MODELING GRAPEVINE WATER USE

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SUMMARY:

The last of a three-year study was completed in 2000. The data collected this past growing season was to establish crop coefficients for grapevines using different trellis systems. The seasonal crop coefficients were derived from the linear relationship between the crop coefficient and percent shaded area beneath a Thompson Seedless grapevine measured at solar noon (between 1230 and 1330 hours, PDT). The slope of this relationship was 0.017. The 0.017 value multiplied by the percent shaded area is the crop coefficient. For example, if the shaded area beneath a vine at solar noon is 20% of the total area allocated to the vine within the vineyard then the crop coefficient is 0.34 (0.017 x 20 = 0.34).

Several different trellis systems were measured at five locations throughout the State of California. These trellises included the lyre, GDC, VSP and vertically split canopies using the Scott Henry and Smart-Dyson trellis systems. Several additional trellis systems were also used such as the 'California Sprawl' and others using various crossarms to support the cordons and foliage catch wires. Shaded area under the vines was determined with the use of a digital camera and software to calculate shade in the image. Results indicated that a trellis that horizontally splits the canopy results in greater shaded area and therefore higher crop coefficients than a trellis that does not. The same is true for canopies that are vertically split compared to a trellis like the VSP. The crop coefficients also take into account row spacing.

At several locations, water meters were installed to measure the amounts of water the grower/cooperators applied and midday leaf water potential was measured. Applied water amounts were compared at the end of the season with estimated vineyard water use (ET_c) during specific intervals. Estimated ET_c was calculated as the product of ET_o times the percent shaded area derived crop coefficients. In most cases when estimated ET_c and applied water amounts were similar, midday leaf water potential values were less negative than –1.0 MPa (-10 bars). When applied water amounts were less than estimated ET_c leaf water potential was more negative than –1.0 MPa. These results indicated that the derivation of crop coefficients from percent shaded area were useful in estimating actual vineyard water use at 100% of ET_c.

The ability of grape growers to predict potential vineyard water is a necessity in California where water can be in short supply or expensive. One can estimate vineyard water use with the following equation: $ET_c = ET_o \times k_c$. Once this is calculated then deficit irrigation practices can be used such that a fraction of full ET_c is applied to the vines either throughout the growing season or during specific phenological events. I have shown over the past several years that one can deficit irrigate grapevines such that water use efficiency is increased, yields can be either maintained or increased with high fruit quality for table, raisin and wine grapes.

Objectives:

1. Refine and validate a model of non-water stressed grapevine water use on Thompson Seedless grapevines grown at the Kearney Ag Center and to determine the appropriate measurements required to model solar radiation interception by different trellis systems.

2. Validate the non-stressed grapevine water use model developed on Thompson Seedless grapevines using wine grape cultivars grown in the premium wine grape regions of California.

3. Establish seasonal crop coefficients for wine grape vineyards with different trellis systems, row spacings and grown in various location around the State of California. The crop coefficient will be determined by using the linear relationship between shaded area beneath the vine at solar noon and crop coefficient developed on Thompson Seedless.

EXPERIMENTS CONDUCTED TO MEET STATED OBJECTIVES:

The vineyards used in this study for the 2000-growing season were located at various sites throughout the State of California. The first commercial vineyard was located in Napa Valley behind the Robert Mondavi Winery near Oakville. Two of the trellis systems available at this location were a lyre and vertical shoot positioned (VSP) on 9-ft. rows. The third trellis was a modified VSP trellis planted 1 x 1 m. All rows were east to west. The second location was at the Department of Viticulture and Enology's Oakville field station. The trellis systems analyzed here were the lyre, Geneva Double Curtain (GDC) and "Y". All rows were oriented somewhat north to south. The third location was at the R.H. Phillips Winery in the Dunnigan Hills region of Yolo County. The trellis systems used at this location were vertically split canopies (i.e. Scott Henry and Smart-Dyson trellises), a "V" trellis, similar to the lyre, and a quadrilateral cordon trained vineyard with no shoot positioning. All rows were north to south except one of the vertically split canopies which was planted to east/west rows. The fourth location was in Livermore Valley in two privately owned vineyards managed by Wente Winery personnel. Both used vertically split canopies with row direction in one vineyard east to west and the other north to south. The fifth location was at the Paul Masson Vineyards northeast of Madera with row direction north to south. The trellis was a 3-foot crossarm with cordons on wires at either end, 55 inches above the berm. The final location was at the Kearney Ag Center (KAC), southeast of Fresno. The trellises used were a VSP, GDC, lyre and vertically split (Smart-Henry) systems. In addition, there was a "California Sprawl" (cordons on a 20 inch crossarm with a single wire above it) and quadrilateral cordon trained vines on a 20-inch crossarm, with a 3-foot crossarm (foliage wires at both ends) 13 inches above the cordon wires.

Beginning early in the growing season, the shaded area beneath three replicate vines was measured at solar noon (1230 to 1330 h PDT) in each vineyard except at KAC where only one vine was used. The shaded area was determined with a digital camera. The image was downloaded to a computer and a software program was used to calculate this area. Shaded area, divided by the land area per vine, was used to calculate percent shaded area.

The crop coefficient for the particular vineyard was determined by multiplying the percent shaded area by 0.017. The 0.017 value was the slope of the regression comparing percent shaded area on the ground and the crop coefficient using Thompson Seedless grapevines growing in a weighing lysimeter at the Kearney Ag Center in 1998 and 1999. The intercept was very close to zero so it was not included in the calculation. For example, if the percent shaded area was 20% then 20 was multiplied by 0.017 to give a crop coefficient of 0.34.

At several sites water meters were installed in each vineyard to record water amounts that the cooperator applied. Water meters were read every time measurements of shaded area were taken. In rows adjacent to where shaded areas were monitored, emitters were either removed or added such that water received by those vines were approximately 50 or 150% the amount of water the cooperator applied. Lastly, vine water status was determined for vines in each vineyard (including those receiving 50 and 150% of the applied water) by measuring midday, leaf water potential using a pressure chamber.

At the end of the growing season, calculated vineyard ET (ET_c) for the period between measurements of shaded area was determined by using the following equation:

$$ET_c = k_c \times ET_o$$

where, k_c was the crop coefficient calculated from shaded area measurements and ET_o (potential ET) was obtained from the closest CIMIS weather station to each vineyard. Estimated values of ET_c were compared with the applied water amounts recorded over the same time period. Measurements of midday leaf water potential were used to assess potential discrepancies between calculated ET_c and applied water based upon the following assumption: vines irrigated at 100% of ET_c will not have a midday water potential value more negative than –1.0 MPa (-10 bars).

The final portion of this study was to collect more data validating the calculation of crop coefficients for a VSP trellis by measuring percent shaded area at solar noon in vineyards where I had previously established reliable crop coefficients. Measurements of shaded area at solar noon were taken in vineyards at Oakville, Gonzales, Paso Robles and Edna Valley. Vineyards at those locations were being used to determine the effects of irrigation amounts on vine productivity. The crop coefficients determined by measuring shaded area at solar noon were compared to the seasonal crop coefficients being used at the time to schedule irrigation amounts at 100% of ET_c (see Figure 7 from "Modeling Grapevine Water Use" Final Report to the American Vineyard Foundation, 2000).

RESEARCH ACCOMPLISHMENTS AND RESULTS:

An assumption I've used for the past several years is that water use per unit length of row is a function of the trellis and not of row spacing. This implies that the amount of shaded area beneath a vine is the same regardless of location and/or row spacing. In the 2000-growing season I used the same trellis at several locations. For example, I measured the shaded area beneath a lyre trellis system at three locations and a "V" trellis (similar to the lyre) at a fourth location (Figure 1). Two of these trellises were planted on east/west rows and two on north/south rows. When the shaded area was determined on these vines (and the vine spacing was standardized to 6-ft. (1.83 m)) that area was similar across the four vineyards. Maximum shaded area was approximately 2.8 m^2 late in the season. At approximately 700 degree days shaded area for the Kearney and R.H. Phillips sites were greater than 3 m^2 per vine, higher than for the lyre systems at Mondavi and the Oakville Field Station. This was due to the fact that the vines at Kearney and R.H. Phillips were not hedged until after that date. Once hedged, shaded areas at those two locations were similar to those in Napa Valley. Like-wise, the shaded areas beneath vertically split canopies were similar at four locations for all but a few times during the 2000-growing season (Figure 2). The very high values for the vertically split canopies at Kearney and one of the Wente vineyards around 500 degree days was due to the bottom portion of the split canopy being trained downward. Once the shoots were in place, shaded areas at all sites were somewhat similar. Hedging after 1000 degree days maintained shaded area of the vertically split canopies at approximately 1.7 m^2. These results would indicate that crop coefficients, calculated from percent shaded area for a trellis system that horizontally spreads the canopy at one location, would be appropriate at other locations. In addition, a trellis that vertically splits the canopy in a row that runs east/west would also be appropriate at other locations. The above would be true when time was measured with degree-days and the vineyards were farmed the same.

The usefulness of determining the crop coefficients for all trellis systems in a row direction that runs north/south may be limited. For two vineyards using a VSP trellis the percent shaded area beneath the vine at solar noon (1300 hours, PDT), varied only slightly during the 1999-growing season (Figure 3). The shaded area beneath a vertically split trellis, planted to north/south row differed from the same trellis planted to east/west rows later in the growing season (Figure 4). It was found, though, that the shaded area for the vertically split trellis on north/south rows was similar to that of east/west rows when measured either an hour earlier or later of solar noon for measurements taken in July (Figure 5). These results would indicate that the measurements of shaded area for north/south rows, especially for a vertically split canopy, need to be adjusted for time of day. However, it is felt that the derivation of crop coefficients, from shaded areas of east/west rows, is useful for the establishment of crop coefficients for north/south rows of both VSP and vertically split trellises.

At each location and vineyard the seasonal crop coefficients were calculated from the percent shaded area measured at solar noon. The calculated crop coefficients were ultimately a function of row spacing; since shaded area per vine, was divided by the total land area per vine within the vineyard. The crop coefficients for the 1 x 1 m and lyre trellis systems increased rapidly early on in the season (Figure 6). Between 300 and 400-degree days after March 15th the crop coefficients leveled off or decreased slightly for the lyre trellises and 1 x 1 m spacing. This was due to the fact that the cooperator shoot thinned these vineyards. The maximum crop coefficient for the 1 x 1-m spacing vineyard was greater than 0.85 while those of the lyre trellises were between 0.8 and 0.9 (Figure 6). The crop coefficients, for these vineyards, leveled off after 900-degree days as the vines were hedged. The maximum crop coefficient for the VSP trellis was approximately 0.5. The crop coefficients determined at the R.H. Phillips Winery were greatest for the Quadrilateral cordon trained vineyard followed by the "V" and Scott Henry trellised vineyards late in the growing season (Figure 7). The smallest seasonal crop coefficients at this location were for the Smart-Dyson trellis, for rows planted east/west. The differences in the seasonal crop coefficients between the two vertically split canopies at R.H. Phillips was due to the fact that the Scott Henry trellis was in a vineyard with a 6 foot row spacing while those for the Smart-Dyson were calculated based upon 9 foot row spacings. The highest seasonal crop coefficient for vines grown at the Kearney Ag Center was for the Syrah vines trained to quadrilateral cordons with a foliage wire 13 inches above the cordons (Table 1). Crop coefficients greater than 0.8 were recorded on the GDC and lyre trellises and for the California Sprawl system. The crop coefficients for the Smart-Dyson and VSP trellises were similar to one another at this location.

In order to calculate estimated water use for vines in several of the vineyards during weeks in which shaded area was not measured, crop coefficients were interpolated (Tables 2, 3 and 4). This was done for vineyards where water meters had been installed and the cooperators were regularly scheduling irrigations. In Tables 5 through 8, calculated vine water use (ET_c) was compared with the amount of water the cooperator applied for that specific time interval. In addition, midday leaf water potential was measured on the last date of each interval. It was assumed that vines were using water amounts equivalent to full ET_c, if midday leaf water potential was less negative than –1.0 MPa (-10 bars). For example, estimated vine water use for the lyre trellis at Oakville between May 23rd and July 16th was 247 gallons per vine while applied water during that time was 137 gallons (Table 5). Midday leaf water potential measured on three dates during that time frame was never lower than -0.85 MPa. This would indicate that even though vines were deficit irrigated by the cooperator during that interval, there must have been enough soil moisture to meet the ET requirements of the vines, i.e. the vines were not stressed for water. It was not until August, when water was cut back dramatically and the soil moisture had been depleted that significant water stress was measured on these vines (midday leaf water potential was –1.35 MPa). Leaf water potential readings taken in the 1 x 1-m vineyard indicated that those vines were not stressed for water even late in the growing season (August 10th to September 5th). When a comparison of estimated ET_c with applied water is made in that vineyard, one can see that applied water amounts were very close to estimated ET_c (Table 5). Midday leaf water potential values also indicated that very little water stress occurred in that vineyard.

At the R.H. Phillips vineyards in May, applied water and adequate soil moisture resulted in midday leaf water potentials indicating very little vine stress (Table 6). However, for the period from June 1st to June 20th, all vineyards were deficit irrigated by the cooperator (when compared to estimated ET_c) and vine water status measurements confirmed this observation (all midday leaf water potential were more negative than –1.0 MPa). In fact, most of the vineyards were deficit irrigated throughout the remainder of the growing season with the exception of the Chardonnay vineyard. There are some apparent anomalies regarding estimated ET_c, applied water amounts and values of midday, leaf water potential values at this location. For example, applied water amounts in the Chardonnay vineyard were greater than my estimated ET_c between July 9th and August 17th but midday leaf water potential measured on July 29th and August 17th indicated that the vines were stressed for water. A limitation to this study was the fact that I did not know when the water was applied. The majority of the 75 gallons applied to the Chardonnay vineyard during the July 9th to July 29th period (when I estimated vineyard ET_c was 54 gallons), could have been applied earlier on in that interval, such that by the time I took my water potential readings the vines may have been stressed for water. It should be pointed out that the vines were being irrigated at the time I took my measurements possibly indicating the cooperator felt the vines needed an irrigation.

The applied water amounts in the Livermore Valley Cabernet Sauvignon were greater than my estimated ET_c values (Table 7). Midday leaf water potential readings also indicated that the vines were not stressed for water until late in the growing season. The Merlot vines also had more water applied during the June 24th to September 9th interval than estimated ET_c. Perhaps the reason for the water potential readings indicating water stress was the fact that the majority of the water applied took place earlier on in the interval between readings. The same could be said for the Paul Masson vineyard in Madera County (Table 8).

The relationship between the derived crop coefficient using percent shaded area and the crop coefficient being used on the day in which the measurements were taken were highly correlated with one another (Figure 8). The coefficient of determination (r^2) value for data collected in 1999 was 0.82, while the addition of data from the 2000-growing season increased that value to 0.86.

OUTSIDE PRESENTATIONS OF RESEARCH:

Portions of the data collected in this study were presented to the North Coast Viticulture Research Group's monthly meeting in Santa Rosa on February 16, 2001 and the Central Coast Grape Symposium in Santa Maria on March 8, 2001. In addition, copies of the final report of this project have been sent to numerous individuals requesting the information.

RESEARCH SUCCESS STATEMENTS:

The first two objectives of this proposal were completed during the 1999-growing season. Research conducted during the 2000-growing season was to develop seasonal crop coefficients for vines using different trellis systems and to continue to validate crop coefficients developed for a VSP trellis (Objective 3). This objective was completed during 2000 utilizing the relationship between the crop coefficient and the percent shaded area measured beneath the vine at solar noon for Thompson Seedless grapevines grown in the weighing lysimeter at the Kearney Ag Center. Such a relationship has also been found on peach trees growing in a weighing lysimeter at the same location (R.S. Johnson, personal communication). The slopes of the relationship between k_c and percent shaded area beneath both vines and trees were very similar (0.017 for grapes versus 0.016 for trees).

The results indicated that shaded areas measured under a vine at solar noon were a function of trellis and that these areas were similar to one another in different vineyards as long as the vines were farmed similarly and the data expressed as a function of degree-days. Shoot removal and hedging vines at different times changed the amount of shaded area cast on the ground throughout the season. Row direction of trellis systems that horizontally separated the foliage had little effect on the amount of shaded area measured at solar noon under the conditions of this trial. The same could be said a VSP trellis in the two row directions. I did find trellises that vertically split canopies, such as the Scott Henry and Smart-Dyson, differed when using north/south and east/west row directions. Late in the growing season the shaded area beneath a north/south row was less than that of an east/west row. Measurements of shaded area under the vine of a north/south row can be similar to those of an east/west row when measured at different times during the day. For example, the shaded area under a north/south row at 2:00 p.m. was similar to that of an east/west row measured at solar noon (1:00 p.m.). However, I feel that crop coefficients developed on east/west rows for a particular trellis system, are appropriate for the same trellis system planted on north/south rows.

At four of the vineyard locations, a comparison was made between my estimated vine water use and water applied by the grower/cooperator for specific intervals during the growing season. In most cases, when applied water was less than I would have predicted the vines needed to replace water used, midday leaf water potential generally was more negative than –1.0 MPa, except early in the growing season where there was adequate moisture in the soil profile. Those results were also dependent upon irrigation frequency. The results obtained in this study would indicate that ET_c, using crop coefficients derived from percent shaded area would be useful to grape growers in estimating potential vineyard water use at 100% of ET_c.

The crop coefficients developed on the trellis systems used this past growing season could be directly transferred to a commercial situation using the same trellis systems. However, one must remember that the crop coefficients developed in this study are applicable only for the specified row spacing. For example, the seasonal crop coefficients for the lyre trellis at Oakville are only appropriate for 9-foot row spacings. If one has a lyre system using 10-foot row spacings then the crop coefficients developed on the 9-foot row spacing must be adjusted. For example, if the k_c for the lyre trellis using a 9-foot spacing were 0.8, then the k_c for a 10-foot row would be 90% (or 0.9) (9 feet ÷ 10 feet = 0.9) of that value to yield a k_c of 0.72. Similarly, the adjusted k_c for a lyre trellis with 12-foot row spacing would be 0.6 (k_c for 12 ft. row) = k_c for 9 ft. row (or 0.8) multiplied by 0.75 (9 feet ÷ 12 feet = 0.75) = 0.6.

The above data is also useful for trellis systems not used in this study. Since there is a good relationship between percent shaded area and the crop coefficient, growers could use this data in their own vineyards. One could estimate the amount of shaded area beneath a vine by using a measuring tape, a grid of some sort or a digital camera (with the appropriate software). Personnel at the R.H. Phillips Winery used a measuring tape to estimate percent shaded area in various vineyards during the 2000-growing season. It should be pointed out that determining the shaded area under some trellis systems (such as with vertically split canopies, especially the portion being trained downward) and early in the growing season or in newly planted vineyards, is difficult with a measuring tape as the canopies are very discontinuous. Below is an example of how potential vineyard water use could be derived:

A. Row spacing = 10 ft.
B. Vine spacing = 6 ft.
C. Area per vine = 60 ft^2
D. Average width of measured shaded area between two vines = 3 ft.
E. Shaded area per vine = B x D = 6ft. x 3 ft. = 18 ft^2
F. Percent shaded area = E ÷ C = 18 ft^2 ÷ 60 ft^2 = 0.3 or 30%
G. Crop coefficient (k_c) = F x 0.017 (slope of relationship between k_c and percent shaded area of Thompson Seedless) = 30 x 0.017 = 0.51
H. Vine water use = ET_o (obtained from CIMIS) x k_c

FUNDS STATUS:

The funds to date have been used or encumbered to hire summer help in taking the measurements, my technician's salary and to pay travel expenses.

Table 1. Calendar date in 2000, degree-days (>10°C from 15 March) and estimated crop coefficients for Chardonnay vines trained to a Scott Henry, Lyre, Wye (GDC), and VSP trellises, and Syrah vines using a California Sprawl system or quadrilateral cordon system with foliage wires above the cordons at the Kearney Agricultural Center. All row spacings are 12 feet, except for the Syrah vines, which had an11-foot row spacing. Row direction for all treatments was east/west. *

		Trellis System					
Calendar Date	DDs	Scott Henry	Lyre	GDC	VSP	California Sprawl	Quad Cordons
		Crop Coefficient (k_c)					
April 18	226	0.24	0.38	0.28	0.27	0.24	0.41
April 28	293	0.27	0.54	0.36	0.35	0.47	0.58
May 5	356	0.27	0.51	0.48	0.44	0.62	0.64
May 13	417	0.32	0.54	0.56	0.66	0.74	0.83
May 22	512	0.46	0.61	0.88	0.53	0.80	0.74
June 5	693	0.49	0.81	0.77	0.51	0.77	0.88
June 27	1016	0.43	0.62	0.79	0.49	0.87	1.01
July 21	1357	0.47	0.71	0.77	0.47	0.71	0.88
Aug. 21	1898	0.46	0.69	0.71	0.46	na	Na
Sept. 5	2044	na	na	0.74	0.53	0.81	0.99

* The estimated crop coefficients were derived from percent shaded area measurements made on the calendar dates indicated in the left-hand column. Most values are the result of shaded area measured beneath the same individual vine at solar noon on all dates. In several instances, two to three vines were used. Degree-days were obtained from UCIPM using the CIMIS weather station located at the Kearney Ag Center. The designation 'na' indicates that no data was collected.

Table 2. Calendar date in 2000, degree days (>10°C from 15 March), and estimated crop coefficients for a Lyre and VSP trellis systems planted to 2.74 m (9 ft) rows and a 1 x 1 m vine and row spacing at the Robert Mondavi vineyards in Oakville. Row direction for all vineyards was east/west.

		----------Trellis system/planting density ----------		
Calendar Date	DDs	Lyre	VSP	1x1m
		---------------- Crop Coefficient (k_c) ----------------		
April 3	110	0.15	0.12	0.15
April 10	144	0.18	0.13	0.22
April 17	175	0.21	0.14	0.29
April 24*	208	0.24	0.15	0.36
May 1	248	0.35	0.17	0.51
May 8*	283	0.49	0.19	0.67
May 15	308	0.49	0.20	0.67
May 22*	383	0.49	0.23	0.67
May 29	454	0.55	0.26	0.70
June 5*	507	0.64	0.28	0.74
June 12	556	0.66	0.31	0.78
June 19	645	0.71	0.34	0.79
June 26*	713	0.76	0.37	0.80
July 3	769	0.77	0.40	0.83
July 10	823	0.78	0.43	0.85
July 17*	880	0.79	0.45	0.87
July 24	948	0.80	0.47	0.87
July 31	1012	0.82	0.48	0.87
Aug. 7*	1088	0.83	0.49	0.87
August 14	1160	0.83	0.50	0.87
August 21	1233	0.83	0.52	0.88
August 28	1302	0.83	0.54	0.89
September 4*	1348	0.83	0.55	0.91
September 11	1413	0.83	0.55	0.91
September 18	1500	0.83	0.55	0.91
September 25	1568	0.83	0.55	0.91

* Weeks in which k_c was derived from percent shaded area. Degree-days were obtained from UCIPM using data from the Oakville CIMIS weather station.

Table 3. Calendar date in 2000, degree-days (>10^oC from 15 March), and estimated crop coefficients for four trellis systems at the R.H. Phillips Winery. The trellis systems consisted of a quadrilateral cordon with no foliage wires (cultivar Sauvignon blanc), a Scott Henry trellis (Chardonnay), a "V" trellis (Cabernet Sauvignon) and a Smart-Dyson trellis system (Syrah). Row spacings for the Sauvignon blanc, Chardonnay, Cabernet Sauvignon and Syrah vineyards were 12, 6, 12 and 9 feet, respectively. The Chardonnay vineyard actually had two row spacings, 5 and 7 feet. Therefore, it was assumed that the average row width was 6 feet. Row direction for the above vineyards was north/south, north/south, north/south and east/west, respectively.

		---Trellis Type---			
Calendar Date	DDs	Quad-Sprawl	Scott Henry	"V" trellis	Smart-Dyson
		---Crop Coefficient (k_c)---			
April 24	222	0.39	0.36	0.25	0.17
May 1*	266	0.47	0.41	0.30	0.24
May 8	311	0.54	0.45	0.35	0.30
May 15*	342	0.60	0.53	0.37	0.40
May 22	430	0.65	0.61	0.38	0.51
May 29*	516	0.72	0.62	0.48	0.52
June 5	580	0.79	0.63	0.58	0.54
June 12	637	0.80	0.65	0.65	0.55
June 19*	756	0.80	0.67	0.72	0.56
June 26	847	0.80	0.69	0.80	0.48
July 3*	928	0.88	0.71	0.67	0.49
July 10	990	0.96	0.74	0.67	0.49
July 17	1065	0.93	0.70	0.67	0.49
July 24*	1151	0.89	0.67	0.67	0.49
July 31	1235	0.86	0.64	0.67	0.49
August 7	1336	0.85	0.68	0.67	0.50
August 14*	1419	0.85	0.70	0.65	0.52
August 21	1502	0.85	0.72	0.60	0.55

* Weeks in which the k_c was derived from percent shaded area. The measurement of shaded area beneath the vines began April 20, 2000. Degree-days were obtained from UCIPM using the CIMIS weather station located near Zamora.

Table 4. Calendar date in 2000, degree-days (>10^{o}C from 15 March), and estimated crop coefficients of a vineyard in Livermore Valley and another in Madera County. The trellis system in Livermore Valley was a vertically split canopy (Smart-Dyson) in a Cabernet Sauvignon vineyard. Row direction was east/west using 11-foot row spacing. The Chardonnay vineyard in Madera County used a unidirectional, bilateral cordon on a 36-inch crossarm, with no foliage wires. The row width was 11 feet and direction was north/south.

Livermore Valley			Madera County		
Calendar Date	DDs	k_c	Calendar Date	DDs	k_c
April 17	179	0.15	April 17*	186	0.26
April 24*	207	0.15	April 24	219	0.32
May 1	242	0.15	May 1*	265	0.38
May 8*	278	0.17	May 8*	321	0.42
May 15	306	0.17	May 15	361	0.47
May 22*	376	0.45	May 22*	435	0.51
May 29	432	0.48	May 29	520	0.54
June 5*	482	0.60	June 5*	593	0.57
June 12	526	0.53	June 12	653	0.59
June 19	619	0.48	June 19	761	0.62
June 26*	693	0.44	June 26	869	0.64
July 3	754	0.46	July 3*	966	0.64
July 10*	808	0.48	July 10	1040	0.65
July 17	868	0.49	July 17	1129	0.66
July 24	933	0.49	July 24	1221	0.67
July 31	999	0.49	July 31*	1305	0.69
August 7*	1089	0.49	August 7	1508	0.70
August 14	1159	0.50	August 14	1702	0.70
August 21	1224	0.51	August 21	1898	0.70
August 28	1295	0.52	na	na	na
September 4*	1345	0.53	na	na	na

* Weeks in which the k_c was derived from percent shaded area. Degree-days were obtained from UCIPM using CIMIS weather stations at Walnut Creek for the Livermore Valley and the CIMIS station located close to the city of Madera. The designation 'na' indicates no data were collected.

Table 5. Estimated ET_c, applied water amounts (AW) and midday leaf water potential (Ψ_l) of Cabernet Sauvignon grapevines grown at the Robert Mondavi Winery, near Oakville as a function of trellis type or planting density. ET_c was determined by multiplying the estimated crop coefficients by potential ET (ET_o). ET_o was obtained from the Oakville CIMIS station. Values are in gallons per vine for ET_c and applied water and MPa for Ψ_l. Midday leaf water potential values are those for vines receiving 100% of the water the cooperator applied for the specified time interval and measured on the second date in the "Dates" column.

	Trellis system/Planting density								
	Lyre			VSP			1 x 1 m		
Dates	ET_c	AW	Ψ_l	ET_c	AW	Ψ_l	ET_c	AW	Ψ_l
5/23 to 6/5	52	17	-0.72	29	4	-0.70	16	5	-0.80
6/6 to 6/27	99	59	-0.85	51	14	-0.95	27	19	-0.92
6/28 to 7/16	96	61	-0.75	49	18	-0.95	25	20	-0.80
7/17 to 8/9	112	89	-1.00	55	51	-1.00	29	44	-0.80
8/10 to 9/5	118	33	-1.35	58	22	-1.23	30	19	-1.05
Total*	477	259		242	99		127	107	

* These values are the sums of each row within a column.

Table 6. Estimated ET_c, applied water amounts and midday leaf water potential (Ψ_l) of several vineyards at the R.H. Phillips Winery. The Syrah vineyards were planted to east/west (E/W) and north/south (N/S) rows. The calculated ET_c values for the Syrah N/S row used the crop coefficients generated from the shaded area of the Syrah E/W row. ET_o was obtained from the Zamora CIMIS weather station. Other information as found in Table 5.

	Vineyard														
	Sauvignon blanc			Chardonnay			Cabernet Sauvignon			Syrah E/W			Syrah N/S		
Dates	ET_c	AW	Ψ_l	ET_c	AW	Ψ_l	ET_c	AW	Ψ_l	ET_c	AW	Ψ_l	ET_c	AW	Ψ_l
5/18 - 5/31	77	82	-0.85	25	14	-0.85	50	41	-0.88	46	20	-0.87	46	14	-0.86
6/1 - 6/20	169	109	-1.18	47	28	-1.38	127	35*	-1.23	88	18	-1.40	88	15*	-1.23
6/21 - 7/8	150	150	-0.87	42	71	-0.97	137	35	-1.25	70	46*	-1.22	70	29*	-0.97
7/9 - 7/29	206	209*	-1.10	54	75*	-1.11	155	63	-1.15	85	54*	-1.55	85	36*	-1.50
7/30 - 8/17	162	153	-1.27	42	67*	-1.23	126	67*	-1.23	71	66*	-1.53	71	44*	-1.35
Total	771	698		211	255		595	241		360	204		360	138	

* Vines were being irrigated at the time water meters were read and water potential readings taken.

Table 7. Estimated ET_c, applied water amounts and midday leaf water potential of two vineyards in Livermore Valley. Rows in the Cabernet Sauvignon vineyard were oriented east to west while rows in the Merlot vineyard were oriented north to south. The crop coefficients generated in the Cabernet Sauvignon vineyard were used for the Merlot vineyard. ET_o was obtained from the CIMIS station mentioned in Table 4. Other information as found in
Table 5

	---------- Cabernet Sauvignon ----------			------------------- Merlot------------------		
Dates	ET_c	AW	Ψ_l	ET_c	AW	Ψ_l
6/24 – 6/6	54	16	-0.75	54	45	-0.58
6/7 – 6/28	99	98	-0.80	99	54	-0.95
6/29 – 7/14	65	95	-0.72	65	67	-1.13
7/15 – 8/10	117	132	-0.76	117	124	-1.16
8/11 – 9/7	105	207	-1.13	105	180	-1.10
Total	440	548		440	470	

Table 8. Estimated ET_c, applied water amounts and midday leaf water potential for the Chardonnay vineyard in Madera County. ET_o was obtained from the CIMIS station mentioned in Table 4. Other information as found in Table 5.

Dates	ET_c	Applied Water	Ψ_l
6/8 – 7/7	195	128	-1.03
7/8 – 7/31	176	210	-1.28

Figure 1. Shaded area measured at solar noon beneath a lyre trellis system (or a "V" trellis at R.H. Phillips) at four locations in 2000. The row directions were east/west for the Mondavi and KAC vineyards and north/south for the Oakville Field Station and R.H. Phillips sites. The shaded area was normalized to a vine spacing of 1.83 m (6 feet).

Figure 2. Shaded area measured at solar noon beneath a vertically split trellis system at four locations in 2000. Row directions for all vineyards were east/west. Other information as found in Figure 1.

Figure 3. The percent shaded area throughout the day beneath a VSP trellis in a Chardonnay vineyard on 7-foot rows running east to west in Carneros and a VSP trellis in a Cabernet Sauvignon vineyard on 6-foot rows running parallel to Highway 29 (somewhat north to south) at Oakville. Vine spacings were 5 feet and 1 m for the Carneros and Oakville vineyards, respectively. Data were collected in 1999.

Figure 4. Shaded area measured at solar noon beneath vertically split canopies at the R.H. Phillips vineyards and in Livermore Valley (Wente N/S and E/W). The row directions were east to west (E/W) and north to south (N/S).

Figure 5. The percent shaded area beneath two vertically split canopies, with different row directions, at the R.H. Phillips Vineyards in Yolo County measured hourly from 11 a.m. to 3 p.m. on July 8, 2000.

Figure 6. Seasonal crop coefficients derived from percent shaded area measured beneath vines at solar noon for different trellis systems in Napa Valley. With the exception of the 1 x 1-m vineyard, row spacings used in the calculation of percent shaded area was 9 feet. The Lyre trellis N/S was from the Oakville Field Station while the others were from the Robert Mondavi vineyards at Oakville.

Figure 7. Seasonal crop coefficients derived from percent shaded area measured beneath vines at solar noon for different trellis systems at R.H. Phillips Vineyards. Row spacings for the Quad Cordon and "V" trellis vineyards were 12 feet, Scott Henry trellised vineyard 6 feet and the Smart-Dyson E/W vineyard, 9 feet.

Figure 8. The correlation between the crop coefficient derived from the relationship between percent shaded area and the k_c of Thompson Seedless (see final report to the AVF, 2000, "Modeling Grapevine Water Use", Figure 6), and the crop coefficient the PI was using at the time shaded areas were measured in several different wine grape vineyards. Shaded areas were measured and data collected in the 1999 and 2000-growing seasons.