Project Title:

Deficit Irrigation Management Strategies and the Influence of Extended Maturation on Vine Health, Fruit Yield and Quality: Syrah in Region III-IV.

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Objectives

The objective of this study is to determine the effects of irrigation management and extended maturation strategies on Syrah in Region III-IV. Vines, must, and wine were measured/tested to quantify treatment effects.

EXPERIMENTAL SITE AND METHODS

A Syrah vineyard using FPMS clone 6 on SO4 rootstock established in 1998 were used in this trial. The site is located near the town of Galt, California. Vine and row spacing is 5 and 11 feet, respectively. Vines are trained to Livingston Divided Canopy (LDC) and are shoot-positioned. The site has a moderate water-holding capacity, increasing in "stoniness" with depth. The soil was ripped prior to planting to a depth of 6 feet. The well water supply is of good quality delivered via a drip irrigation system. The drip irrigation system was designed and installed to facilitate independent water delivery to individual 32 plots. A plot consists of twenty vines in each of three adjacent vine rows. An irrigation controller and electric solenoids were used to control irrigations. A drip irrigation system with 2 emitters per vine was installed in the experimental area with the application rate of 0.47 gallons per hour per vine at 15-psi operational pressure. Emitter flow rate was measured in each plot area. Emission uniformity averaged 92% after chlorination and line flushing. Data were taken from the 16 central vines located in the center row. The experimental design is a randomized complete block, split-split-plot design with four replications of each of three irrigation strategy treatments. Standard cultural practices were utilized throughout the season provided by the cooperating grower. The total experimental area is about 2.4 acres Shoot thinning was utilized each year to remove non-productive shoots in all plots. Fertilization consisted of fall applied potassium sulfate (150 lbs/A K) applied via a solutionizer through the drip system to all treatments each year.

Irrigation Strategy Treatments

Irrigation strategies chosen include full potential water use (I-1) and 2 deficit irrigation approaches. Both deficit approaches relied on a level of water stress [-14 bars midday leaf water potential (MDLWP)] to occur prior to the initiation of irrigation. After the leaf water potential threshold was reached, irrigation volume was based on (1) land surface shaded at noon to determine a crop coefficient (Kc), (2) the evapotranspiration reference (ETo) using the Lodi CIMIS station #166, and (3) a 50% regulated deficit irrigation level (RDI). The relationship between land surface shaded at midday and Kc was developed by Larry Williams at the Kearney Ag Center using grapevine in a weighing lysimeter. Essentially, shaded area × 1.7 × ETo × RDI % = irrigation volume applied. Treatment I-3 received 50% on a weekly irrigation schedule until harvest of all maturity treatments. Treatment I-2 was irrigated like I-3 until 19º Brix (21 ºBrix in 2005) was reached. At that time, the irrigation volume was increased to 100% based on the canopy size and the current ETo. Irrigation was the same for all plots in the experimental area during establishment of the trial in the 2003 season; with treatments imposed 2004 – 2008.

Fruit Maturation Treatments

Maturity treatment targets were 24º, 26º, and 28 ºBrix (B-24, B-26 and B-28). Harvest date was determined by sampling berry Brix of each treatment. When the berry samples indicated the Brix treatment level was near, harvest was scheduled for the next day. Fruit maturation treatments were imposed from 2005 through 2008.

Crop Load Treatments

Crop load treatments were varied by the number of 2-bud spurs on each vine. The 14-spur treatment (S-14) resulted in 5.6 primary buds per foot of row and 0.51 buds per square foot. The 18-spur treatment (S-18) resulted in 7.2 buds per foot of row and 0.65 buds per square foot. The 18-spur treatment resulted in about a 28% increase in buds over the 14-spur treatment. Crop load treatments were imposed 2006-2008 by splitting the fruit maturation treatments plots.

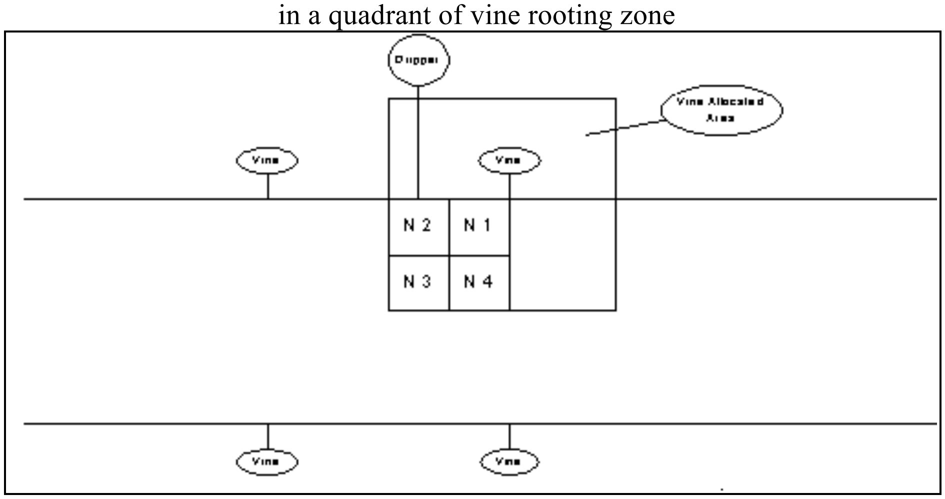
Vine Water Status

Data were collected throughout the 2004 to 2008 growing season to monitor vine water status. Mid-day leaf water potential was determined using a Scholander type pressure chamber. Measurements were taken on recently expanded mature, sun-exposed leaves from 1100 to 1400 hr on three representative vines per individual plot. Two measurements were made on each vine. Data collected after irrigation was initiated were collected just prior to the beginning of the weekly irrigation cycle.

Soil Water Content

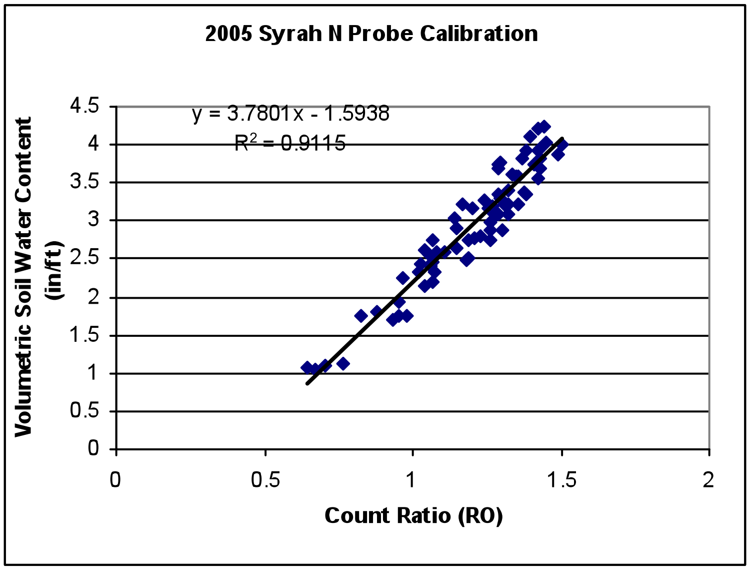
Soil moisture extraction was measured throughout all seasons using a neutron probe to a soil depth of 105 inches. Single access well was installed in each plot totaling 32 wells. One vine in each irrigation treatment was instrumented with a grid pattern of access wells (Figure 1). Each well represents 3.4 square feet of surface area. The combined area represents one quarter of the vines allocated area.

Figure 1. Placement of intensive neutron probe wells in a quadrant of vine rooting zone



Soil samples were collected from the wells and volumetric water content measured along with the neutron probe count ratio prior to trial establishment. A calibration was developed between soil volumetric water content and count ratio at the site (Figure 2).

Figure 2. Neutron Probe Calibration



Irrigation Scheduling

No irrigation was applied until mid-day leaf water potential reached –14 bars in the two deficit treatments. The full water treatment was irrigated when leaf water potential reached -8 bars for the initial irrigation. After the targeted leaf water potential was reached irrigation volume was based on (1) land surface shaded at noon to determine a crop coefficient (Kc), (2) the evapotranspiration reference (ETo) using the Lodi CIMIS station #166, and (3) a 50% regulated deficit irrigation level (RDI). The relationship between land surface shaded at midday and Kc was developed by Larry Williams at the Kearney Ag Center using grapevine in a weighing lysimeter. Essentially weekly irrigation in the deficit treatments was determined by:

Shaded area × 1.7 × ETo × RDI % = irrigation volume applied.

The full irrigation treatment was determined similarly but using an RDI% of 100%. Treatment 2 was irrigated like treatment 3 – a 50% RDI until the fruit reached 19 ºbrix (21º in 2005). At that time the RDI was changed to 100%.

RESULTS and DISCUSSION

Water Use

The consumptive use of each plot was measured as a sum of depleted soil moisture volume, applied water volume, and effective in-season rainfall. Soil water disappearance was based on the grid of neutron probe wells in the quadrant of the vines allocated area. An evaluation of available stored moisture was made each year at bud break. Soil moisture was again measured prior to irrigation and used to determine soil water use during this period. Soil moisture was again measured after harvest and at leaf drop and used in the same fashion. In some years, 2006 in particular, rainfall continued to replenish the profile in excess of the calculated vine water use until May. Therefore, rainfall in excess of vine use which would have been considered as an input to the soil storage was considered runoff or deep percolation. The full profile status was verified by neutron probe soil water measurements. In the 2006 case, estimates of water use were used during the period of time when rainfall occurred in excess of soil storage capacity.

In-season rainfall was measured on site. Irrigation volumes were measured using calibrated water meters. Table 1 shows the average of the years 2005-2008 water consumption components at both harvest and as a seasonal total adding post harvest irrigation volumes. The seasonal water volumes consumed by the deficit treatments I-2 and I-3 compared to irrigation treatment I-1 was 69% and 55% respectively. Total applied water when compared to the full potential treatment (I-1) was 50% for irrigation treatment I-2 and 36% for the irrigation treatment I-3. Essentially, the increase in applied water between the deficit treatments was on average 4.2 inches applied to treatment I-2 from 19 ºBrix to harvest. This amount varied substantially over the years, primarily due to soil water content at bud break, in-season rainfall, and variable time periods from the increased water application time and harvest.

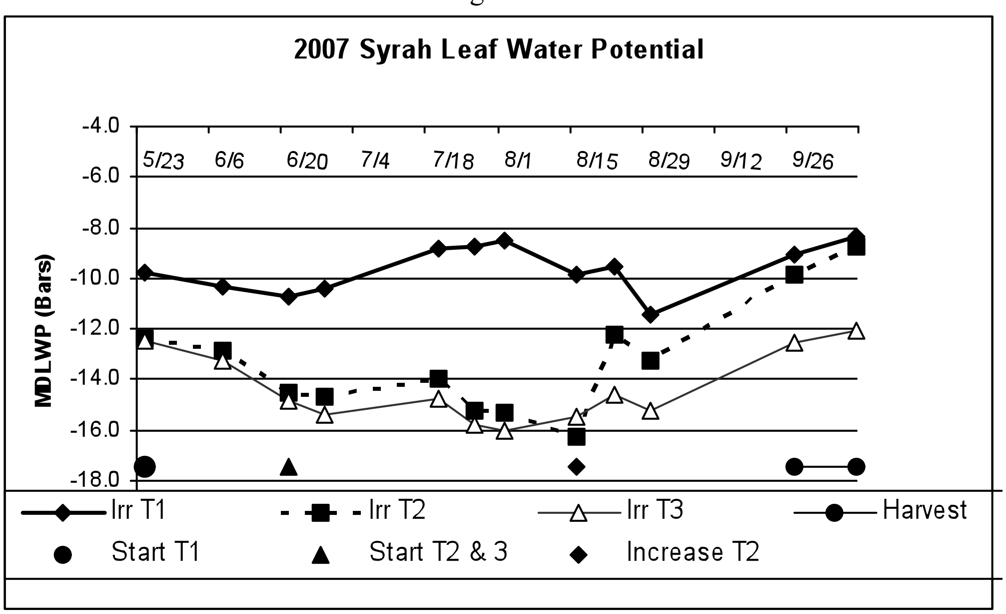
Table 1. Water Consumption Components Average of 2005-2008

Irrigation Strategy	Water Applied (in) Pre harvest	Water Applied (in) Post harvest	Soil Use (in)	Effective In-Season Rainfall (in)	Total Water Consumed (in) Pre harvest	Total Water Consumed (in) Inc. Post Harvest	% of Irrigation Strategy 1 Pre Harvest	% of Irrigation Strategy 1 Seasonal
1	28.8	2.1	4.8	1.1	34.7	36.7	100	100
2	13.3	2.1	8.3	1.1	22.7	24.8	68	69
3	9.3	1.9	7.2	1.1	17.6	19.5	53	55

Vine Response to Water Deficits

The vine response to water deficits was monitored by measuring midday leaf water potential (MDLWP). Irrigation treatment I-1 received irrigation volume to meet full potential water use in combination with stored soil moisture. Weekly irrigations continued until the final maturity harvest times. For clarity leaf water potential data presented are for 2007 only. The other years results are quite similar with the exception of irrigation start dates and harvest date. Irrigation began on May 25th in 2007, at which time leaf water potential was a level of -9.9 bars, indicating a non-stressed condition (Figure 3). The seasonal average (May 24 – Oct 9) was -9.6 bars ranging from -8.6 to -11.6 bars.

Figure 3.



Irrigation treatments I-2 and I-3 received no irrigation until a MDLWP of -14.5 was reached on June 22. Irrigation water volumes were then applied weekly at the rate of 50% of calculated full potential continuing to harvest for treatment I-3. MDLWP was measured periodically until harvest with the differences related to climatic conditions and the length of time the measurement was made from the weekly irrigation. The seasonal average MDLWP for irrigation treatment I-3 (5/22 – 10/09) was -14.4 bars. Berry sampling and Brix analysis on August 17 indicated the 19 ºBrix level was reached in treatment I-2 at which time the volume of irrigation water was increased from 50% to full potential as indicated on Figure 3 by a ♦ symbol. The MDLWP averaged a 2.6 bar reduction in water stress when compared to the sister Treatment 3 after the irrigation volumes were increased. The average MDLWP for Treatment 2 after August 17th was -11.0 bars. In the case of Treatment 3, the volumes of water applied generally stabilized the MDLWP at an average of -13.6 bars after the initiation of irrigation, for the remainder of the season. The solid bar on Figure 3 indicates the harvest date range.

Fruit

The extent of veraison was rated visually when 100% of the clusters on the full water treatment (I-1) had some color. All plots were rated on July 18 2007 as to the percent of the clusters which had some color. The differences were found between the full potential irrigation strategy and the deficit regimes with I-1 at 92% and the deficit treatments at 79%. Treatment I-1 had been irrigated since May 25 where as treatments I-2 and I-3 were irrigated on June 22.

Canopy

Canopy size was evaluated by maximum shoot length and land surface shaded at midday. Significant differences in canopy size were found between irrigation treatments and spur treatments (Table 2). Shoot lengths of irrigation treatment I-1 were longest at 74 cm followed by I-2 at 70 cm and I-3 at 64 cm. Irrigation treatment I-1 and I-3 were significantly different from each other similar to the level of water consumption. Land surface shading was measured using digital photography and pixel color density evaluating software to determine the percent land surface shading as an indicator of canopy size. Significant differences were found between irrigation treatments with I-1 the highest ground shading at 62 % followed by I-3 at 52% and I-3 at 48%. The land surface shaded measurements in Table 3 are from 8/16/07. Significant differences in shoot length were found between Brix treatments – a first for this trial and possibly an anomaly. No Significant differences in shoot length were found between the S14- and S18-spur treatments.

Table 2. Canopy Measurements

	Shoot Length (cm)	Land Surface Shaded
Irrigation		
I-1	74.2 a[a]	62a
I-2	69.7 ab	48 b
I-3	64.1 b	52 b
P =	0.0148	0.0480
Brix		
24	72.8 a	
26	64.2 b	
28	71.1 a	
P =	0.0301	
Spurs		
14	70.3	
18	68.4	
P=	0.4847	
Interactions	NS	

[a] *Different letters in the same column indicate significant differences as indicated by the stated p value using Duncan's means separation test.*

Yield

The fruit weight of each of 15 data vines within each plot was measured. Harvest date was determined by sampling berries for ºBrix of each treatment. When the berry samples indicated the Brix treatment level was near, harvest was scheduled for the next day. Data presented are an average of treatment years 2005-2008.

Vine yield compared across all Brix and spur treatments, indicated differences among all irrigation treatments (Table 4). Treatment I-1 averaged 22.2 pounds per vine (8.8 tons/acre) compared to the deficit treatments at 17.0 pounds per vine for I-2, and 14.1poundsper vine for I-3. The yield reductions from full irrigation were 23% and 36 % for treatments I-2 and I-3 respectively.

Significant yield differences were also found between all the Brix treatments (Table 3). The yield of Brix treatment B-24, the lowest level of maturity, was significantly higher than the B-26 and B-28 treatments. The yield reduction from B-24 to B-26 was 10% while B-24 to B-28 treatments was 18%.

A significant difference was found between the spur treatments S-14 and S-18. The S-18 was 16% higher in yield than S-14 treatment. No significant interaction between irrigation, Brix level or spur number treatments were found to exist.

Vine yield varied from year to year with 2006 significantly higher than other years at an average of all treatments of 22.0 pounds per vine. The 2006 year was a high winter and spring rainfall year. Yield in 2005 was significantly lower than the other years at 13.8 pounds per vine—the season in which hail damage occured. Years 2007 and 2008 were similar and significantly different than the 2005 and 2006 at an average of 16.3 pounds per vine.

Table 3. Yield and Yield Components, 2005-2008 Syrah, Galt

	Yield (lb/vine)	Relative Yield (%)	Berry Size (g)	Relative Berry Size (%)	Fruit Load (berry/vine)	Relative Fruit Load (%)
Irrigation						
I-1	22.1 a[a]	100	1.52 a	100	6342 a	100
I-2	17.0 b	77	1.29 b	85	5779 b	91
I-3	14.1 c	64	1.20 c	79	5209 c	82
P =	0.0000		0.0000		0.0000	
Brix						
24	19.6 a	100	1.43 a	100	5839	100
26	17.7 b	90	1.35 b	94	5774	99
28	16.1 c	82	1.24 c	87	5719	98
P =	0.0000		0.0000		0.8396	
Spurs						
14	16.3 b	84	1.34	100	5461 b	90
18	19.3 a	100	1.33	99	6093 a	100
P=	0.0001		0.4969		0.0002	
Year						
2005	13.8 c	63	1.51 a	100	3954 d	56
2006	22.0 a	100	1.43 b	95	7027 a	100
2007	16.5 b	75	1.15 d	76	6416 b	91
2008	16.2 b	74	1.28 c	85	5712 c	81
P=	0.0000		0.0000		0.0000	
Interactions	NS		NS		NS	

[a] *Different letters in the same column indicate significant differences as indicated by the stated p value using Duncan's means separation test.*

Yield Components

Berry size was measured as weight (g) per berry from 5 clusters per plot (20 per treatment). Berry size was significantly different between each irrigation treatment. Irrigation treatment I-1 was the highest at 1.52 g/berry with I-2 at 1.29 g/berry, followed by I-3 at 1.20 g/berry (Table 3). Berry size as a function of maturity significantly declined at each extended maturity level. Maturity treatment B-24 berries were the largest at 1.43 g/berry with the intermediate maturity (B-26) at 1.35 g/berry, followed by the longest maturity treatment (B-28) at 1.24 g/berry. No significant differences were found between spur treatments. Significant differences in berry size between each year also exist. Generally, the lower yield years and lower fruit load years have the highest berry size. However the 2006 season is an exception.

Fruit load, as measured by number of berries per vine, was found to be significantly different between each irrigation treatment. In comparison to I-1 the fruit load was reduced by 9% in 1-2 and 18% in I-3 (Table 3). No significant differences in fruit load were found between Brix treatments. The fruit load was significantly larger (10%) in the S-18 spur treatment due to the increased spur and bud numbers over the S-14 treatment.

There is a statistically significant relationship between yield and fruit load. The R-Squared statistic indicates that the model as fitted explains 74.4% of the variability in yield with respect to fruit load. The correlation coefficient equals 0.86, indicating a moderately strong relationship between the variables.

There is a statistically significant relationship between yield and berry weight; however, the R-Squared statistic indicates that the model as fitted explains 20.1% of the variability in yield. However, the correlation coefficient equals 0.45, indicating a relatively weak relationship between these variables.

Upon further analysis, the numbers of clusters (or the fruit load packets) were significantly higher in the irrigation treatment I-1 compared to I-2 or I-3 (Table 4). Cluster number was reduced in I-2 and I-3 in relation to I-1 by 7% and 18% respectively. The reduction in cluster number is a typical multi-year effect of the irrigation treatments—water deficits result in fewer clusters the following year. The number of clusters is correlated with the amount of consumed and applied water. No crop reduction by cluster or shoot thinning was performed, as only non-bearing shoots were removed in May of each year.

As would be expected, no significant differences in the number of clusters were found between Brix treatments. The numbers of clusters increased by 14% as a result of the 28% increase in spur number in the S-18 vs the S-14 treatments. Cluster number varied significantly between years with 2005 and 2008 being the lowest and 2006 and 2007 the highest with about a 10% average difference. Hail occurred after bloom in 2005 causing cluster and berry removal as well as shoot tip damage resulting in the lowest cluster number of all the years.

Cluster size (lbs/cluster) was significantly larger in I-1 when compared to the other treatments—about 20% larger. Cluster weight was significantly reduced with increasing Brix treatments. Brix-24 treatment resulted in the largest clusters with Brix-26 reduced by 9% and Brix-28 reduced by 17% when compared to the Brix-24 treatment. Cluster size was significantly larger in the Spur-14 treatment by 6% when compared to Spur-18 treatment. Cluster size was lowest in 2005, the year in which hail damage occurred, and in 2007, both being significantly different than the other treatments. Cluster size was largest in 2006 with 2008 being intermediate.

Table 4. Yield and Yield Components, 2005-2008 Syrah, Galt

Treatment	Cluster Number (clusters/vine)	Relative Cluster No. (%)	Cluster Size (lbs/cluster)	Relative Cluster Size (%)
Irrigation				
I-1	57.5 a[a]	100	0.37 a	100
I-2	53.4 b	93	0.30 b	81
I-3	47.4 c	82	0.29 b	78
P =	0.0000		0.0000	
Brix				
24	52.3	98	0.35 a	100
26	52.8	99	0.32 b	91
28	53.2	100	0.29 c	83
P =	0.7935		0.0000	
Spurs				
14	48.9 b	86	0.33 a	100
18	56.6 a	100	0.31 b	94
P=	0.0000		0.0500	
Year				
2005	48.7 b	87	0.28 c	70
2006	54.6 a	98	0.40 a	100
2007	56.0 a	100	0.29 c	73
2008	51.6 b	92	0.31 b	78
P=	0.0001		0.0000	
Interactions	NS		NS	

[a] *Different letters in the same column indicate significant differences as indicated by the stated p value using Duncan's means separation test.*

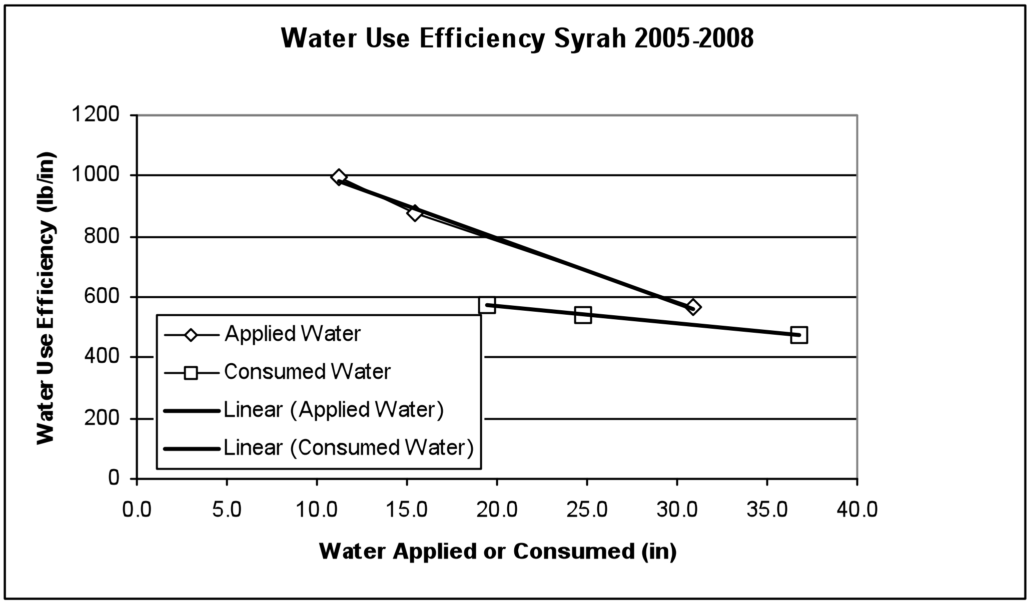
Water Use Efficiency

Water use efficiency can be viewed from the perspective of the amount of grapes per unit of applied water consumed or the total water consumed. Total water consumed (ETc) includes soil water contribution, effective in season rainfall, and irrigation water. The applied and total consumed (ETc) water is shown in Table 1 while yield is shown in Table 3. Using applied water volumes or consumed water for comparison, irrigation treatment I-1 was the least efficient while the I-3 treatment was highest in water use efficiency (Table 5). The increase in applied water use efficiency correlates with lower applied water treatments. Using total consumed water as a measure of water use efficiency, results in less difference between treatments in water use efficiency. This is a result of increased water application in I-1and to a lesser extent 1-2, resulting in water remaining in the soil at the end of the season. Water use efficiency whether using applied water or consumed water vs yield results in a linear relationship (Figure 4).

Table 5. Water Use Efficiency, 2005-2008 Syrah, Galt

2005-2008 Irrigation Treatment	Lbs Product / Acre Inch Water Applied Water	Relative(% of highest) WUE	Lbs Product / Acre Inch Water Consumed Water	Relative(% of highest) WUE
I-1	567	57	471	83
I-2	875	88	543	95
I-3	997	100	573	100

Figure 4.



Fruit Quality

One cluster from each vine (20 per treatment) was collected at each harvest and delivered to the laboratory for juice analysis. The fruit composition analysis was based on this sample.

Irrigation Treatment. The juice sugar level was found to be significantly different between irrigation treatments. The highest ºBrix level occurred in irrigation treatments I-3 followed by I-2 and then I-1. The range was 0.9 ºBrix and was a result of estimating the correct harvest date and Brix level. Irrigation treatment I-1 was significantly over estimated while I-3 was under estimated by berry sampling. Juice pH levels in irrigation treatment I-3 were significantly higher than the other treatments at pH 3.91. Treatments I-1 and I-2 were the same at pH 3.85. Comparing the irrigation treatments across the other factors finds malic acid content, and titratible acidity were significantly higher in the full irrigation (I-1) than both deficit treatments (Tables 6 and 7). The relationship between titratable acidity and malic acid content is moderately strong with an R-squared statistic of 59.4% and a correlation coefficient of -0.69 (Figure 5.). The relationship between juice potassium content and pH is also moderately strong with an R-squared statistic of 78.2 % (Figure 6). Anthocyanins and phenolics behaved similarly under the irrigation treatments with less water consumed having a greater content. The tartaric to malic acid ratio was significantly increased by the deficit irrigation treatments from 1.66 in the full water treatment to an average of 2.44 in the deficit treatments

Brix Treatments. The ºBrix treatment targets were 24, 26, and 28 ºBrix. The actual averages were 24.2, 25.6, and 27.3. However for year-to-year continuity, the target ºBrix levels are used in this report. Comparing the ºBrix treatments across the irrigation and spur treatments finds a significant positive (increasing) relationship between ºBrix treatments and pH; and a negative (decreasing) relationship with titratible acidity as a function of increasing ºBrix. Malic acid content was significantly lower in the deficit treatments when compared to the full water treatment. Tartaric acid content was significantly higher in the B-28 treatment when compared to the B-24 and B-26 treatments. Malic acid contents were not significantly different; however the ratio of tartaric acid to malic acid was higher in the deficit treatments. Anthocyanins and phenolics behaved similarly under the irrigation treatments with less water consumed, having a larger content than the I-1 treatment.

Spur Treatments. No significant differences were found between any measured juice parameter.

Difference between Years. Years 2005 and 2007 resulted in higher juice sugar content than years 2006 and 2008 as result of picking time selection—not as a result of the years influence. Juice pH was higher in 2007 and 2008 than 2005 and 2006. Interestingly, the potassium content did not strictly follow the general overall positive relationship. Potassium and phenolics were not significantly different between years. All other measured juice parameters were different from each other due to climatic and crop load conditions.

Table 6. Fruit Composition Analysis, 2005-2008 Syrah, Galt

Treatment	º Brix	pH	Potassium (mg/L)	Titratable Acid (g/L)
<u>Irrigation</u>				
I-1	25.2 c[a]	3.85 b	2044 a	0.42 a
I-2	25.7 b	3.85 b	1915 b	0.36 b
I-3	26.1 a	3.91 a	2050 a	0.36 b
P =	0.0000	0.0254	0.0039	0.0000
<u>Brix</u>				
24	24.2 c	3.68 c	1598 c	0.42 a
26	25.6 b	3.83 b	2004 b	0.37 b
28	27.3 a	4.11 a	2408 a	0.35 c
P =	0.0000	0.0000	0.0000	0.0000
<u>Spurs</u>				
14	25.6	3.87	2004	0.38
18	25.8	3.87	2002	0.38
P =	0.2818	0.8246	0.9641	0.7033
<u>Years</u>				
2005	26.2 a	3.78 b	1930	0.46 a
2006	25.3 b	3.78 b	2009	0.39 c
2007	25.9 a	3.98 a	2080	0.26 d
2008	25.4 b	3.94 a	1994	0.41 b
P =	0.0000	0.0000	0.0739	0.0000

[a] *Different letters in the same column indicate significant differences as indicated by the stated p value using Duncan's means separation test.*

Table 7. Fruit Composition Analysis, 2005-2008 Syrah, Galt

Treatment	Tartaric Acid (mg/L)	Malic Acid (mg/L)	Tartaric:Malic Ratio	Anthocyanins (mg/g)	Phenolics (mg/g)
Irrigation					
I-1	4663	2949 a[a]	1.66 b	1.11 b	1.37 b
I-2	4768	2206 b	2.41 a	1.16 ab	1.44 ab
I-3	4893	2207 b	2.47 a	1.20 a	1.47 a
P =	0.1998	0.0000	0.0000	0.0014	0.0454
Brix					
24	4514 b	2533	1.91 b	1.08 b	1.33 b
26	4513 b	2455	2.26 a	1.20 a	1.46 a
28	5297 a	2375	2.38 a	1.19 a	1.50 a
P =	0.0000	0.1805		0.0000	0.0001
Spurs					
14	4759	2451	2.15	1.14 b	1.41
18	4790	2457	2.21	1.18 a	1.43
P =	0.7668	0.9399	0.5153	0.0650	0.3393
Years					
2005		2883		1.11 b	1.43
2006	5167 a	2731 a	2.11 b	1.18 a	1.44
2007	4362 c	1824 c	2.67 a	1.21 a	
2008	4795 b	2778 a	1.76 c	1.12 b	
P =	0.0000	0.0000	0.0000	0.0143	0.7496

[a] *Different letters in the same column indicate significant differences as indicated by the stated p value using Duncan's means separation test.*

Figure 5. Relationship between titratable acidity and malic acid in the juice

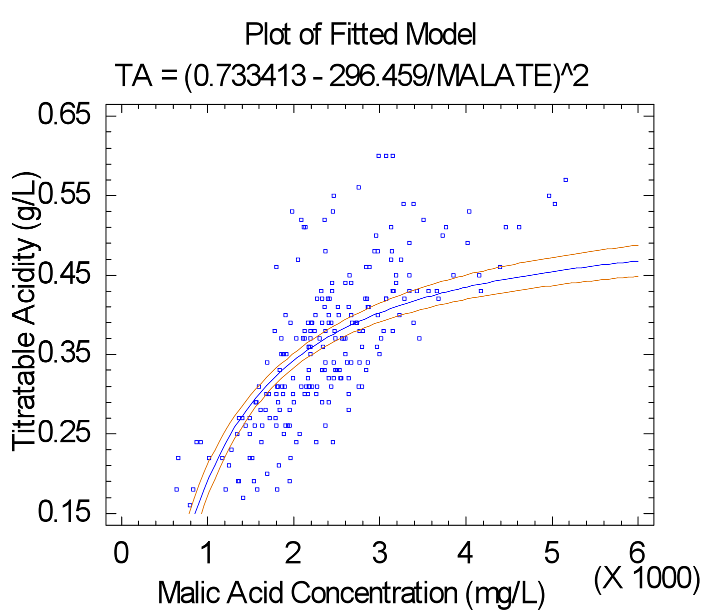
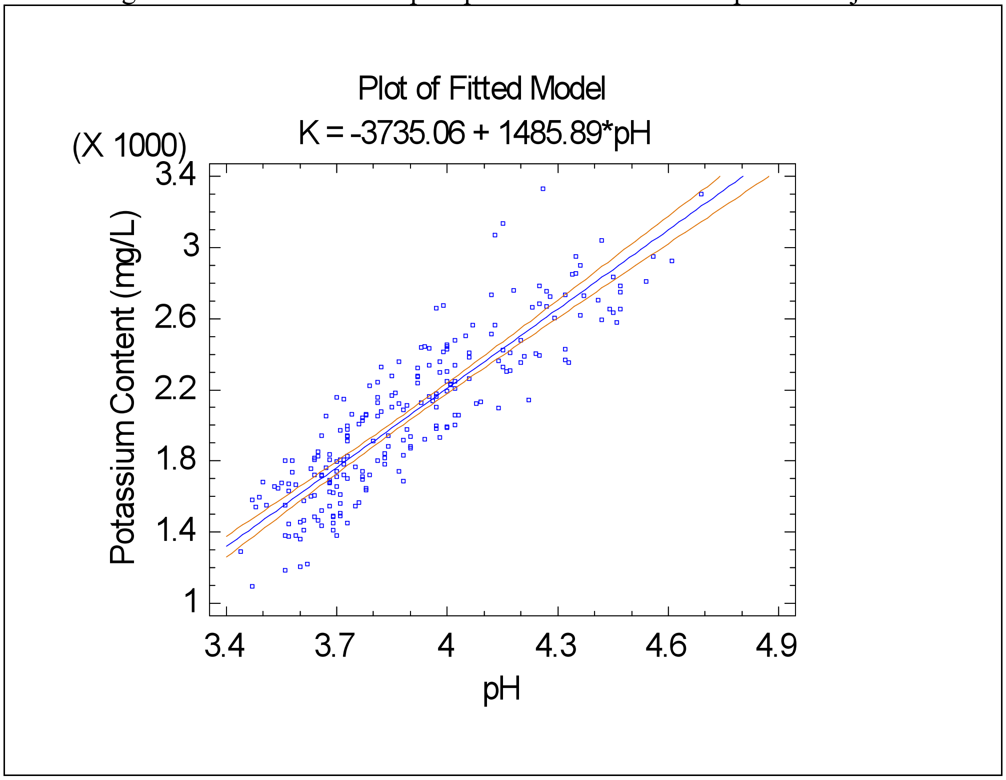


Figure 6. Fitted relationship of potassium content and pH of the juice



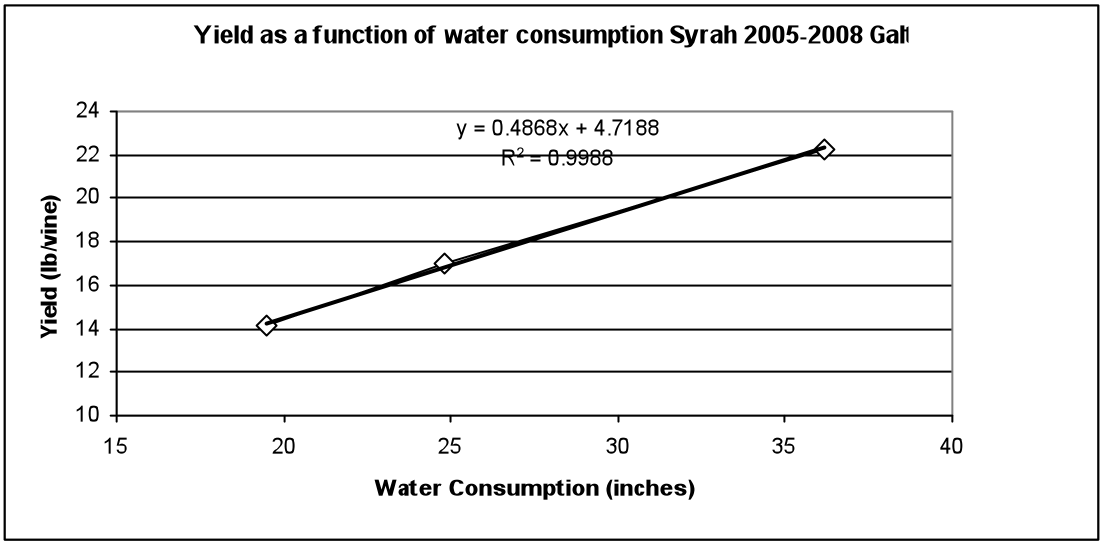
CONCLUSION

Three levels of fruit maturity were compared across three different irrigation strategies in a region III/IV Syrah vineyard during 2004 through 2008. Data presented are from years 2005 through 2008 since the long term effects of water deficits are of greatest interest. Significant differences in level of water stress were found between all treatments as measured by seasonal average midday leaf water potential each year. The average levels of water stress within irrigation treatments were similar each year. Irrigation treatment I-2, received an additional 4.0 inches of water at 19 ºBrix in contrast to treatment I-3. This strategy improved vine water relations significantly from increased water application through the remainder of the season. Water consumption was also significantly different among all irrigation treatments. The applied water varies by year as a function of climatic conditions during the season and different amounts of stored moisture at the beginning of the season. Consumed water volumes were similar within irrigation treatment between years. The deficit irrigation treatments I-2 and I-3 consumed 68% and 53% of the full potential consumptive use treatment I-1as an average of years 2005 through 2008. Both the deficit irrigation treatments resulted in higher water use efficiency compared to the full water treatment. Water use efficiency whether using applied water or consumed water vs. yield resulted in a linear relationship.

Yield

Significant yield reductions occurred with deficit irrigation and extended maturation. Yield reductions, compared to full water (I-1) treatment, were: I-2 at 23% less yield and I-3 at 36% less. The mitigating effect of additional irrigation at 19 ºBrix (I-2) was to reduce yield loss due to deficit irrigation. The deficit irrigation treatment I-2 received 4.0 inches of irrigation water more than the I-3 vines. However, the relationship between yield and water consumption remains linear (Figure 6). When yield is plotted as a function of water consumption (Figure 7), it is a strong linear relationship with a R-squared statistic of 99.9%.

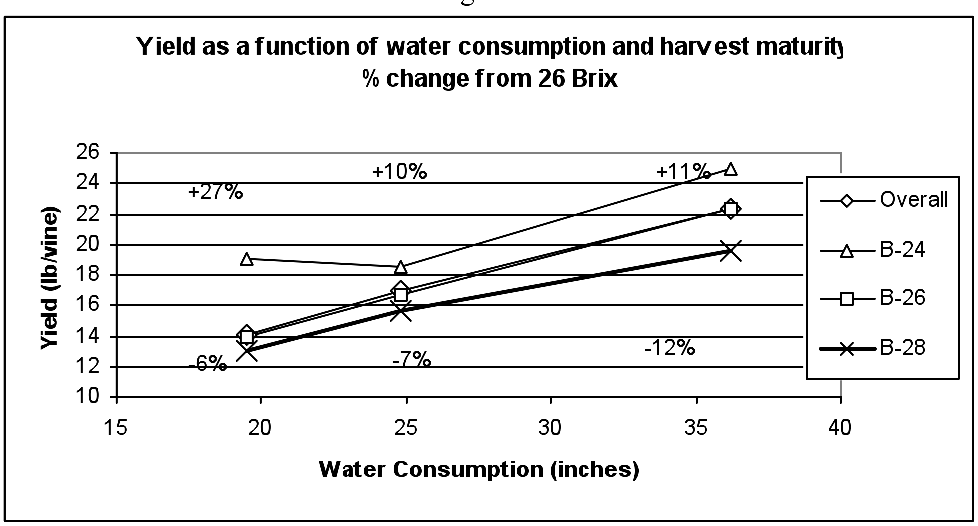
Figure 7.



Yield component analysis using simple regression revealed fruit load differences explain 74.4% of the differences in yield while berry size explains 20.1%. The same irrigation treatments were imposed in the 2004 through the 2008 season. Water deficits in I-2 and I-3 were responsible for the decreased cluster number and fruit load. The number of clusters per vine was significantly reduced by 18 % in the continual deficit treatment 1-3 when compared to the other two treatments. Irrigation treatment I-2 cluster number was also significantly reduced from the full water treatment (I-1) by 7%.

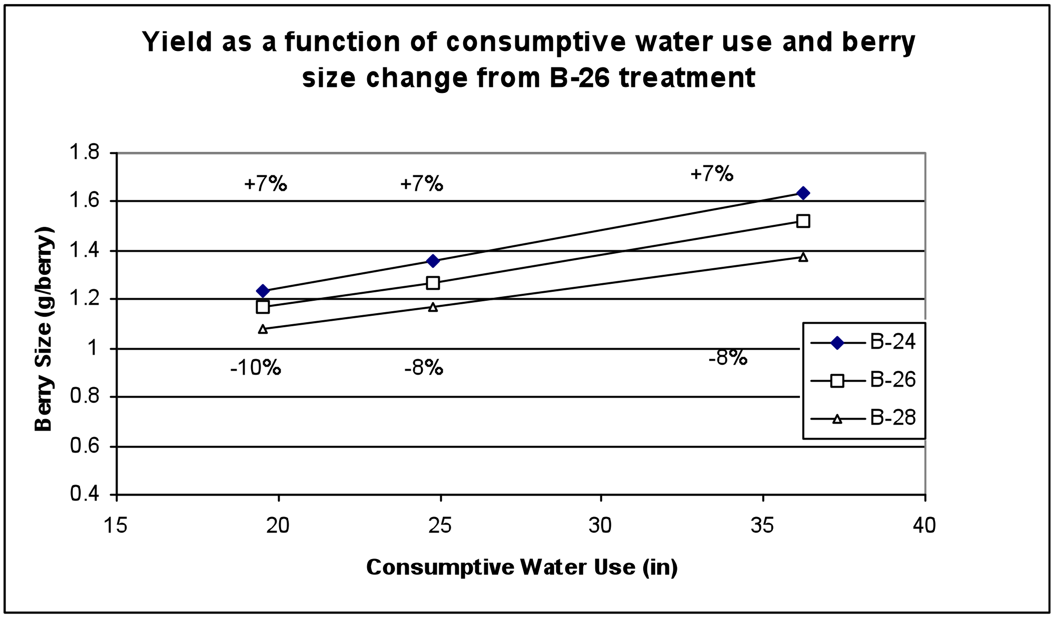
Significant yield reductions were also found between maturity (Brix) treatments across irrigation and spur treatments (Figure 8). Figure 8 illustrates the effect of water consumption upon yield combined with the change in yield due to extended maturities (or Brix treatments). This figure can be used to visualize the change in yield, as a result of different maturities across irrigation treatments. An example: consider the lowest irrigation level (I-3) where the effect of a 26 to 24 Brix maturity change would result in a 27% yield gain.

Figure 8.



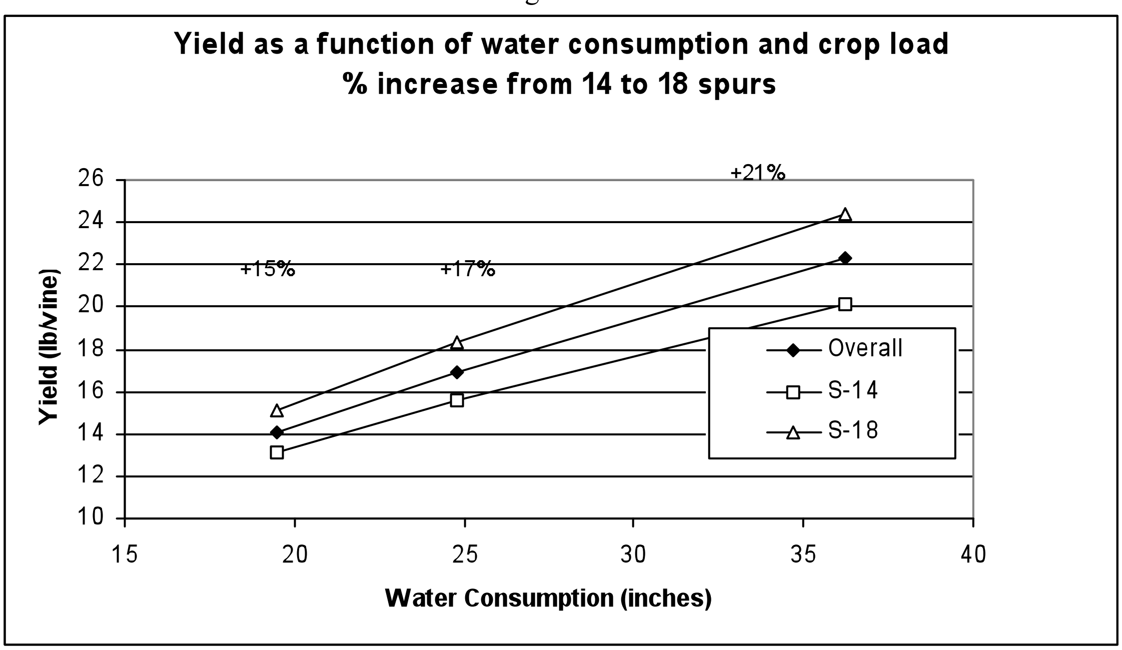
The average yield reduction from B-24 to B-26 was 10% while B-26 to B-28 was 18%. The yield reduction was primarily due to reduced berry size. Figure 9 illustrates the effect of berry size on yield at the different irrigation levels. It is a fairly linear change in berry size from B-24 to B-28 maturities.

Figure 9.



The mitigating effect of adding crop load by pruning to 28% more spurs was to increase yield by 16% across all irrigation and Brix treatments. Figure 10 illustrates the relationship between water consumption and yield as the spur number changes. As the spur number increases from 14 to 18 per vine the yield increases 17% in the mid level irrigation treatment while it increases 21% in the full irrigation treatment.

Figure 10.



Utilizing the relationships in figures 8 and 10, growers can select irrigation, crop load, and maturity strategies to produce a specific yield to quality balance that is appropriate for their targeted market.

Fruit Quality

Significant differences in fruit quality, as measured by juice analysis, were found between irrigation strategies and maturity strategies. Generally, full water and earlier maturities lagged other treatments in quality parameters.

Irrigation Treatments Juice sugar level was found to be significantly different between irrigation treatments, increasing in relation to the consumed water volumes with the highest ºBrix level in irrigation treatments I-3 followed by I-2 and then I-1. The range was 0.9 ºBrix and was a result of estimating the correct harvest date and Brix level. Juice pH levels in irrigation treatment I-3 were significantly higher than the other treatments at pH 3.91. Treatments I-1 and I-2 were the same at pH 3.85. Comparing the irrigation treatments across the other factors finds malic acid content and titratible acidity were significantly higher in the full irrigation (I-1) than both deficit treatments. The relationship between titratable acidity and malic acid content is moderately strong as is the relationship between juice potassium content. Anthocyanins and phenolics behaved similarly under the irrigation treatments with less water consumed having a greater content. The tartaric to malic acid ratio was significantly increased by the deficit irrigation treatments from 1.66 in the full water treatment to an average of 2.44 in the deficit treatments

Brix Treatments The ºBrix treatment targets were 24, 26, and 28 ºBrix. The actual averages were 24.2, 25.6, and 27.3. However, for year-to-year continuity the target ºBrix levels are used in this report. Comparing the ºBrix treatments across the irrigation and spur treatments finds a significant positive (increasing) relationship between ºBrix treatments and pH; and a negative (decreasing) relationship with titratible acidity as a function of increasing ºBrix. Malic acid content was significantly lower in the deficit treatments when compared to the full water treatment. Tartaric acid content was significantly higher in the B-28 treatment when compared to the B-24 and B-26 treatments. Malic acid contents were not significantly different; however the ratio of tartaric acid to malic acid was to be higher in the deficit treatments. Anthocyanins and phenolics behaved similarly under the irrigation treatments with less water consumed, having a larger content than the I-1 treatment.

Spur Treatments. No significant differences were found between any measured juice parameter.

Summary

Deficit irrigation techniques and extended maturation (or delayed harvest) strategies each reduce yield over time as a result of decreased fruit load from fewer clusters and smaller berries while extended maturation decreases berry size. When comparing a full water irrigation strategy (I-1) to the continual deficit treatment (I-3) the yield reduction was 36%. The deficit strategy I-2 significantly improved yield over the continual deficit treatment I-3 however the increased applied water resulted in a predicted increased yield by preserving berry size. The improvement in yield I-2 over I-3 occurred while changes in most juice parameters were unchanged. The strategy of increasing fruit load by pruning to 30% more primary buds resulted in a 16% average yield boost while vine balance seems not to have been affected; no significant delay in harvest was found; and changes in Juice components were not significant.

Utilizing water deficits, extended maturity harvest, and pruning to more spurs each has a distinct effect on yield and fruit quality. Any combination of these strategies should be carefully considered and compared to the quality changes and always compared to the value of the crop.