf petiole and the plane of the lamina (blade)
- Internode growth is inhibited
- Reduced tendril growth in relation to the shoot tip
- Reduced number and length of lateral shoots
- Abscission of oldest leaves

Fruit Composition

Potential wine quality is largely determined by the composition of the fruit. The solute composition of fruit at harvest is sensitive to vine water status throughout its development. Moderate water deficits can increase the rate of sugar accumulation resulting in an earlier harvest. If deficits are severe and/or the vine is carrying a large crop, sugar accumulation is generally slowed resulting in delayed harvest since the final increases in sugar are mostly driven by berry dehydration rather than sugar production. The result is a fruit with poor balance of solutes and reduced wine quality potential.

Water deficits result in only moderate decreases in total acidity; however, malic acid is apt to decrease sooner with early season water deficits. Deficit irrigation causing moderate water deficits typically reduces malic acid concentrations in half (Figure D-7) More water stress at the threshold and lower RDI 35% further reduce malic acid content. With malic acid declining, the greatest effect of water deficits on the fruit is an increase in the tartaric to malic acid ratio. Juice acidity measured by pH, can also be reduced by water deficits.

Table D-1. Lodi Merlot 2000

Treatment (Threshold/RDI%)	Must Malic Acid Concentration(g/L)
Full potential	3.83
-13/60%	1.92
-13/35%	1.45
-15/60%	1.27
-15/35%	1.14

From Terry Prichard 2000

Wine Color

Water deficits can directly increase wine color by enhancing the production of pigments found in the skin of red wine varieties. Reductions in vine canopy using water deficits also allow diffuse light into the fruit zone, which increases skin pigment. Figure D-8 shows the increase in phenolics and anthrocyanins in berries of cabernet franc grown in the north coat of California as a result of irrigation treatment. The early deficit treatment (pre-veraison) resulted in increased phenolics and anthrocyanins over the control and the late deficit treatment. The continual deficit treatment further increased anthrocyanins.

Table D-2. Skin Phenolics and Anthrocyanins in Cabernet Franc

Treatment	Skin Phenolics mg/cm2	Skin Anthocynins mg/cm2
Control(grower std)	0.46	0.51
Early Deficit (pre-veraison)	0.56	0.61
Late Deficit (post veraison)	0.52	0.59
Continual Deficit (pre and post veraison)	0.57	0.65

From Matthews and Anderson 1984

Table D-3 shows the result of a Cabernet Sauvignon trial conducted in Lodi where water stress was imposed and light at the fruit level and the wine hue and phenoclics were measured as a consequence of treatment. The light measured at the fruit level was significantly reduced when compared to all of the deficit treatments. The increased light strongly correlates with improved hue and phenolics,

Table D-3. Lodi Cabernet Sauvignon Light at fruiting level and wine analysis Treatments as a percentage of full potential water use with pre or post veraison deficits					
	Cumulative Light	Absorbance 420 nm	Absorbance 520 nm	Color Hue	Phenolics (Abs 280 nm)
T1 (100%)	1.32 d	0.162 d	0.169 f	0.962 a	29.9 c
T2 (70%, post ver)	2.19 cd	0.227 bc	0.289 bc	0.789 bc	36.6 abc
T3 (70%, Pre ver)	1.70 cd	0.226 bc	0.268 bcd	0.847 b	33.1 cde
T4 (50%Post ver)	4.00 bc	0.295 a	0.373 a	0.790 bc	39.3 a
T5 (50%Pre ver)	3.20 cd	0.250 ab	0.335 ab	0.745 c	38.2 ab

Additionally, a decreased berry size may also indirectly contribute to improved wine color by a larger skin to volume ratio. In areas that experience severe climatic conditions for weeks at a time (Central Valley) excessive fruit exposure can raise the berry temperature, reversing the accumulation of pigments and causing poor berry color. Enhancement of color pigments (anthrocyanins) and flavor compounds (phenolics) appears to be a consistent result of better light exposure.

Vine Water Deficits Caused by Reduced Soil Water Availability

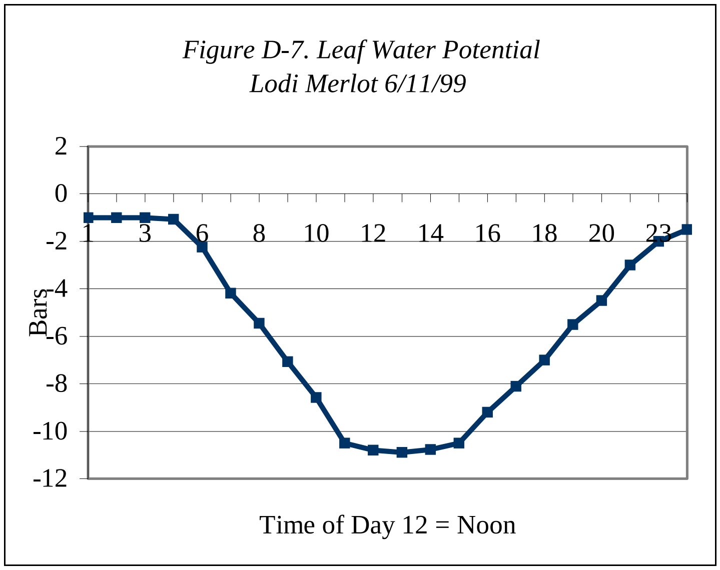
As available water to the vine becomes limited through depletion of winter-stored soil water or irrigation water, a level of availability is approached where the vine cannot sustain the full potential water use. It is at this point that the vine begins to undergo a water deficit. Essentially, a deficit occurs when the evaporative demand is greater than the roots can absorb.

Water Deficits

Water deficits occur when the energy expressed to the canopy creates a water demand that exceeds the vine's ability to extract moisture from the soil.

Under normal early-season conditions, (1) water is readily available in the root zone, (2) the vine is not at full canopy expansion, and (3) the atmospheric-driven demand is small. Therefore, under normal early season conditions, water deficits are uncommon in most if not all winegrowing regions of California. As the season progresses without irrigation, the canopy expands, climatic conditions intensify and the soil is further depleted of available water. It is at this time that the vine's water demand can exceed water uptake from the soil causing water deficits. Cooler growing regions and a greater volume of available water in the soil from winter storage or irrigation will cause water deficits to be postponed to later in the season. Generally, water deficits do not *begin* to occur until the vine has extracted about 50 percent of the available soil water contained in the root zone. Soil depth, texture and the total water stored in the root zone can influence this rule of thumb.

As water deficits begin, they occur only for a short period of time at the peak water demand period of the day. The vine recovers from water deficits initially by controlling the stomata in the leaves to limit leaf water loss. Additional recovery occurs when atmospheric conditions relax in the later part of the day and during darkness hours. This cycle continues each day, depending on the climate, available soil moisture and to some extent, root extensiveness. Without irrigation, the deficits become longer in duration and more severe as the season progresses. Water deficits are monitored using a pressure chamber to measure midday leaf water potential. *Figure D-7* illustrates a typical mid season vine water status measured over a 24-hour period.



Timing of Water Deficits

A review of winegrape irrigation research yields two conclusions in comparing the timing of water deficits: 1) moderate pre-veraison to veraison water deficits usually produced higher quality fruit and therefore wines; and 2) were usually the "best option" treatment for maintaining yields. In all cases, severe late season water deficits were more risky in terms of fruit quality and yield.

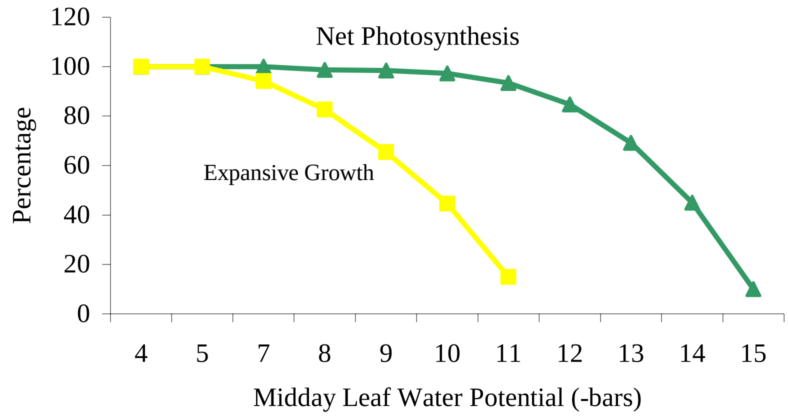
Early Season Deficits

Under normal early-season conditions, (1) water is readily available in the root zone, (2) the vine is not at full canopy expansion, and (3) the atmospheric-driven demand is small. Therefore, under normal early season conditions, water deficits are uncommon in most if not all winegrowing regions of California.

Pre-Veraison Deficits

As the season progresses without irrigation, the canopy expands, climatic conditions intensify and the soil is further depleted of available water. It is at this time that the vine's water demand can exceed water uptake from the soil causing water deficits. Cooler growing regions and a greater volume of available water in the soil from winter storage or irrigation will cause water deficits to be postponed to later in the season. Moderate water deficits at this time can control expansive vegetative growth while allowing photosynthesis to continue unabated (*Figure D-8*). This is the basis for successful deficit irrigation

Figure D-8. Relative rate vs. leaf water potential



Post-Veraison Deficits

Canopy size and climatic conditions drive water use at its maximum rate at this time. Even vineyards with the largest soil resource and cool climate will experience water deficits with out irrigation.

Postharvest Deficits

Water deficits at this time do not affect the current year's crop however severe deficits at this time can lead to low vine carbohydrate reserves to begin the next season. The post harvest root flush period requires soil moisture for the roots to expand. Trunk and root growth is responsive to excess photosynthate after harvest. If vine are defoliated after harvest it is questionable whether to apply water and re-leaf the vine.