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IRRIGATION SCHEDULING OF WINE GRAPES UNDER CONDITIONS OF LIMITED CANOPY[1]

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Abstract. **Wine grape (*Vitis Vinifera* L.) growers often limit canopy development and use deficit irrigation to enhance product quality. This report describes a water-budgeting procedure that used reference evapotranspiration (ET_o) combined with crop, canopy, and soil-water availability coefficients to predict irrigation needs. The 'four-point method' was employed to define the crop-coefficient function; in which, crop growth indicators were used to 'fine-tune' the function for the specific site, crop, and year. The water-budget computations were performed with a spreadsheet computer program. The irrigation scheduling method was verified by comparing predicted soil-water content to measured soil-water content for two crop seasons under replicated field conditions (R^2=0.80). By accounting for the limited canopy and soil-water deficit conditions, predicted irrigation requirements were reduced by 40 percent from that computed based only on ET_o and a crop coefficient. The procedure is applicable to other horticultural corps and can be used for sprinkler or micro irrigation.**

Canopy management, whether through pruning and training systems, leaf removal, or summer hedging, is commonly practiced by wine grape growers. Deficit irrigation, applying water at less than a fully-water level, is also a commonly observed condition in California Central Coast vineyards. Both deficit irrigation and canopy hedging reduce crop evapotranspiration. Deficit management may not be precise since it is generally performed based on the intuition and experience of vineyard managers (Clark, 1993). The procedure described in this report is intended to provide a tool for irrigators to improve the precision of deficit irrigation management.

The California Department of Water Resources (DWR) maintains a network of over 80 electronic weather stations which provide reference ET (ET_o) for irrigation scheduling. This network is known as the California Irrigation Management Information System (CIMIS). The usage of this system by growers, however, has been low (Craddock, 1990). One of the reasons for the low grower usage has been the difficulty in converting the ET_o values to irrigation duration and frequency. This was a particular concern of wine grape growers who often limit canopy development by hedging and also practice deficit irrigation to enhance product quality, both of which complicate irrigation scheduling. Commercial irrigation scheduling software is available; however, the software has not gained widespread acceptance (Pleban, 1993).

A typical observation of growers and consultants that have used CIMIS, in the California coastal wine grape growing region, was that the basic procedure, which typically does not account for reduced canopy or deficit irrigation, resulted in the over-estimation of irrigation requirements. Since many growers were familiar with and use LOTUS 123[2] or compatible spreadsheets for other farming operations, it appeared feasible to use this commercial software to develop an irrigation scheduling tool which could account for the additional factors of canopy and available soil water. The spreadsheet program was based on a water-budgeting procedure which accounted for changes in soil-water content (SWC) and then indicated that irrigation was needed after a predetermined withdrawal level had been reached. Additionally, a replicated field experiment was conducted to validate and demonstrate the water-budgeting procedure.

Methods and Materials

Budgeting Procedures. Daily change in the soil water content (SWC) was accounted for as follows:

$$SWC_{(i+1)} = SWC_{(i)} - ET_{c(i)} + IR_{(i)} + RE_{(i)} \qquad \text{Eq [1]}$$

where,

$SWC_{(i)}$ = SWC on day (i),
$ET_{c\,(i)}$ = crop evapotranspiration on day (i),
$IR_{(i)}$ = irrigation on day (i),
$RE_{(i)}$ = effective rainfall on day (i).

Of these water-budget components, RE was computed directly from measured rainfall; any rainfall that occurred in excess of the soil-water deficit at the time of the rainfall event was considered ineffective rainfall (either runoff or deep percolation) and was deducted from the accounting process. Irrigation amounts were computed from irrigation event duration (run-time) based on irrigation system hydraulic parameters. ET_c was determined as follows:

$$ET_c = ET_o * K_c * C_p * S_m \qquad \text{Eq [2]}$$

where,

ET_o = reference ET (obtained through CIMIS)[3]

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[2]The use of the trade name does not imply endorsement.

[3]ET_o was computed by the modified Penman (1948) method.

K_c = crop coefficient,

C_p = canopy coefficient,

S_m = soil moisture availability factor.

Since the crop coefficient (K_c) function is dynamic through the growing season, accurate irrigation scheduling may require adjusting the crop coefficient to match the crop growth status, which may vary from year to year depending on temperature, sunlight, and other factors. The following is a description of the method used to determine K_c.

The growing season was separated into three segments (rapid growth, mid-season, and late season) and three linear equations were used to approximate the crop coefficient function (Snyder et al., 1989). This has been referred to as the 'four-point method'. The three linear segments are depicted in Fig. 1. The length and starting date of each segment is adjustable. The dates corresponding to each segment are identified as follows (plant growth stage indicators in parenthesis were used for wine grapes):

D_B = beginning of rapid growth (bud-burst[4]),

D_C = beginning of mid-season (cane-drop[5]),

D_D = end of mid-season or start of decline (veraison[6]),

D_E = end of late season (harvest),

D_i = current day.

The K_c for each segment is given as follows:

Rapid Growth $K_{c\text{-}rg} = K_{c1}+_{b1}*(D_i - D_B)$ Eq [3]

Mid-season $K_{c\text{-}ms} = K_{c2}$ Eq [4]

Late-season $K_{c\text{-}ls} = K_{c2}+_{b2}*(D_i - D_D)$ Eq [5]

where,

$b_1 = (K_{c2} - K_{c1})/(D_C - D_B)$ Eq [6]

$b_2 = (K_{c3} - K_{c2})/(D_E - D_D)$ Eq [7]

Date DD is the combined length of the rapid growth plus mid-season and is determined from a percentage factor (P_d). P_d is the percent of the total season at which the crop begins to decline (see Fig. 1) and is given as follows:

$D_D = (P_d/100)*(D_E - D_B)$ Eq [8]

This method allows the user to easily change any of the crop coefficient parameters, thus improving the procedure's flexibility for use with different crop varieties and climatic conditions. The canopy factor, C_p, in Eq. 2 is especially important if canopy development is restricted or if young trees or vines are being irrigated. Based on data from young deciduous trees (Snyder et al., 1989), C_p was computed as follows:

$C_p = [3.05+(2.56*G_s)-(0.016*G_s^2)]$ Eq [9]

where,

G_s = percent of ground shaded at solar noon during mid-season.

The above relationship may need additional refinement for wine grapes due to the various trellis configurations that are employed within the industry. A typical Chardonnay grown under California Central Coast conditions results in a canopy which shades 30-40 percent of the ground at solar noon. This computes to a C_p of 0.65 to 0.80. Eq. 9 is shown graphically in Fig. 2.

Under deficit-irrigated conditions, a water-budgeting procedure may need to take into account the change in available soil water and how that change influences crop ET rates. A soil moisture availability factor (S_m) is included in Eq. 2 to account for reductions in available soil water under deficit irrigation conditions. The modified Penman equation used by CIMIS to calculate ET_o is based on the assumption that water is not limited (Pruitt et al., 1987). As long as there is adequate

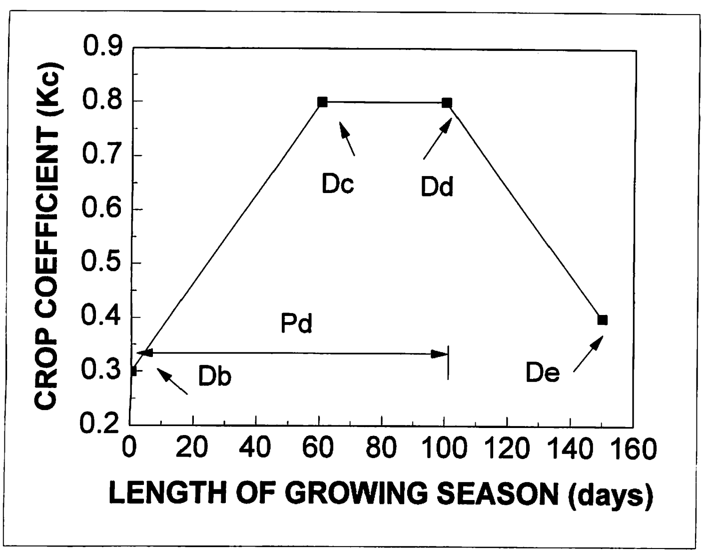

Figure 1. Adjustable crop coefficient function for wine grapes.

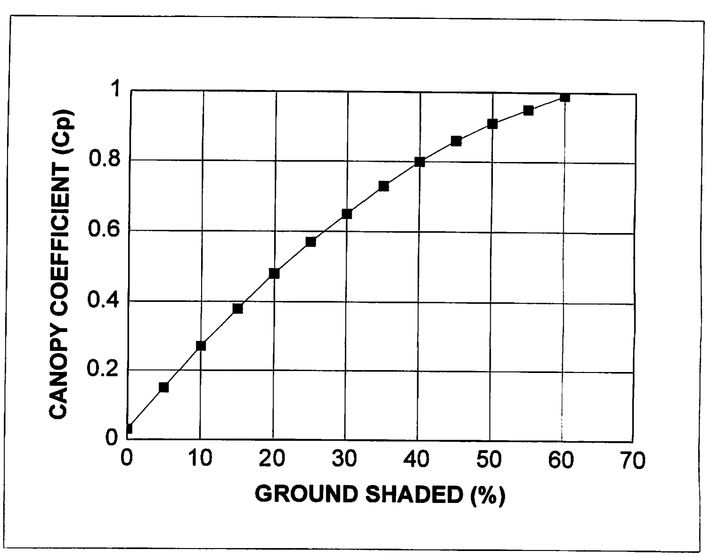

Figure 2. Canopy coefficient as a function of ground shaded at solar noon during mid-season.

[4]Bud-burst refers to the emergence of the new bud and the end of dormancy.

[5]Cane-drop is the point in the crop's vegetative development where the weight of the cane is greater than the canes strength to support its growth in an upright direction, thus the cane drops and the canopy spreads.

[6]Veraison is the point is the wine grape growth process when the berries begin to color and soften.

soil water, transpiration rates will depend primarily on the amount of energy available; however, when soil water becomes limited, transpiration rates will decrease (Denmead and Shaw, 1962). In actual irrigation scheduling, irrigation water is often withheld to a point at which soil-water is limited. The reduction in transpiration can be estimated as follows:

$$S_m = (A_w/100)^Z \qquad \text{Eq [10]}$$

where,

A_w = percent of available soil water remaining,

Z = a parameter to account for soil, crop, and ET_o.

The Z parameter represents the influence of the ET rates on soil-water extraction. At high ET rates, the limiting influence of the soil is greater. This relationship is a practical approximating tool; however, because of the complexity of soil and plant factors, it is not a precise relationship. For wine grapes grown on coarse to loamy sand, the following Z parameter was used: Z = ET_o (inches) for the day. Fig. 3 provides a graphical interpretation of Eq. 10.

Numerous irrigation system parameters are required to compute an accurate water-budget. For micro irrigation these include: the emitter pressure-discharge coefficients, spacing and number of emitters, the wetted soil volume, soil-water holding capacity, rooting depth and distribution, number of emitters per vine, average subunit pressure, area of irrigated and non-irrigated zones, and estimated application efficiency.

Field Experiment. To demonstrate and verify the water-budgeting procedure, a field experiment was conducted at Whitehills Vineyard in Santa Maria, CA. The field experiment consisted of five replications of three treatments in a randomized complete block design. The soil at the site was predominately Corralitos Loamy Sand. The experimental block consisted of approximately 25 acres of Chardonnay (*V. vinifera*) vines on Gewurztraminer rootstock. The vines were planted on 10-ft row spacings with 5.25-ft plant spacings. Cultural practices were the industry standard. Since California wine grape growers frequently deficit irrigate, two of the irrigation treatments were deficit irrigated. The three treatments were as follows: 1) non-stressed - irrigation water was provided at a rate to replace plant evaporative requirements as computed by the previously described procedure; 2) fifty percent of the water applied to Treatment 1, imposed at veraison; and 3) fifty percent of the water applied to Treatment 1, imposed at fruit set. The irrigation water treatment rates were implemented by installing emitters with proportionally different discharge rates which produced the desired application amounts. Irrigation water to the entire block was metered and amounts applied to each treatment were determined by proportion.

Estimated SWC was compared to that measured by a neutron probe. Fifteen neutron probe access tubes were installed, one in each plot. The neutron probe was gravimetrically calibrated at the site (Pitts, 1993). The SWC was measured at 6-inch increments to 4-ft, approximately each week, starting in April and continuing to harvest.

Beginning in the first of June, canopy area was estimated each week by measuring the ground shaded at solar noon. Ten random observation were made in each plot and averaged by treatment.

To evaluate the effects of irrigation treatments on vine vigor and capacity and on fruit quality and quantity, the following procedures were employed. Samples of fruit consisting of 200 berries (20 berries from each of 10 vines per plot) were taken on Sep. 1, Sep. 13, Sep. 27, and Oct. 10. The samples were analyzed by laboratory staff at Meridian Winery in Paso Robles, California for average berry weight, soluble solids (°Brix), titratable acidity, and pH. In 1994, all fruit were harvested from the 10 data vines in each plot and separated according to the level of infection from *Botriytis Cineria*, a fungal rot of grapes. *Botriytis Cineria* was common in the Santa Maria area in 1994 due to an unusual rainfall event that occurred in September that contributed to the high levels of fungal rot. Clusters with greater that a 1.5-inch diameter spot of *Botriytis* were counted as rot and weighted separately from the sound fruit. Fruit yield was taken from the remaining 20 vines in each plot.

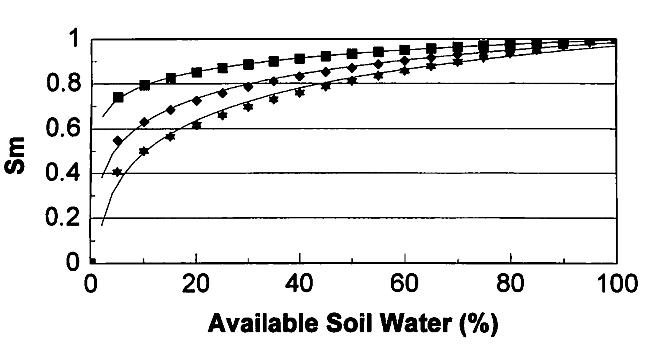

Figure 3. Soil moisture availability as a function of soil water content and ET.

Results and Discussion

Table 1 shows the crop coefficient parameters that were employed based on observed crop growth factors. Bud-break occurred on about Mar 15 and on Mar 10 in 1993 and 1994, respectively. In 1994 overall development was slower than 1993 and both cane drop and harvest occurred approximately two weeks later in 1994.

Fig. 4. shows the average ground shaded for each treatment. A slight reduction in canopy development due to deficit irrigation was observed. Maximum canopy development was approximately 32 percent ground shaded by mid-July. Canopy hedging was performed during the week of July 20th in 1995. Following hedging the canopy extension was approx-

Table 1. Crop-coefficient parameters used for Chardonnay grapes grown in Santa Maria, Ca.

Year	D_B	D_C	D_E	P_d	K_{c1}	K_{c2}	K_{c3}
1993	16-Mar	30-May	15-Sep	73	0.2	0.78	0.3
1994	10-Mar	15-Jun	30-Sep	76	0.36	0.78	0.2

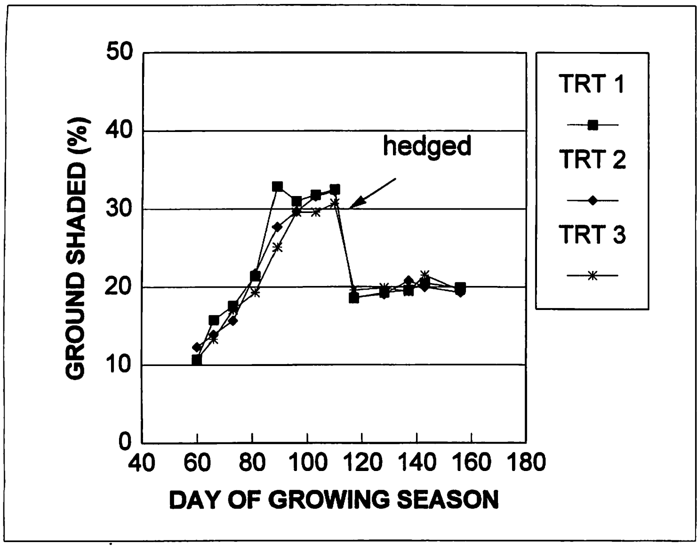

Figure 4. Canopy size as described by ground shaded, 1994.

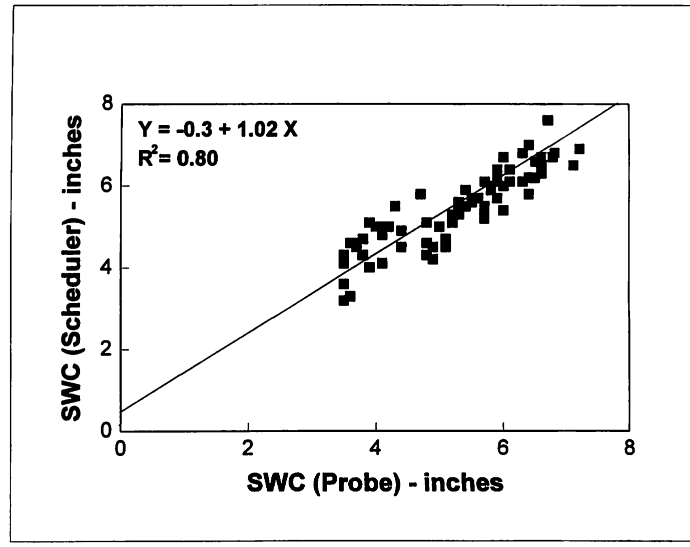

Figure 6. Predicted (scheduler) soil water content verses measured (neutron probe), 1994.

imately 20 percent ground shaded, and this held relatively constant for the remainder of the season.

Fig. 5 shows an example of the water-budget for a 9-day period in early April. Since the soil water monitoring was done with a neutron probe, SWC was budgeted as total water rather than available water. Available water has been traditionally defined as the water held in the root zone between field capacity and the permanent wilting point. Available water was assumed to be 50 percent of total water, thus a depletion level of 50 percent available water represents approximately 25 percent of total water.

Fig. 6 compares SWC as estimated by the water-budget method to the SWC measured with the neutron probe in 1994. Each data point represents the average measured SWC from five replicates. The neutron probe access tube was located approximately 12 inches from the drip emitter, thus these values represent water content of the area wetted by the drip irrigation system. The volume of the wetted area is dynamic and was not precisely modeled by this procedure. The wetted area was assumed to take constant cylindrical shape. Overall there was good agreement between the estimated SWC (Scheduler) and the measured SWC (Neutron meter) (R^2 = 0.80).

Fig. 7. compares 1993 and 1994 ET_0 and ($ET_0 \times K_c$) to the computed seasonal evapotranspiration for Treatment (TRT) 1, 2, and 3, respectively. From bud-burst to harvest ET_0 was approximately 32 inches each year. The difference between ($ET_0 \times K_c$) and TRT 1 was predominately the effect of the canopy coefficient. While the difference between the computed ET_c for TRT 1 and TRT 3 was predominately the effect of the soil moisture availability factor. Irrigation amounts for TRT 2 were cut back at veraison, which corresponds to the beginning of decline on the crop curve. Thus, there was little difference in ET_c between TRT 1 and 2. Reference ET (ET_0) was more than 4 times the water applied to TRT 3.

Spreadsheet Scheduler

Date	Rain (in)	Run-time (hours)	ETo (in)	ETc (in)	Soil-H2O (%)	Soil-H2O (in)	N. Probe (in)
01-Apr			0.15	0.03	85	6.77	6.8
02-Apr			0.21	0.04	84	6.73	
03-Apr			0.19	0.04	82	6.58	
04-Apr			0.15	0.03	81	6.45	
05-Apr			0.15	0.03	79	6.32	6.2
06-Apr			0.14	0.03	77	6.19	
07-Apr			0.17	0.03	76	6.05	
08-Apr			0.10	0.02	74	5.95	
09-Apr		9.0	0.15	0.03	88	7.00	6.9

Figure 5. An example of the water budget for the spreadsheet scheduler.

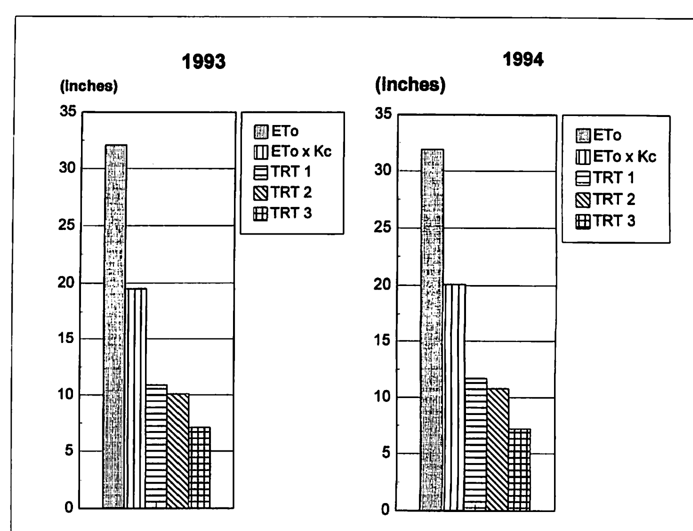

Figure 7. Reference evapotranspiration (ET_0), $ET_0 \times K_c$, ET for treatment 1, ET for treatment 2, and ET for treatment 3.

Table 2. Irrigation water applied (inches).

Year	Treatment 1	Treatment 2	Treatment 3
1993	10.7	9.4	6.3
1994	11.5	10.2	6.4
Mean	11.1	9.8	6.4

Table 2 shows the corresponding water application amounts for all three treatments for both years. The difference between computed ET_c and irrigation water applied represents effective rainfall, change in SWC from the beginning to the end of the season, and irrigation efficiency. Rainfall amounts during the growing seasons totaled 0.57 inch and 1.31 inch in 1993 and 1994, respectively. The applied irrigation amounts compared to an ET_o for each year of more than 30 inches. The computed ET_c was approximately 20 inches if canopy and soil moisture factors were not taken into account. Therefore, a scheduling procedure that used the coefficients C_p and S_m resulted in more than 40 percent less irrigation water being applied. Slightly more irrigation water was applied in 1994, albeit a cooler year, due to the longer growing season.

Table 3 shows the average yield for each treatment. Reducing the amount of irrigation water following veraison did not reduce total yield. There was yield reduction for TRT 3, however, it was small in comparison to the reduction (40%) in water applied. Although significant yield differences were observed, the level of *Botriytis* rot was exceptionally high in all treatments in 1994. Therefore, any conclusions as to the effect of irrigation treatment on yield would be premature at this time.

Table 3. Wine grape yield (tons/ac).

Year	Treatment 1	Treatment 2	Treatment 3
1993	6.1[1]	6.4	5.9
1994	5.4	5.2	4.7
Mean	5.8a	5.8a	5.3b

[1]Means with same letter are not significantly different at (P>0.05).

Summary and Conclusions

This project demonstrated a method of water-budget irrigation scheduling using CIMIS and published crop coefficients. The procedure was verified by comparing predicted soil-water content to measured soil-water content. Scheduling irrigations for coastal California wine grapes, by accounting for the typically reduced canopy and limited soil moisture conditions, resulted in approximately 40 percent reduction from predicted irrigation requirements. Other elements critical to precise irrigation scheduling, which often are not accurately determined and can contribute to error, are microirrigation system performance parameters and the soil wetted-volume. Although early and late season refinement was needed, published crop coefficients proved to accurately predict crop irrigation requirements. Reducing irrigation following veraison did not appear to diminish yields, however, reducing irrigation following fruit-set did lower yields. These are preliminary observations that require additional years of data to verify. Accurate water management may or may not result in reduced water consumption by vineyards, but it may be an important management tool for enhancing wine grape yields and quality.

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