[1]IRRIGATION WATER REQUIREMENTS OF WINE GRAPES IN THE SONOITA WINE GROWING REGION OF ARIZONA

Donald C. Slack and Edward C. Martin
Department of Agricultural and Biosystems Engineering

INTRODUCTION

This study was undertaken to determine both the total water requirements and irrigation water requirements for wine grapes grown in the Sonoita wine producing region of Southeast Arizona. Based on extensive information in the literature, crop coefficient curves were developed for two different groupings of wine grapes: Cabernet Sauvignon and Sauvignon Blanc - Chardonnay - Pinot Noir. The crop coefficients were developed using a "growing-degree-day" base which will allow their application across a wide range of climatic conditions. The crop coefficients were utilized together with long-term historical weather data from the region to estimate water use of wine grapes and , with average rainfall taken into account, seasonal irrigation requirements. Water requirements were estimated from "bud break" in the spring until well after grape harvest. This period was assumed to be from April 1, through October 1 for the Cabernet and from March 25, through October 1 for the other varieties. Average annual rainfall in the area is 17.8 inches. During the period April 1 to October 1, the average rainfall is 11.5 inches and the total crop evapotranspiration for Cabernet Sauvignon was estimated to be 15.8 inches. The resulting "deficit" to be made up by irrigation would thus be 4.3 inches. However, even the best irrigation systems are not 100% efficient and rainfall early in the season is insufficient to provide plant requirements. Thus total irrigation requirements for the growing season were calculated as 5.91 inches which amounts to 353 gallons per plant. The slight additional rainfall attributed to the last week of March was considered negligible and thus the irrigation requirement for the Sauvignon Blanc - Chardonnay - Pinot Noir group was also 5.91 inches or 353 gallons per plant. These estimates are based on clean-tilled vineyards with no grass growing between rows. Grass cover can increase the water requirements by as much as 100% since the maximum crop coefficient for wine grapes is only 0.53 for a grass based reference (i.e. the grass coefficient would be 1.0). In other words, wine grapes use only about half as much water as green grass 8-15 cm (3-6 inches) in height!

Background and Objectives:

The Arizona Wine industry has grown in the past ten years into a viable industry which marketed approximately 50,000 gallons of Arizona produced wine in 1994. Much of this production comes from the Appellation Sonoita region near Elgin, Arizona. Concern has arisen in recent years that water resources of the region may not be sufficient to sustain extensive development of vineyards in the area. This concern is predicated, in part, on the assumption that significant amounts of

---

This is a part of the University of Arizona College of Agriculture 1999 Wine Grape Research Report, index at: http://ag.arizona.edu/pubs/crops/az1148/

irrigation water are required for production of wine grapes. However, a thorough study of the irrigation water requirements for wine grapes in the region has not been undertaken. In a previous study of the suitability of water harvesting techniques for wine grapes in the region, Cadot, et al. (1989) estimated that a maximum of 7.8 inches of irrigation water would be required to supplement available rainfall when water harvesting methods were used. This estimate was for the driest of 20 years of simulated weather data and utilized consumptive use data developed for table grapes (Erie, et al., 1981) near Phoenix (Litchfield Park and Mesa). Water requirements of grapes, however, varies considerably with cultural practices (Doorenbos and Pruitt, 1984) including tillage practices and the level of stress tolerated. Generally, some degree of stress is desired in wine grapes prior to harvest to increase sugar content and maintain relatively small grapes which results in a higher ratio of skin to juice than is normal with table grapes where large turgid grapes are desired. Thus, this study was undertaken in order to better define the water use and irrigation requirements of wine grapes in Arizona and to help growers more effectively plan and manage irrigation. Several specific objectives were pursued: first to quantify a relationship between "growing-degree-days" (GDD) and crop evapotranspiration; secondly to define crop coefficients for the primary varieties grown in the region and finally to utilize this information together with historical weather data to calculate consumptive water use during a growing season and irrigation water requirements.

Evapotranspiration and Crop Water Requirements:

Evaportranspiration (ET) represents the water loss from a combined surface of vegetation and soil. ET is dependant upon several factors including; the stage of plant growth and development, the evaporative "demand" of the atmosphere, soil water availability, vine cultivar, insect damage and overall plant health and cultural practices (Mullins, 1992). Large and high trellis systems generally produce greater yields than systems which produce a smaller total leaf area. It is often assumed that the larger systems use more water. Williams and Matthews (1990) found that girdling grape vines decreases the water use of the vines for approximately one month after the girdling takes place. Irrigation frequency also has an effect on vine water use. If the soil water is depleted to the point that the vines are stressed, the use of water by the vines will decrease (Grimes and Williams, 1990).

Various methods for estimating crop water use from meteorological information have been proposed and are currently in use. Most ET estimation methods use four factors:

1.An estimate of reference evapotranspiration (ET_r) based on a specific reference crop. The two most common reference crops are cool-season grass and alfalfa. The estimates are made using semi-empirical equations and meteorologic data.

2.A crop coefficient (K_c) which describes both the dynamic seasonal and developmental changes in crop ET in relation to ET_r. The crop coefficient is thus a variable which is a function of the crop stage of phenological development and architecture.

3.A soil dryness factor (K_d) which describes the effect of low water content on transpiration and which has a close interrelationship to such properties as rooting depth and soil water holding capacity.

4.A soil wetness factor (K_{co}) which describes the increase in ET due to soil surface wetness immediately after rain or an irrigation.

Crop water use is estimated using these factors in an equation:

$$ET_c = ET_r * ((K_c * K_d) + K_{co})$$

where ET_c is the estimated crop water use amount in the same units as ET_r and all K factors are unitless. While several methods are available for estimating reference crop evapotranspiration, the most commonly used are: the Jensen-Haise (radiation) method; the Penman (combination) method; the Pan Evaporation method and , more recently, the Penman-Monteith equation. The FAO Modified Penman method (Doorenbos and Pruitt, 1984) is probably the most widely used of these methods and is the one utilized by the Arizona Meteorological Network (AZMET) to estimate both hourly and daily ET_r . This equation is expressed as:

$$ET_r = c * [W * R_n + (1 - W) * f(u) * (e_a - e_d)]$$

where c is an adjustment factor to compensate for the effect of day and night weather conditions, W is a temperature related weighting factor, f(u) is a wind function, R_n is net radiation equivalent in inches/day and (e_a - e_d) is the vapor pressure deficit. This equation is also utilized by the Arizona Irrigation Scheduling program (AZSCHED) (Fox, et al. 1996) to estimate daily ET_r. The FAO Modified Penman equation was the method used in this research to calculate daily reference crop evapotranspiration and these calculations were made using the AZSCHED program.

Some researchers have found that for a wide range of both annual and perennial crops, heat is the most single important climatic variable affecting the rate of phenological development and achievement of physiological maturity (and therefore K_c) under normal conditions of solar radiation (Slack, et al., 1994). A convenient way to express the accumulation of heat is in the form of “growing-degree-days” or “growing-degree-hours”. This method is preferable to the other widely used method of expressing K_c which is either as a fraction of the growing season or as “days after emergence” for annual crops or “days after budbreak” for deciduous fruit crops such as grape vines. This report uses growing-degree-days calculated in the simplest form which, for a particular crop, is:

$$GDD = T_{mean} - T_{base} \qquad \textbf{(3)}$$

where T_{mean} is the daily mean air temperature and T_{base} is the minimum daily mean air temperature required for crop growth. This is a unique characteristic of the crop. Equation 3 is valid for $T_{base} \leq T_{mean} \leq TG_{max}$ where TG_{max} is the daily mean air temperature above which crop growth and development is constant. For example, a crop which has $T_{base} = 10^oC$, a daily mean air temperature of 20^oC and TG_{max} of 25^oC would yield 10 degree-days of growth per day. On the other hand if the daily mean air temperature was 30^oC, the degree-day accumulation for one day would be 15 (25-10) since the maximum temperature for growth is $25^o C$.

The use of water by wine grapes is characterized by low water use early in the growing season and after harvest and by high demand when canopies are fully developed. Crop coefficients have been developed for table and wine grapes in different places around the world (Bucks, et al., 1985; Tosso and Torres, 1986; Doorenbos and Pruitt, 1984). All such curves have the characteristic of low values early and late in the season with peak values in mid-season. Bucks, et al. (1985) determined a maximum crop coefficient for Perlette, which is a table grape variety, in the Phoenix area to be 0.63. Table I shows these crop coefficients as a function of both time and GDD.

Table I.Semi-monthly K_c values and semi-monthly accumulated GDD values for Perlette grapes for Phoenix, Arizona.

Semi-monthly Period	Cumulative GDD	Crop Coefficient K_c
15-28 Feb	38.0	0
1-15 Mar	114.0	0.07
16-31 Mar	212.2	0.21
1-15 April	340.4	0.35
16-30 April	510.4	0.50
1-15 May	705.2	0.52
16-31 May	936.1	0.45
1-15 June	1194	0.61
16-30 June	1478.7	0.63

Wine grapes are harvested at a higher accumulation of GDD. In Maipo Valley Chile this accumulation was about 1.2 times that of Perlette for Pinot Noir, Sauvignon Blanc, Chardonnay and Cabernet Sauvignon varieties (Villaseca, et al., 1986; Tosso and Torres, 1986). If a similar relationship exists between these varieties in Arizona, we might expect the maximum accumulation of GDD to be around 1800. To further assess the duration of the growing season in terms of GDD, we calculated GDD for a typical growing season using historical temperature data (Sellers, et al., 1985). A "calendar" of phenological development stages for two varietal groupings is shown in Table II. This information is based on personal communication with Dr. Gordon Dutt who has produced these varieties in the Elgin, Arizona area (Dutt, 1995).

Table II.Phenological stages for wine grapes at Elgin, Arizona (Dutt, 1995)

	Wine Grape Variety	
Growth Stage	Pinot Noir-Sauvignon Blanc-Chardonnay	Cabernet Sauvignon
Bud Break	4th week March	1st week April
Green Shoot	1st week April	2nd week April
Bloom	1st week May	2nd week May
Veraison	2nd week Aug.	2nd week Aug.
Maturity	4th week Aug.	1st week Sept.

Based on these growth stages and a base temperature for growth of 10° C, corresponding accumulations of GDD for each of these periods were developed and the crop coefficient data of Table I modified to correspond to the typical management of wine grapes whereby they are water stressed near the veraison stage to maintain a small fruit size thus providing a greater percentage of skin per unit volume of grape juice. Table III shows the resulting crop coefficient values as a function of accumulated GDD for the two variety groupings. It should be pointed out that these coefficients are for fully mature vines (approximately five years old) and that for younger vines the water use and therefore the crop coefficients be less.

Figure 1 illustrates the coefficient in graphical form for the Cabernet Sauvignon grape variety in terms of days after bud break (assumed to be April 1). Figure 2 is the same graph expressed in terms of GDD (°F basis: 50°F = 10°C). Figures 3 and 4 illustrate the same information for the Pinot Noir, Sauvignon Blanc and Chardonnay varieties.

Water Status and Wine Quality:

Grape quality is largely determined by the composition and size of the fruit. While large size is an important quality factor for table and raisin grapes, small size is preferred for wine grapes, particularly for the red wine grapes since fermentation is conducted with the skins. Small grape size (large surface to volume ratio) is preferred since the dermal tissue (skin) contains most of

Table III.Crop coefficients for wine grapes as a function of accumulated growing degree days (^{o}C basis: to convert to ^{o}F basis, multiply by 9/5).

K_c	GDD (Pinot Noir, etc)	GDD(Cabernet Sauvignon)
0	0	0
0.07	146	162
0.21	272	301
0.35	436	483
0.5	653	725
0.52	903	1001
0.45	1310	1300
0.50	1410	1370
0.50	1510	1443
0	1800	1800

the color and flavor-producing compounds. Clearly, smaller grapes are produced on vines that experience water deficits than on vines that are continually without stress.

The concentration of sugars in wine grapes determines the final alcohol content and its influence on wine flavor. Wine grapes typically contain 21 to 24 % fermentable sugar at harvest. Harvesting after this level of sugar is reached tends to reduce total yield by increasing the number of dry grapes (raisins).

The accumulation of sugar is much less sensitive to water deficits than is fruit growth. Hence, irrigation generally increases yield while frequently having little effect on sugar concentration. When sugar accumulation is affected, it is delayed by increased turgidity in the grapes. Organic acid levels normally range from 6 to 12 grams per liter (expressed as tartaric acid equivalents) in wine grapes at harvest. The acid level in grapes is important to balance the acidity of the wine. A moderate decrease in titratable acidity was observed where plant want status indicated significant water deficits (Bravado, et al., 1986).

Sotomayor and Lavin (1984), found that wines from high water level vines were lower in alcohol, extract total polyphenols, color intensity and pH and higher in titratable acidity than vines which experienced some degree of water stress. In addition to laboratory analysis, sensory evaluation detected differences in color, aroma, body, taste, astringency and general quality between wines from continuously unstressed vines and those that were stressed after veraison.

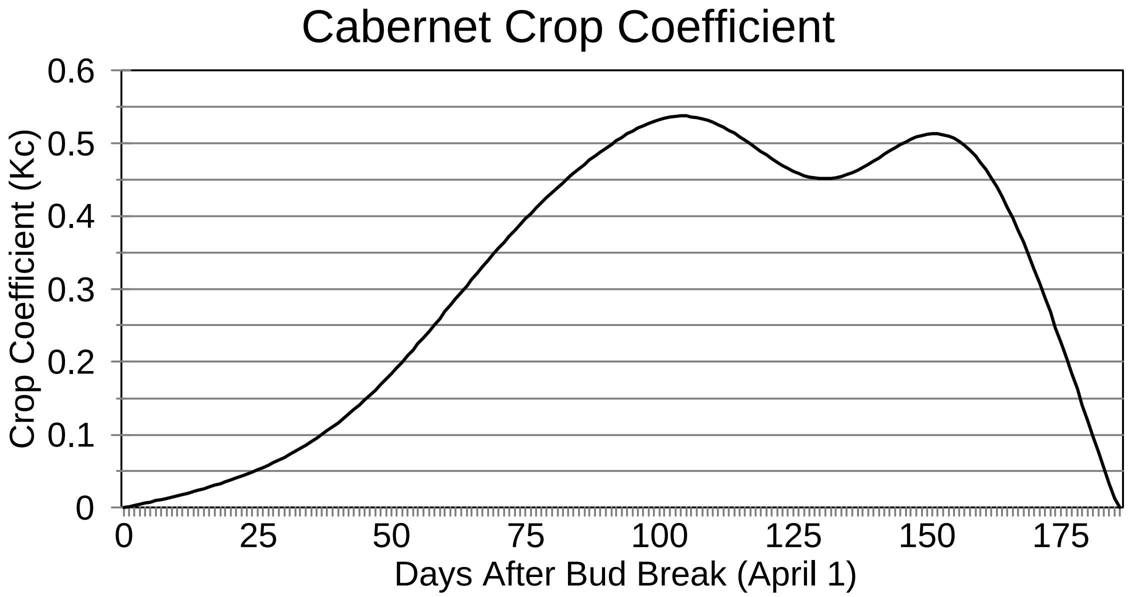

FIGURE 1.Crop Coefficient Curve for Cabernet Sauvignon Grapes as a Function of Days After Bud Break.

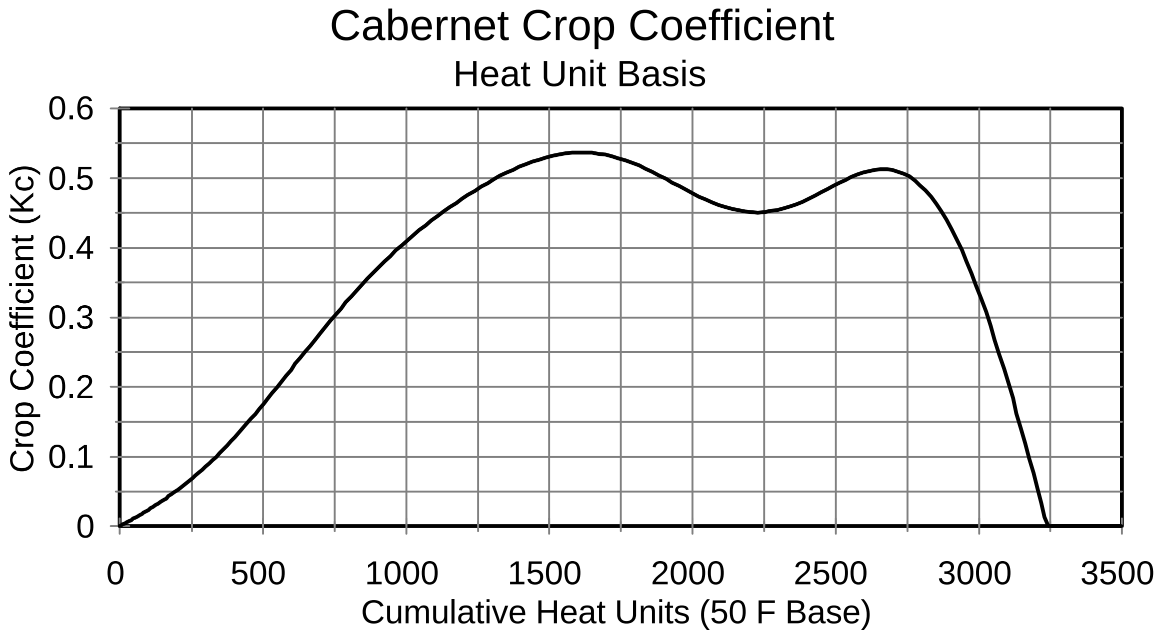

FIGURE 2.Crop Coefficient for Cabernet Sauvignon Grapes as a Function of Growing-Degree-Days

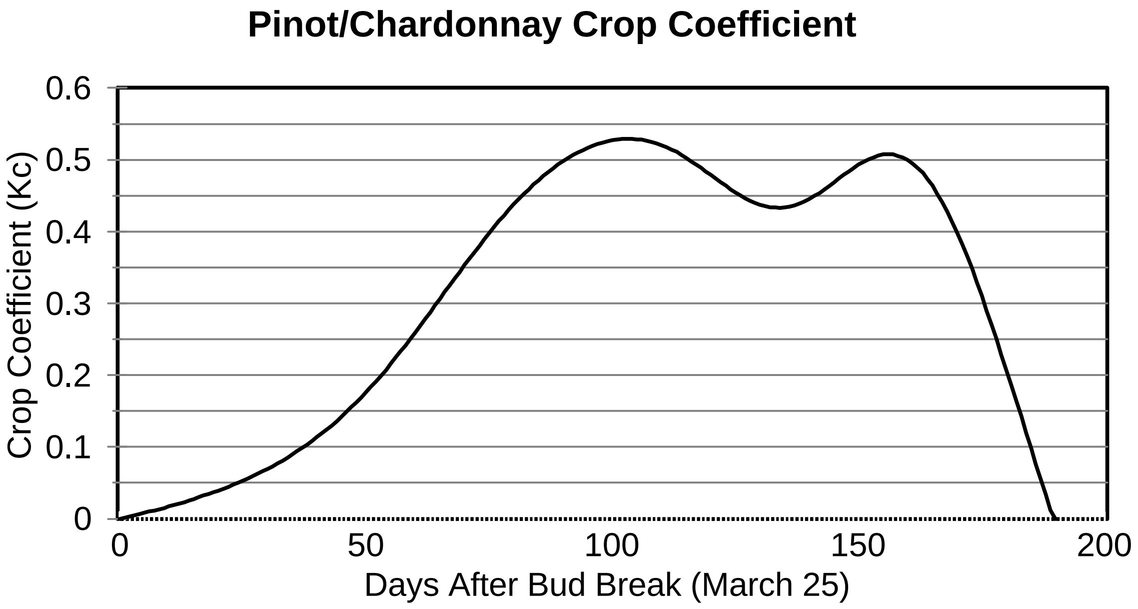

FIGURE 3.Crop Coefficient Curve for Pinot Noir, Sauvignon Blanc and Chardonnay Grapes as a Function of Days After Bud Break

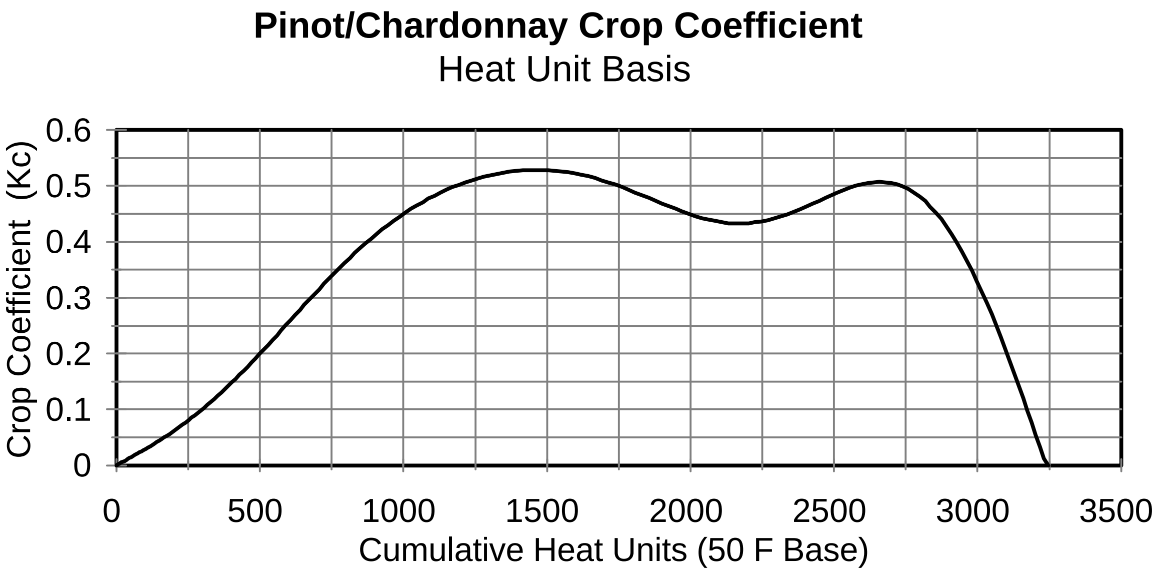

FIGURE 4.Crop Coefficient Curve for Pinot Noir, Sauvignon Blanc and Chardonnay Grapes as a Function of Growing-Degree-Days.

Wines from stressed treatments were *always superior in every way* to those from continuously unstressed vines! Thus for wine grapes, it is recommended that some degree of stress be allowed to occur after veraison (the onset of color change) which occurs at about 1300 GDD (^{0}C) for both of the variety groups shown in Tables II and III. For this reason, the crop coefficient is reduced from 0.52 to 0.45 and allowed to increase again only to 0.50 prior to harvest. This contrast with the crop coefficient of 0.63 shown in Table I for Perlette table grapes where large fruit is desired at harvest.

Water Use and Irrigation Requirements for Wine Grapes in the Sonoita Region

In order to assess the irrigation water requirements and water use of wine grapes in the Sonoita wine growing region, a “typical” location of Sonoita Vineyards was selected. The soil at this location is a Whitehouse soil which is typical of the region with an available water holding capacity of 6 inches in a maximum rooting depth of 4.92 feet (Cadot, 1989). A drip irrigation system is typically used for wine grape production and these systems generally operate at a level of 90% efficiency (90% of the water applied winds up in the root zone and can be fully utilized by the plant). While the root zone is capable of holding 6 inches of water, irrigation is typically undertaken well before all of that water is depleted. For most fruit crops, including wine grapes, a typical level of allowed depletion is 45%. Thus, irrigation is recommended whenever 2.7 or more inches of soil water has been depleted. Since the average annual precipitation at this location (Canelo, Sellers, et al., 1985), is 17.8 inches and 11.1 inches of this occurs during the growing season for wine grapes, it is quite likely that in normal years the root zone should be near “field capacity” in terms of water content as a result of winter rains (field capacity is the amount of water which remains in the root zone after the soil has been fully irrigated and any excess water allowed to drain from the soil profile). Figure 5 illustrates the average cumulative rainfall in inches at the Canelo meteorological station. For the illustration presented in this report the assumption was made that the root zone contained 6 inches of available water at bud break. Of course, in drought years or in years where significantly less than 6 inches of rain occurs between October first and April first, the vineyard should be irrigated prior to bud break to bring the root zone to near field capacity.

An irrigation water requirement calculating program, AZSCHED, was utilized to calculate daily evapotranspiration and irrigation requirements based on long-term historical weather data from the Canelo weather station which is the nearest such station in the region. The long-term weather data was obtained from Sellers, et al. (1985) and used to construct a complete data set for Canelo/Sonoita which is included in this report on an AZSCHED program diskette. The crop coefficients shown in Table III were also incorporated into this program. The program uses a soil water balance approach to determine when irrigation is required and how much is required to bring the soil back to field capacity. While the program calculates ET and irrigation requirements in inches, the results are presented in gallons per plant since most growers utilize drip irrigation systems which have emitters calibrated in gallons per hour.

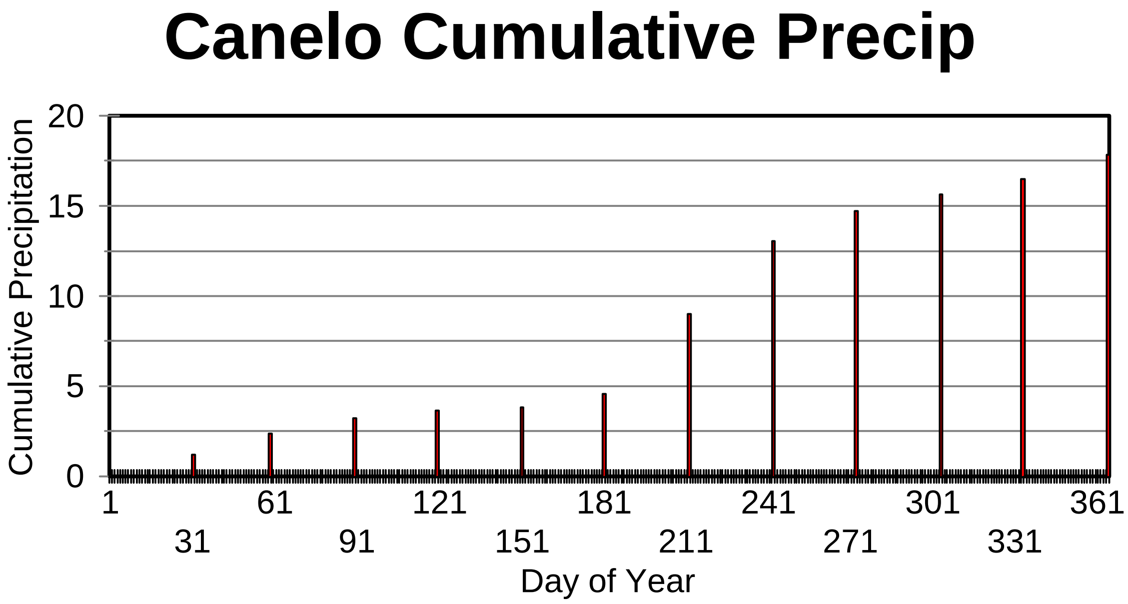

FIGURE 5.Cumulative Rainfall at Canelo, Arizona. Historical Average.

Figure 6 illustrates weekly water use in gallons per plant (per week) for the Cabernet Sauvignon variety. Maximum water use occurs during the fourteenth week after bud break or about the first week of July. At this time the vine is using about 64 gallons of water per plant per week (9 gallons per day). Fortunately this corresponds to the onset of significant summer rains which, although amount to the equivalent of only 30 gallons per week during the first week of July as can be seen from figure 7, increase to an average of 90 gallons per week the following week. While ET exceeds rainfall from the fourth week after bud break through the 14th week, irrigation is not required until the first week of June (week 10) if the soil profile was at field capacity at the beginning of the season. With the weekly rainfall illustrated in figure 7, one inch (60 gallons per plant) of irrigation would be required during the first ,second, third and fourth weeks of June. An additional one inch irrigation is required the second week of July and then a final one inch irrigation at the end of the second week of August. Figures 8 and 9 illustrate similar relationships for the Pinot Noir-Sauvignon Blanc-Chardonnay varieties and in an "average" rainfall year, the irrigation timing and amounts would be similar. Of course, actual irrigation timings and amounts will depend on actual rainfall occurrences and amounts as well as other weather related factors such as temperature and humidity. Figures 10 and 11 illustrate daily water use for Cabernet and the Pinot grouping respectively for the "average" weather conditions analyzed. Note that the maximum daily water use is on the order of 9 gallons per day per plant for both variety groups. This compares very favorably with other fruit crops. For example mature grapefruit trees use a much as 75 gallons per plant per day! The AZSCHED program and manual have been attached to this report and it could be used to assess other scenarios of rainfall and weather.

Summary:

Historical weather data from the Canelo station were used to develop estimates of reference crop evapotranspiration for the primary growing season for wine grapes in the Sonoita wine growing region of southeast Arizona. Crop coefficients for two different variety groups were developed from the literature and from growing season temperature distributions. The coefficients were then used in a computer model, AZSCHED, to estimate both the water requirements of the wine grapes and the corresponding irrigation requirement for a "typical" season. Results indicate that, if "over winter" rains are sufficient to fill the soil profile prior to bud break, only 6 inches of irrigation is required for the entire season, primarily throughout the month of June and after monsoonal rainfall begins to diminish in late August. Average growing season rainfall is 17.8 inches in the region with 11.1 inches occurring during the wine grape season. Total growing season water requirements for both types of wine grapes is about 16 inches. For a typical vineyard this translates to about 960 gallons of water per plant. However, an inch of rainfall provides 60 gallons of water for plant use. Thus, after accounting for irrigation efficiency, only 360 gallons of irrigation (6 inches) would be required per plant per season during a typical season. Maximum water use for wine grapes occurs during the first week of July and amounts to about 9 gallons per day per plant. Typical rainfall during that time period however, provides half of the water required and after the first week of July, further irrigation would normally not be required until mid to late August. A clean-tilled vineyard uses only about half of the water that would be used by a cover of green grass under the same climatic conditions! Crop coefficient curves for the two wine grape variety groups have been incorporated into the AZSCHED crop data base as well as long term "default" weather data for the Sonoita/Canelo region of Arizona. This will allow growers or others to assess the water and irrigation requirements of wine grapes in “real-time”, providing that they have access to daily temperature data.

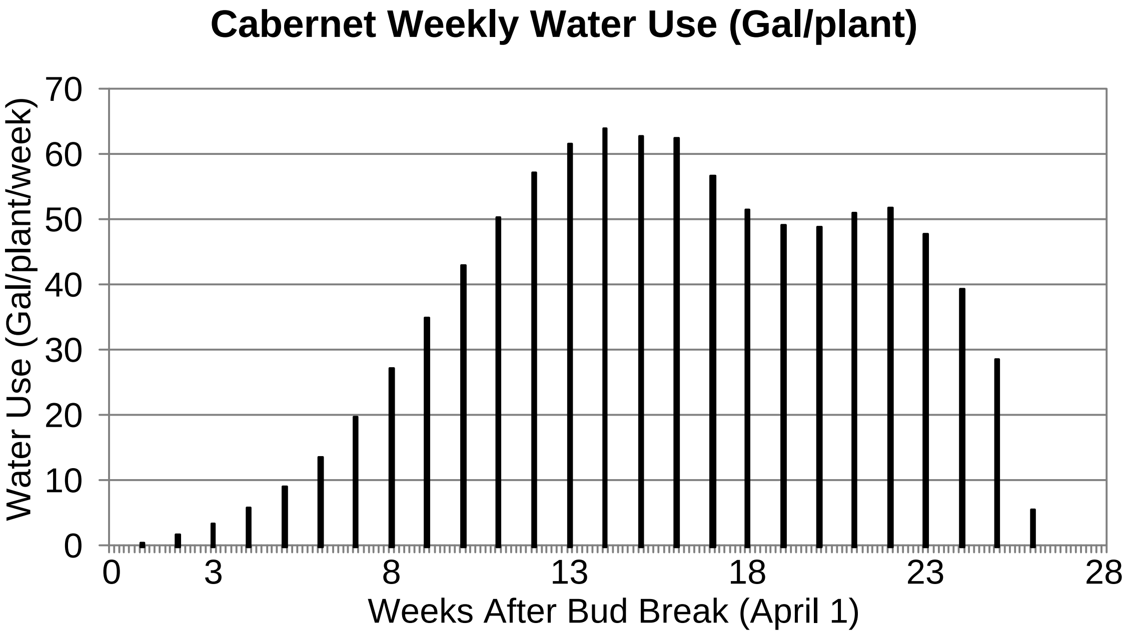

FIGURE 6.Weekly Water Use for Cabernet Sauvignon Grapes at Elgin, Arizona

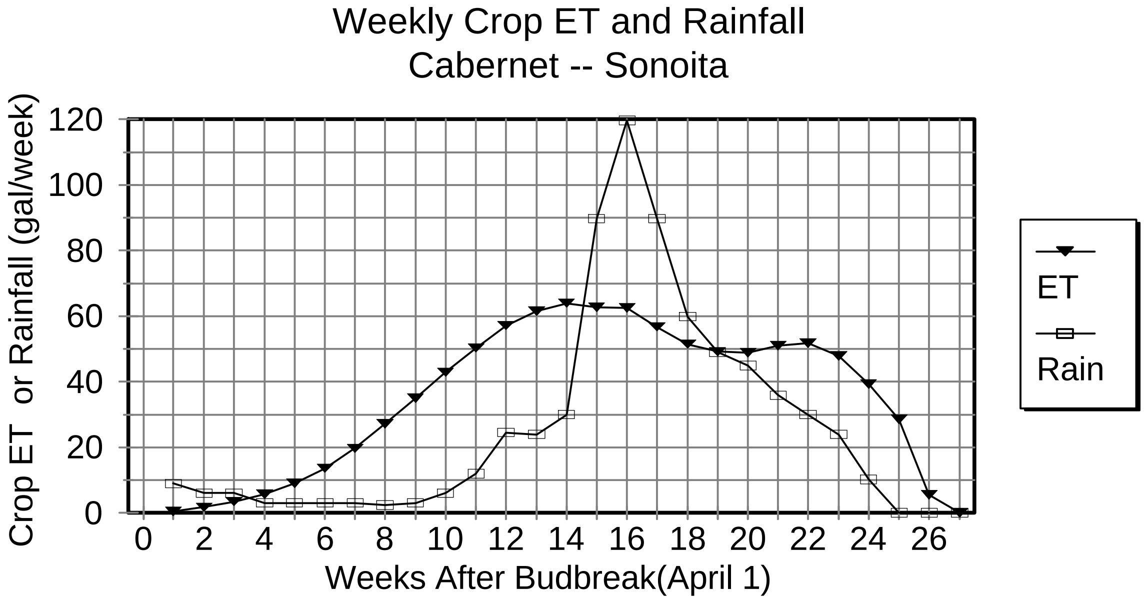

FIGURE 7.Weekly Water Use and Rainfall for Cabernet Sauvignon Grapes at Elgin, Arizona

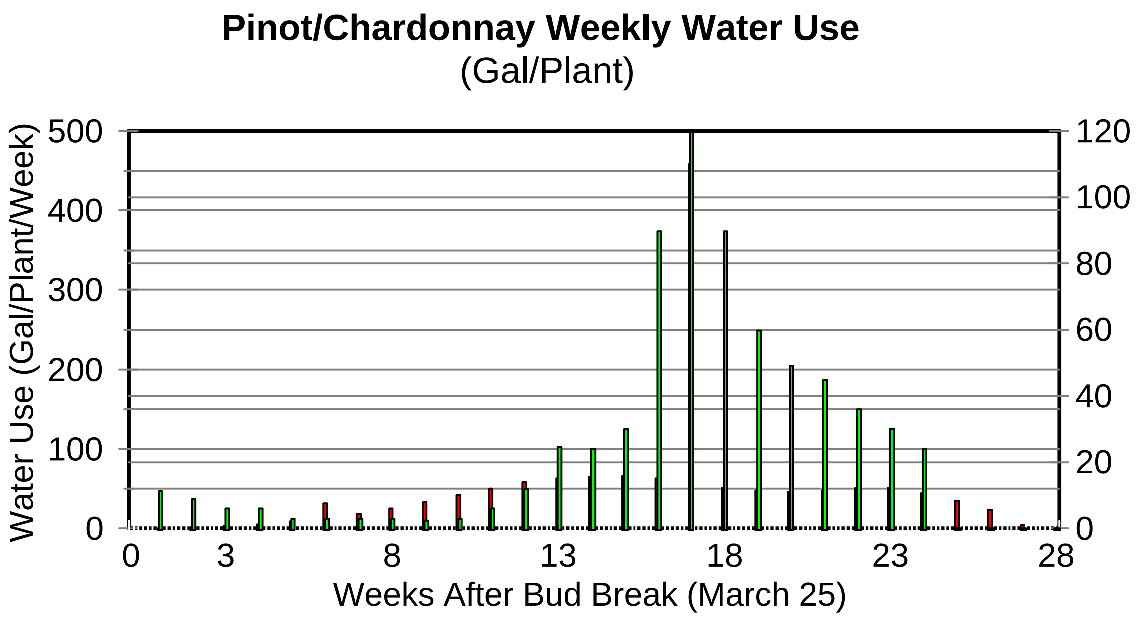

FIGURE 8.Weekly Water Use for Pinot Noir, Sauvignon Blanc and Chardonnay Grapes at Elgin, Arizona.

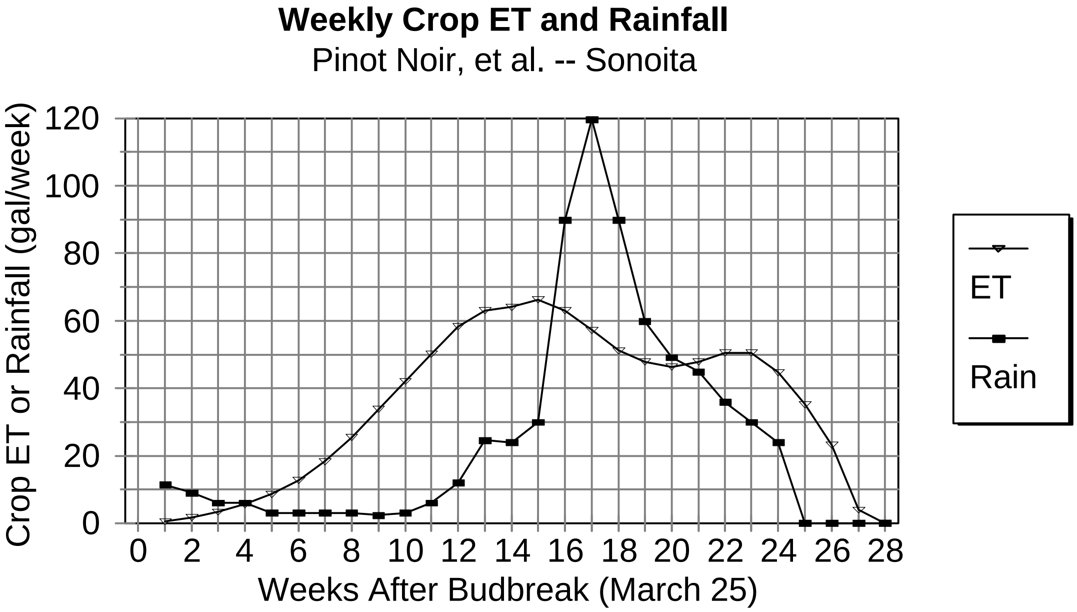

FIGURE 9.Weekly Water Use and Rainfall for Pinot Noir, Sauvignon Blanc and Chardonnay Grapes at Elgin, Arizona.

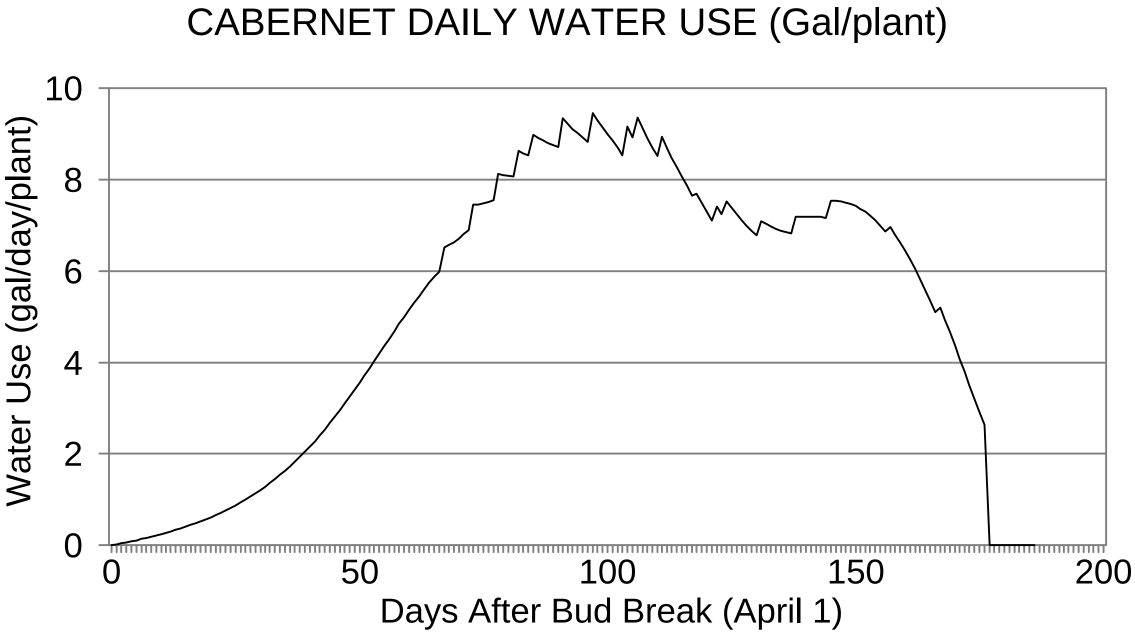

FIGURE 10.Daily water use for Cabernet Sauvignon Grapes at Elgin, Arizona.

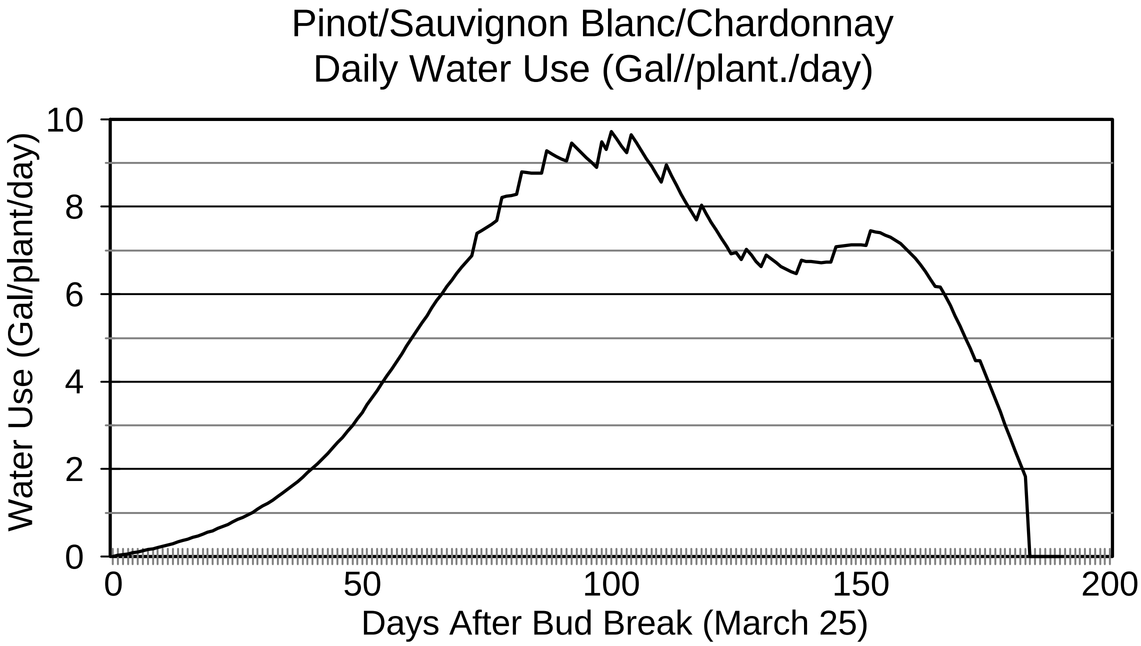

FIGURE 11.Daily water use for Pinot Noir, Sauvignon Blanc and Chardonnay Grapes at Elgin, Arizona.

References:

Bravado, B., Y. Hepner, C. Loinger, S. Cohen and H. Tabacman. 1985. Effect of Irrigation and Crop Level on Growth, Yield and Wine Quality of Cabernet Sauvignon. Am. J. Enol. Vitic. 36:132-139.

Bucks, D.A., O.F. French, F.S. Nakayama and D.D. Fangmeier. 1985. Trickle Irrigation Mangement for Grape Production. In Drip/Trickle Irrigation in Action. Proceedings fo the Third International Drip/Trickle Irrigation Congress. ASAE. St. Joseph, MI. Pp:204-211.

Cadot, P.D., 1989. Development of a Model for Design of Water Harvesting Systems in Small Scale Rainfed Agriculture. M.S. Thesis. Department of Agricultural and Biosystems Engineering. The University of Arizona. Tucson, AZ. 155p.

Cadot. P.D., D.C. Slack and G.R. Dutt. 1989. A Design Model for Small Scale Water Harvesting Systems. ASAE Paper No. 89-5520. Presented at the 1989 International Winter Meeting of the Am. Soc. Of Agri. Engrs. New Orleans, LA. Dec. 1989. 17p.

Doorenbos, J. and W.O. Pruitt. 1984. Crop Water Requirements. Irrigation and Drainage Paper No. 24. Food and Agricultural Organization of the United Nations. Rome, Italy. 94p.

Dutt, G.R. 1995. Personal Communication

Erie, L.J., O.F. French, D.A. Bucks and K. Harris. 1981. Consumptive Use by Major Crops in the Southwestern United States. USDA Conservation Research Report No. 29. 42p.

Fox, F.A. Jr., E.C. Martin, D.C. Slack and L.J. Clark. 1996. AZSCHED - Arizona Irrigation Scheduling. Users Manual and Software Version 1.3. The University of Arizona, Cooperative Extension Service, Department of Agricultural and Biosystems Engineering. 39p + diskette.

Grimes, D.W. and L.E. Williams. 1990. Irrigation Effects on Plant Water Relations and Productivity of Thompson Seedless Grapevines. Crop Sci. 30:255-260.

Mullins, G.A., A. Bouquet and L.E. Williams. 1992. Biology of the Grapevine. Cambridge University Press. 239p.

Sellers, W.D., R.H. Hill and M. Sanerson-Rae. 1985. Arizona Climate- The First One Hundred Years. University of Arizona. Tucson, AZ. 143p.

Slack, D.C., F.A. Fox, Jr., E.C. Martin and L.J. Clark. 1994. Growing-Degree-Day Based Crop Coefficients for Irrigation Management. Proceedings of the Fourth National Congress of Agricultural Engineering. Mexican Association of Agricultural Engineers. Queretaro, Mexico. October, 1993. pp 7-13.

Sotomayor, J.P. and A.A. Lavin. 1984. Drip Irrigation of Two Types of Vineyard cv. Pais (syn. Mission) in the Dryland of Cauquenes (Chile). I. Effects on Wine Composition and Quality. Agricultura Tecnica (Chile). 44(1):21025.

Tosso, J. and J.J. Torres. 1986. Relaciones Hidricas de la Vid Bajo Diferentes Niveles de Riego, Usando Goteo, Aspersion y Surcos. Evapotranspiration and Water Use Efficiency. Agricultura Tecnica (Chile). 46(2):193-198.

Villaseca, S., R. Novoa and I. Munnoz. 1986. Fenologia y Sumas de Temperatura en 24 Variedades de Vid. (Phenology and Sum of Temperatures Above 10 ^{o}C in 24 Grape Varieties). Agricultura Tecnica (Chile). 46(1):63-67.

Williams, L.E. and M.A. Matthews. 1990. Grapevine. In Irrigation of Agricultural Crops. B.J. Stewart and D.R. Nielsen, Ed. Agronomy Monograph No. 30. Am. Soc. Agron. Madison, WI. pp1019-1055.