Wine Grape Irrigation Management

by

Dr. Charles Burt
Irrigation Training & Research Center (ITRC)
BioResource and Agricultural Engineering Dept.
Cal Poly
San Luis Obispo, CA 93407-0730

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Due to the many varieties, soils, canopy sizes, trellis designs, growth stages, etc. of wine grape crops, there is no "one" optimum ETc value for wine grapes in any area with a specific ETo value. In more technical terminology, there is no one crop coefficient "Kc" that is valid.

The Classic "ET" Approach

One concept that is commonly mentioned by wine grape growers is that of "full ETc". This approach is technically very sound, and is used extensively around the world on most crops. The general concept is:

$$\text{Full ETc} = \text{Kc} \times \text{ETo}$$

where ETc = crop and soil ET
Kc = a published crop coefficient, that is primarily dependent upon the canopy size
ETo = a reference ET value, computed directly from weather information such as CIMIS

A rational approach to irrigation scheduling takes into account good records of weather and proper crop coefficients. However, for a large operation with numerous small fields, there just isn't enough time to take detailed real-time soil and plant measurements, process those data, and continuously modify the irrigation schedule. So having a relatively simple process at the start of the year that will utilize weather data has a lot of merit, assuming that plant indicators, yields, and yield qualities are assessed throughout the season and scheduling adjustments are made for the next year's irrigation program.

That said, there are very few crops that are as complicated to irrigate with the ET approach as wine grapes. Four categories of complications that seem particularly apparent for Central Coast wine grape growers who want to use the classic "full ETc" approach are:

1. There is some uncertainty as to how the Kc should be adjusted based on canopy size and canopy shape (height, vertical density of leaves).

2. In the early part of the season, there can be challenges with accounting for how much stored soil moisture (from rainfall) contributes to the ETc, versus how much needs to be supplied by the irrigation system.

3. Most wine grape growers apply some type of "% of full ET" factor to achieve specific vine performance via stress. The "% of full ET" factor will vary during the season, by crop variety, and by the target wine quality.

4. The ETo data may be incorrect. One of the challenges with wine grapes in the coastal regions of California is that the ETo varies tremendously within a few miles. Additionally, there are only few CIMIS stations to measure the weather variations. Therefore, growers often rely on inexpensive, private weather stations. The quality of the information can be highly variable, so the different weather stations, on the same day with the same identical weather, will provide different values of "ETo". As a result, the understanding of what is an appropriate "Kc" to use in other areas can be challenging.

These challenges are discussed below, one at a time.

Crop Coefficient, Kc. With the “full ETc” equation (Full ETc = Kc × ETo) rearranged, the crop coefficient, Kc, can be defined as:

$$Kc = \frac{\text{Full ETc}}{\text{ETo}}$$

One Kc formula found in California wine grape literature is:

$$Kc = .002 + .017x$$
where x = % shading at noon (Williams, 2001)

However, at a high percentage shade (also referred to as "percentage cover", or "percentage canopy") such as 100%, this formula gives a Kc of about 1.7, which is far beyond what is commonly accepted as a possible maximum value of about 1.25 to 1.30 for any crop.

Figure 1 shows two curves: one with the formula by Williams (2001), and another showing what ITRC considers to be a more likely Kc value for "full ET". It is obvious that this difference introduces confusion when talking about what reduction factor should be applied to "full ETc" if the computation of "full ETc" is different among growers.

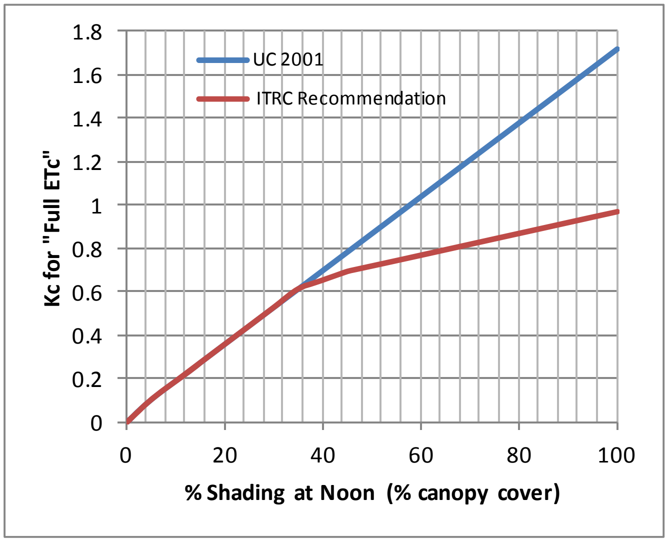

Figure 1. Recommended Kc values for initial estimates of "full ETc" before the "Percentage of ETc" factor is applied

ITRC recognizes that there is still something to be learned in this area. For example, how does one determine "canopy size" or canopy percentage? That is, what percentage of the ground surface is shaded by the canopy at mid-day? It is well understood that the Kc value depends on the shape of the trellis in addition to the percent shade at noon. One technique utilizes a solar panel that is placed on the ground surface at various points under and between plants. This technique provides a different amperage output depending upon the amount of shading, thus giving a simple reading of percentage cover.

The example below shows one possible method for adjusting the Kc value based on the Height/Width ratio.

Rule: If you have an established Kc and a Height/Width ratio
modify the Kc as follows:
for a new Height/Width ratio, FOR THE SAME % CANOPY SHADING

New Kc = Old Kc * (1 + .55*(New HWR)/Old HWR - 1)

Where HWR = the Height/Width ratio of the trellis
and the Width = (% Canopy Shading/100)* Row spacing

For example:	Old % shade =	30	gives>	0.51	old Kc
	Old Height =	6	feet		
	Old spacing =	10	feet		
Computed:	Canopy width =	3	ft		
	Old HWR =	2			
	Assume new height =	7	feet		
	new HWR =	2.3		(same width)	
New Kc		0.56			

Soil Moisture Contribution to ETc. This is an important consideration at the beginning of the irrigation season. Certainly, irrigation stress cannot be induced if there is a deep, moist soil with a high available water holding capacity. Computations are complex because during the early season, while the canopy is developing, the ET of the cover crop may be much greater than the ET of the grape vines. Additional complications arise because different wine grape rootstocks have different rooting patterns; some tend to spread out and others may go as deep as 20 feet (rare with Central Coast vineyards because the soil is often much shallower than this).

Although there is a section later in this technical note regarding computations of a soil moisture balance, the reality is that such a computation is problematic because of the large variations in soils and soil depths, and the uncertainties in cover crop ET values. Therefore, the "when to first irrigate" rules for grape growers tend to rely on plant vigor indicators rather than on soil moisture balance computations.

Percentage of Full ET. It is common practice among most wine grape growers to start with the "full ETc" value and then apply a factor such as "70%" to that ETc, thereby irrigating to some "percentage of full ETc". One of the most difficult things to translate from "ART" to "SCIENCE" is how growers will treat grapes that produce $40/bottle wine, as opposed to $6/bottle wine. In general, grapes that are destined for more expensive wine are grown with smaller berry sizes. In other words, the "% of full ETc" will vary, depending upon the variety, time of season, and market destination.

In short, premium grape growers may use as low as 50% of "full ETc" prior to verasion, but other growers who are focused more on volume may apply closer to 90% during this time.

Incorrect ETo data. There is no easy answer to the problem of inconsistent ETo data. Even with high-quality CIMIS weather stations, a good analysis of weather data begins with checks of the solar radiation and relative humidity data. The sensors for those data are subject to errors, which are even more prevalent with inexpensive weather stations. If a grower wants to use excellent ETo data, a good option is likely to have a few very high-quality weather stations using standard CIMIS equipment, and then to have a more intense grid of stations that only monitor temperature and precipitation. There are techniques that ITRC uses to extrapolate the CIMIS ETo values to other areas, based on temperature differences. This requires some work.

Recommendations for Wine Grape Irrigation on the Central Coast

The following are guidelines to procedures and techniques for wine grape irrigation.

1. Never rely on just one tool. Use all three of these:
   - *Weather-based ET estimates*. Utilize real-time weather data from a well-situated, neighboring weather station to develop estimates of ETo.
   - *Plant observations*, including leaf bomb measurements for either leaf water potential, or stem water potential, and simple observations of berry size and vegetative vigor.
   - *Soil measurements*. Different people prefer different devices, but the most important thing is to actively measure different depths, and occasionally dig backhoe pits. With sandy and sandy loam soils, or shallow soils, it is particularly important to monitor soil moisture at various depths in addition to using leaf water potential readings. This is shown in the three hypothetical soil moisture characteristic curves in **Figure 2**. The key point is that the vast majority of the AVAILABLE water held in a sandy loam soil is held at a matrix potential between (0) and (-2) bars. Once that soil moisture is used up, the matrix potential plummets rapidly.

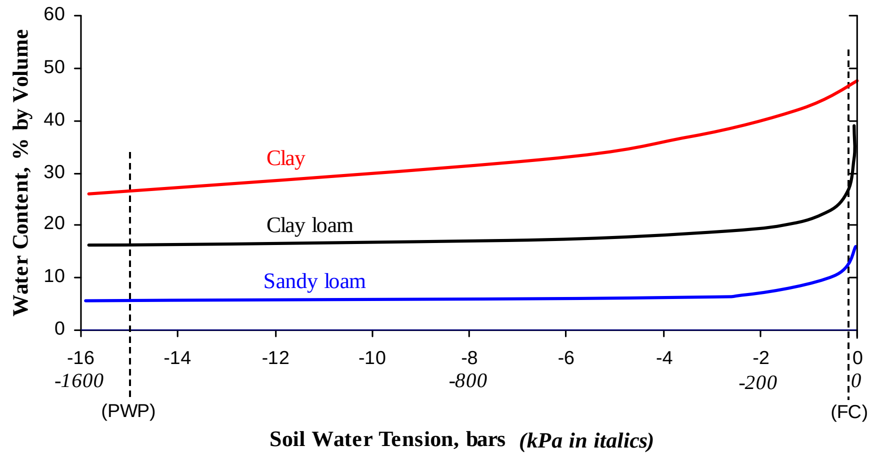

Figure 2. Example of soil moisture content curves

What this means in a practical sense is that if a manager waits until the leaf water potential equals (-12) bars, with a sandy or sandy loam soil, there is a reasonable chance that the leaf water potential can quickly drop because suddenly there isn't much soil moisture remaining.

Therefore, one must always weigh the possibilities:

- Irrigate no sooner than the target leaf water potential, which is "just on the edge", or
- Wait until the plant is "just on the edge" and risk having a hot day, an irrigation scheduling problem, or understand that there is a DU of less than 1.0 in the field, and risk losing the crop.

2. A requirement for good water management it that it is essential that the system be blocked out by soil types and depths as well as by variety and plant spacings because of the impact of rain storage, differences in plant stress due to various moisture contents, and numerous other factors.

3. It is always essential to have an excellent (better than 0.85) irrigation system Distribution Uniformity (DU). Measure it on existing systems, and specify it (better than 0.92) on new systems.

4. Keep excellent records, by date. This means that flow rates are measured and frequency/durations of irrigations are known.

5. Sampling locations for soil moisture and for plant water status must be near "average" emitters to give an "average" result.

6. Although most people schedule irrigations with long intervals between irrigations, an examination of plant physiology and photosynthesis seems to indicate that it would be best to maintain a "consistent desired" stress for Regulated Deficit Irrigation (RDI).

7. Start the plant growth period (prior to bud break) with a full soil profile of water.

8. Do not stress the grape vines until the desired canopy size is achieved.

9. Once the desired canopy size is achieved (or just before then), and after fruit set, reduce irrigation to stop tendril and shoot growth. Moderate stress (or somewhat higher) should be maintained until veraison. For high value red grapes (for which small berries are desirable) it may be desirable to have some of the basal leaves fall down just before veraison. This may equate to irrigating at "50% of full ETc". Other less valuable grape varieties will have less ETc reduction.

10. "Full ETc" for grapes can be estimated using **Table 1** on the next page.

11. After veraison, increase the irrigation frequency to maintain turgid berries and maintain the canopy.
    - Do not allow vegetative growth to restart. This means it is good to have some Regulated Deficit Irrigation (RDI).
    - Protect the fruit (do not lose leaves). This means that excess RDI is harmful.
    - Continue photosynthesis, and thereby continue sugar accumulation. This means excess RDI is harmful.

12. Talk to your good neighbors, verify results, keep good records, and use information such as this as a starting point as opposed to the final word.

Table 1. Full ETc estimates for wine grapes.

		Ballpark (Gallons per acre per day) for central coast wine grapes at various **% Ground Shading** - Cal Poly ITRC 2012										
Typical Days in May-Aug	ETo, in/day	20%	25%	30%	35%	40%	45%	50%	55%	60%	65%	70%
	0.11	1,075	1,329	1,582	1,836	1,955	2,075	2,150	2,224	2,299	2,373	2,448
	0.12	1,172	1,449	1,726	2,003	2,133	2,263	2,345	2,426	2,508	2,589	2,671
	0.13	1,270	1,570	1,870	2,170	2,311	2,452	2,540	2,629	2,717	2,805	2,893
	0.14	1,368	1,691	2,014	2,337	2,489	2,641	2,736	2,831	2,926	3,021	3,116
Cool	0.15	1,466	1,812	2,158	2,504	2,667	2,829	2,931	3,033	3,135	3,236	3,338
	0.16	1,563	1,932	2,301	2,671	2,844	3,018	3,127	3,235	3,344	3,452	3,561
	0.17	1,661	2,053	2,445	2,838	3,022	3,207	3,322	3,437	3,553	3,668	3,783
	0.18	1,759	2,174	2,589	3,004	3,200	3,395	3,517	3,639	3,762	3,884	4,006
	0.19	1,856	2,295	2,733	3,171	3,378	3,584	3,713	3,842	3,971	4,100	4,228
Moderate	0.2	1,954	2,415	2,877	3,338	3,555	3,772	3,908	4,044	4,180	4,315	4,451
	0.21	2,052	2,536	3,021	3,505	3,733	3,961	4,104	4,246	4,389	4,531	4,674
	0.22	2,150	2,657	3,165	3,672	3,911	4,150	4,299	4,448	4,598	4,747	4,896
	0.23	2,247	2,778	3,308	3,839	4,089	4,338	4,494	4,650	4,807	4,963	5,119
	0.24	2,345	2,899	3,452	4,006	4,266	4,527	4,690	4,853	5,016	5,178	5,341
	0.25	2,443	3,019	3,596	4,173	**4,444**	4,716	4,885	5,055	5,224	5,394	5,564
	0.26	2,540	3,140	3,740	4,340	4,622	4,904	5,081	5,257	5,433	5,610	5,786
	0.27	2,638	3,261	3,884	4,507	4,800	5,093	5,276	5,459	5,642	5,826	6,009
	0.28	2,736	3,382	4,028	4,674	4,978	5,281	5,471	5,661	5,851	6,041	6,231
	0.29	2,833	3,502	4,171	4,840	5,155	5,470	5,667	5,864	6,060	6,257	6,454
Real hot	0.3	2,931	3,623	4,315	5,007	5,333	5,659	5,862	6,066	6,269	6,473	6,676
		Example:	ETo of .25"/day (pretty warm, but not real hot)									
			40% ground shading at mid-day									
			Gallons/day/acre =		4,444							
		Assume a 6' x 10' vine spacing ==>				726	vines/acre					
		Gallons/vine/day =			4750/726 =	**6.1**	Gallons/day					
						**Before applying "% of ETc" factor						

Other Background Information

There has been an abundance of research on wine grape irrigation. As noted earlier, the challenge is always how to apply it to a specific field. Publications and the notes below may help shed some light on the theory and thinking behind some research results. Some recommended reading includes:

1. Winegrape Irrigation Scheduling Using Deficit Irrigation Techniques, by Terry Prichard. http://ucanr.org/sites/CE_San_Joaquin/files/35706.pdf
2. Deficit Irrigation of Quality Winegrapes Using Micro-Irrigation Techniques, by Prichard, Hanson, Schwankl, Verdegaal, and Smith. http://www.lodiwine.com/Final_Handbook.pdf
3. Irrigation of Wine Grapes in California, by Larry Williams. http://www.practicalwinery.com/novdec01p42.htm

Recommendations for First Irrigation Date

A "pre-irrigation" is different from the "first irrigation". In general, wine grape growers try to have a "full soil profile" of water prior to bud break. If there has been sufficient rain, then there may be no "pre-irrigation" required. However, if there has been insufficient rain, growers will typically operate their drip systems long enough to bring the wetted volume of soil to field capacity.

Williams (2011) noted the following for the first irrigation of the season:

- - White wine cultivars: -10 bars or more negative Leaf Water Potential (LWP) has been reached.
- - Red wine: -12 bars or more
- Date of 1st irrigation
  - This may be at the beginning of May near Fresno
  - It may be early June or later near Napa
  - The date depends on the rooting depth, rainfall, AWHC, etc.

The bottom line is that at the beginning of the season most wine grape growers want to rapidly achieve their desired canopy size and aren't interested in stressing the vines until that happens. Once the canopy size is obtained, or relatively soon before then, there is a movement to "RDI" as explained below.

Regulated Deficit Irrigation (RDI)

Regulated Deficit Irrigation, known as “RDI”, simply means that during one or more stages of plant growth, the irrigation management is regulated to deliberately achieve an ETc that is less than the potential (100%) ETc. In the past, this has been referred to as “irrigating to some percentage of ETc”.

There are numerous reasons to use RDI. Typical reasons include:

- Reducing vegetative matter, especially prior to veraison. Excess vegetative matter can:
  - Require extra pruning
  - Provide excessive fruit shading
  - Stimulate fungal diseases
- Controlling berry size, primarily after veraison. RDI will typically reduce berry size. Potential benefits include:
  - A greater skin/pulp ratio, which can improve quality of wine
  - Better aeration between berries, thereby reducing diseases
  - Smaller chance of large berries that, with some varieties, will split when they push against adjacent berries – causing disease problems.

In most cases, the total yield will be reduced with RDI as compared to irrigating for 100% ETc. The difficulty is in quantifying these effects. Three basic questions still face grape growers:

1. What specific level of stress is best?
2. What should the timing and duration of that stress be?
3. Should there be multiple optimal levels of stress for different growth stages?

We know that the actual impacts of RDI depend upon the variety, rootstock, general vigor of the plant, trellising technique, severity of RDI, and its timing.

Achieving RDI

1. Reduced vegetative growth and vigor can be achieved using several techniques, including using chemical growth regulators, selecting less vigorous grape varieties and rootstocks, and selecting special pruning techniques. Girdling with table grapes has been used for decades as a physical means to regulate growth. However, one of the most effective techniques to manage vegetative growth is via the irrigation system. As one moves from a rainy area (such as Napa or the Central Coast of California) to the desert (e.g., the southern San Joaquin Valley), careful water management is less of an option and more of a necessity in managing vigor.

2. "Traditional" furrow or border strip irrigation wets large percentages of the soil volume. Therefore, it is difficult to achieve RDI because one cannot manage the water for a "constant" deficit or plant stress. The nature of furrow and border strip irrigation is that it is possible to completely avoid stress by irrigating frequently, but it is impossible to hold a desired level of stress – simply because a large root zone, when irrigated, goes completely to field capacity. After irrigation with furrows or border strip on well-aerated soils, stress disappears.

   Some furrow and border strip irrigators have, for many decades, practiced "Partial Rootzone Drying" (PRD) [this is discussed later]. When they irrigate, they only irrigate half of the furrows or border strips at once, thereby wetting only one side of a vine row. This enables the farmers to irrigate the whole field in half the time it would normally take if every furrow was irrigated. They then irrigate the field again, but this time they irrigate the alternate side of each row.

   With furrow and border strip irrigation, this PRD practice has the following characteristics:
   a. One side of the plant is under no stress at any time.
   b. One side of the plant is under stress at any time.

   The result is that the plant as a whole does not experience a wide cycling of soil matrix potential (water content). Research on PRD in Australia in the 1990's indicated that this practice is physiologically better for the vines than irrigating both sides of the plant simultaneously. However, we now know that PRD with drip does not work.

3. With drip irrigation in a vineyard with only a small portion of the total soil wetted (e.g., less than 30% of the total soil volume receives water), an interesting phenomenon often occurs. With grapes, the first irrigation (as noted earlier) is sometimes withheld to help discourage excess vegetative growth. As a result of both grape vine ET and the ET of cover crops, the complete soil is often fairly dry when the first irrigation occurs. Therefore, the source of the majority of the ET water for the rest of the season will come from the wetted area supplied by emitters.

   What has often (but not always) been observed in almonds and grapes is this: With a restricted root system, even though part of that wetted area is maintained moist (soil matrix potentials are fairly close to zero), the plant ET is reduced. Once stress begins to occur, it can be difficult to remove the stress even though one applies what should be adequate for 100% ET.

   Two important notes are related to this observation:
   a. Growers often see no correlation between matrix potential (measured about 1' away from the emitter) and leaf water potential.
   b. It is extremely important to watch deep moisture because if the active root zone is too restricted, a few hot days can quickly cause excessive vine stress, resulting in large drops in yield. Furthermore, it can be difficult for the grapes to "recover" to a larger ET rate once they have been stressed excessively if there is a restricted root zone.

4. In areas of hot climates (e.g., the Fresno, Bakersfield, and Coachella areas), some grapes can have water stress without the growers really trying to achieve it. Furthermore, with very hot climates some growers believe that having a large soil wetted area is quite important – hence the trend towards using microsprayers on grapes in the Delano-Bakersfield area. Some growers believe that the combination of a larger water and nutrient reservoir is better for the vines in those climates, especially for table grapes.

5. Emphasizing point (4) above, when temperatures start to reach about 98 degrees in the Lodi area, it has been found that RDI needs to be abandoned and the full ET needs to be met. During the summer of 2005 near Lodi, growers who anticipated the heat spikes did well in keeping the foliage through the season. Growers who did not had detrimental early leaf loss, and had difficulty obtaining the desired sugar levels.

6. Nutrient deficiencies can cause adversely severe effects on vines that are treated with RDI.

7. In general, RDI is associated with drip irrigation. However, in order to realistically manage a vineyard for RDI, one must be capable of supplying the same amount of water to different plants throughout a field. This means the Distribution Uniformity of the drip system (accounting for all factors) must be better than 0.85. Furthermore, because rainfall water storage is so important in determining the optimum date of the first irrigation, the irrigation system must be blocked out so that:
   a. There is only one soil type and depth in a block (i.e., the total available water holding capacity in the root zone is the same throughout the block), and
   b. The actual control of the blocks must be such that it is easy to control the timing of irrigation in different blocks with ease.

   These requirements of an excellent DU and proper blocking of the field will add about $100-$1000/acre to the cost of a drip system on vines.

Partial Rootzone Drying (PRD)

The PRD concept is to alternately irrigate two sides of a vine so that the wet/dry sides alternate. The proposed benefit has been to reduce vegetative vigor while suffering no decrease in yield or quality. Furthermore, this was reported to be accompanied by a reduced ET, which resulted in water savings.

There is an abundance of literature from Australia and some researches in California on the topic of PRD. Benefits were by no means consistent and appeared to be heavily influenced by the soil type, irrigation method, percent of soil wet by the irrigation method, and whether the adoption of PRD is simultaneously associated with other changes in irrigation management. In summary, the purported benefits of PRD were:
1. Reduced ET
2. Reduced canopy vigor
3. No reduction in yields
4. No reduction in wine quality

The reported physiological mechanism of PRD in vines is this: Abscisic acid (ABA) is synthesized in drying roots and leaves. The chief function of ABA is to control the closing of the stomata (the cell void through which water vapor passes during transpiration). High levels of ABA enhance the closing of stomata, restricting the exit of water vapor but also restricting the entrance of CO_2 (and with less CO_2, there is less photosynthesis).

If part of the root system is slowly dried (and produces ABA) while the rest of the root system is kept moist, grape berry growth is not adversely affected.

However, since 2003 it has been generally accepted by researchers and growers in California that ***there is no obvious benefit to PRD***. Evidently, much of the early PRD research results were related more to applying less water (i.e., RDI), rather than the PRD effect itself. The general conclusion since 2003 is that good management of RDI is more effective and cheaper than attempting PRD. Two papers from Australia and one paper from Israel, presented at the IVth International Symposium on Irrigation of Horticultural Crops (Sept 2000, Davis CA, published in *Acta Horticulturae* 664, Dec. 2004) regarding PRD on wine grapes all concluded there was no unique response to PRD when compared against the same amount of RDI.

Timing of Stress for Wine Grapes as Reported by Three Researchers

The three examples given below are typical of what can be found through a literature search.

1. Williams, 2001
   - Variety, location: Cabernet Sauvignon, Chardonnay; Napa to Edna Valley; various rootstocks.
   - The research applied continuous ET reduction to accomplish 75% of full ET (when compared to 1.25 ET). Results were:
     - 2-5% reduction in berry weight
     - 0-19 % reduction of total yield
     - 0-21% reduction in pruning weight

2. Prichard et al., 1997
   - Variety, location: Cabernet Sauvignon, Dogridge rootstock, bilateral-cordon trained on 7.5 x 11' spacing – Lodi, Calif.
   - The research examined severe pre-veraison and moderate post-veraison stress. This treatment had more impact than severe post-veraison stress. The results, when compared to 100% ET, were:
     - *Reduced wine pH*
     - Reduced wine potassium (K)
     - *A significant increase in wine color density*
     - *A 19% yield reduction as compared to 100% ET*

3. Mayne, 1999
   - Variety, location: Results near Mendoza, Argentina (varieties not specified)
   - Evidently, these were similar trials as in Prichard, above. They found slightly different results than Pritchard. Both report an increase in wine color density and a yield reduction, but there are differences in wine pH results. However, Pritchard induced some level of stress throughout the season, not only before and after veraison.
   - Mayne reports that RDI before veraison will:
     - Reduce growth of buds
     - *Increase pH*
     - *Reduce total titratable acidity*

     RDI after veraison will:
     - Reduce yield
     - Reduce soluble solids
     - *Increase pH*
     - *Reduce titratable acidity*
     - Increase "quality of wine" because of the larger skin/pulp ratio of smaller berry sizes, resulting in more anthocyancs and phenols and color

   Berry growth is most sensitive to RDI applied 4-5 weeks after veraison

Other Points to Consider for Wine Grape Irrigation

1. Stress at different times of the season will impact different aspects of vine/berry growth, as seen in **Figure 3**.

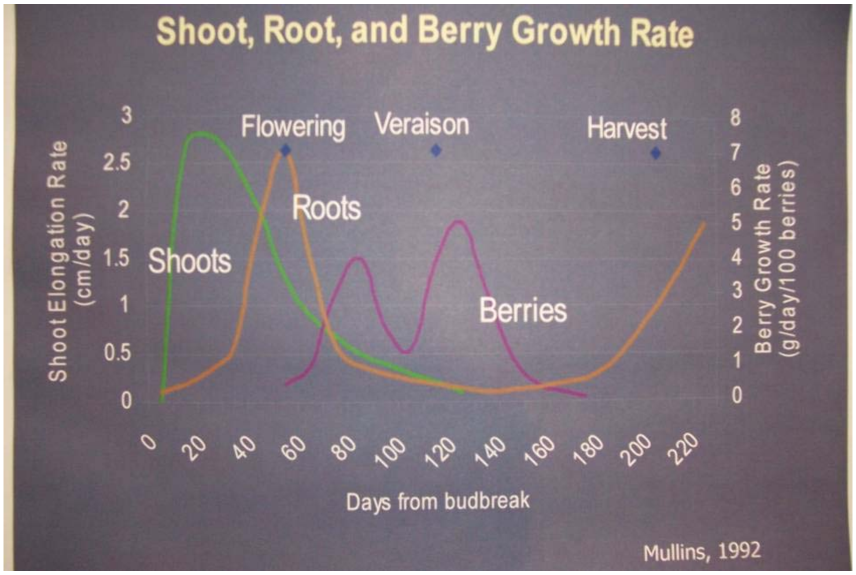

Figure 3. Growth by plant part and date (Prichard et al, 2004)

2. **Figure 3** shows that vegetative control should ideally be accomplished prior to veraison by inducing water stress. It can be difficult to accomplish this stress on heavy, deep soils because there is so much rainwater stored in the soil. As a result, in many areas with low ET rates and a small percent canopy cover, irrigation does not begin until veraison.

3. Expansive vegetative growth can be restricted by water stress without impacting net photosynthesis.

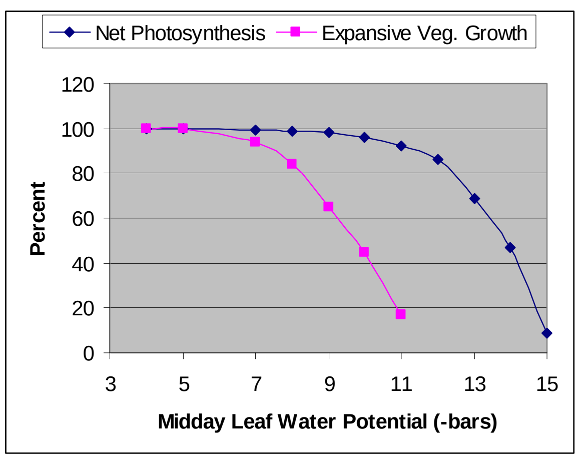

Figure 4. Relationship between leaf water potential, vegetative growth, and photosynthesis for a "typical" wine grape

Approximate dates for Paso Robles Cabernet Sauvignon (Central Coast)

Bloom – May 20 Veraison – July 24 Harvest – Sept. 27

Plant and Soil Sensors

"Tension" is a synonym for "Pressure". There are many units used to describe pressure, including:

1 bar	= 100 centibars
	= 1.01 atmosphere, atm.
	= 100 kilopascals, kPa
	= 0.1 Megapascals, MPa
	= 33.4 feet
	= 100 joules/kg
1 kPa	= 0.01 bars
1 MPa	= 10 bars

Some reference points are listed in **Table 2**.

Table 2. Units of Plant and Soil Water Tension

Item	Bars	kPa
Soil matrix potential, at:		
Saturation	0.0	0
Field Capacity (in the field)	-0.02 to -0.06	-2 to –6
Field Capacity (in a lab analysis)	-0.33	-33
Permanent wilting point	-15	-1,500
Leaf water potential at the beginning of stress for a healthy, vigorous vine	-10	-1,000
Range of leaf water potential that irrigation managers may attempt to maintain during the summer	- 10 to -16	

<u>Leaf Bomb (Pressure Chamber)</u>

The following tips are from UC irrigation specialists Larry Williams and Terry Prichard for leaf water potential measurement. Stem water potential is somewhat different because it involves putting an aluminum bag over a leaf while still attached, and leaving it there for a half hour or so before cutting it off.

- Select young, fully extended leaves on the outside of the canopy, exposed to direct sunlight (no shading).
- Leaf must not be yellow, diseased, or have insect damage.
- Take at least two samples per vine.
- Sample at solar noon (plus or minus 1.5 hour).
  - First, put a plastic sandwich bag around the leaf.
  - ***During the whole process, do not break any leaf veins.***
  - Then cut the petiole with a SHARP razor blade.
  - Within 10 seconds of enclosing the leaf in the plastic bag, place it inside the pressure chamber.
- Pressurize the leaf at a rate of less than 1 bar per second, slowing to 0.2 bar/sec as you near the leaf water potential.
- Use a magnifying glass to see when sap begins to exude. ***It should not form a drop or even a hemisphere or lens.***

Soil Moisture Sensors

With drip irrigation, the soil moisture content (and therefore the soil moisture tension) is different at every point. On one extreme, directly below an emitter one will find the highest soil moisture levels, and outside the wetted soil area, one will find the lowest moisture levels. Between these two locations, in a 3D image, one finds a gradation of soil moisture contents. Therefore, if one places a sensor 1' away from another one (either higher or lower or to one side), one will obtain a different reading.

With drip irrigation, then, one is looking for TRENDS when one examines soil moisture tension readings. Is the soil getting dryer, wetter, or staying the same? Is the upper part of the root zone staying moist, but the lower part of the root zone drying out with time? (This indicates consistent under-irrigation.) When one irrigates, is there a change in the reading for the lower sensors? (This indicates that water has reached that depth.) How long does it take for the irrigation water to show up at the lower sensor? (If it shows up in 1 hour, and the irrigation lasts 2 hours, this indicates over-irrigation for about 1 hour.)

Proper positioning of soil moisture sensors is important. **Figures 5 and 6** illustrate the proper siting for two or three sensors at one location.

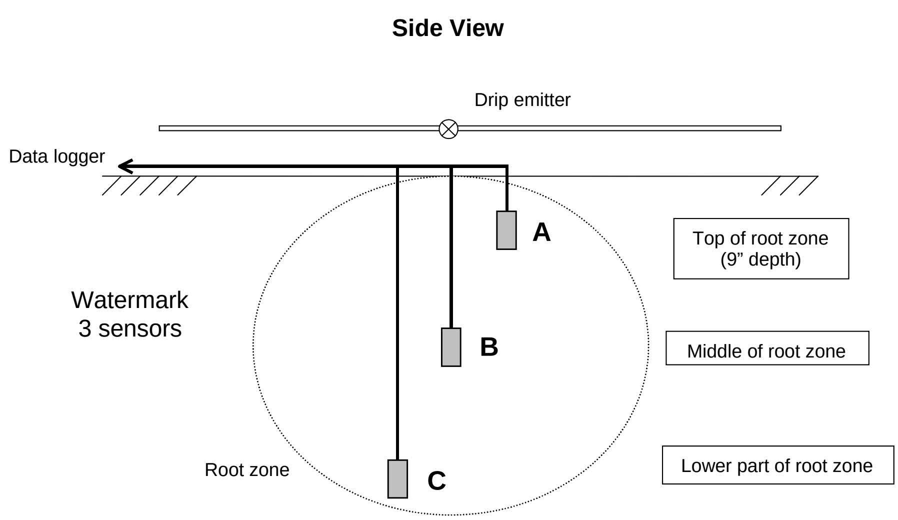

Figure 5. Side view of Watermark or Capacitance probe installation

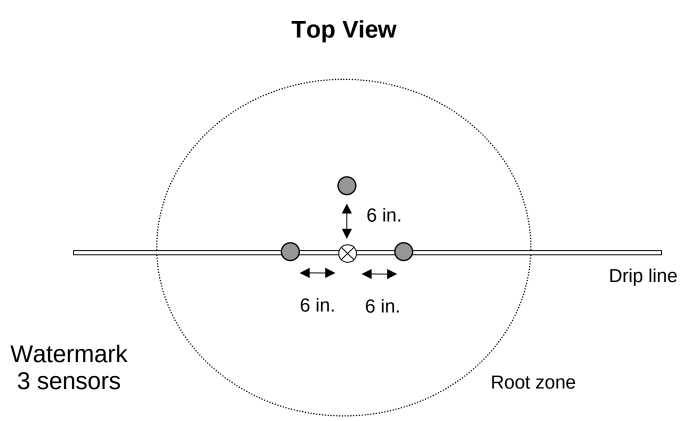

Figure 6. Plan view of soil moisture sensor installation

Example Results of Soil Moisture Monitoring in Solano County

The following field example used the soil water balance computations, together with observations of the soil water volume (within the drip wetted pattern) from a capacitance probe.

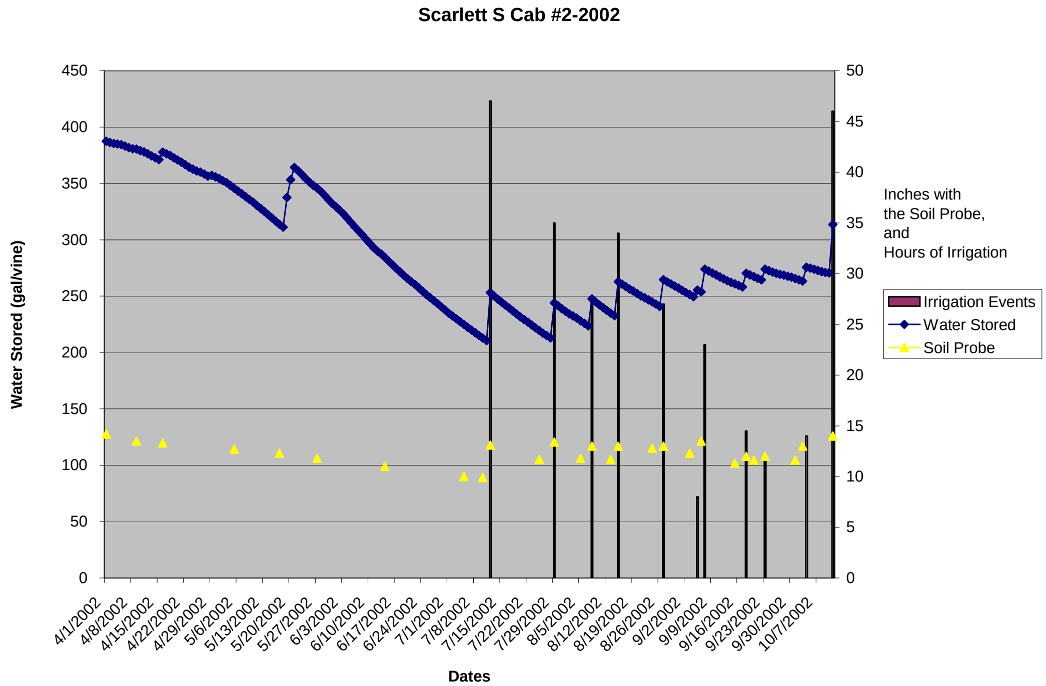

Figure 7. Example of successful irrigation scheduling in Solano County by Lisa Tenbrink of ITRC. Veraison was about July 22.

Figure 7 shows the following:

- In BLUE (thick zig-zag line segments on the upper part), the <u>gallons</u> of water (per vine) stored in the whole root zone, as estimated by the classic water balance worksheet (see example on next page).
- YELLOW triangles, showing actual <u>inches of water</u> measured by a vertical capacitance probe located 6” away from the emitter, with measurements every 4” in depth to a total depth of 40”.
- Dark vertical lines, showing <u>hours</u> of irrigation events by date.

There are several observations that can be made from the figure above:

1. The ESTIMATED moisture content in the soil slowly climbed in the last half of the season, as the MONITORED (granted, in a very restricted area near the emitter) moisture content stayed relatively constant during that time. This shows the difficulty of trying to reconcile a theoretical balance (with numerous assumptions) with soil moisture measurements (that have a very small sample area).
2. In this particular case, the first irrigation was before veraison.
3. After getting down to 40”, the moisture content, measured near the emitter, was not allowed to significantly decrease after veraison.

**The two practices that made this successful (in terms of both quality and quantity) as compared to “typical” irrigation were:

1. The soil was not allowed to dry down as much before veraison as is typical.
2. The moisture content in the wetted area remained fairly constant once veraison was reached – as opposed to letting it decline.

Example of a Soil Moisture Accounting Spreadsheet

Shown below is an example of a soil moisture accounting procedure. It has all of the classical components of ETo, Kc, AWHC, precipitation, etc.

												Kc - Parameters
Title:		Irrigation Scheduler				Date:	03-30-95					-
Filename:		SCHEDULE.WK1	WK3	Version:		2.1 Spec Wine Grape Exp						B1
Author:		Don Pitts, Irrigation Engineer, IFAS, University of Florida										B2
Address:		PO Drawer 5127, Immokalee, FL 33934										KC1
Description:		Irrigation Scheduler Worksheet										KC2
Inputs:	//////////////	////////////////	////////////////	////////////////		////////////////	////////////////		////////////////			KC3
Farm :		Scarlett South		Number of Plants in Block:					8465			Pd
Block :		2		Plant Spacing............:					8			DA
Crop :		Cab		Row Spacing (ft).........:					10			DB
Owner :		Lanza Vineyards		Wetted Area (sq ft)......:					12			DC
Irrigator:		Ken & Larry		Soil WHC (in/ft).........:					1.3			DD
Area (ac):		15.5		Rooting Depth (ft).......:					6			DE
Year :		2002		Emitters Per Plant.......:					2			PER
Emitter :		Netafim		Application Efficiency...:					95			SHADED %
k-value :		1.13		Average Pressure (psi)...:					20			
x-value :		-0.03		Soil-water on Day 1 (%)..:					100			
Soil :		Sandy Loam										
				Canopy (%)...............:					20			
-----------	-------------	---------	---------	---------		---------	---------		---------			
Emitter Flow Rate (gph).:			0.50									
-----------	-------------	---------	---------	---------		---------	---------		---------			
	Sprinkler	Irrigation			ETc	*Total Soil-H2O*		Cum Water				Water
Day	or Rain	Run-time	ETo	ETc	Cum	Soil-H2O	Soil-H2O	Use	Probe			Stored
	(inches)	(hours)	(inches)	(inches)	(inches)	(percent)	(inches)	(inches)	(inches)	Kc		(gal/vine)
-----------	-------------	---------	---------	---------	---------	---------	---------	---------	----------			-----------
01-Apr			0.17	0.03	0.03	100	7.77	0.03	14.2	0.38		387
02-Apr			0.13	0.02	0.05	99	7.75	0.05		0.38		386
03-Apr			0.10	0.02	0.07	99	7.73	0.07		0.39		385
04-Apr			0.05	0.01	0.08	99	7.72	0.08		0.40		385
05-Apr			0.07	0.01	0.09	99	7.71	0.09		0.40		384
06-Apr			0.14	0.02	0.12	99	7.68	0.12		0.41		383
07-Apr			0.14	0.03	0.14	98	7.66	0.14		0.42		382
08-Apr			0.11	0.02	0.16	98	7.64	0.16		0.42		381
09-Apr			0.04	0.01	0.17	98	7.63	0.17	13.5	0.43		380
10-Apr			0.15	0.03	0.20	97	7.60	0.20		0.44		379
11-Apr			0.11	0.02	0.22	97	7.58	0.22		0.44		378
12-Apr			0.18	0.03	0.25	97	7.55	0.25		0.45		376
13-Apr			0.20	0.04	0.29	96	7.51	0.29		0.46		374
14-Apr			0.17	0.03	0.32	96	7.48	0.32		0.46		373
15-Apr			0.16	0.03	0.36	95	7.44	0.36		0.47		371
16-Apr	0.15		0.08	0.02	0.37	97	7.58	0.22	13.3	0.48		378
17-Apr			0.14	0.03	0.40	97	7.55	0.25		0.48		376
18-Apr			0.15	0.03	0.43	96	7.52	0.28		0.49		375
19-Apr			0.22	0.04	0.48	96	7.47	0.33		0.50		373
20-Apr			0.17	0.04	0.51	95	7.44	0.36		0.50		371
21-Apr			0.19	0.04	0.55	95	7.40	0.40		0.51		369
22-Apr			0.21	0.04	0.60	94	7.35	0.45		0.52		367
23-Apr			0.22	0.05	0.64	94	7.31	0.49		0.52		364
24-Apr			0.16	0.04	0.68	93	7.27	0.53		0.53		363
25-Apr			0.14	0.03	0.71	93	7.24	0.56		0.54		361
26-Apr			0.08	0.02	0.73	93	7.22	0.58		0.54		360
27-Apr			0.15	0.03	0.77	92	7.19	0.61		0.55		358
28-Apr			0.15	0.04	0.80	92	7.15	0.65		0.56		357
29-Apr	0.04		0.11	0.03	0.83	92	7.16	0.64		0.56		357
30-Apr			0.11	0.03	0.85	91	7.14	0.66		0.57		356
01-May			0.13	0.03	0.89	91	7.10	0.70		0.58		354
02-May			0.16	0.04	0.92	91	7.07	0.73		0.58		352
03-May			0.14	0.03	0.96	90	7.03	0.77		0.59		351
04-May			0.20	0.05	1.01	90	6.98	0.82		0.60		348
05-May			0.22	0.05	1.06	89	6.93	0.87	12.7	0.60		346
06-May			0.20	0.05	1.11	88	6.88	0.92		0.61		343

Figure 8. Example soil moisture accounting spreadsheet

How Much Water Should Be Applied Per Irrigation?

For a given ETo demand, it stands to reason that a certain soil moisture content *and a certain active root wetted area in the soil* will create a specific root stress, which will in turn create a specific leaf water potential at midday.

If you accept this thesis, then once the ideal leaf water potential (stress level, such as –12 bars) is reached, ideally you would begin to replenish the soil water at the same rate as it is being removed. This is, after all, the concept of the classic soil/water balance. However, why not just observe the soil moisture content (down to about 6' of depth for vines) and try to maintain the same AVERAGE soil moisture content at that location, from that date onwards?

This gives two indicators to attempt to manage simultaneously:

1. A fairly consistent leaf water potential and visual plant status.
2. A fairly constant average soil moisture content (down to 6') near the emitter. Depending upon the soil and root characteristics, the average soil moisture content may need to slightly rise or decline with time after the initial irrigation to maintain a consistent plant status.

The leaf water potential measurement has already been described. The physical layout of Watermark sensors around the emitter has also previously been described. The same layout can be used with a wide variety of capacitance probes (that give a measure of water volume, rather than matrix potential).

In general, what one will see with proper scheduling is virtually no change is matrix potential or moisture content at the deep sensor. If one does see an increase in soil moisture content there, there is one big question: Did the water "just reach" that sensor, or did it continue to drain down below it for some time? The measurement will show the same result in both cases.

The easiest way to answer this, while also keeping a record of actual irrigation dates, is to hook a drip hose pressure sensor into the datalogger. It will indicate when irrigation events start and stop. If, for example, the deep sensor sees a change in moisture three hours after an irrigation begins and the irrigation continues for another three hours, then basically, the irrigation was twice as long as it should have been.

Table Grape Quality and Dormancy in the Coachella Valley (from Neja, 1990)

Note
Stress of 12.5% more than the "standard" irrigation treatment results in droopy vines with Perlettes Note – table grapes are harvested in June in Coachella Valley.
"Standard" treatment definition: - When shoot tips begin to trail the ground and the leaf canopy is uniform down the vine row (trellis is filled), reduced the daily water application amount to discourage vigorous shoot-tip growth. Instead, encourage only moderate tip growth during the pre-harvest and harvest period for early harvest and good berry size. - Stop shoot-tip growth within 2-5 weeks after 15-20% defoliation of the old basal leaves, during the transition period from moderate harvest time tip growth to the no shoot tip growth post-harvest period. Continue a daily, but limited water schedule. - Mid-late September, hold the leaf canopy in a no growth or no re-growth state. Allow the shoot tip (tiny terminal leaf) to wither, but maintain about 75% of the harvest time canopy through mid to late September. Use these post-harvest Kc values: July 0.45 – 0.50 August 0.50 – 0.55 September: 0.45 – 0.50 (Note that a Kc of 0.75 is needed with a 120 deg. heat wave; the Kc is lower with 115 deg. head. This indicates a weakness of the vine root system in acquiring water, which may be related to a reduced rooting system.) - Apply an "adequate amount" of water during post-harvest rains of more than 0.5" to dilute salts in the root zone. This may delay the date of drought-induced defoliation, but it's essential. - Terminate irrigation in mid to late September to initiate a drought-induced defoliation and dormancy. This gives much better results than terminating in November. - In Nov-December, after defoliation, rewet the root zone. But wait long enough to be sure that you do not stimulate re-growth right away.
To stimulate dormancy (**accumulate degree-days of dormancy**), in Nov-Dec., sprinklers (typically hand move) are placed every 4th row and are operated during the daytime on the dormant vines. This can drop daytime temperatures by as much as 12 deg. F.

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