Winegrape Irrigation Scheduling Using Deficit Irrigation Techniques

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The main purpose of controlling the application of irrigation water to winegrapes is to produce high quality fruit. The volume of irrigation water required to produce high quality fruit varies from year to year, depending primarily on the extensiveness of the vine canopy, soil resources, and climatic conditions of both the previous winter and current season. However, regardless of the exact volume of applied water, the goal is to ensure irrigation produces the desired effect on the vine and fruit. Controlling irrigation application often results in supplying less water than the full potential water requirement of the vineyard. This practice is known as deficit irrigation.

Each vineyard can be very different in location (climate), soil-water capacity, vigor and trellis design. Production goals may also depend on the variety and wine program to which the fruit is destined. Each of these factors exclusive of irrigation can significantly affect production and quality. The first step to balance vine vegetative/reproduction structures and therefore, improve fruit quality is vineyard design, which includes proper selection of rootstock, variety clone, planting density, and trellis design for a particular location, soil, and climate. Once planted and the vines are mature, irrigation can be used to maximize fruit quality. Unfortunately, even with the best plans, vegetative growth can be excessive causing reduced fruit quality. In these cases, an irrigation strategy utilizing water deficits can be adopted to optimize fruit yield and quality. Deficit irrigation is the management of irrigation, which causes vine water deficits to occur. Various timings and severity of the deficits can be used to achieve specific vineyard objectives.

This paper seeks to present a method of determine **when** to begin irrigation and to subsequently to determine **how much** water to apply. It also presents some of the effects of irrigation strategies upon the vine and fruit. Growers of quality winegrapes can use this information and experiences herein presented to determine their own irrigation strategy in pursuit of their individual vineyard goal.

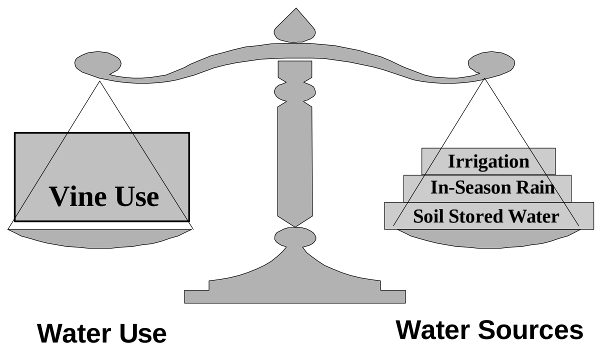
Irrigation Scheduling Concepts

When and How Much.

An irrigation-scheduling program should determine **when** to irrigate and **how much** water to apply to achieve specific objectives. The objective most often expressed are to have a predictable influence on vine growth, yield, and fruit quality.

Yields of most crops are directly related to the volume of consumed water. Therefore, full potential water use (all the plant can use) is desirable. Maintaining adequate but not excessive soil moisture can successfully accomplish scheduling for these crops for the entire season. Soil moisture monitoring methods or estimates of crop water use is commonly utilized to schedule irrigations. However, the production of quality winegrapes usually requires the use of an irrigation strategy that provides for less than full potential vine water use. Additionally, it may be desirable to use a strategy, which causes water deficits to occur at specific times and of different deficit severities. This calls for a different scheduling methodology, which can regulate the amount, and timing of water deficits.

Vineyards can use water from a variety of sources. These most typically include soil stored moisture, effective in-season rainfall and irrigation. Other water sources can include ground water from shallow or intermittent water tables. All of these sources combine to supply the appropriate quantity of water for optimal vine performance.



The Benefits of Irrigation Scheduling
• Reduced costs (energy and water).
• Control of excess vegetative growth.
• Reduced cost of hedging and multiple leaf removal.
• Reduced disease susceptibility
• Increased fruit quality
• Reduced environmental risks (off site and percolation movement)
• Reduced fertilizer losses (deep percolation)

Water Sources.
Soil stored water which will be available to the vine over the season depends on many variables. Some of the most important factors are root zone depth, soil water holding capacity and the amount, frequency and duration of rainfall events. Rainfall that falls after bud break is termed in-season rainfall. It can be effective in contributing to the vine water use if in adequate quantity to recharge soil moisture. The final vine water source is applied irrigation water. Irrigation can be applied in adequate quantities (volume) to meet full potential vine water use or restricted to cause the desired effect on fruit quality

Rooting Depth.
Vine roots can explore deeply into soils if limiting layers are not encountered. Vine water use in deep well aerated soils has been reported to depth of 20 feet. Vineyards located shallow soils or those with root zone limiting conditions can be much less. In low rainfall areas and irrigated frequently with micro-irrigation systems, vines may not develop a deep root system even if soil conditions are not limiting.

Soil Water Holding Capacity.
Water in the soil resides within soil pores in close association with soil particles. The largest pores transport water to fill smaller pores. After irrigation, the large pores drain due to gravity and water is held by the attraction of small pores and soil particles. Soils with small pores (clayey soils) will hold more water per unit volume than soils with large pores (sandy soils). After a complete wetting and time is allowed for the soil to de-water the large pores, a typical soil will have about 50% of the pore space as water and 50% air. This is a condition generally called field capacity or the full point. Clayey soils can also hold more water unavailable to the plant.

Soil Water Measuring Devices.
Many devices are available to which can estimate the amount of water contained in the root zone at bud break. Typically measurements are made with devices, which can be calibrated to read in volumetric water content. A measurement at the root zones driest, usually harvest time, then compared to the reading at bud break. The difference between these two measurements is the amount of water that the vine will remove by harvest. Many devices only measure the water status of the soil, which cannot be easily correlated to a volumetric measure of water content.

Developing an Irrigation Strategy

Effects of Vine Water Supply on Vine and Fruit.
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 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. 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 to 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. 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, and delay fruit maturation and harvest.

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 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 reduced yield. However as previously mentioned, water deficits at this time are unusual in most winegrape regions of California. 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.

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 19% yield reduction was from a 10 to an 8 ton per acre Cabernet Sauvignon yield. The quality of the 10-ton/acre crop was very poor. Additionally, these yield reductions generally require moderate deficits to be repeated for one to two years before the yield reductions occur. Water deficits, as mentioned above, can reduce yield by reducing berry size. 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.

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. 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.

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 light into the fruit zone, which increases skin pigment. 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 (anthocyanins) and flavor compounds (phenolics) appears to be a consistent result of better light exposure.

Regulated Deficit Irrigation.

Regulated deficit irrigation (RDI) is a term for the practice of regulating or restricting the application of irrigation water causing the vine water use to be below that of a fully watered vine. By restricting irrigation water volumes, soil water available to the vine becomes limited to a level where the vine cannot sustain the full potential water use. It is at this point that the vine begins to undergo a water deficit. RDI can be a consistent reduction (i.e., consistent reduction of planned irrigation volumes over the entire season) or the reduction can vary over the irrigation season to induce the desired vine response at the appropriate time.

Figure 1 shows the biweekly water use for full potential and the water use of the deficit treatment, which produced the best yield/quality relationship in a mature Cabernet Sauvignon vineyard in Lodi California over five seasons. The upper line represents the full potential water use of a mature vineyard. It is the volume of water consumed by the vineyard that occurs under conditions where soil water availability is not limited and canopy size is near 50-60 % of the land surface shaded at midday measured at maximum canopy expansion. About 30% less water was consumed by the deficit irrigation regime on a seasonal basis.

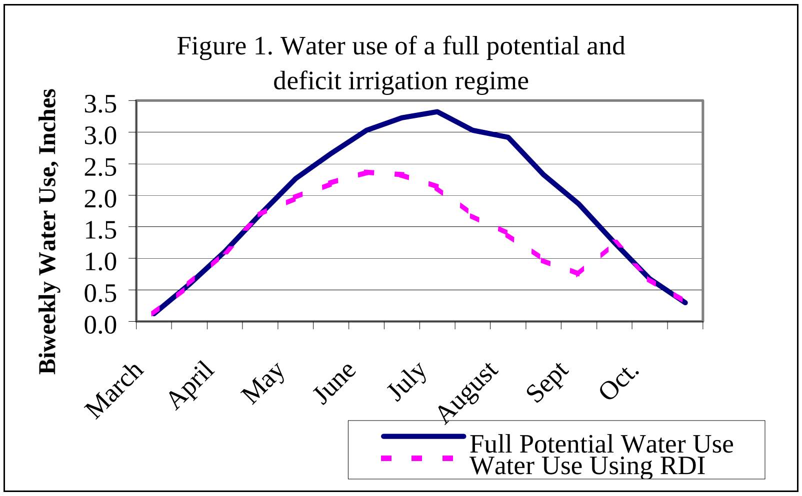


Figure 1. Water use of a full potential and deficit irrigation regime

Deficit Threshold Irrigation.

The Deficit Threshold Irrigation method (DTI) relies on a predetermined level of midday water deficit (the threshold) to begin irrigation. After the threshold is reached, a reduced water regime is used based on a portion of full water use (RDI%). The goal of the Deficit Threshold Irrigation method combined with post threshold Regulated Deficit method is to improve fruit quality and minimize yield reductions.

This method requires measurements of vine water deficits. The measurement device is called a pressure chamber often referred to as a pressure bomb. To measure vine leaf water status, a leaf is removed from the vine at midday and placed in the chamber with the petiole through a silicone grommet exposed to the atmosphere. The leaf is covered with a plastic bag just prior to removing the leaf. The purpose is to reduce the loss of water from the leaf while the measurement is made. Pressure is applied in the chamber until the sap exudes from the petiole. The pressure required to exude the sap is an indication of the level of water stress the vine is experiencing. A measurement made in this fashion is called midday leaf water potential

Determining When to Begin Irrigation

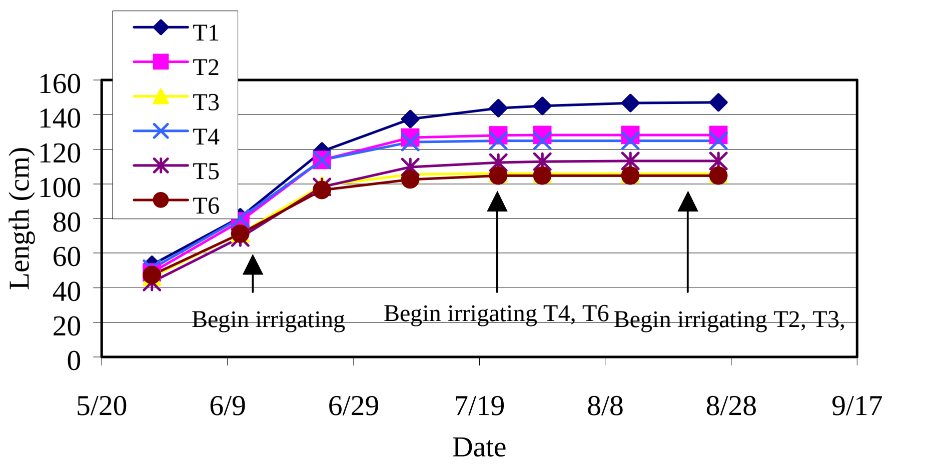
Many of the symptoms of water deficits are visual and therefore can be observed or easily measured. However, for a method to be used to determine when to begin irrigation, it must not only be easy to use but also reliable. It should be able to predict a certain level of water deficits each season. A number of these indicators have been proposed and are in use to determine when to begin irrigation. They include shoot length, shoot growth rate, and tip ratings. Measurement of plant water status through direct methods using a pressure chamber and indirect methods using infrared devices to measure canopy temperature are also in use.

Shoot Length.

Shoot lengths are influenced by water deficits if the deficits occur soon enough to slow shoot growth more than the normal slowing as veraison is approached. Figure 2 shows shoot growth of the Cabernet Sauvignon vineyard near Hopland, California for the 1999 season. The full irrigation (T1) began receiving irrigation June 1st while treatments 4 and 6 began on July 16th at

–12 bars. All non-irrigated treatments had stopped growing by July 9th. Even with irrigation, the growth slows with time. It appears that shoot length is a better indicator of the seasonal strategy rather than an indicator of when to begin irrigation.

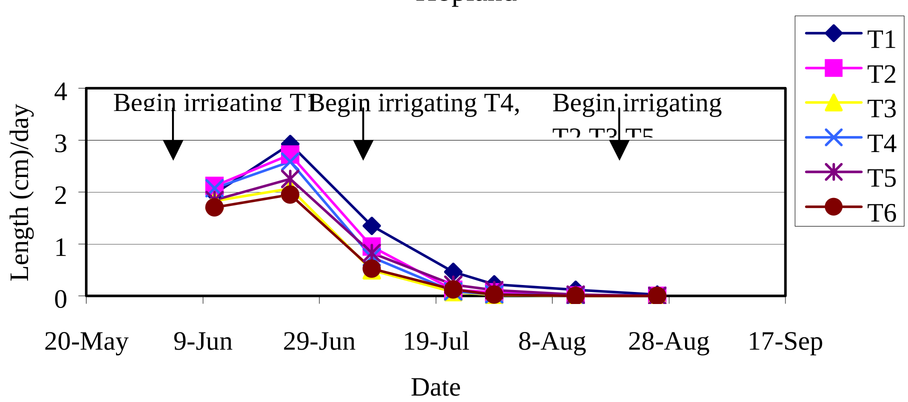
Figure 2. Shoot length, Cabernet Sauvignon, 1999 Hopland



Shoot Growth Rate.

Shoot growth rate starts out high at bud break and increases with time to a maximum usually in mid-June then declines rapidly to near zero within about 30 days (Figure 3). Shoot growth was about 0.75 cm/day when treatments 4 and 6 reached the –12 bars midday leaf water potential. Treatment 5 reached –12 bars after all growth had stopped on August 13th. In the year 2000 in the same trial, –12 bars was reached at 0.2 cm/day growth rate. Based on the results, it seems the slowing of growth rate varies as does midday leaf water potential, (and therefore water deficits), but is not strongly related.

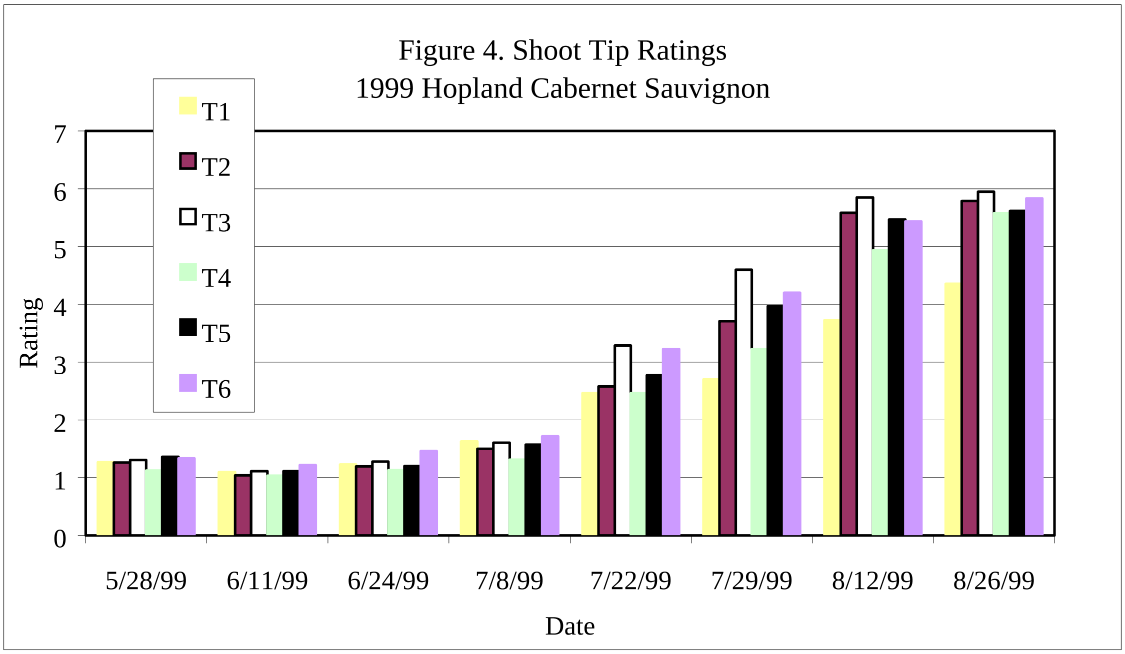
Figure 3. Shoot growth rates, Cabernet Sauvignon, 1999 Hopland



Shoot Tip Condition.

Another indicator used to determine when to begin irrigation is shoot tip condition. A rating system has been devised using numbers 1-6. A rating of 1 is when the tendril extends past the tip. A rating of 2 is when the tendril is equal to the tip, a 3, when tendril is behind the tip. A 4 is tendril yellow, a 5 when there is no tendril present, and a 6 when the tip growing point is dead.

In the same Cabernet vineyard, all tip readings prior to July 22 were from 1 to 1.5 and not significantly different between treatment and dates. The July 22 readings increased to an average of 2.7 with no difference between treatments including the T1, which had been receiving water since June 1st. On July 29th, the average had increased to 3.6 with no significant differences between the treatments irrigated on July 16th (T4 and 6) and those not yet irrigated (T2, 3, and 5). On August 12, the average of all yet to be irrigated treatments (T2, 3 and 5) was 5.4. Based on the results, shoot tip ratings increase in a linear fashion once shoot growth declines. Tip ratings do not seem to be responsive to irrigation unless it begins early in the season.

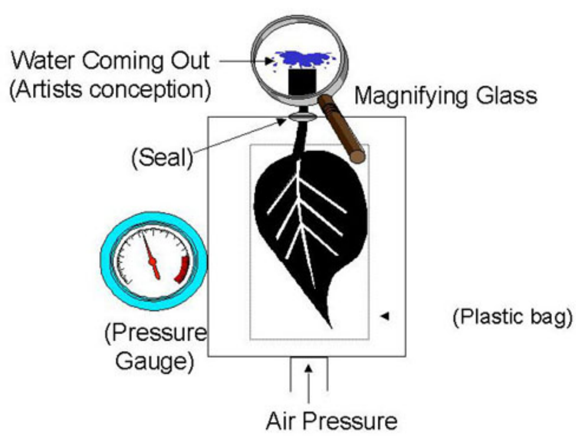


***Midday Leaf Water Potential*.**

Water is pulled from the soil up through the plant with a suction force as water evaporates from the leaves. Water within the plant mainly moves through very small-interconnected cells, collectively called xylem, which are essentially a network of pipes carrying water from the roots to the leaves. The water in the xylem is under tension, and as the soil dries, or for some other reason the roots become unable to keep pace with evaporation from the leaves, then the tension increases. Under these conditions, the vine experiences a water deficit.

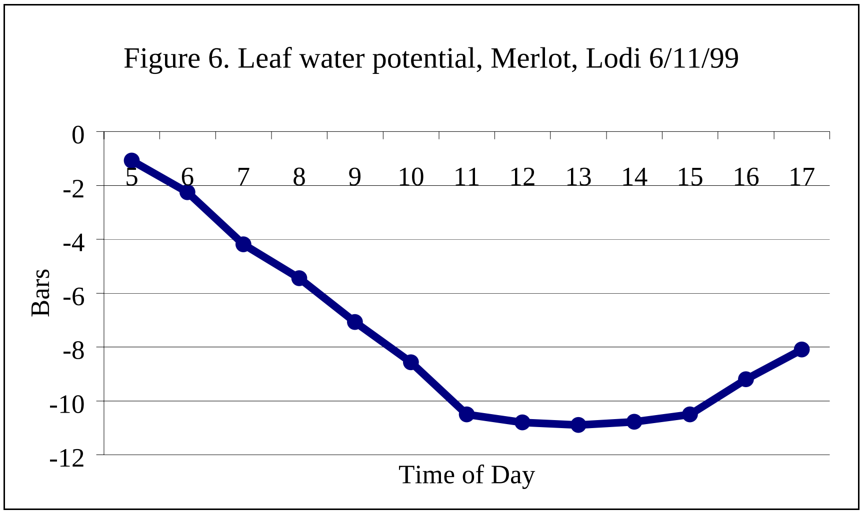
The pressure chamber (often called a pressure bomb) is a device for applying air pressure to a leaf where most of the leaf is inside the chamber but a small part of the leaf stem (the petiole) is exposed to the outside of the chamber through a seal (Figure 5). The amount of pressure that it takes to cause water to appear at the petiole tells you how much tension the leaf is experiencing on its water: a high pressure means a high amount of tension and a high degree of water stress. The units of pressure most commonly used are the Bar (1 Bar = 14.5 pounds per square inch) and the Mega Pascal (1 MPa = 10 Bars).

Figure 5. Parts of a pressure chamber.



The pressure chamber measures leaf water potential using a positive pressure to overcome the force (tension) under which the water is held in the leaf. The tension therefore is expressed as a negative number. Typical mid season reading for a well watered vine would be -9 bars. The physics of how the water moves from the leaf to the atmosphere is more complex than just "squeezing" water out of a leaf, or just bringing water back to where it was when the leaf was cut. However in practice, it is only important for the operator to recognize when water just begins to appear at the cut end of the petiole and note the pressure required.

The loss of water from the leaf is not constant throughout the day and varies with a number of factors including the environmental demand. This factor can be minimized however by measuring when the leaf water potential is relative static. Before the sun reaches the leaf in the morning, the vine has had a chance to uptake water and translocates it to all parts of the plant. The leaf water potential is the least negative at this time. As the sun contacts the leaf and heats the surface, the rate of transpiration increases, causing a more negative leaf water status. During the midday (solar noon), the water potential is again static at the daily maximum deficit (Figure 6).



Factors that Influence Leaf Water Potential.
The most important factors are:

- weather conditions at the time of sampling, and
- soil dryness

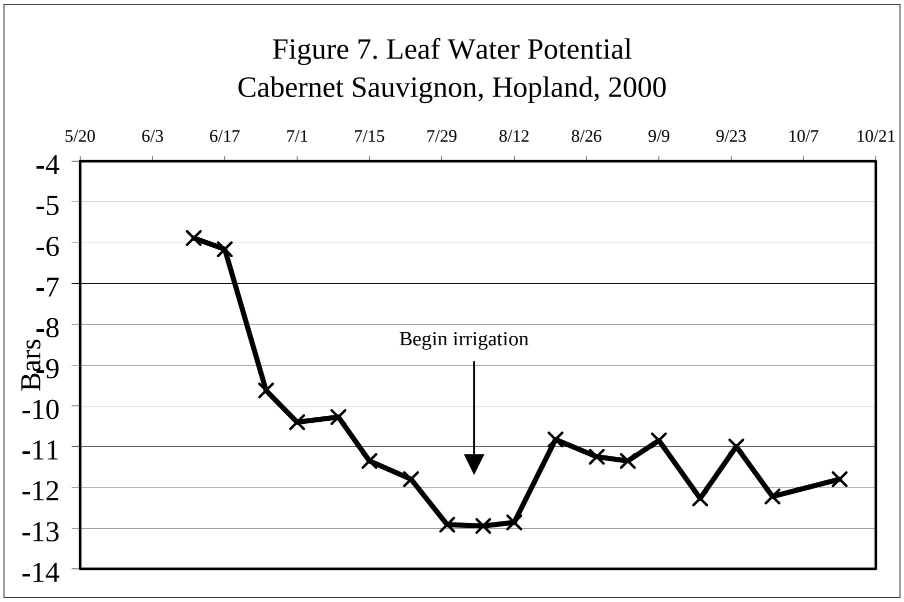
In all cases, hotter and dryer conditions cause more negative water potential. For midsummer conditions in California, the values of water potential measured on a fully irrigated grapevine will typically be between -7.0 bars and -10.0 bars. To minimize the effect of temperature, measurements should be taken only when average conditions exist. For example: If average midday temperatures are 92ºF., measurements can be made on days with midday temperatures of 90 to 95º with no need to make an adjustment for climate. Cloudy or foggy days or days with high winds should be avoided. The level of water stress as gauged by the midday leaf water potential can be generalized as shown in Table 1.

Table 1. Levels of winegrape water deficits measured by midday leaf water potential

1	less than -10 Bars	no stress
2	-10 to -12 Bars	mild stress
3	-12 to -14 Bars	moderate stress
4	-14 to -16 Bars	high stress
5	above -16 Bars	severe stress

The relationship of soil dryness to water potential is straightforward: as the soil becomes dryer, water potential will become more negative. The pressure chamber is indicative of soil dryness throughout the root system as a whole. This is very different from soil-based monitoring methods, which measure moisture in a portion of the root zone.

The vine responds to soil dryness as influenced by the environmental demand by expressing a more negative leaf water potential (Figure 7.). The water potential is effectively moderated by weekly irrigation.



Operation and Use of the Pressure Chamber

The leaf should be covered to prevent water loss just before removal from the plant. This practice minimizes water loss from the leaf. A small thin sandwich bag is most commonly used. The use of a bag lessens the need to complete the measurement quickly, thereby making measurements more consistent.

Vine Selection.
It is important to select vines for measurement that represent the average vine condition. Select those that do not have obvious nutritional, disease or other visual problems. All vineyards are variable in terms of soil uniformity. If distinct differences in soil type/depth occur in the vineyard, select vines in each area or block to monitor differences. Mark vines so the same vines can be measured each sampling.

Sample Number.
The number of vines, which are measured depends somewhat on the variability of the vineyard; however it is necessary to measure enough leaves to closely approximate the average condition. For a 20-acre vineyard, selection of six vines located in all parts of the vineyard should be adequate. Select two leaves per vine for measurement.

Leaf Selection.
Shaded leaves in the interior of the canopies will not accurately represent the maximum leaf water potential and should be avoided as a sample. Young leaves, which have not achieved full size, should also be avoided. Select a leaf that has been in full sun for a few hours from the sun side of the vine. This will be the south side of east-west rows and the west side of north-south rows.

Sample Collection.
It is most convenient to cover the leaf with the plastic bag then pick the leaf from the plant by

gently snapping the leaf off at its connection to the shoot and then re-cut the leaf petiole with a sharp razor. The leaf petiole is inserted through the sealing ring of the chamber and then re-cut after the seal is tightened

Measurement.
With the leaf inside the chamber, the measurement is made by simply increasing the pressure in the chamber until water begins to come out of the xylem that is exposed at the petiole cut surface. Usually, the pressure at which water appears is very definite. Using a hand lens, the water coming out of the petiole cut surface looks like an up welling of water from a porous surface.

The rate of pressure increase should be no more than 0.3 bars per second (Naor and Peres, 2001). A leaf with a reading of –10 bars would take a minimum of 30 seconds. Additionally, a fast rate of pressurization can cause gauge overshoot due to the time taken to stop the pressurization or read the gauge. If you overshoot, nearly the same value can be obtained if you re-measure the same leaf. You should also get nearly the same value (typically within 0.5 bar) when you measure adjacent leaves on the same shoot, so this is a good way to check your reproducibility or compare the effects of different operators or techniques. The practice of rapidly increasing pressure to near the expected reading, then increasing the pressure slowly to the end point is discouraged due to unacceptably high error.

***Problems*.**
There are two common problems that can make the endpoint difficult to detect: bubbling and the appearance of non-xylem water. If there are breaks in the leaf inside the chamber, then air can be forced through the xylem and come out of the cut end. If this air pushes some water out, or if there is a little fluid from the cells at the cut surface, then the air coming out can bubble through the water, and it can look like there is water coming out when in fact it is just the same water being bubbled around. Discard the leaf and select another sample.

Non-xylem water can occur when you squeeze the petiole in the seal and water is physically squeezed out the cut end. If you think it is the endpoint, note the pressure, then dry off the cut end and raise the pressure a bit. If more water comes out of the cut surface, then it probably was the endpoint, but if it remains dry, then it probably was non-xylem water.

***Reproducibility*.**
Two or more leaves on the same vine should give almost identical readings, i.e., within about 0.5 bars. It is good practice for beginners to sample more than one leaf per vine to check for reproducibility of measurement. With experience, only one leaf per vine is necessary. You should also get nearly the same value if you re-measure the same leaf. This is done once you see the first endpoint by reducing the pressure enough that water disappears into the petiole, and then increasing the pressure until you see the endpoint again. Different vines can give different readings, however, and these will reflect real differences in water potential, so it is important to keep track of each vine separately.

Selecting an Appropriate Deficit Threshold and RDI.

Selecting an Appropriate Deficit Threshold.

The appropriate Deficit Threshold can be determined through experimentation or experience gained by selecting a relatively safe threshold and observing the results then making adjustments for the next season based on the results. There is an emerging consensus that the severity of the deficit threshold is less important than when the deficits begin to effect vegetative growth. It is known that red varieties are more tolerant of increased deficits and tend to have improved fruit qualities when compared to white grapes.

Experimentation in the Southern Sacramento Valley and in the North Coast indicate the –12 to –15 bars is a reasonable deficit threshold however there are factors which should influence your decision.

Red grapes tolerate and benefit more from a more negative threshold. White and sparkling varieties tend to develop more tannins and more color, which may not be desirable favoring a less negative threshold. Red varieties such as Zinfandel usually benefit from a more negative threshold from a character and bunch rot perspective, Cabernet Sauvignon likewise from a character perspective. Merlot is more sensitive and benefits from a less negative threshold.

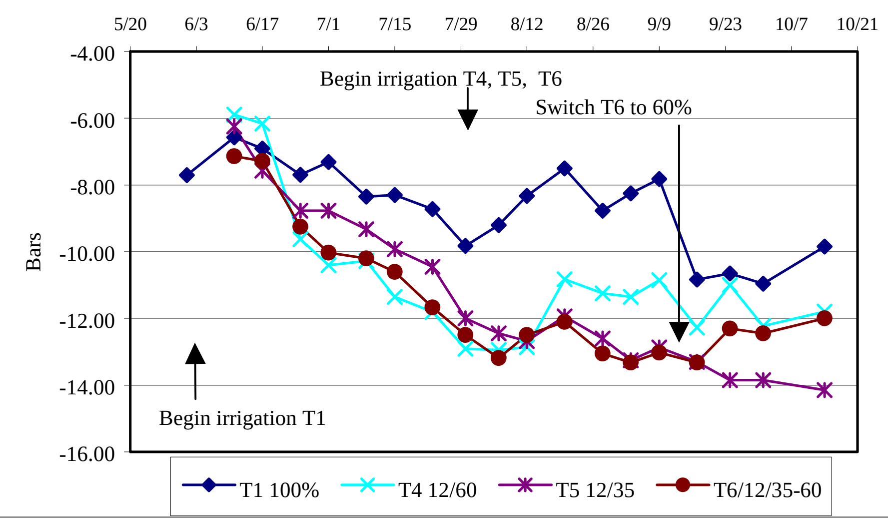
Vines in deep soil and high total water holding capacity soils located in a cool may not reach the predetermined threshold by harvest or the threshold may be reached only after a sustained severe climate period. In shallow soils/ low water holding capacity soils the threshold may be reached too early in the season causing water deficits in berry development Stage I. Water deficits at this time will cause smaller berries, which will reduce yields. To avoid this situation irrigation can forestall the reaching of the threshold until the appropriate time.

Rootstock differences seem to make no difference in the threshold selected; however, the rate at which the threshold is reached seems to be rootstock dependent. The more vigorous and root extensive rootstocks will be slower and more predictable in the increase in water stress as the approach the threshold. Less vigorous rootstocks will increase in water stress in a more rapid fashion especially when climatic conditions are harsher.

Selecting a Post Threshold RDI%.

Trials have been conducted using post threshold regulated deficits (RDI) of 35% and 60% of full potential water use. Varieties include Zinfandel, Cabernet and Merlot on Freedom and 5C rootstocks. Generally, the RDI 35% leads to increased levels of water stress from the threshold level to harvest. The length of time from the threshold to harvest determines the ultimate level of stress using the RDI 35%. Figure 8 shows the results of four treatments, two thresholds (-12 and –14) at two RDI percentages. They are denoted as 12/60 and 12/35 with the threshold RDI. Included for comparison is the full potential water treatment. Also included is a treatment, which its RDI received 35% for one half the period from the threshold to harvest then the RDI was increased to 60%. Generally, the leaf water potential remains at or near the threshold if the RDI% is near 60%. At an RDI of 35% the stress increases towards harvest. The result of too little water towards harvest can be delayed maturity (sugar accumulation), loss of fruit leaf cover and lower berry size.

Figure 8. Leaf Water Potentials
Cabernet Sauvignon, Hopland, 2000



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Determining How Much Water to Apply

***Estimating Full Potential Water Use*.**
The full potential water use varies as a result of climatic conditions and the size of the canopy. The climate factor can be estimated using the reference evapotranspiration (ETo) values. Normal or average years data can be used for planning with real time (the current year) to determine the actual use. Water use is also influenced by vine canopy growth from bud break to full canopy expansion. Canopy growth is accounted for by a modifying factor of the ETo called the Crop Coefficient (Kc). The Kc varies from a small value after bud break and increases as the vine canopy expands to maximum size. Together, these factors (ETo x Kc) 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. Canopy management practices such as hedging or canopy disruption by machine harvesting can further modify this pattern by reducing the energy interception of the vine and therefore the Kc. Vines with a larger canopy will have a larger leaf area exposed to the atmospheric conditions that drive water use and, therefore, will have a greater water use.

To estimate the water use of an area of land planted to winegrapes (ETc), it is necessary to quantify the extent of canopy coverage by measuring the percentage of land surface shaded by the vine canopy. Row spacing can have a significant influence on percent land surface shaded since closer row spacing increases the percent land surface shading. In addition, trellis design, vine health, and vigor as a result of rootstock/scion combination, soil conditions, and pests will affect the land surface shaded. Vine training, trellis type, and spring growth conditions can influence the rate of canopy expansion and, therefore, the land surface shaded at any point in time. The herein described method for estimating land surface shading seems to work well with bilateral or quadrilateral trellis systems, but less so when vertical shoot positioning (VSP) vineyards are measured. VSP canopies have the minimum land surface shaded at solar noon and therefore may require a different method to account for the canopy/land surface relationship. Research is currently underway to develop a reliable method for use with VSP and similar trellis systems.

These variables that contribute to land surface shading can significantly affect vine water use. The percentage of land surface shaded can be measured midday. Vine water use increases as the percent of land surface shaded increases up to a practical winegrape coverage limit (one that still allows for cultural operations) of 50-60 percent. The practical ramifications are that wider spaced rows, young winegrapes or low vigor vines with a small canopy have a lesser percentage land surface shaded and use less water on a per- acre basis than vines with a full canopy.

Generally, a canopy which establishes at a faster rate, i.e., cane-pruned or a quadrilateral system, increases early water use (at a faster rate) and can, at full expansion, have a larger percent land surface coverage.

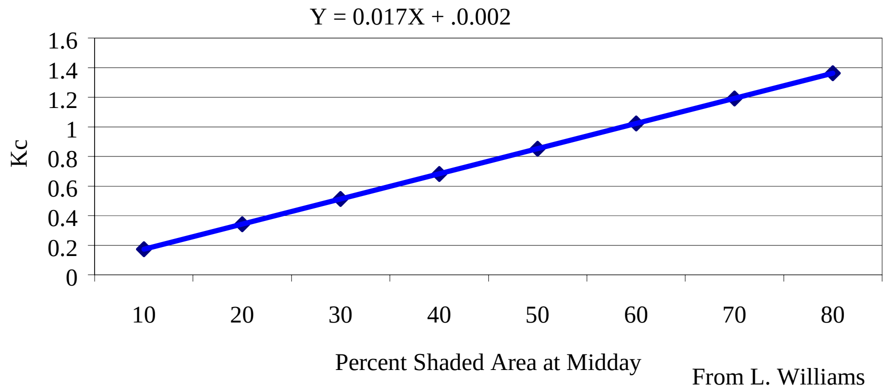
Evapotranspiration Reference Values.
Evapotranspiration Reference Values (ETo) are calculated using measurements of climatic variables including solar radiation, humidity, temperature, and wind speed and expressed in inches or millimeters of water. A one-inch depth of water use, like rainfall or irrigation water, is equal to 27,158 gallons per acre of land. ETo values most closely approximate the water use of a short mowed full coverage grass crop. ETo values are collected and made available by the CIMIS Program. The California Irrigation Management Information System (CIMIS) is managed by the State of California Department of Water Resources, which collects, maintains and supplies reference evapotranspiration (ETo) values from nearly 100 weather stations throughout California. Both historical averages (normal) and real time (current year) values are available. CIMIS is on the web at: **http://www.cimis.water.ca.gov**

Crop Coefficient (Kc).
The crop coefficient can be best determined in a vineyard by measuring the shaded area of the vineyard floor at any time during the season using the relationship between midday shaded area and the Kc. Larry Williams demonstrated in a weighing lysimeter at the UC Kearney Ag Center that vineyard water use increases linearly with the percentage of land surface shaded by the crop (Figure 9). He suggests measuring the percent shaded at midday and using the relationship to determine the Kc. The equation to describe the relationship between the crop coefficient Kc and percent shaded area is:

$$Kc = 0.002 + 0.017 \times \text{the percent shaded area}$$

The procedure would entail measuring the average shade on the floor at midday of (as an example) a 10-foot row spacing with 6-foot vine spacing. The average amount of shade between two vines is measured at 50% of the 60 square foot vine area. Using the relationship: Kc= (50 X 0.017) + 0.002 = 0.85, the Kc can be determined at any time during the season. The Kc as well as the shaded area increases to a maximum near veraison. However, it can change if hedging or mechanical harvest reduces the canopy later in the season. Using the Deficit Threshold Irrigation method, the Kc need only be determined after the deficit threshold is met and irrigation begins. This usually occurs after the canopy has stopped expanding. Absent any changes in canopy size, Deficit Threshold Irrigation requires only a single shading measurement to determine the Kc for use from the start of irrigation through harvest.

Figure 9. Relationship between land surface shaded and crop coefficient (Kc) after Williams 2002



Calculating Winegrape Full Potential Water Use.
The product of ETo and Kc yields the full potential water use.

ETo x Kc = Full Potential Water Use (ETc).

Table 2 shows the ETo and the Kc along with the calculated potential water use for winegrape, (Lodi CA) for each two-week period from bud break to leaf drop. Average ETo's, along with the Kc's, are used. The bud break date used was April 1st.

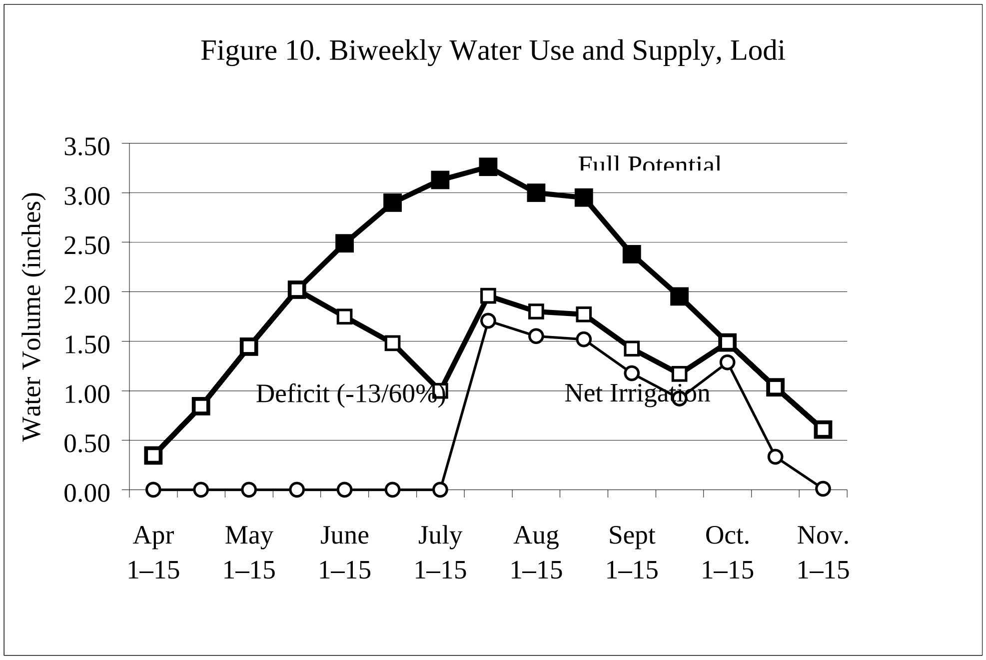
Table 2. Estimated full potential winegrape water use, Lodi CA				
Time Period	Days from Bud break	ETo Inches/Period	Crop Coefficient Kc	Full Potential Water Use (in)
Apr 1–15	0-15	2.66	0.13	0.35
Apr 16–30	16-30	3.01	0.28	0.84
May 1–15	31-45	3.44	0.42	1.44
May 16–31	46-61	3.74	0.54	2.02
June 1–15	62-76	3.83	0.65	2.49
June 16–30	77-91	3.97	0.73	2.90
July 1–15	92-106	3.96	0.79	3.13
July 16–31	107-122	3.93	0.83	3.26
Aug 1–15	123-137	3.53	0.85	3.00
Aug 16–31	138-153	3.43	0.86	2.95
Sept 1–15	154-168	2.83	0.84	2.38
Sept 16–30	169-183	2.41	0.81	1.95
Oct. 1–15	184-198	1.98	0.75	1.49
Oct. 16–31	199-214	1.52	0.68	1.03
Nov. 1–15	215-229	1.05	0.58	0.61
TOTAL		45.29		29.84

Calculating the Amount of Water to Apply Using the Deficit Threshold /RDI Method.
After the -13 bar threshold was achieved (July 16th in this example), the net irrigation requirement can be calculated from the threshold date to the end of the season using average ETo values. When real time ETo and effective rainfall values become available, they can be substituted into the following table to account for the variance from normal ETo values and the actual effective rainfall (Table 3). Using a 60% Regulated Deficit percent, the net irrigation (not including additional which may be added to overcome irrigation system inefficiency)requirement can be calculated using the formula:

Net irrigation requirement of the deficit regime =
Full Potential Water Use x 60 RDI% - Effective In-season Rainfall – Soil Contribution

Table 3. Winegrape Irrigation, Deficit Threshold Method Using RDI 60%								
Date Period	Days from Bud break	ETo Inches/ Period	Crop Co-efficient Kc	Potential Water Use (in)	RDI Co-efficient Krdi	Effective Rainfall (in)	Soil Contri-bution Post Threshold (in)	Net Irrigation Require-ment (in)
Apr 1–15	0-15	2.66	0.13	0.35		0		0
Apr 16–30	16-30	3.01	0.28	0.84		0		0
May 1–15	31-45	3.44	0.42	1.44		0		0
May 16–31	46-61	3.74	0.54	2.02		0		0
June 1–15	62-76	3.83	0.65	2.49		0		0
June 16–30	77-91	3.97	0.73	2.90		0		0
July 1–15	92-106	3.96	0.79	3.13		0		0
July 16–31	107-122	3.93	0.83	3.26	0.6	0	0.25	1.71
Aug 1–15	123-137	3.53	0.85	3.00	0.6	0	0.25	1.55
Aug 16–31	138-153	3.43	0.86	2.95	0.6	0	0.25	1.52
Sept 1–15	154-168	2.83	0.84	2.38	0.6	0	0.25	1.18
Sept 16–30	169-183	2.41	0.81	1.95	0.6	0	0.25	0.92
Oct. 1–15	184-198	1.98	0.75	1.49	1	0.2		1.29
Oct. 16–31	199-214	1.52	0.68	1.03	1	0.7		0.33
Nov. 1–15	215-229	1.05	0.58	0.61	1	0.6		0.01
TOTAL		45.29		29.84		1.50	1.25	8.50

After harvest (October 1st), the vines are irrigated at full vine water use levels. Notice the RDI percent changes to 1.0 (100%) after harvest. The soil contribution is the amount of water that continues to be withdrawn from the winter rainfall supplied soil-stored water after irrigation is initiated. The total amount extracted is relatively small (only 1.5 inches after the threshold). The amount of water that is extracted after the threshold is dependent upon the soil characteristics of depth and texture. The volume of water extracted after the threshold can be determined by measuring the water content at the threshold and at harvest. This value (available soil water content after the threshold) remains fairly constant from year to year in a given field. This remaining available water is difficult for the vine to extract and is generally extracted linearly from the threshold through harvest. Figure 10 shows the water use of the full potential and deficit regime for comparison.



Monitor the Effects of the Strategy

Measuring vine performance makes it possible to improve the irrigation both during the current year and for the following season. Post threshold measurements of leaf water potential and vegetative growth can be made during the season. Fruit quality, yield components, and maximum shoot length and pruning weights can be measured at harvest. Fruit quality can be visual, based on fruit/ wine quality and the all important winemaker comments.