VITICULTURE CONSORTIUM

Comprehensive Project Report, March 2000

PROJECT TITLE: Development of Irrigation Management Strategies to Improve Fruit Quality

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SUMMARY OF PROJECT:

This project seeks to develop an approach to vine water management appropriate to cooler growing regions that will provide growers the tools they need to know when to begin to irrigate, when to schedule subsequent irrigations and how much water to apply each time they irrigate. This research project utilized midday measurements of leaf water potential (LWP) as a threshold or trigger point to determine when to begin supplying irrigation water. After a threshold LWP has triggered the start of the irrigation season, water was supplied at a fraction of full vine water use. It was our goal to use water management, defined as the timing and quantity of applied water, to impose vine water deficits as a means of producing desirable must and wine characteristics. In order to fully evaluate such an approach, vine and must/wine measurements must be taken over numerous years.

Irrigation management strategies for red winegrape varieties, which rely on methods that can insure repeatable results, have not been developed for mature vines in cool regions. Climactic water demand and soil moisture loss variables are commonly used to schedule irrigations in the warmer growing regions in the state; however, these can grossly over estimate the amount of water necessary to insure high fruit quality. Growers are aware of this and realize they must "deficit irrigate" their vines in order to maximize fruit quality. This project will give them the tools they need to select an irrigation management strategy that integrates climate variables common to the cooler growing areas such as spring rains and summer fog.

OBJECTIVES:

1. Determine the effects of irrigation management strategies that apply different amounts of water initiated at various timings on specific components of must and wine.
2. Determine the effects of these strategies on vine growth and crop yield.
3. Define an approach to vine water management appropriate for red winegrapes in cool climate North Coast conditions.

PROCEDURES:

Trial Site

The project site is a 1.4-acre Cabernet Sauvignon vineyard located at the University of California Hopland Research and Extension Center in Mendocino County. The vineyard was planted in 1991 using FPMS clone 8 on 5C rootstock. The irrigation system was designed and installed to facilitate independent water delivery to 24 plots. A plot consists of nine vines in each of three adjacent vine rows. Data were taken from vines located in the center row. Vines are trained to a lyre utilizing quadrilateral cordons and are vertically shoot positioned. Vine spacing is 6 feet and row spacing 10 feet, yielding 726 vines per acre. Standard cultural practices were utilized throughout the season performed by Hopland Research and Extension Center personnel; however, row centers (in addition to vine rows) receive a single application of pre-emergent herbicide to achieve a completely weed-free vineyard floor.

The site has a moderate water-holding capacity, increasing in "stoniness" with depth. Nearly six feet of rocky schist material limits water-holding capacity. The well water supply is of good quality and delivered via a drip irrigation system

Treatments and Experimental Design

There are six irrigation strategy treatments (Table 1). Irrigation strategy treatments were a combination of two LWP thresholds and three post-threshold portions of full potential water use. The thresholds that initiated water applications were -12 and -14 bars. Subsequent water applications were made at 35% and 60% of full vine water use (full ET) through harvest. In addition, a single treatment (Treatment 6) received 35% of full vine water use for about the first half of the period of time from the threshold to harvest and 60% the second half. In 1997 and 1998, 30% (and not 35%) of full vine water use was utilized; however, this resulted in an overly severe water deficit, which delayed harvest. The amount was increased to 35% in those treatments.

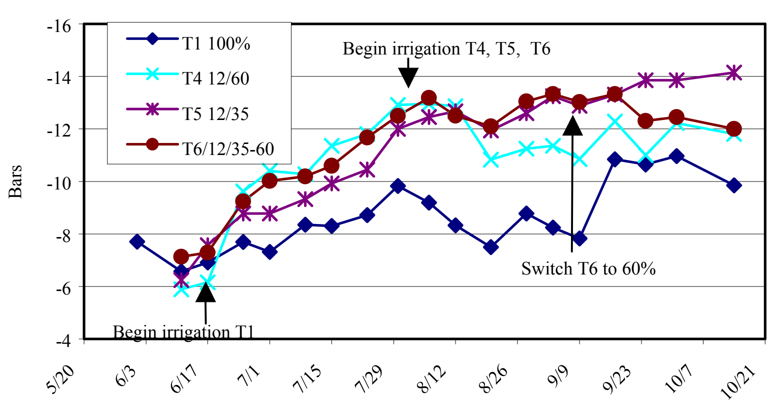
Soil moisture disappearance was measured using a neutron probe in an adjacent area in the vineyard where vines were irrigated with the same strategy as Treatment 1 using a full coverage microsprinkler system. This measured water use was considered full potential water use or 100 percent. The complete array of treatments is shown in Table 1. The experimental design is a randomized complete block with four replications of each of six irrigation strategy treatments. All treatments were irrigated immediately after harvest.

Table 1. Irrigation Strategy Treatments:
Timing of First Application and Volume of Water to be Applied

Treatment Number	Leaf Water Potential Trigger at Which First Irrigation Will Occur	Criteria for Volume to be Applied in Subsequent Irrigation
T1 100%	no trigger	supply full water
T2 14/60	-14 bars	supply 60% of daily full water use
T3 14/35	-14 bars	supply 35% of daily full water use
T4 12/60	-12 bars	supply 60% of daily full water use
T5 12/35	-12 bars	supply 35% of daily full water use
T6 12/35-60	-12 bars	supply 35-60% (variable) of daily full water use

2000 ACTIVITIES:
The vineyard was irrigated uniformly through the 1996 season. Irrigation strategy treatments were first imposed in 1997. All vines were pruned to two bud spurs and averaged 46 primary buds per vine. Shoots were thinned to one per primary bud on May 8, 2000. On June 18, 2000, irrigation commenced on T1. Threshold leaf water potentials were reached, and irrigation began August 1st for T4, T5, and T6 and on August 22nd for T3 and September 3 for T2 (Figure 1). After these dates, subsequent irrigation to replace a treatment-determined portion of full water use was conducted weekly.

Figure 1. Leaf Water Potentials
Hopland Cabernet Sauvignon 2000
Effects of RDI at -12 Bar Threshold



Water was supplied to each treatment using a controller and electric valves. Individual water meters allowed us to measure the irrigation volumes delivered to each treatment. Between bud break and 8 inches of shoot growth, frost control was provided five times with a solid set sprinkler system.

Treatments 1, 3, 4, 5 and 6 were harvested October 19 and 20, while T2 was harvested on October 30, 2000. Fruit was weighed for each vine separately. A portion of the clusters from each vine were combined by plot and crushed with an electric stemmer-crusher. Juice samples were taken and Kendall-Jackson Winery coordinated analysis of Brix, pH, TA, malate and potassium. About 5-7 pounds of fruit from each vine was combined by treatment and delivered to viticulturists at Gallo Sonoma who coordinated winemaking. Average berry weights were determined by randomly selecting 2 clusters from each vine and finding berry number and total berry weights.

2000 RESULTS:

Imposing Irrigation Treatments

Leaf Water Potential Threshold. Irrigation in T2 through T6 commenced when LWP values matched or slightly exceeded the targeted threshold by treatment. Temperatures remained fairly cool during the first part of the 2000 season, leading to gradual changes in leaf water potential. Irrigation on T1 began on June 1, and the other treatments reached their target leaf water potentials over a period of two months (Table 2). The T6 irrigation amounts were switched from 35 to 60% of full ET on September 9, giving 39 days at 35% and 41 days at 60% of full potential water use.

Table 2

Treatment Number	Leaf Water Potential Threshold Which Irrigation Will Occur	Date at Which Treatment Exceeded Threshold and Irrigation Commenced	Harvest Date
T1 100%	no trigger	6/1	10/20
T2 14/60	-14 bars	9/3	10/30
T3 14/35	-14 bars	8/22	10/20
T4 12/60	-12 bars	8/1	10/19
T5 12/35	-12 bars	8/1	10/19
T6 12/35-60	-12 bars	8/1 and 9/ 9*	10/19

*The first irrigation was conducted on 8/1. On 9/9 the volume of applied water was increased. See Table 1.

Irrigation Volumes. Water use of fully irrigated vines (Etc) was calculated for weekly irrigations using the following equation:

$$ETc = ETo \times Kc$$

Where ETo is weekly summation of the daily on-site CIMIS station Reference Evapotranspiration and Kc is the vine development coefficient for that period of time. Actual water use is also measured using a neutron probe in vines irrigated the same as T1 and compared to the estimate.

The full water treatment (T1) received at least the calculated water volume, which maintains adequate available water in the soil root zone. The other treatment received a treatment-determined portion of the full water volume.

Treatment Effects on Vine Water Status.

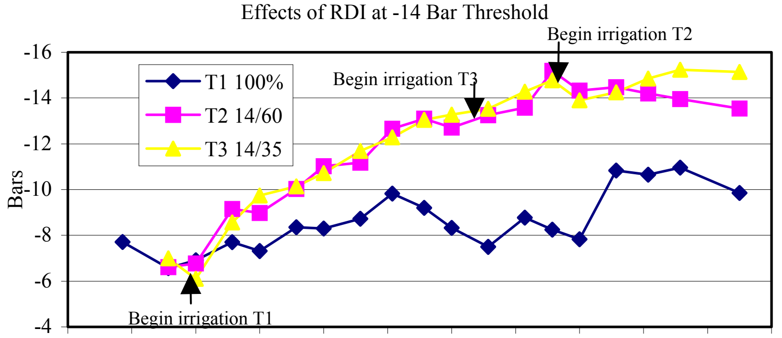
With full irrigation, T1 expressed a lower water stress level than the other treatments throughout the season averaging –8.6 bars from June 1 through October 14 (Figures 1 and 2).

Effect of Regulated Deficit (RDI)

-12 Threshold Across RDI Treatments

Treatments 4, 5, and 6 reached the –12 bar threshold on August 1. From that time, weekly irrigation of 60% of full potential water use occurred until harvest in Treatment 4 and likewise for the 35% Treatments 5 and 6. T6 was switched on September 9 from 35% to 60% halfway through the irrigation season. Figure 1 shows that the vine water status was similar among these treatments until the threshold. After the irrigation treatments were imposed, the regulated deficit irrigation percentage (RDI%) had an effect upon the vine water status. The 60% RDI (-12 bar threshold) maintained a rather constant water status as the season progressed ending near harvest at –11.8 bars. The 35% RDI treatment with the same threshold resulted in a progressively more severe water status ending at –14.1 bars. Treatment 6 tracked with its sister treatment until about two weeks after the RDI was changed to 60%. Vine water status was lessened from about –13.0 to –12.0 in Treatment 6 while Treatment 5 continued to -14.1 over the same time period. In all three treatments, the effect of beginning a weekly irrigation regime or increasing the RDI percent (as in T6) resulted in a positive effect on vine water status after one-two weeks. However in the lower RDI percent treatment, the effect was short lived.

Figure 2. Leaf Water Potentials
Hopland Cabernet Sauvignon 2000
Effects of RDI at -14 Bar Threshold



-14 Threshold Across RDI Treatments

Treatment 3 exceeded the –14 bar threshold on August 22 while Treatment 2 exceeded it on

Sept. 3. Those treatments each received the first irrigation of the season on those dates. Treatment 2 was under the threshold on the August 28 LWP reading but overshot it by the Sept. 3 reading. From a practical perspective, T2 should have been irrigated on August 28. After the first irrigation, weekly irrigations of 60% of full potential water use were applied in Treatment 2 and likewise for the Treatment 3 (35% RDI). Figure 2 shows the vine water status between these treatments was similar until the threshold. After the irrigation treatments were imposed, the regulated deficit irrigation percentage (RDI%) had an effect upon the vine water status. Both treatments show an initial improvement in vine water status due to the irrigation application. However the RDI 35% lost ground over time to end the season at –15.2 bars. After irrigation began, the 60% RDI maintained a rather constant water status as the season progressed ending at –13.5 bars

Effect of a Variable Regulated Deficit

Treatments 5 and 6 received the same RDI percent after the –12 threshold and were similar in water status until the switch to the RDI 60%. The level of water stress in Treatment 6 was reduced by more than 2.0 bars over a 21 day period when compared to Treatment 5 (Figure 1).

60 RDI Across Thresholds Treatments

Treatments 2 and 4 received 60% of full ET following leaf water potential triggers of –14 and –12 bars, respectively. Treatment 4 reached its threshold on August 1. Figure 3 shows the vine water status between these treatments similar until the T4 threshold. After that time, T2 became more stressed until the –14 bar threshold was exceeded on September 3. After irrigation began, water status was improved in both treatments. Vine water status remained more negative in T2 than T4 throughout the season. The effect of the 60% RDI on both –12 and –14 threshold treatments was to maintain the level of water stress that existed at the time the irrigation started; near -12 for the –12 threshold and near –14 for –14 bar threshold.

Figure 3. Leaf Water Potentials
Hopland Cabernet Sauvignon 2000
Effects of Different Thresholds at 60% RDI

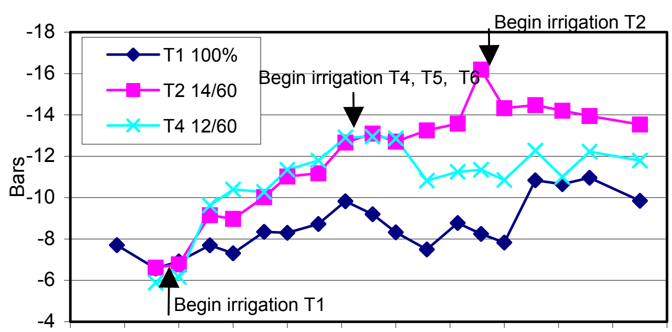
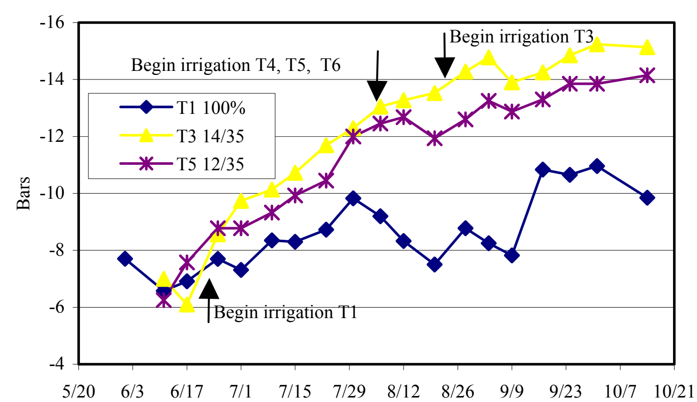


Figure 4. Leaf Water Potentials
Hopland Cabernet Sauvignon 2000
Effects of Different Thresholds at 35% RDI



35 RDI Across Threshold Treatments

Treatments 3 and 5 had leaf water potential thresholds of –14 and –12 bars, respectively, after which they received 35% of full ET. Treatment 5 reached its –12 bar threshold on August 1 while Treatment 3 reached its –14 bar threshold on August 22 for a 21 day difference. Water potential remained lower in T5 than in T3 throughout the season (Figure 4). The effect of the 35% RDI was to cause increasingly more water stress as harvest approached. The slope of the increase between the two treatments was similar with the magnitude relating the threshold value.

Water Use

The amount of water consumed by each treatment was a summation of water volumes extracted from the stored root zone moisture, effective in-season rainfall, and irrigation. Table 3 and Figure 5 show the amounts of each component that contributed to the total water consumed by each treatment. The water used in the irrigation strategy treatments ranged from 39 to 51 percent of the water consumed by the full water treatment (T1). Water volumes applied were least in the –14 bar treatments due to the short amount of time from the threshold to harvest. Treatment 3 (14/35) reached the threshold 18 days earlier than Treatment 2 (14/60). This time difference resulted in approximately the same amount of water applied even though T3 was an RDI 35 and T2 a RDI 60 treatment.

Table 3. Sources and Volumes of Water Consumed Through Harvest and Relative Volume of RDI Treatment Use in Comparison to Treatment One 2000 Hopland Cabernet Sauvignon

	Soil	In season Effective Rain	Irrigation	Total	% of T1
T1 100%	3.0	1.5	22.3	26.9	100
T2 14/60	7.4	1.5	2.4	11.3	42
T3 14/35	6.4	1.5	2.5	10.3	39
T4 12/60)	5.7	1.5	6.5	13.8	51
T5 12/35	7.2	1.5	4.1	12.8	48
T6 12/35-60	5.0	1.5	5.2	11.7	44

Figure 5. Water Sources & Amounts
2000 Hopland Cabernet

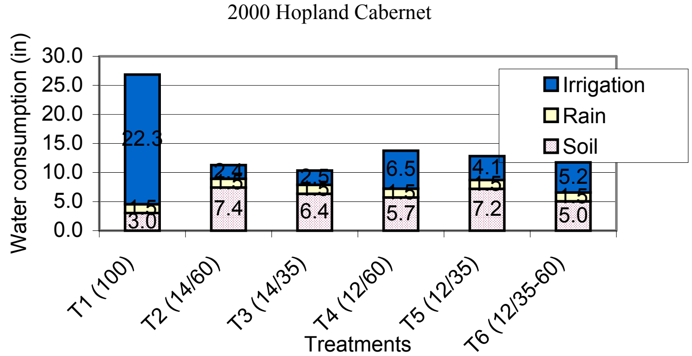
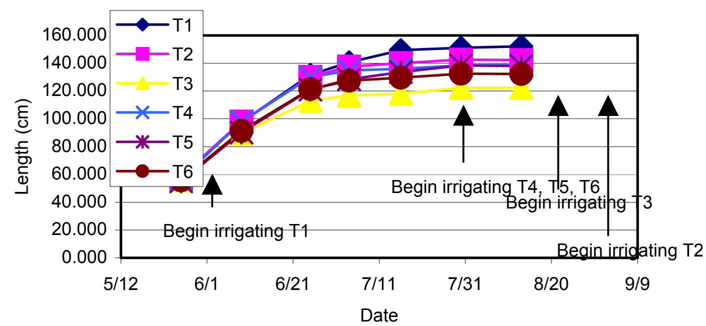


Figure 6. Shoot Length
Hopland Cabernet 2000



Canopy Measurements

Shoot lengths and shoot tip ratings were measured in each treatment every two weeks. Canopy growth was similar to that in 1999. Final shoot lengths were between 122and 152 cm (Figure 6) with the longest average length in the full water treatment (T1). No significant differences in shoot length were found between treatments at any time during the season.

Shoot growth rates calculated as cm/day were the highest early in the season and declined rapidly by August 1 (Figure 7). Significant differences were found between Treatment 1 and all others in the period July 4 – July16. Shoot growth rates did not provide a useful method to distinguish levels of water stress at or near the treatment thresholds. At the threshold of –12 bars no significant differences among treatments were found even though the full water treatment had been irrigated since June 1.

Figure 7. Shoot Growth Rates
Hopland Cabernet 2000

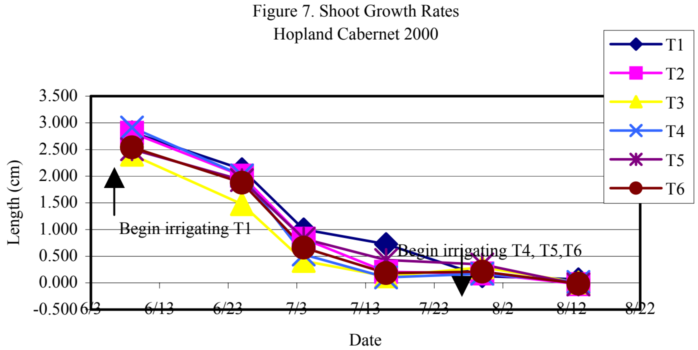
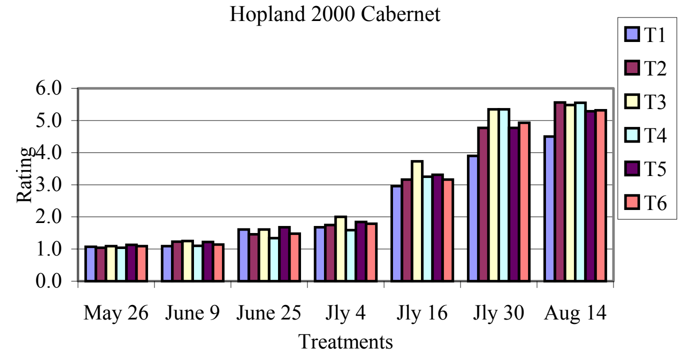


Figure 8. Shoot Tip Ratings
Hopland 2000 Cabernet



Shoot tips were rated on a scale of 1-6 with 1 vigorous and 6 dead. Like shoot growth rates, tip ratings were not able to significantly distinguish between full and deficit irrigation treatments at any time during the season (Figure 8).

Canopy Light Measurements

Measurements of relative light at fruit level were taken periodically in 1999 after veraison using a ceptometer. The only time in which significant differences were found between treatments was near harvest. In 2000, similar results were found (Table 4). The lowest amount of photosynthetic active radiation (PAR) at fruit level was measured in the full water treatment (T1). Light readings measured in the canopy were similar in both years.

Table 4. Canopy Light Measured at Fruit Level
By Treatment (% of Full Sun)
1999 and 2000 Hopland Cabernet Sauvignon

Treatment	10-15-99	9-24-00
T1 100%	4.0 a	2.7 a
T2 14/60	7.9 ab	9.7 ab
T3 14/35	12.5 b	11.4 b
T412/ 60	8.3 ab	5.9 ab
T5 12/35	10.6 ab	4.7 ab
T6 12/35-60	8.5 ab	6.2 ab
P=	0.0202	0.0229
	*	*

* Indicate significance at P ≤ 0.05. In a column, means followed by the same letter are not significantly different at the 0.05 level by Tukey's HSD.

Harvest

The fruit weight of each of seven data vines within each plot was measured. Yields were not significantly different among treatments. The full water treatment (T1) had among the highest average yield, (30.8 lb/vine or 11.2 tons/acre) and T3 (14/35) had among the lowest average yields at 21.3 lbs/vine or 7.7 tons/acre.

Table 5. Harvest Components by Treatment
2000 Hopland Cabernet Sauvignon

Treatment	Yield (lb/vine)	Berry weight (gm/berry)	Fruit Load (berries/vine)	Number Clusters/vine	Cluster weight (gms/cluster)
T1 100%	30.8	1.18 a	14208	90.2	167
T2 14/60	23.1	0.97 b	11899	88.0	141
T3 14/35	21.3	1.04 ab	11892	80.0	131
T4 12/60	22.3	0.99 b	11553	83.1	134
T5 12/35	23.9	1.05 ab	12504	83.8	140
T6 12/35-60	22.0	1.00 ab	13598	90.6	135
P=	0.0555	0.0283	0.5512	0.0594	0.0998
	NS	*	NS	NS	NS

* Indicates significance at P< 0.05. NS=not significant. In a column, means followed by the same letter are not significantly different at the 0.05 level by Tukey's HSD.

Yield Component Analysis

No significant differences were found between treatments at the 5% level in the basic yield component of berry weight or fruit load (berries per vine). However, the full potential water treatment had the highest berry weight (6% level), the highest number of clusters (8% level), and the largest cluster weight (10% level). The number of clusters per vine was generally controlled by the standard cultural practice of shoot removal but as can be seen, it was only partially effective in the full water treatment.

An attempt was made to develop a relationship between the independent variables and the dependent variables, in this case, yield in pounds per vine. The procedure quantifies the linear relationship between variables and measures the strength of the relationship. Using simple regression, berry size explains the largest amount of the variability in yield at 57.6 percent (adjusted r^2). The correlation coefficient equals 0.758675, indicating a moderately strong relationship between yield and berry weight. There is a statistically significant relationship (0.0001) between yield and berry size at the 99% confidence level. The equation of the fitted model is: Yield (lb/Vine) = -14.0756 + 36.6864 ∗ berry weight (g).

The fruit load expressed as berries per vine by itself explains 50.2 percent (adjusted r^2) of the variation in yield. The correlation coefficient equals 0.70866, indicating a moderately strong relationship between the variables. The equation of the fitted model is:

Yield (lb/Vine) = 5.04903 + 0.00151485∗Berries per vine.

Juice Analysis

Harvest of each treatment was determined by berry sampling each plot until the target of 23.5°Brix was reached. Treatments 1, 3, 4, 5 and 6 were harvested October 19 and 20, while T2 was harvested on October 30, 2000. Fruit was weighed and crushed and samples taken for juice analysis and winemaking. Analysis of juice samples indicated that the treatments (with the exception of T2) were ranging in Brix from 22.9 to 23.9, the same range as in 1999. Treatment 2 was harvested at 21.6 °Brix, 10 days later and after significant rainfall when berry sampling indicated no further sugar accumulation (Table 6).

A minimum of 35 pounds of grapes per plot, consisting of fruit selected from each vine, was crushed at harvest to collect juice samples. Malate was highest in the full water treatment (T1) over all other treatments. There were significant differences in pH and potassium levels among the treatments as well, however these differences did not seem to follow water use volumes with the exception of T1, which had among the lowest average pH. A significant relationship exists between treatment consumptive water use (ET) and malate levels in the juice at the 99% confidence level. The equation of the fitted model is:

Malate (g/100ml) = 0.1218 + 0.00835127*ET

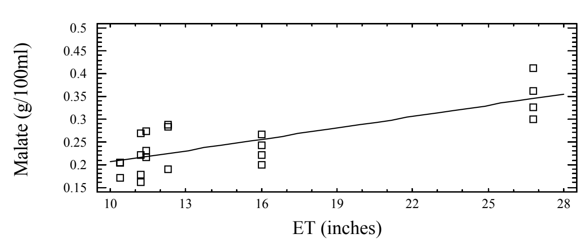
The R-Squared statistic indicates that the model as fitted explains 61.1716% of the variability in malate concentration. The correlation coefficient equals 0.782123, indicating a moderately strong relationship between the variables (Figure 9).

Table 6.
Juice Analysis by Treatment
2000 Hopland Cabernet Sauvignon

Treatment	Brix	pH	TA (gm/l)	Malate (ppm)	Potassium (ppm)
T1 100%	23.0 ab	3.40a	8.1	3505 a	1356 bc
T2 14/60	21.6 b	3.63 c	7.8	2065 b	1393 bc
T3 14/35	22.9 ab	3.47 ab	7.8	1944 b	1205 c
T4 12/60	23.4 a	3.56 bc	7.8	2318 b	1514 ab
T5 12/35	23.9 b	3.52 abc	7.9	2549 b	1533 ab
T6 12/35-60	23.3 a	3.58 bc	7.9	2367 b	1735 a
P=	0.0046 **	0.0007 ***	0.9305 NS	0.0064 **	0.0033 **

,* Indicate significance at P< 0.01, 0.001, respectively. NS=not significant. In a column, means followed by the same letter are not significantly different at the 0.05 level by Tukey's HSD.

Figure 9



Wine Analysis
Not yet available.

SUMMARY

This study is being conducted to evaluate an approach to vine water management appropriate to cooler growing regions that will provide growers the tools they need to know when to begin to irrigate, when to schedule subsequent irrigations, and how much water to apply each time they irrigate. This research project utilizes measurements of midday leaf water potential (LWP) as a threshold to determine when to begin supplying irrigation water. After a threshold LWP has triggered the start of the irrigation season, water is supplied at a fraction of full vine water use. This fraction is called the regulated deficit irrigation (RDI) percentage. It is our goal to use water management, as defined as the timing and quantity of applied water, to impose vine water deficits as a means of producing desirable must and wine characteristics.

The experimental site is located in a Cabernet Sauvignon vineyard at the Hopland Research and Extension Center. Threshold leaf water potentials were reached, and irrigation began on August 1st for T4, T5, and T6 (-12 bar thresholds) and on August 22nd for T3 and September 3 for T2 (both –14 thresholds). Irrigation to replace a treatment-determined portion of full water use was conducted weekly in each deficit treatment.

RDI Effects

When irrigation began at –12 bars, the 60% RDI (T4) maintained a rather constant water status as the season progressed ending near harvest at –11.8 bars. The same threshold in the 35% RDI treatment resulted in a progressively more severe water status ending at –14.1 bars. In general, the 35% RDI treatments showed an initial improvement in vine water status within two weeks after the first irrigation application. However, the 35% RDI with a -14 bar threshold, lost ground over time to end the season at -15.2 bars. After irrigation began with a –14 bar threshold, the 60% RDI maintained a rather constant water status as the season progressed ending at –13.5 bars. Treatments 5 and 6 received the same RDI percent after the –12 threshold and were similar in water status until the switch to the RDI 60%. The level of water stress was reduced in T6 by more than 2 bars over a 21 day period when compared to Treatment 5

Threshold Effects

The effect of the 60% RDI on both –12 and –14 threshold treatments was to maintain the level of water stress of when the irrigation started; near -12 for the –12 threshold and near –14 for –14 bar threshold. The effect of the 35% RDI was to cause increasingly more water stress as harvest approached. The slope of the increase between the two treatments was similar with the magnitude relating the threshold value.

Canopy growth was similar to that in 1999. Final shoot lengths were between 122 and 152 cm with the longest being the full water treatment (T1). Fruit level photosynthetic active radiation (PAR) was also similar to 1999 with significant differences found between the least and most water stressed treatments.

Yields were not significantly different among treatments. The full water treatment (T1) had among the highest average yield, (30.8 lb/vine or 11.2 tons/acre) and T3 (14/35) had among the lowest average yields at 21.3 lbs/vine or 7.7 tons/acre.

Malate was significantly highest in the full water treatment (T1) over all other treatments. . A significant relationship exists between treatment consumptive water use (ET) and malate levels in the juice at the 99% confidence level. There were significant differences in pH and potassium levels among the treatments as well, however these differences did not seem to follow water use volumes.

The results thus far indicate the approach of using leaf water potential as a trigger to begin irrigation and to use portions of full water ET to schedule subsequent application volumes is an effective method of irrigation scheduling that takes into account quality and yield parameters.

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