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 and any interactions.

TRIAL SITE:

A Syrah vineyard located near Galt in Sacramento County serves as the project site. The vineyard was planted in 1998 using FPMS clone 6 on SO4 rootstock. Vine and row spacing is 5 and 11 feet, respectively, resulting in 792 vines per acre. The irrigation system was designed and installed to facilitate independent water delivery to 32 plots. A plot consists of twenty vines in each of three adjacent vine rows. Data were taken from the 16 central vines located in the center row. 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 well water supply is of good quality delivered via a drip irrigation system. 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 utilized to remove non-productive shoots in all plots. Fertilization consisted of fall applied potassium sulfate (130 lbs/A K) applied via a solutionizer through the drip system to all treatments.

TREATMENTS:

Irrigation Strategy Treatments:

Irrigation strategies chosen include full potential water use (I-1) and 2 deficit approaches. Both the 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 was reached irrigation volume was based on (1) land surface shaded at noon to determine a crop coefficient (Kc), (2) the 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 was reached on August 26. At that time, the irrigation volume was increased to 100% based on the canopy size and the current ETo. Irrigation practices were the same for the entire experimental area during the 2003 season with treatments imposed 2004 – 2006.

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 (S18) resulted in 7.2 buds per foot of row and 0.65 buds per square foot. The 18 spur treatment resulted in about a 30% increase over the 14 spur treatment.

Fruit Maturation Treatments:

Maturity treatment targets were 24, 26, and 28 Brix (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. Harvest began with the treatments I-2 and I-3 at the 24 Brix and S-14 treatments on Sept 11. Harvests ended October 20 with irrigation treatment I-1 at 28 Brix for both the S-14 and S-18 treatments. Most all the spur treatments were harvested in pairs with in specific irrigation and Brix strategies. The exception was the B-24 I-2 and I-3 treatments (the first and second harvests (Table 1).

Table 1. Treatments and Harvest Dates 2006

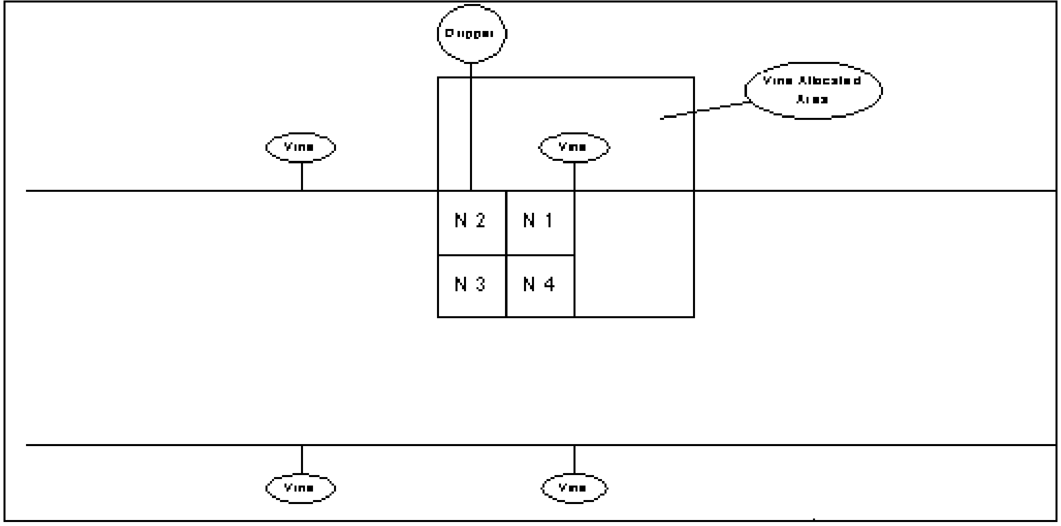
Irrigation Treatment Number	Brix Strategy	Spur Number	Leaf Water Potential Trigger at Which Irrigation Will Occur	Harvest Date
I-1	B-24	S-14	no trigger/ supply full water	Sept 19
	B-24	S-18		Sept 19
	B-26	S-14		Oct 2
	B-26	S-18		Oct 2
	B-28	S-14		Oct 20
	B-28	S-18		Oct 20
I-2	B-24	S-14	-14 bars/ 50%-100%	Sept 11
	B-24	S-18	Increase to 100% at 19º Brix	Sept 13
	B-26	S-14		Sept 26
	B-26	S-18		Sept 26
	B-28	S-14		Oct 17
	B-28	S-18		Oct 17
I-3	B-24	S-14	-14 bars/ 50%	Sept 11
	B-24	S-18		Sept 13
	B-26	S-14		Sept 22
	B-26	S-18		Sept 22
	B-28	S-14		Oct 11
	B-28	S-18		Oct 11

RESULTS

Water Use:

An evaluation of available stored moisture was made at bud break, which indicated a full moisture profile. Subsequent 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. 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. All emitters in each plot were tested for emission uniformity with plots averaging 93%. 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 moisture extraction was measured 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. 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. A calibration was developed between soil volumetric water content and count ratio at the site (Figure 2). In-season rainfall was measured on site. Irrigation volumes were measured using calibrated water meters. Soil water disappearance was based on the grid of neutron probe wells in the quadrant of the vines allocated area. Table 2 shows the water consumption components at both harvest and as a seasonal total. The water volumes consumed by the deficit treatments I-2 and I-3 compared to irrigation treatment I-1 was 66% and 47% respectively. Total applied water when compared to the full potential treatment (I-1) was 41% for irrigation treatment I-2 and 29% for the irrigation treatment I-3. Essentially, the increase in applied water between the deficit treatments was 2.5 inches applied to treatment I-2 from 19º Brix to harvest.

Figure 2.

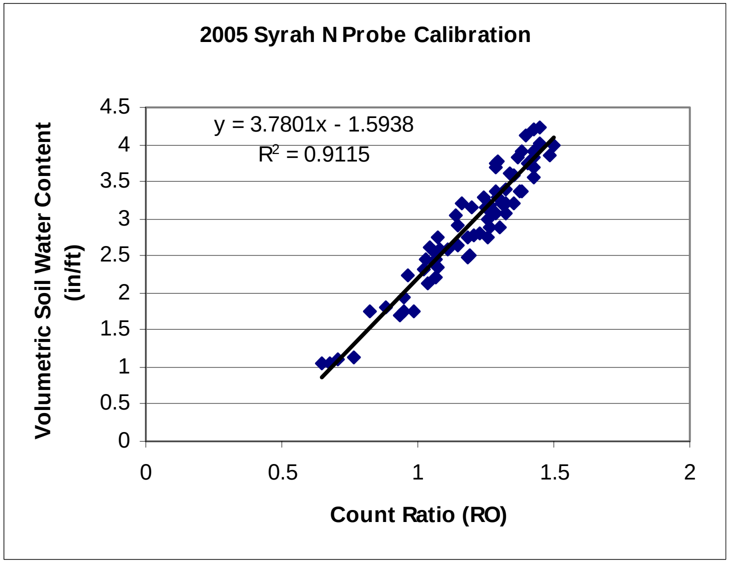
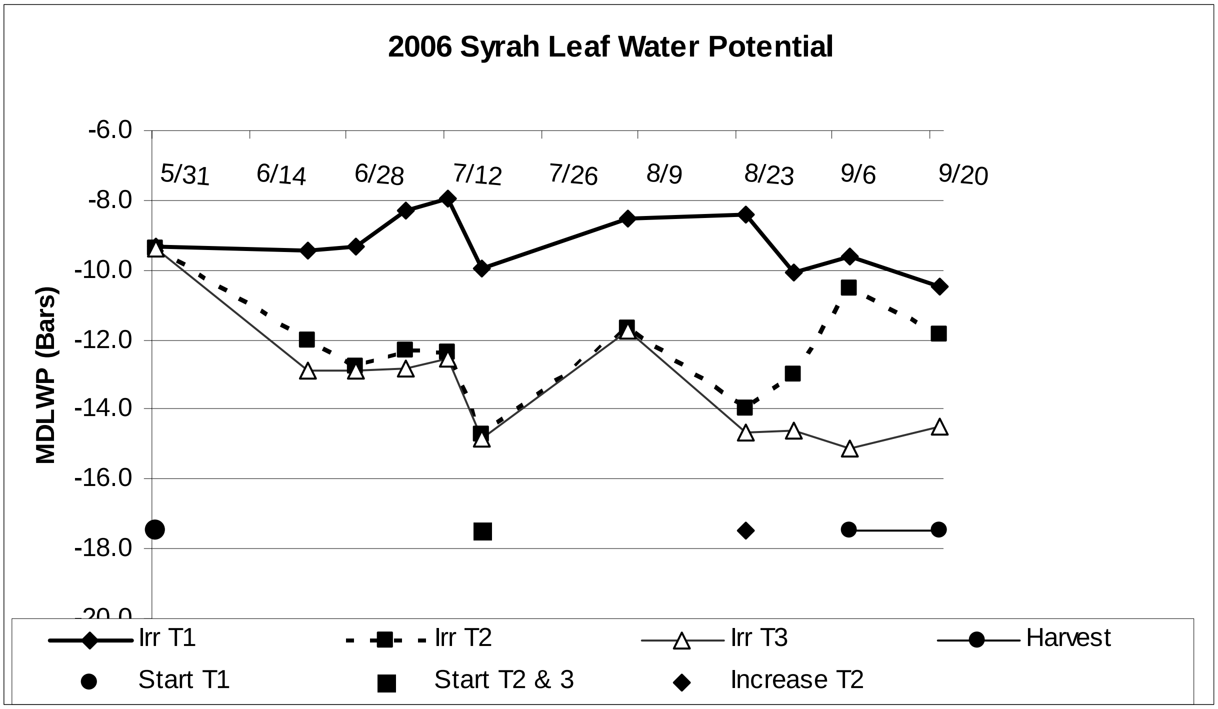


Table 2. Water Consumption Components 2006

Irrigation Treatment	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 Treatment I-1 Pre Harvest	% of Irrigation Treatment I-1 Seasonal
I-1	27.3	3.2	5.70	0.3	33.3	36.6	100	100
I-2	9.7	2.9	9.68	0.3	17.7	20.5	53	66
I-3	6.7	2.0	8.21	0.3	15.3	17.2	46	47

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 harvest. Irrigation began on May 31 at which time leaf water potential was a level of -9.4 bars, indicating a non-stressed condition (Figure 3). The seasonal average (May 31 – Sept 20) was -9.2 bars ranging from -8.1 to -10.9 bars.

Figure 3.



Irrigation treatment I-2 and I-3 received no irrigation until a MDLWP of -14.8 was reached on July 17. Irrigation water volumes were then applied weekly at the rate of 50% of calculated full potential continuing to harvest. 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 (5/29 – 9/20) was -13.3 bars. Berry sampling and

Brix analysis on August 26th indicated the 19º Brix level was reached at which time the volume of irrigation water was increased to full potential as indicated on Figure 1 by an ♦ symbol. The MDLWP averaged a 3 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 23rd was -11.8 bars. In the case of Treatments 3, the volumes of water applied generally stabilized the MDLWP at an average of -14.1 bars after the initiation of irrigation, for the remainder of the season. The solid bar on Figure 3 indicates the harvest date range. Also see Table 1 for harvest date of each treatment.

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 23 as to the percent of the clusters which had some (any?) color. The differences were found between the full potential irrigation strategy and the deficit regimes with I-1 at 98% and the deficit treatments at 84%. Treatment I-1 had been irrigated since May 24 where as treatments I-2 and I-3 were irrigated on July 15, only a week before the measurement.

Canopy: Canopy size was evaluated by maximum shoot length, weight of prunings, and land surface shaded at midday. Significant differences in canopy size were found between irrigation treatments and spur treatments (table 3). Shoot lengths of irrigation treatment I-1 were longest at 66 cm followed by I-2 at 57 cm and I-3 at 50 cm. Each was significantly different from each other following 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 at 71 % followed by I-3 at 55% followed by I-3 at 51%. The land surface shaded measurements in Table 3 are from 8/25/06. The mass of punings followed a similar pattern with I-1 almost double that of I-3. Using simple regression the R-Squared statistic indicates that the model pruning vs. shoot length explains 37% of the variability in pruning mass. The correlation coefficient equals 0.61, indicating a moderately strong relationship between the variables. The other variable is the number of shoots per vine. However, if the total shoot length is calculated based on the spur number and bud number the relationship does not improve. This most probably results from additional shoots that arise from the basal bud or two shoots from one of the primary buds. No significant differences in any canopy measurement were found between Brix treatments. Significant differences in shoot length was found between the 14 and 18 spur treatments finding the S-14 treatment longer than the S-18 treatment, a fact that can also explain the lack of a stronger relationship between prunings and total shoot length per vine.

The crop to pruning ratio is often used to evaluate vine balance between the reproductive and vegetative structures. It can be used to access the extent if any of over cropping. The irrigation treatment I-1 was significantly lower than the deficit treatments at 3.3 which is considered tending toward excess vegetative growth (Table 3). The deficit treatments at a ratio of 5.1 and 4.9 for the I-2 and I-3 respectfully, are considered well balanced.

Table 3. Canopy Measurements

	Shoot Length (cm)	Nodes per Shoot	Node Length (cm)	Pruning Weight lb/Vine	Pruning: Yield ratio	Land Surface Shaded
Irrigation						
I-1	66.2 a[a]	16.4 a	4.0	7.8 a	3.3 a	71a
I-2	56.6 b	14.5 b	3.9	4.4 b	5.1 b	55 b
I-3	49.8 c	12.9 c	3.9	3.9 c	4.9 b	51 c
P =	0.00	0.00	0.12	0.00	0.00	
Brix						
24	57.2	14.5	3.9	5.5	4.6 b	
26	56.8	14.8	3.8	5.2	4.8 b	
28	58.5	14.6	4.0	5.5	4.0 a	
P =	0.74	0.85	0.20	0.18	0.01	
Spurs						
14	59.6 a	15.0	4.0	5.4	4.3	
18	55.4 b	14.2	3.9	5.4	4.6	
P=	0.03	0.12	0.21	0.79	0.075	
Interactions	NS	NS	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:
The fruit weight of each of 15 data vines within each plot was measured. 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.

When comparing yield across all Brix and spur treatments, differences were found between each irrigation treatment (Table 4). Treatment I-1 at 23.5 pounds per vine (10.0 tons/acre) compared to the deficit treatments at 22.0 pounds per vine for I-2, and 18.5 for I-3. The yield reductions from full irrigation were 19 and 27 % for treatments I-2 and I-3 respectively.

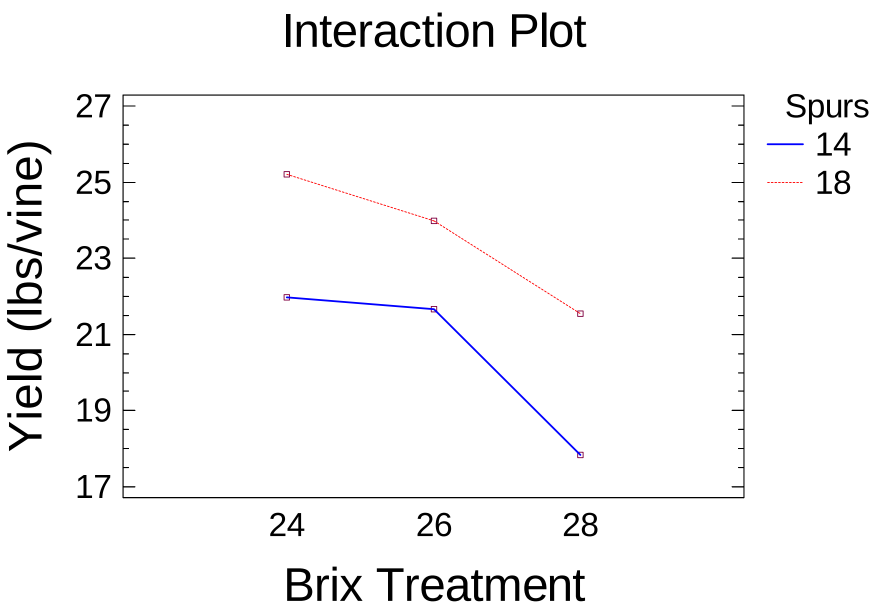
Significant yield differences were also found between the Brix treatments (Table 4). Brix treatment B-24 and B-26 were not significant from each other however both were significantly different from the B-28 treatment. The yield reduction from B-24 to B-28 was 18%.

A significant difference was found between the spur treatments S-14 and S-18. The S-18 was found to be 12% higher than S-14 treatment.

No significant interaction between Irrigation, Brix level or Spur number treatments were found to exist.

By increasing the number of two-bud spurs the yield reduction from 26 to 28 Brix is entirely eliminated (figure 4) and increased the 24 and 26 Brix level.

Figure 4



Yield Components:
Berry size was measured as weight (g) per berry from 5 clusters per plot (40 per treatment). Berry size was found to be significantly larger in highest level of irrigation treatment than the other irrigation treatments and larger in the lowest Brix treatment B-24 (Table 4). No significant differences were found between spur treatments.

Fruit load (number of berries per vine) was found to be significantly higher in the irrigation treatments I-2 when compared to treatment I-3. Irrigation treatment I-1 was not significantly different than I-1 or I-3. No significant differences in fruit load were found between Brix treatments. The fruit load was significantly larger in the S-18 spur treatment due to the increased spur and bud numbers.

There is statistically significant relationship between Yield and berry weight however, the R-Squared statistic indicates that the model as fitted explains only 18% of the variability in yield. The correlation coefficient equals 0.42, indicating a relatively weak relationship between the variables.

There is a statistically significant relationship between yield and fruit load. The R-Squared statistic indicates that the model as fitted explains 81% of the variability in yield. The correlation coefficient equals 0.88, indicating a moderately strong relationship between the variables.

Upon further analysis, the number of clusters or the fruit load packets (clusters) are significantly higher in the irrigation treatment I-1 when compared to I-3 (Table 5). Irrigation treatment I-2 was not significantly different than I-1 or I-3. The reduction in clusters is a typical multi-year effect of the irrigation treatments—deficits result in fewer clusters the following year. The surprise finding is that the I-2 does not differ from I-1 and in fact has a higher number of clusters than I-1. No crop reduction by cluster or shoot thinning was performed. Only non-bearing shoots were removed on May 18th. No significant differences were found between Brix treatments B-24 and B-26; however B-28 was significantly lower in yield by 9%. When comparing I-1 (full irrigation) and I-3 (standard deficit treatment) berry size and cluster size were found to be significantly larger with both higher level of irrigation and lower Brix at harvest. The I-3 treatment was competitive with I-1 in cluster number but lower in berry size.

Table 4. Yield and Yield Components
2006 Syrah, Galt

	Yield (lb/vine)	Relative Yield %	Berry Size (g)	Relative Berry Size %	Fruit Load (berry/vine)	Relative Fruit Load %
Irrigation						
I-1	25.3 a[a]	100	1.64 a	100	6993 a b	93
I-2	22.0 b	87	1.34 b	82	7527 a	100
I-3	18.5 c	73	1.27 b	77	6619 b	88
P =	0.00		0.00		0.03	
Brix						
24	23.4 a	100	1.51 a	100	7078 a b	95
26	23.0 a	98	1.33 b	94	7431 a	100
28	19.3 b	82	1.14 b	88	6630 b	89
P =	0.00		0.00		0.05	
Spurs						
14	20.5 b	88	1.42 a	100	6609 b	88
18	23.4 a	100	1.41 a	99	7484 a	100
P=	0.00		0.81		0.00	
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.*

Table 5. Yield and Yield Components
2006 Syrah, Galt

	Cluster Number (Clusters/vine)	Relative Cluster No. %	Cluster Size (lbs/Cluster)	Relative Cluster Size %
Irrigation				
I-1	54.3 a[a]	96	0.46 a	100
I-2	56.8 a b	100	0.38 b	83
I-3	53.0 b	93	0.34 c	74
P =	0.05		0.00	
Brix				
24	56.1 a	99	0.41 a	100
26	56.6 a	100	0.40 a	98
28	51.6 b	91	0.37 b	90
P =	0.00		0.00	
Spurs				
14	50.3 b	85	0.40 a	100
18	59.3 a	100	0.39 a	98
P=	0.00		0.31	
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. The applied and total consumed (ETc) water is shown in Table 2 while yield is shown in Table 4. Regardless which measure of water use efficiency used, irrigation treatment I-1, the treatment consuming the most water was least efficient (Table 6). An increase in efficiency is possible using the deficit irrigation level I-3 which was the highest in applied water while I-2 is highest in total consumed water.

Table 6. Water Use Efficiency
2006 Syrah, Galt

	Lbs Product / Acre Inch Water	
Irrigation Treatment	Applied Water	Consumed Water
I-1	656	548
I-2	1390	848
I-3	1692	853

Fruit Quality:
One cluster from each vine (40 per treatment) was collected at each harvest and delivered to the laboratory for juice analysis on the day of harvest. The fruit analysis was based on this sample. The juice

sugar level was found to significantly vary by irrigation and Brix treatments (Table 7). The highest Brix level was found in irrigation treatment I-2 and I-3 averaging 25.7 Brix followed by I-1 at 24.4 Brix across all Brix and spur treatments. Essentially the full irrigation delayed sugar accumulation, while the increase in irrigation late in the season (I-2) had no effect on comparison to the continual deficit treatment. Comparing the irrigation treatments across the Brix and spur treatments finds malate content, potassium content, and titratible acidity and pH significantly higher in the full irrigation (I-1) than both deficit treatments.

The Brix treatments target was 24, 26, and 28 Brix. In reality the levels when averaged to the closest whole number is 24, 26 and 27. However for year-to-year continuity the target Brix levels are used in this report. Comparing the Brix treatments across the irrigation and spur treatments finds a significant increasing relationship between Brix treatments and pH and a decreasing relationship with titratible acidity as a function of increasing Brix. Malate was significantly higher in the B-24 treatment in comparison to the B-26 and B-28 treatments while the opposite is true for potassium content. Malate concentration typically decreases as the season progresses and is higher under conditions of abundant vegetative growth. The treatment with the highest water consumption (I-1) was significantly higher in malate than the deficit treatments when compared across all Brix treatments. The Brix treatments followed a significant reduction in malate from the Brix-24 to Brix-28.

No significant differences in measured juice parameters were found between spur treatments across irrigation and Brix treatments.

Table 7. Juice Analysis
2006 Syrah, Galt

Treatments	° Brix	Potassium (mg/L)	Malate (mg/L)	TA (g/L)	pH
Irrigation					
I-1	24.4 b[a]	2249 a	3778 a	4.58 a	3.81
I-2	25.8 a	1850 b	2183 b	3.58 b	3.77
I-3	25.5 a	1929 b	2234 b	3.59 b	3.79
P =	0.00	0.00	0.00	0.00	0.42
Brix					
24	23.6 c	1727 c	2931 a	4.38 a	3.61 a
26	25.5 b	2042 b	2669 b	3.75 b	3.80 b
28	26.8 a	2259 a	2595 b	3.62 c	3.94 c
P =	0.00	0.00	0.00	0.00	0.00
Spurs					
14	25.2	2022	2770	3.96	3.78
18	25.2	1997	2693	3.87	3.79
P =	0.90	0.65	0.35	0.12	0.84
Interactions					
Irr/Brix	NS	0.03	0.02	0.00	NS
Irr/Spurs	NS	NS	NS	NS	NS
Brix/Spurs	NS	NS	NS	0.0119	NS

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

Summary

Three levels of fruit maturity were compared across three different irrigation strategies in a region III/IV Syrah vineyard. Significant differences in level of water stress were found between all treatments as measured by seasonal average midday leaf water potential. Irrigation treatment I-2 which received additional water at 19º Brix in contrast to treatment I-3 improved water relations significantly throughout the remainder of the season. Water consumption was also significantly different between all irrigation treatments. The deficit irrigation treatments I-2 and I-3 consumed 66% and 47% of the full potential consumptive use treatment I-1. Both the deficit irrigation treatments resulted in higher water use efficiency when compared to the full water treatment.

Significant yield reductions occurred with deficit irrigation. Yield reductions, when compared to full water (I-1) treatment, were; I-2 at 13% and I-3 at 27%. The mitigating effect of additional irrigation as harvest approached (I-2) was to reduce yield loss due to deficit irrigation by half or 27% to 13%.

The deficit irrigation treatment I-2 received 3 inches of irrigation water more than the I-3 vines as harvest approached. This strategy resulted in a significantly higher in yield than the I-3 treatment of continual deficit treatment. Yield component analysis using simple regression revealed fruit load differences explain 77.6% of the differences in yield while berry size explains 17.7%. The same irrigation treatments were imposed in the 2004 and 2005 season, which explains the increased cluster number and fruit load in the full irrigation treatment (I-1). The number of clusters per vine was significantly reduced by 7 % in the continual deficit treatment 1-3 when compared to the other treatments. Irrigation treatment I-2 cluster number was not significantly different from the full water treatment (I-1)

Significant yield reductions were also found between Brix treatments across irrigation and spur treatments. There was no significant reduction in yield between B-24 and B-26 treatments. The yield reduction from B- 26 to B-28 was 18 %. The yield reduction was due to both reduced fruit load and berry size. No interaction between irrigation and Brix or spur treatments were found to exist.

The mitigating effect of adding crop load by pruning to 30% more spurs was to increase yield by 28% across all irrigation treatments.

The juice sugar level was found to significantly vary by irrigation and Brix treatments. The highest Brix level was found in irrigation treatment I-2 and I-3 averaging 25.7 Brix followed by I-1 at 24.4 Brix across all Brix and spur treatments. Essentially the full irrigation delayed sugar accumulation, while the increase in irrigation late in the season (I-2) had no effect in comparison to the continual deficit treatment. Comparing the irrigation treatments across the Brix and spur treatments finds malate content, potassium content, and titratible acidity and pH significantly higher in the full irrigation (I-1) than both deficit treatments.

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Deficit irrigation techniques and extended maturation strategies each reduce yield over time as a result of reduced fruit load from fewer clusters and smaller berries. However, the deficit strategy I-2 significantly improved yield over the full deficit treatment I-3. The strategy of increasing fruit load by pruning to 30% more primary buds also looks promising in recovering some of the yield loss while vine balance seems not to have been effected; no significant delay in harvest was found; and changes in Juice components were minimal.

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