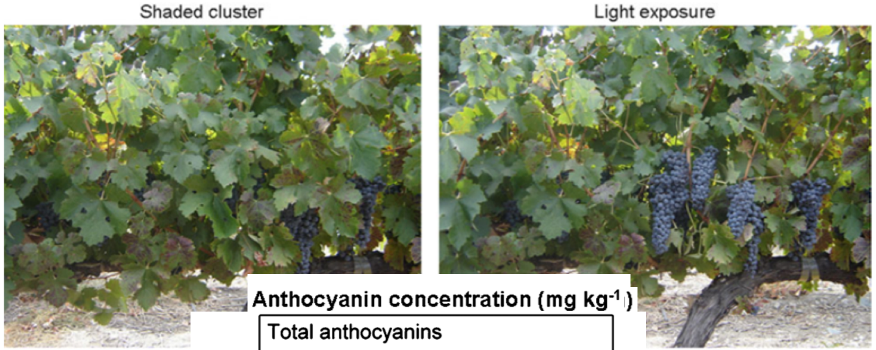
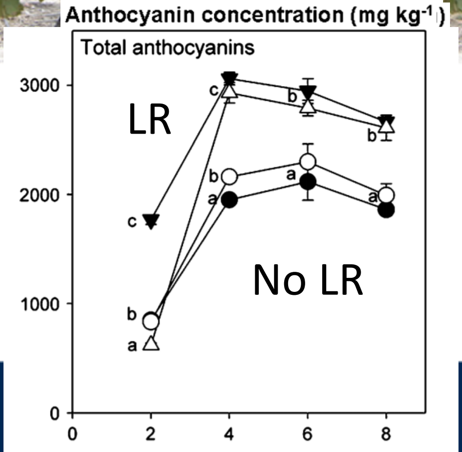
Grapevine Water Requirements for Optimal Yield and Quality A Case Study in Oakville AVA

S. Kaan Kurtural

Introduction

- Grapevine needs a suite of canopy management practices
  - Dormant pruning
  - Green pruning
    - Shoot removal
    - Leaf removal
- Flavonoids and sun exposure
  - May have a beneficial effect





Matus et al. 2009

EXPOSED LEAF AREA

Carbon (CO_2) assimilation

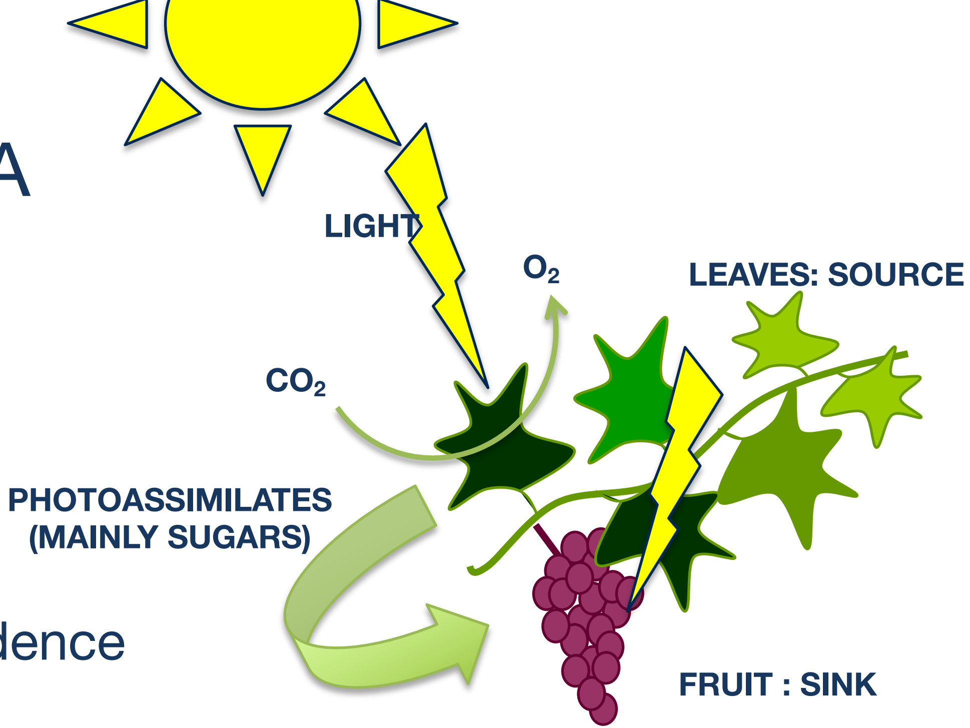
- Ripening
- Yield precursors

Canopy microclimate

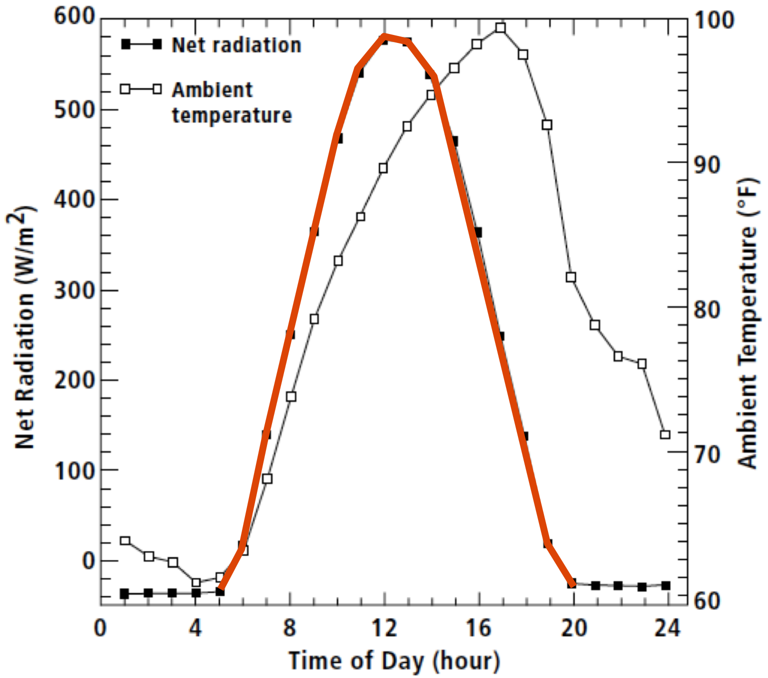
- Fruit composition
- Fungal infection incidence

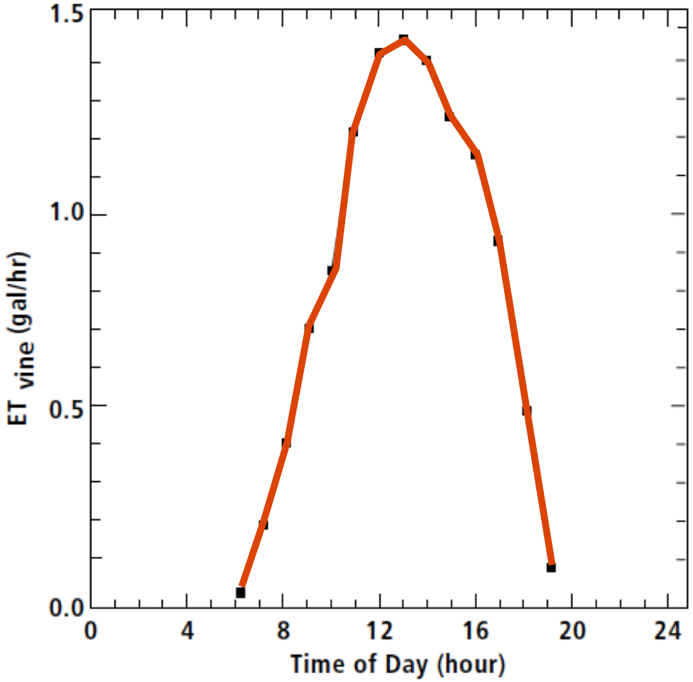
Irrigation requirements

- Leaf area
- Transpiration



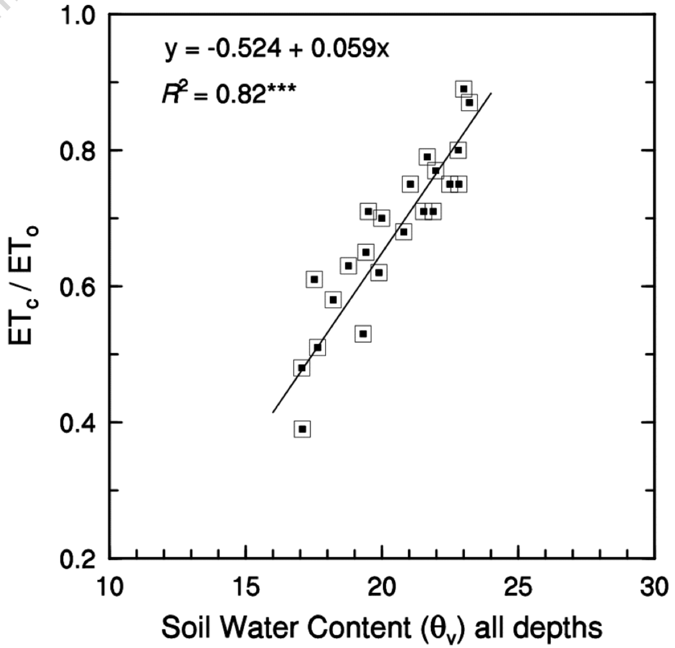
Solar radiation drives vine evapotranspiration

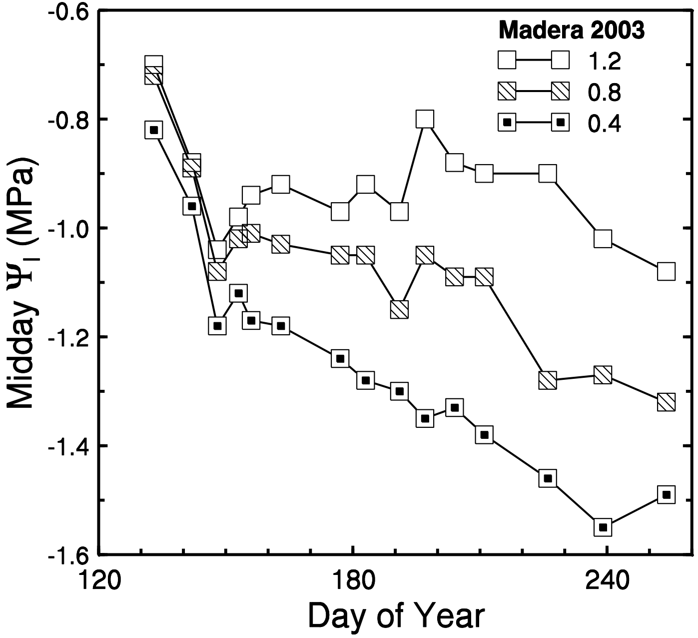




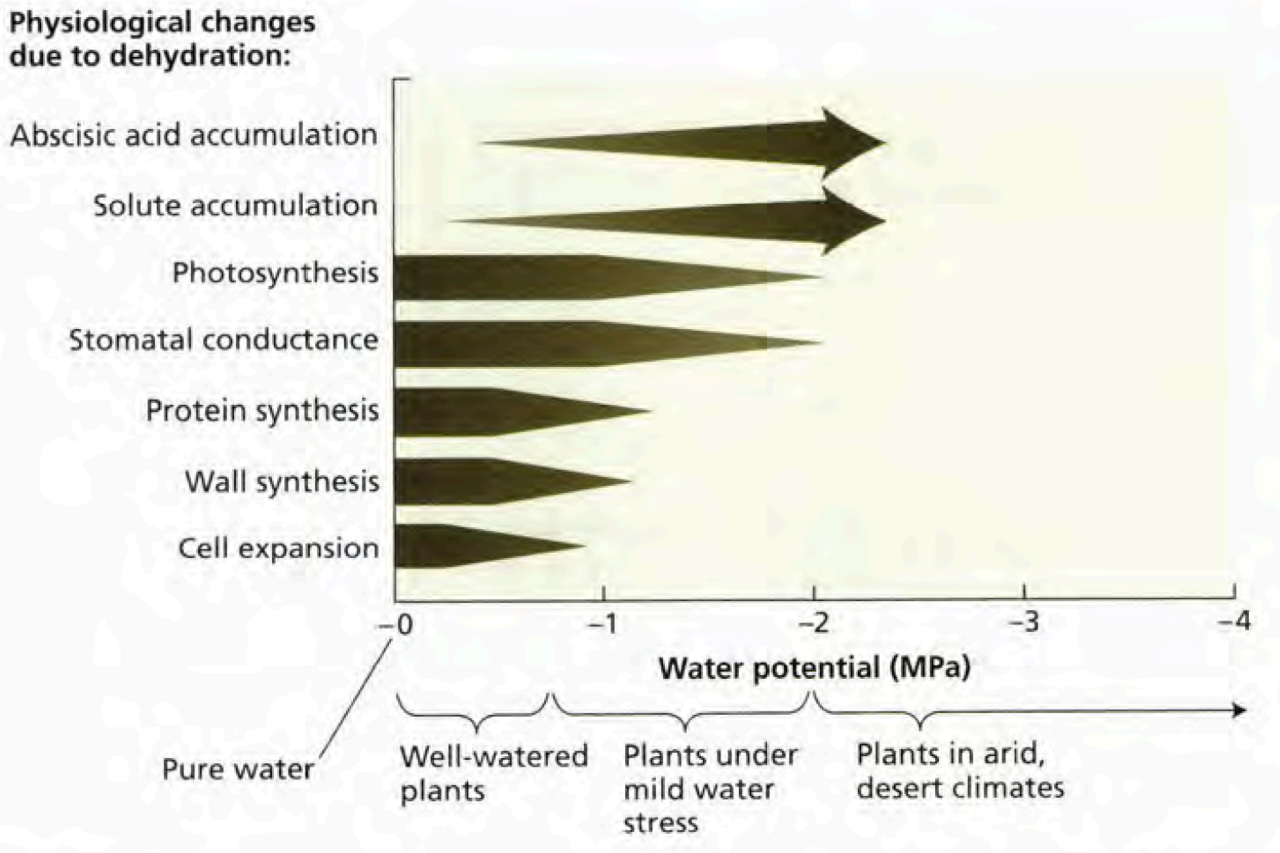
LEW (2000)

Water use declines with depletion

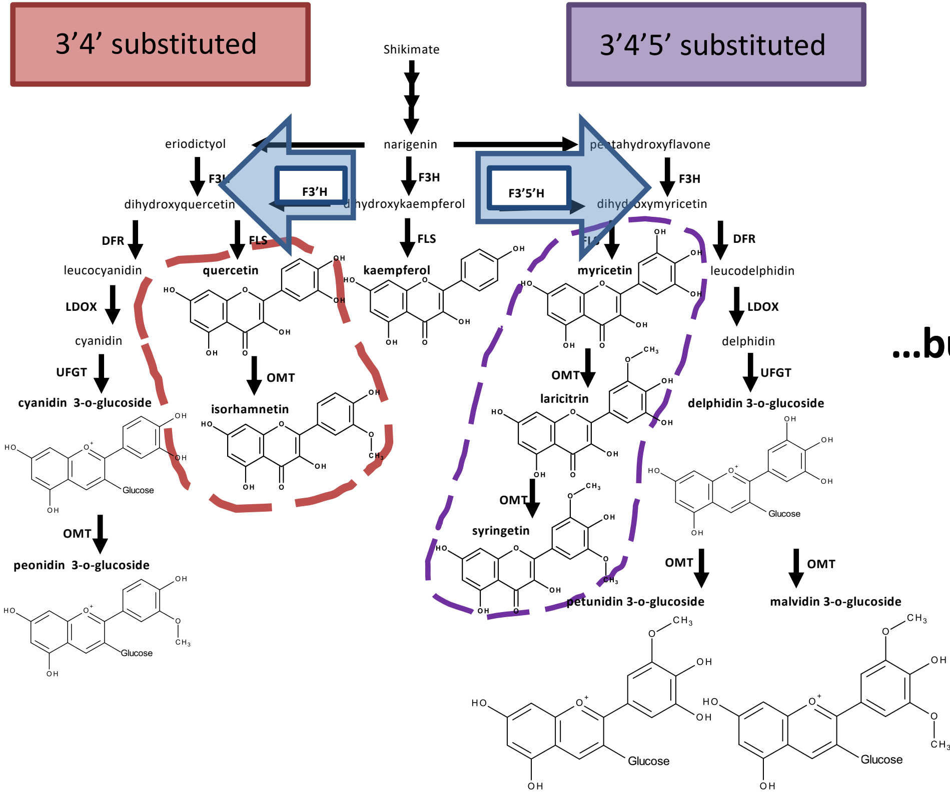




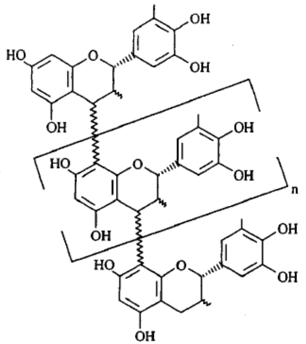
Water deficits affect grapevine physiology



Water deficits affect secondary metabolism in *Vitis* sp.

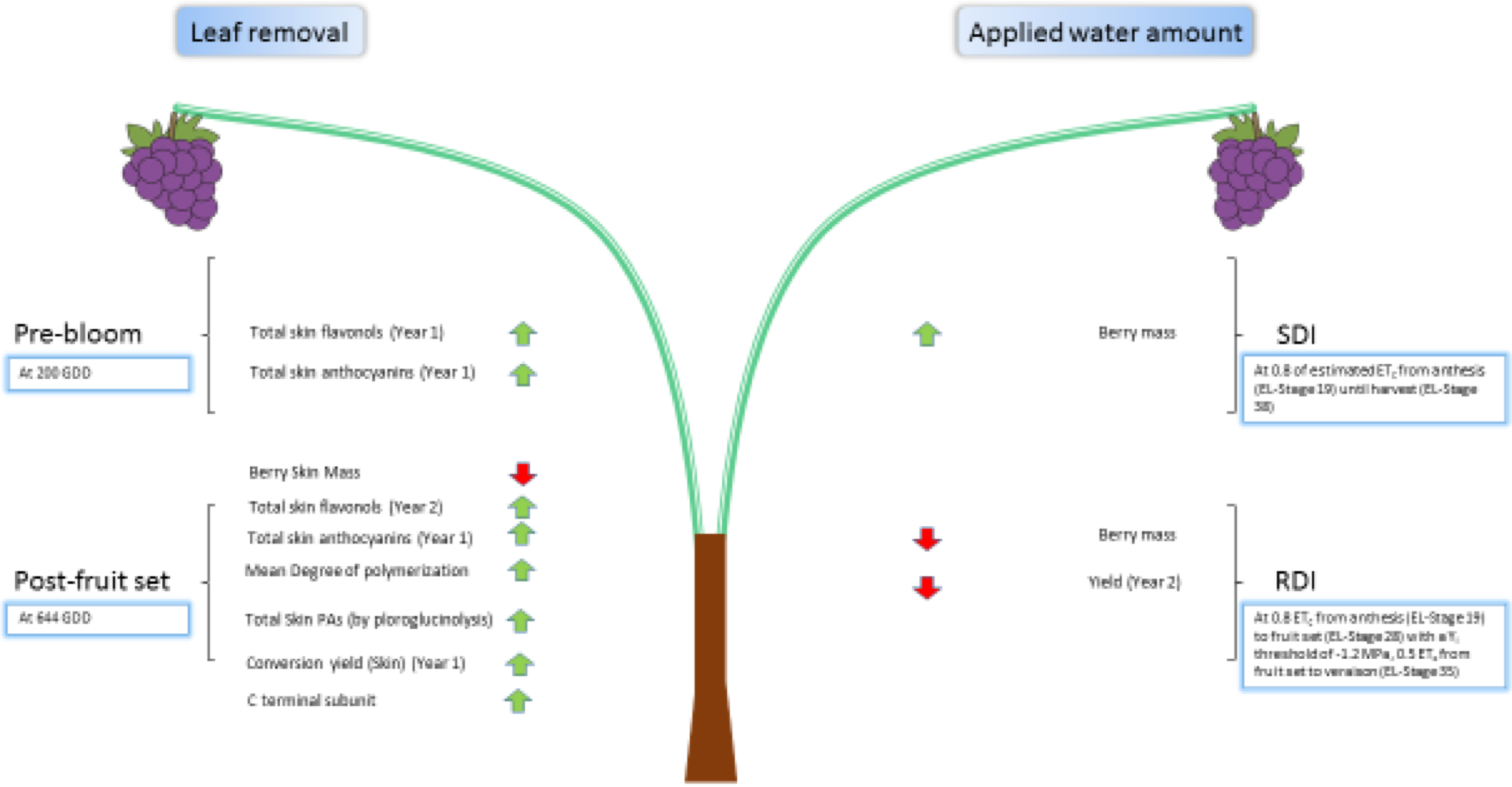


…but proanthocyanidins?



Castellarin et al., 2007 (Planta; BMC Plant Biology; Plant Cell and Environment)

Previous work in hot climate (Yu et al. 2016 JAgFoodChem)



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Experiment

- Randomized complete block
- 3 leaf removal (mechanical)
  - Control
  - Pre-bloom (200 GDD)
  - Post-fruit set (602 GDD)
- 3 applied water amounts
  - 25% ETc
  - 50% ETc
  - 100% ETc (Control)

- Conducted at UC Davis Oakville Experimental Vineyard Napa Co. CA
- Bale loam soil series (USDA 2013)
- Drip-irrigated 4 L/vine/hr system
- Spacing 2.4 m x 2.0 m (row x vine)

Variables monitored

- Primary metabolism
  - Canopy
  - Plant water status
  - Leaf gas exchange
  - Yield components
  - Berry chemistry
- Secondary metabolism
  - Flavonols
  - Anthocyanins
  - Proanthocyanidins

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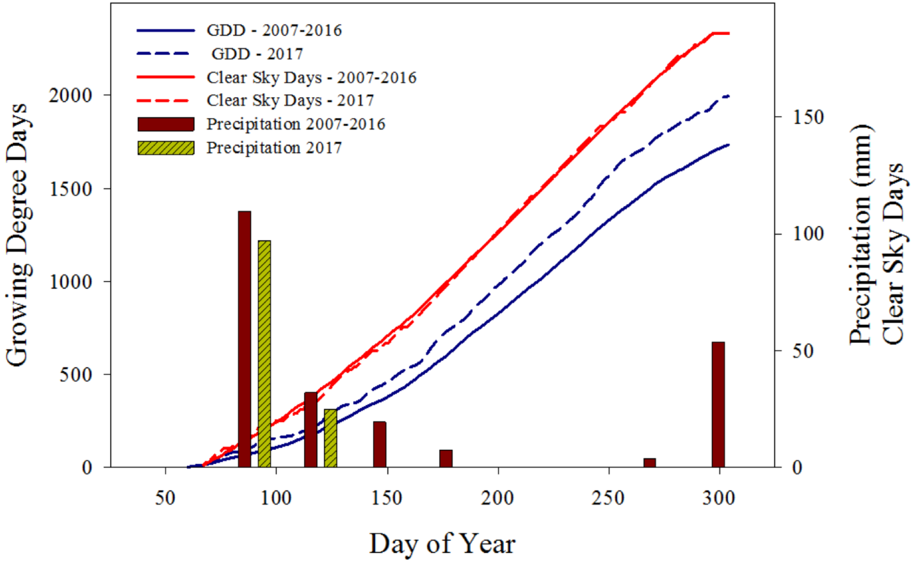
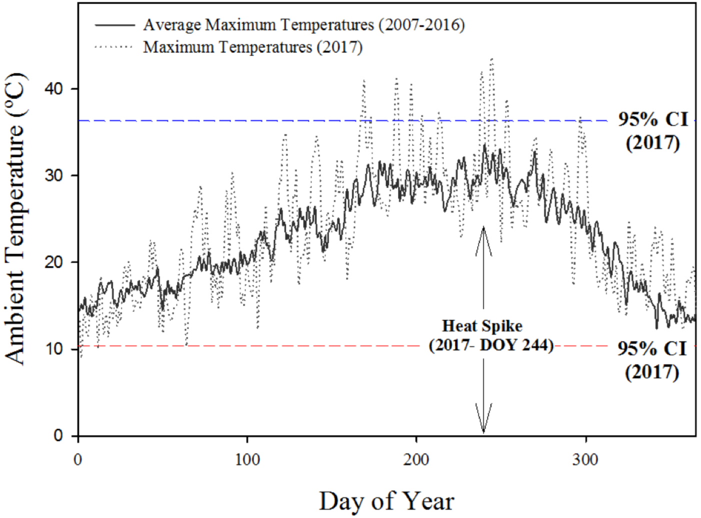
RESULTS

Weather at the experiment site





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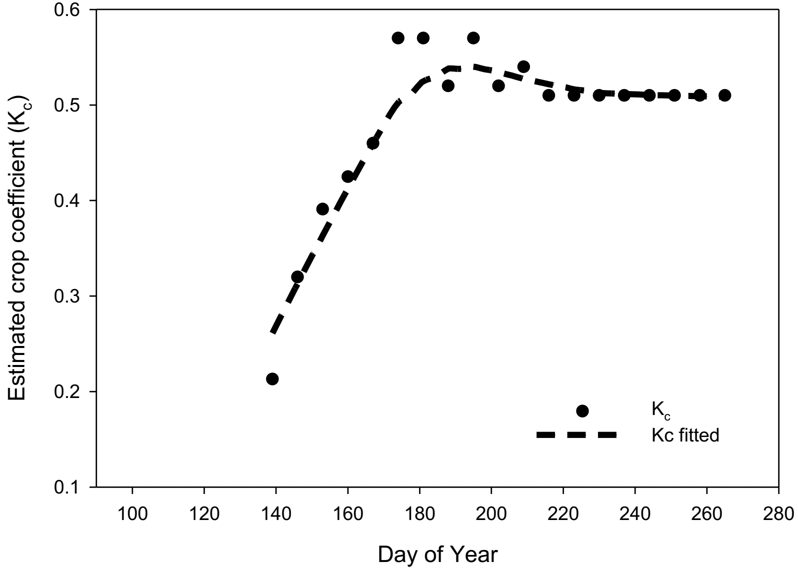
Estimated crop coefficient and applied water amounts



Phenology stage	Applied water (L/vine)		
	100% ETc	50% ETc	25% ETc
Bud-break to fruit set (9 April-31 May)	187.4	93.7	46.9
Fruit-set to veraison (31 May-23 July)	887.4	443.7	221.9
Veraison to harvest (23 July-12 Sept.)	810.8	405.4	202.7
Sum (L/vine)	1885.7	942.8	471.4

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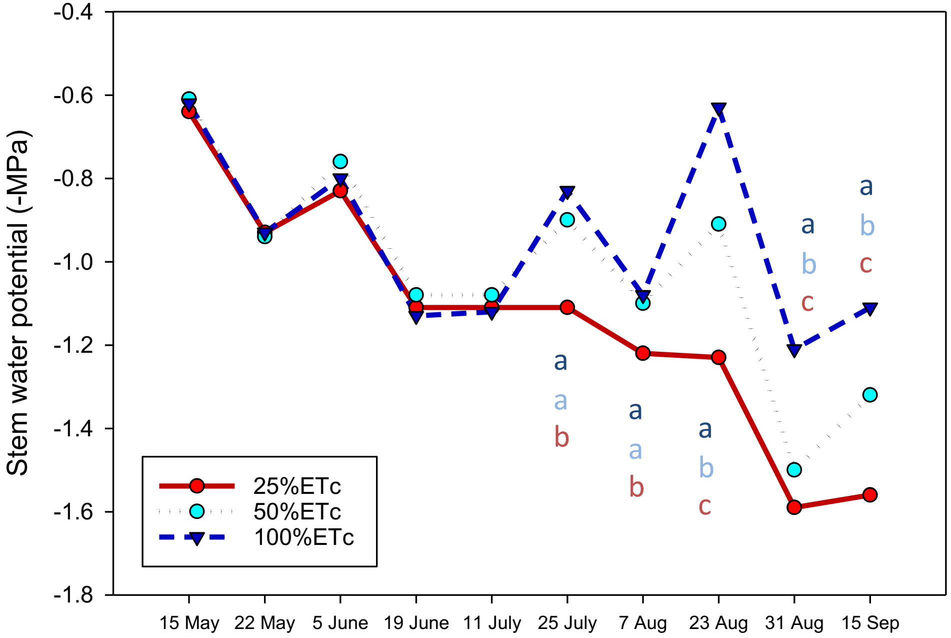
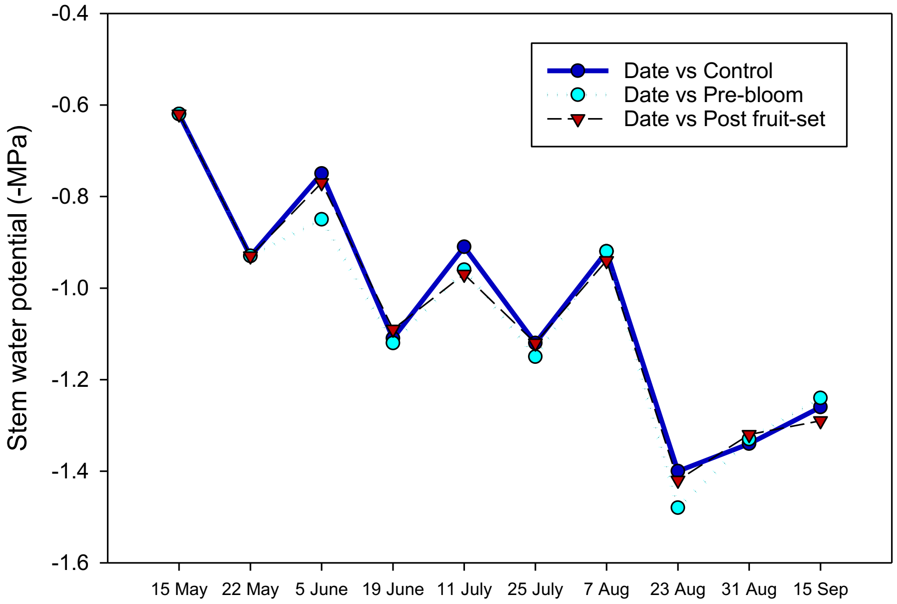
Plant water status





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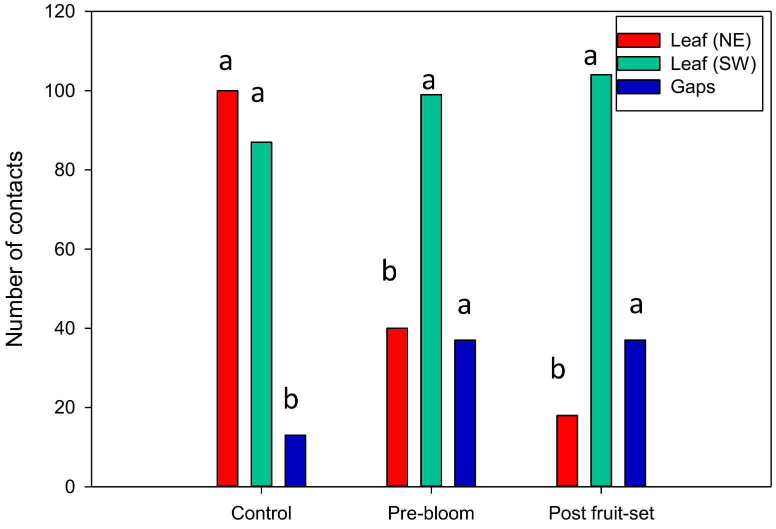
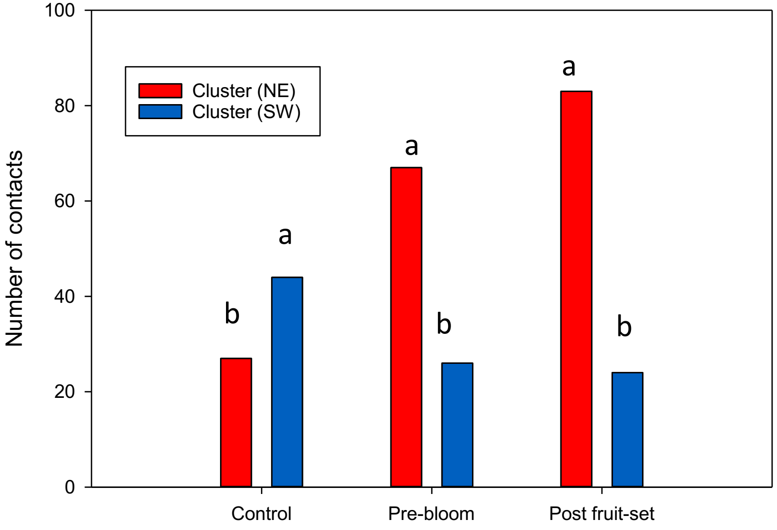
Canopy microclimate at veraison





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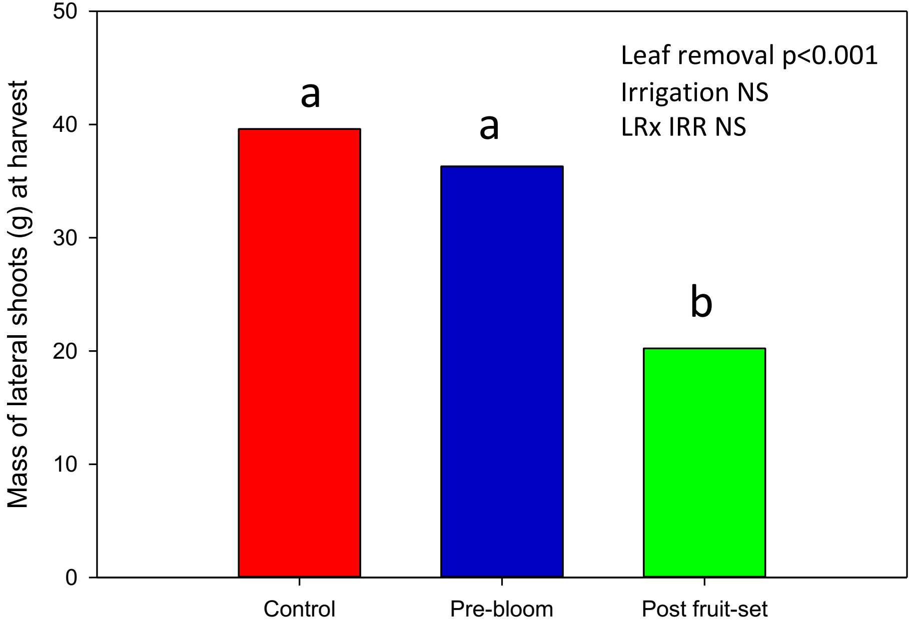
Vegetative compensation of canopy at harvest



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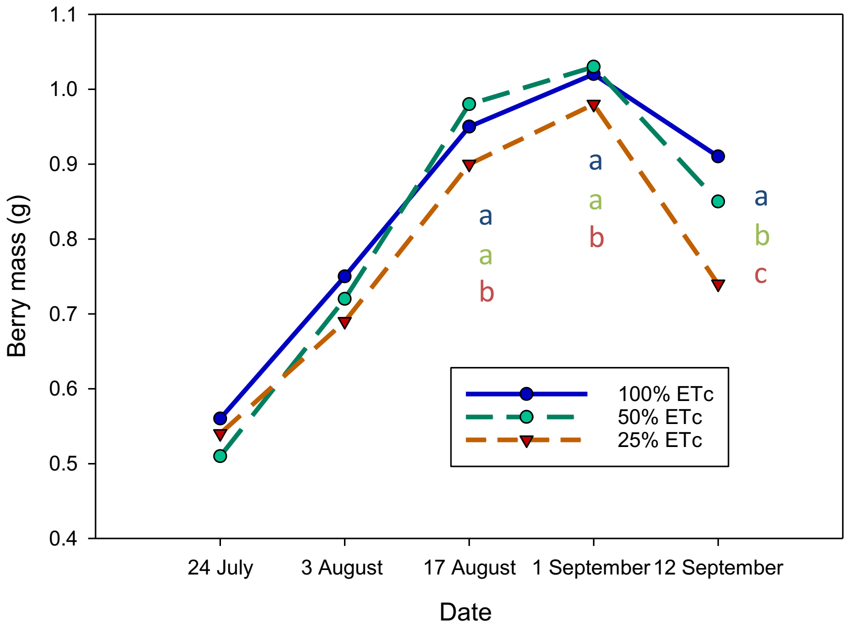
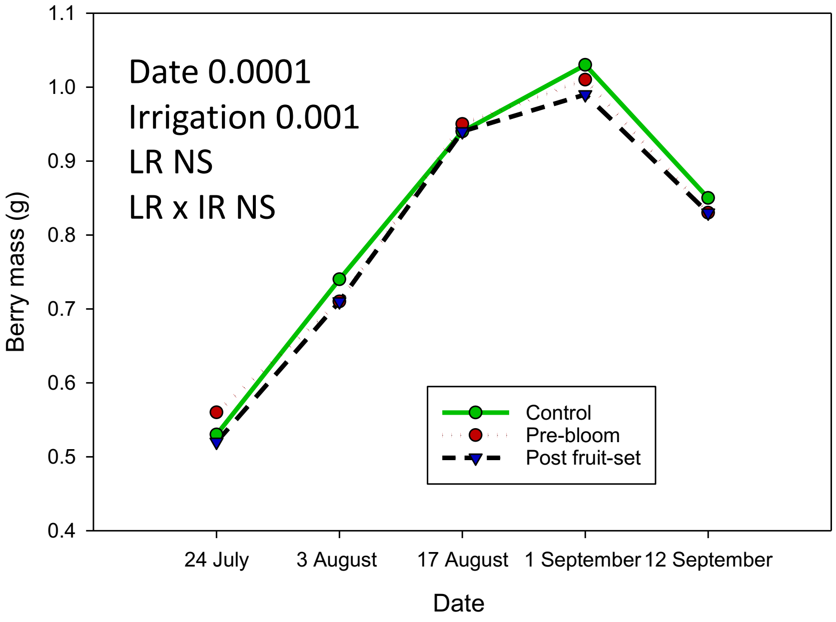
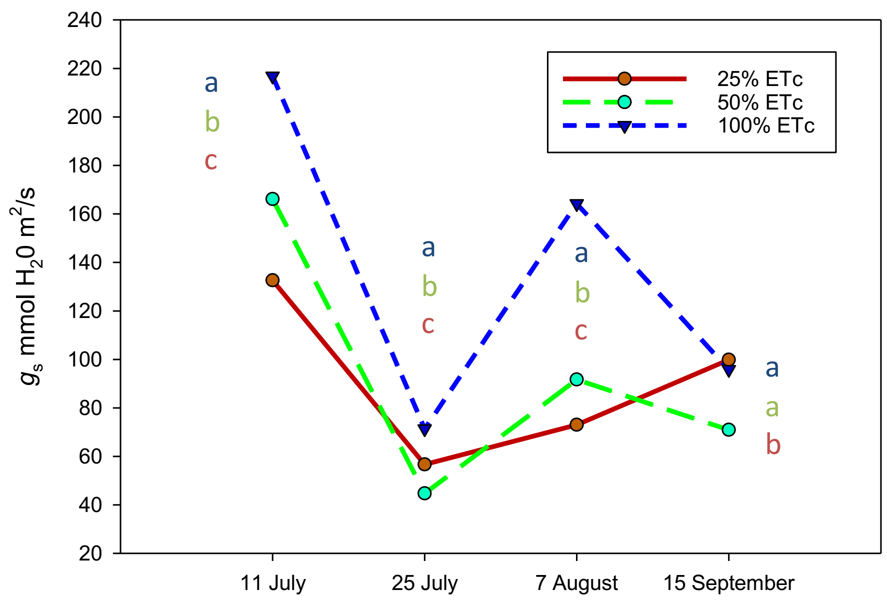
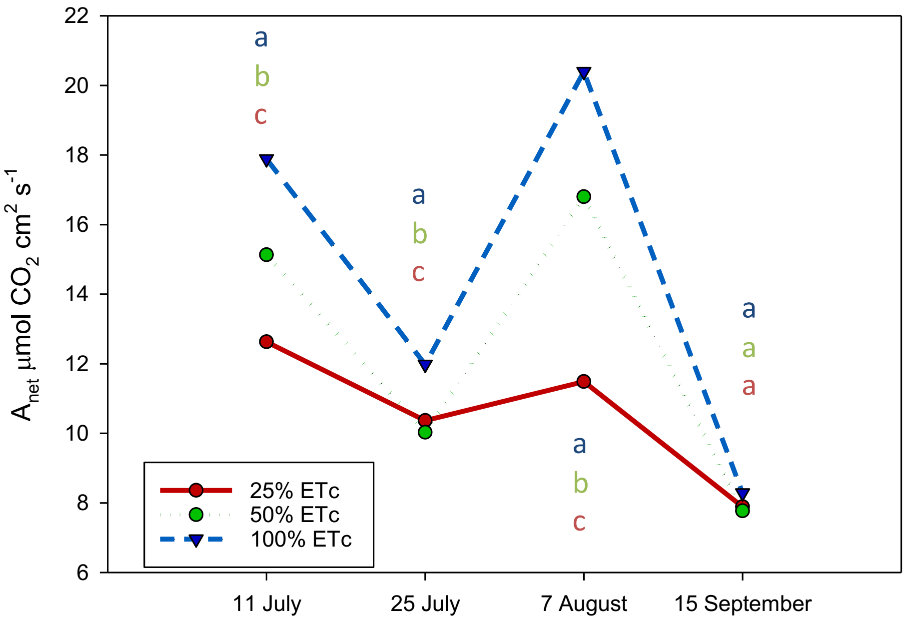
Berry mass development





Net gas exchange





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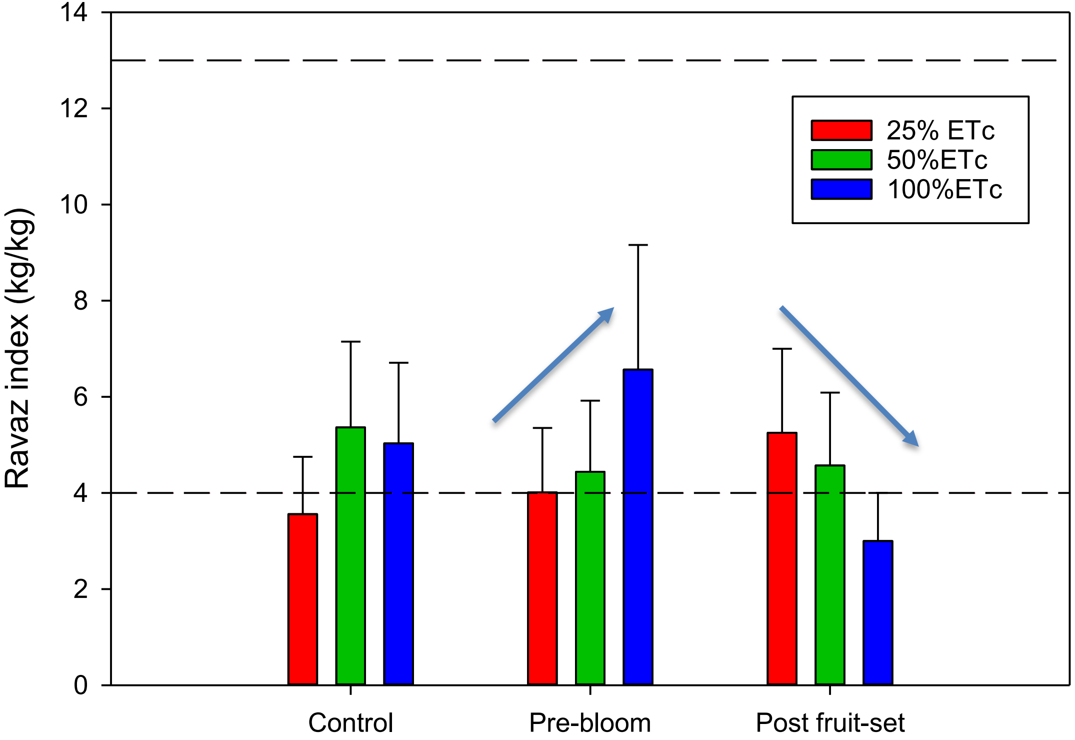
Components of yield

	Berry mass (g)	Skin mass (mg)	Cluster wt (g)	Berries/cluster	Cluster/vine	Yield (t/ha)
Irrigation						
100%ETc	0.93 a	1.011	111 a	119	35	8.3 a
50%ETc	0.88 b	1.117	98 b	111	39	8.1 a
25%ETc	0.72 b	1.043	84 c	116	36	6,2 b
P value	0.0001	0.0877	0.0001	0.9450	0.0915	0.0001
Leaf removal						
Control	0.85	1.068	103	121	37	7.5
Pre-bloom	0.83	1.073	91	109	37	7.1
Post fruit-set	0.83	1.031	100	120	37	7.7
P value	0.9550	0.6164	0.0618	0.0781	0.9963	0.3776
LR x IRR	0.4490	0.0794	0.0909	0.2611	0.1756	0.1756

Vine balance

Range: 4 to 13 kg/kg



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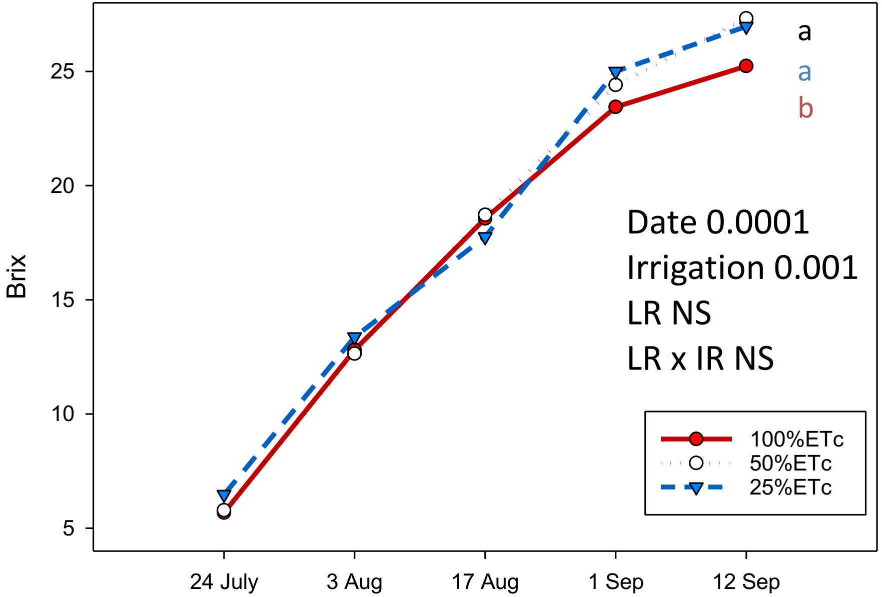
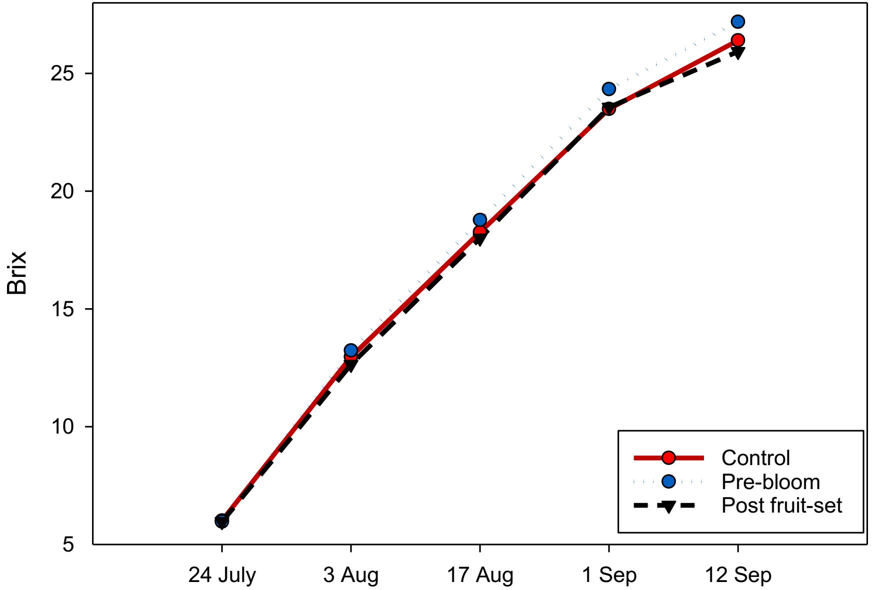
Berry chemistry





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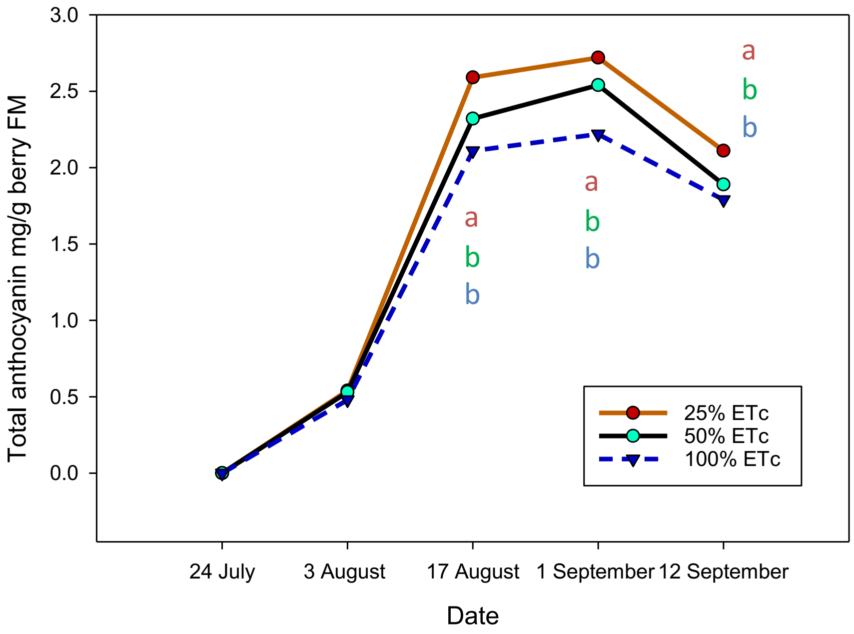
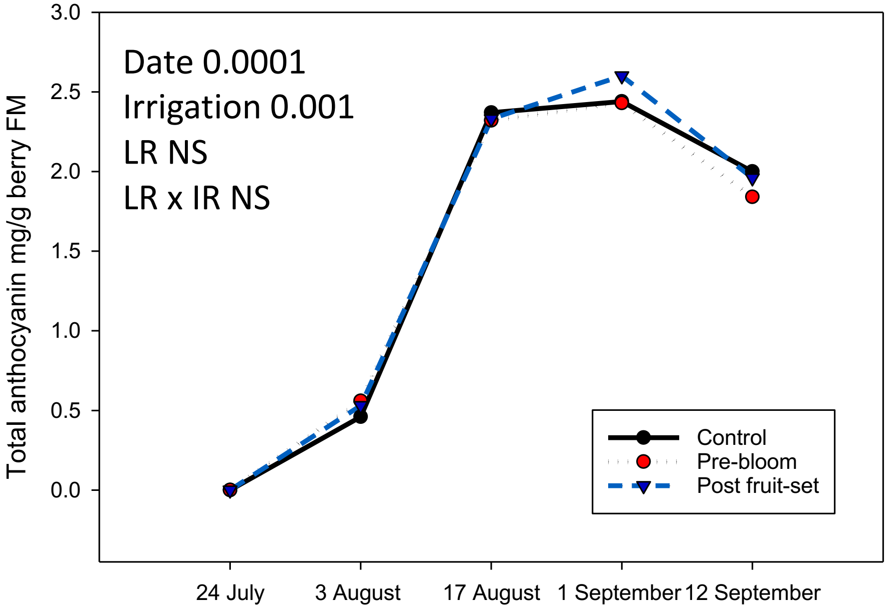
Anthocyanin content and concentration at harvest

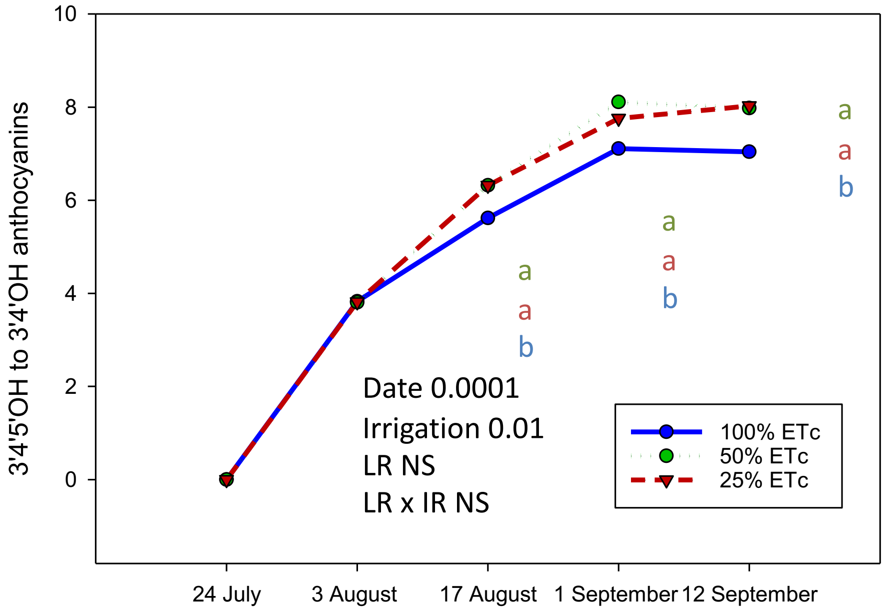
	Skin mass (mg)	Total anthocyanin (mg/berry)	Total anthocyanin mg/g FM
Irrigation			
100%ETc	1.011	1.682	1.785 b
50%ETc	1.117	1.639	1.897 b
25%ETc	1.043	1.710	2.113 a
P value	0.0877	0.8710	0.0364
Leaf removal			
Control	1.068	1.709	2.000
Pre-bloom	1.073	1.582	1.834
Post fruit-set	1.031	1.740	1.960
P value	0.6164	0.4790	0.3599
LR x IRR	0.0794	0.7480	0.6954

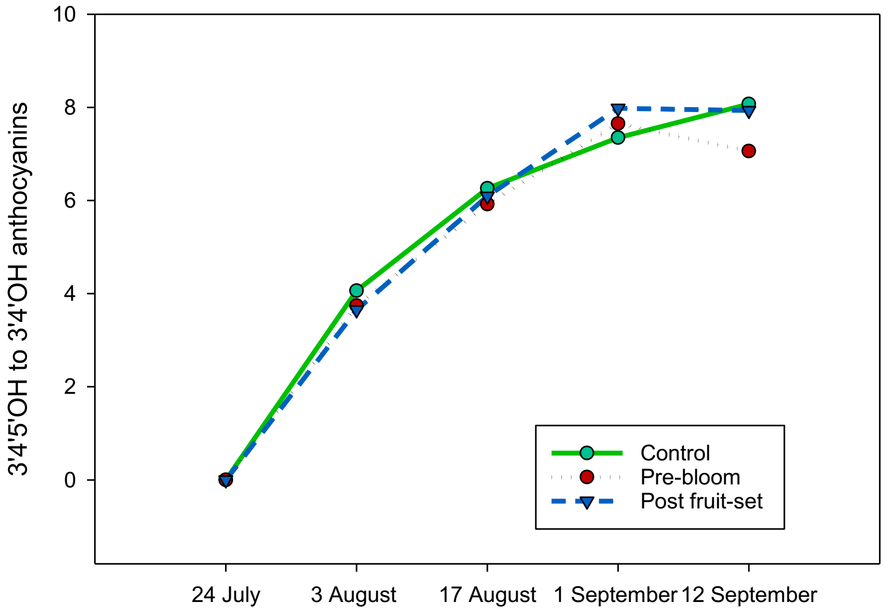
Kinetic development of total anthocyanin concentration





Hydroxylation ratio of anthocyanins





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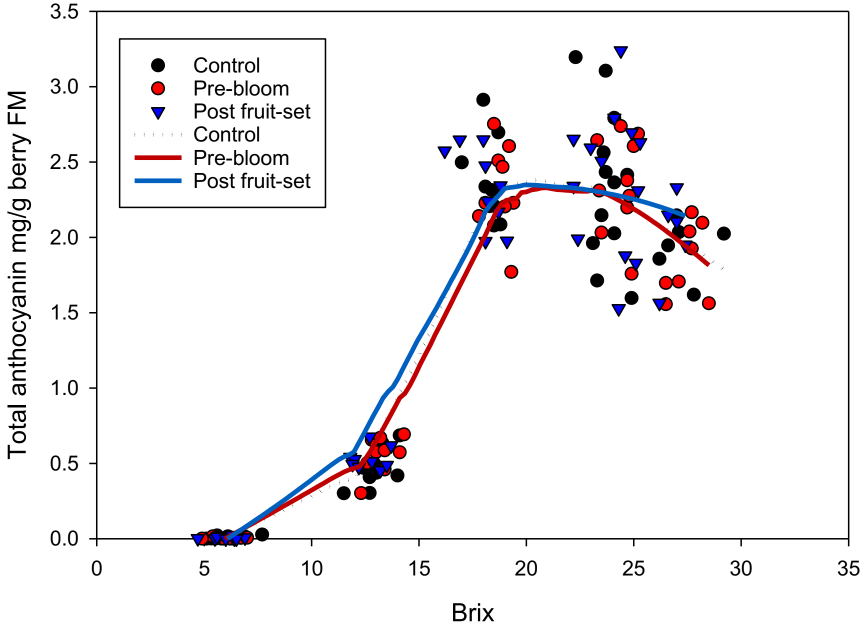
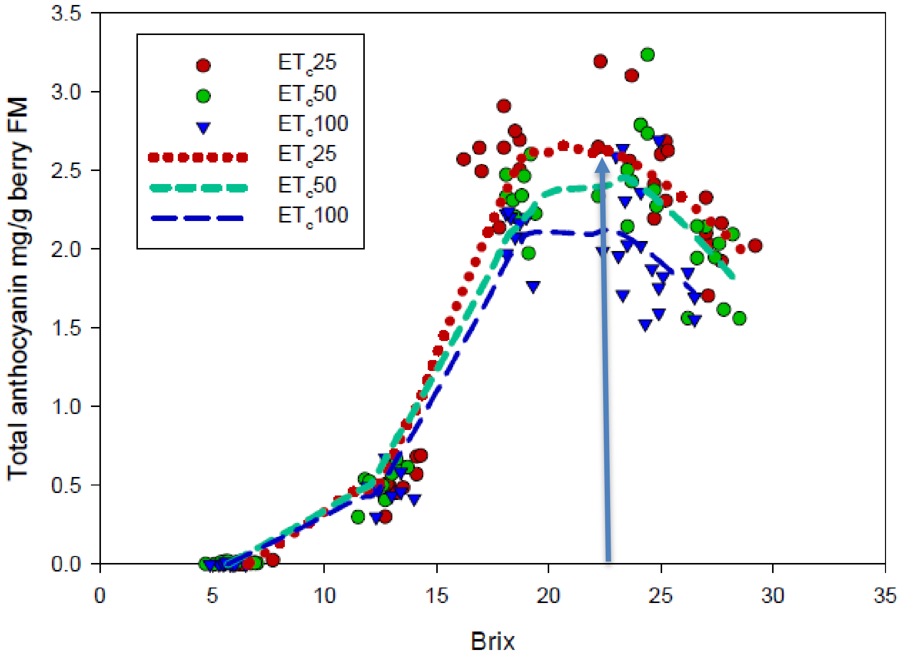
Regression of Brix vs total anthocyanin





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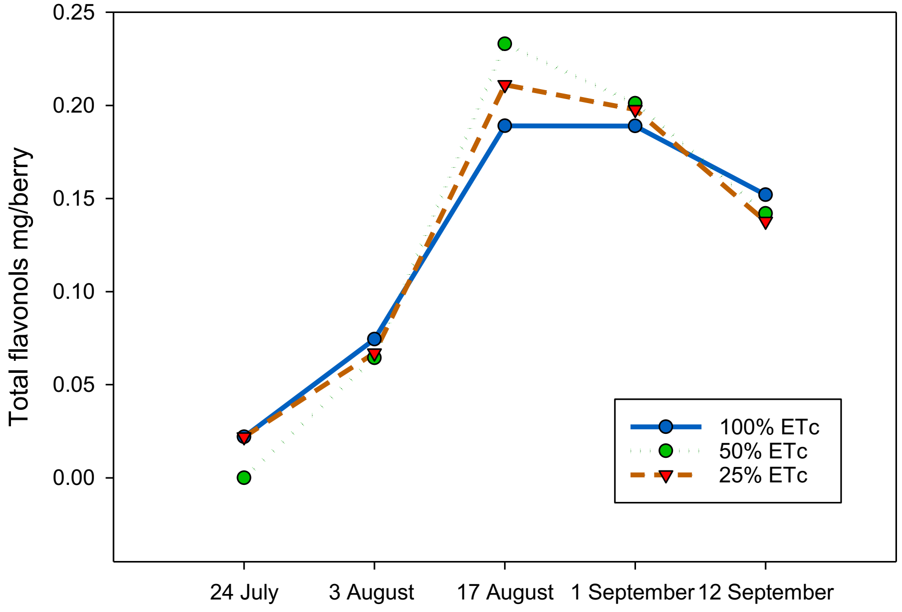
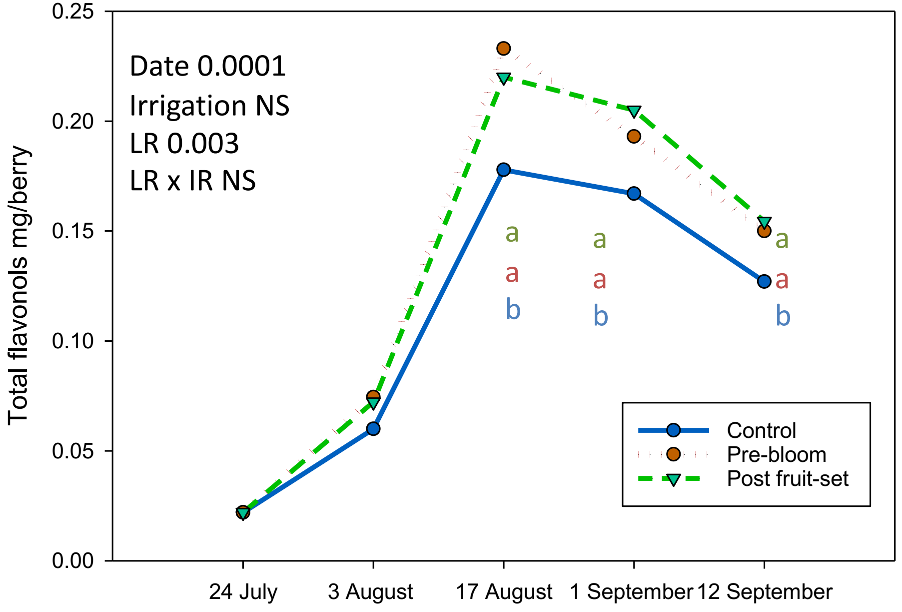
Total flavonols content and concentration

	Skin mass (mg)	Total flavonols (mg/berry)	Total flavonols mg/g FM
Irrigation			
100%ETc	1.011	0.153	0.163
50%ETc	1.117	0.136	0.153
25%ETc	1.043	0.143	0.187
P value	0.0877	0.1905	0.0625
Leaf removal			
Control	1.068	0.127 b	0.152 b
Pre-bloom	1.073	0.151 ab	0.177 a
Post fruit-set	1.031	0.154 a	0.175 a
P value	0.6164	0.0132	0.0160
LR x IRR	0.0794	0.1082	0.1249

Kinetic development of total flavonol content





Proanthocyanidin content and concentration

		Proanthocyanidins	
	Berry mass (g)	Total proanthocyanidins (mg/berry)	Total proanthocyanidins (mg/g berry)
Irrigation			
100% ETc	0,910 a	3,73 a	3,93
50% ETc	0,854 ab	3,25 ab	3,63
25% ETc	0,743 b	2,86 b	3,70
p-value	0,0157*	0,0687*	0,654
Leaf removal			
C	0,850	3,36	3,93
EL	0,825	3,13	3,63
LL	0,832	3,35	3,70
p-value	0,8903	0,7639	0,658
LR x IRR			
p-value	0,6625	0,3623	0,292

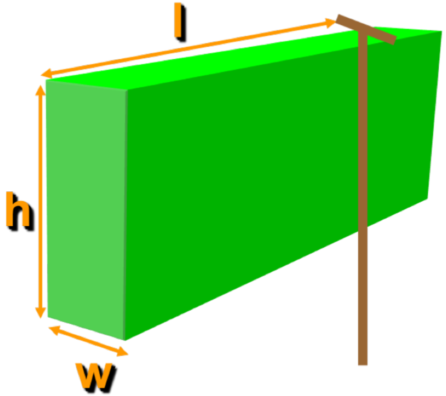
Proanthocyanidin composition (mg/berry) at harvest

	Total proanthocyanidins (mg/berry)						
	C-P	EGC-P	ECG-P	EC-P	C	EC	mDP
Irrigation							
100% ETc	0,051	1,906 a	0,117	1,497	0,116	0,045	43,4
50% ETc	0,048	1,639 ab	0,114	1,304	0,107	0,039	41,5
25% ETc	0,042	1,432 b	0,104	1,152	0,088	0,038	42,5
p-value	0,438	0,0463*	0,61	0,3345	0,0566	0,0816	0,5900
Leaf removal							
C	0,048	1,705	0,113	1,347	0,102	0,039	44,2
EL	0,048	1,555	0,107	1,280	0,098	0,042	41,6
LL	0,046	1,718	0,115	1,326	0,109	0,040	41,7
p-value	0,9284	0,05963	0,8151	0,8179	0,6075	0,6991	0,3080
LR x IRR							
p-value	0,2390	0,2827	0,6241	0,4632	0,2396	0,7176	0,4111

Plant Material and Research Site

- Merlot (01)/Freedom
- Planted in 1998
- Located in Merced County
- 80 acre research site
- 2.1m x 3.1m spacing (N-S)
- Whitney and Rocklin Sandy-Loam soil
- Drip irrigated
- Head trained and cane pruned to six-canes

Canopy Architecture
North Valley Cane-Pruned



Irrigation Treatments

Irrigation hours

- calculated based on weekly CIMIS Et_o

Sustained Deficit Irrigation (SDI)

- control treatment
- received 80% of ET_c from bloom to harvest
- dynamic grape coefficient factor (K_c) included
- leaf Ψ maintained at -1.2 MPa

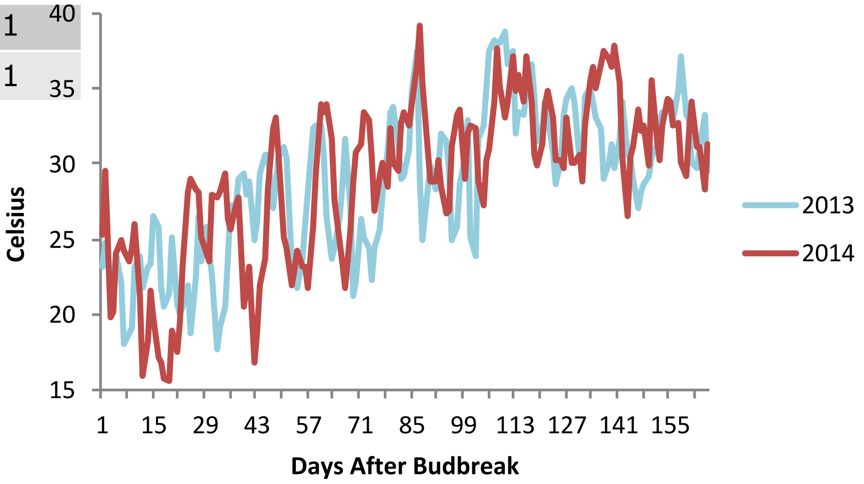
Regulated Deficit Irrigation (RDI)

- received 80% of ET_c from bloom to set and from veraison to harvest
- received 50% of ET_c from set to veraison
- dynamic grape coefficient factor (K_c) included
- leaf Ψ maintained at -1.4 MPa

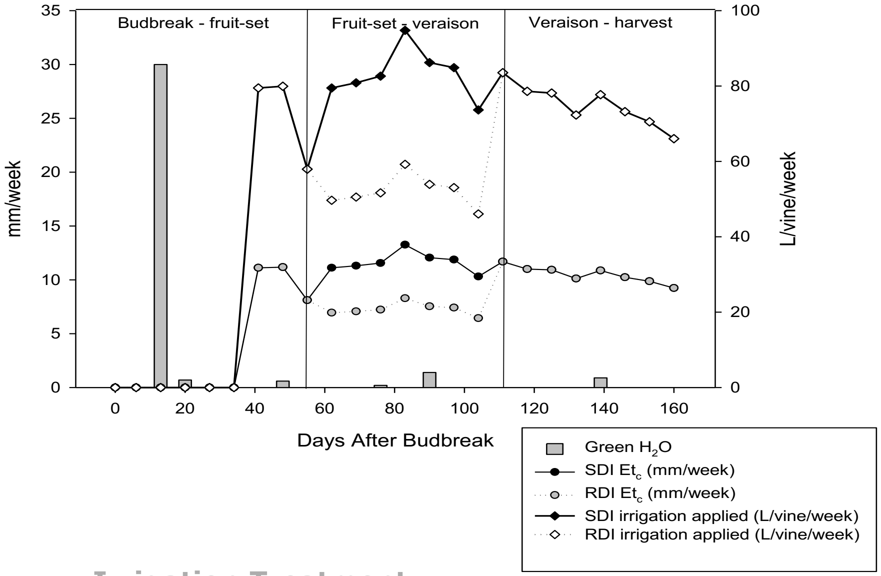
Results

Daily Ambient Temperature Maxima

Number of Days	2013	2014
> 32^{o}C	61	71
> 37^{o}C	10	11

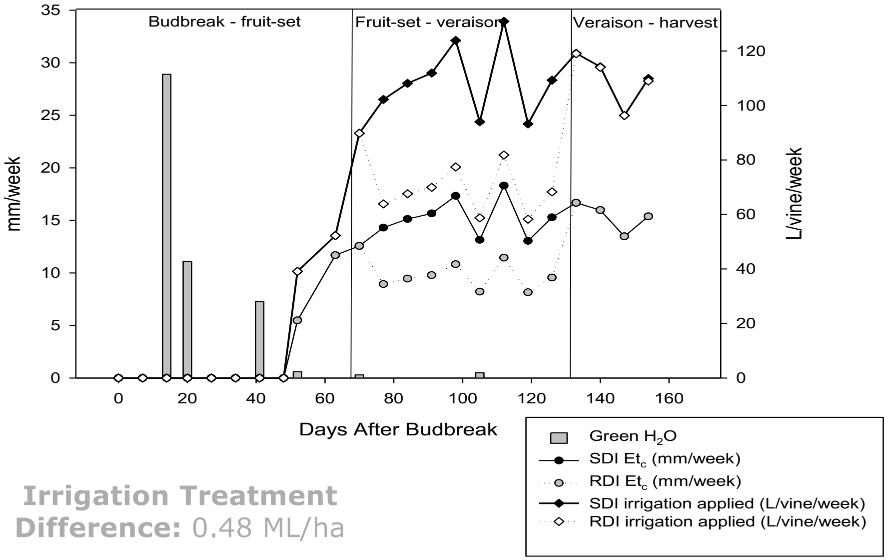


Seasonal Water Relations
2013



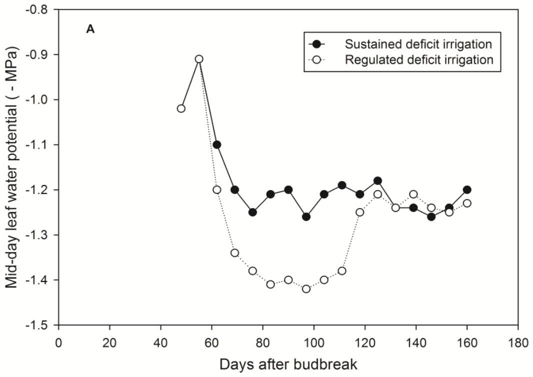
Irrigation Treatment Difference:
0.34 ML/ha

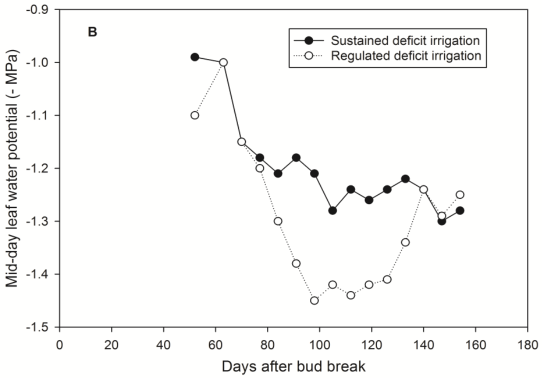
Seasonal Water Relations
2014



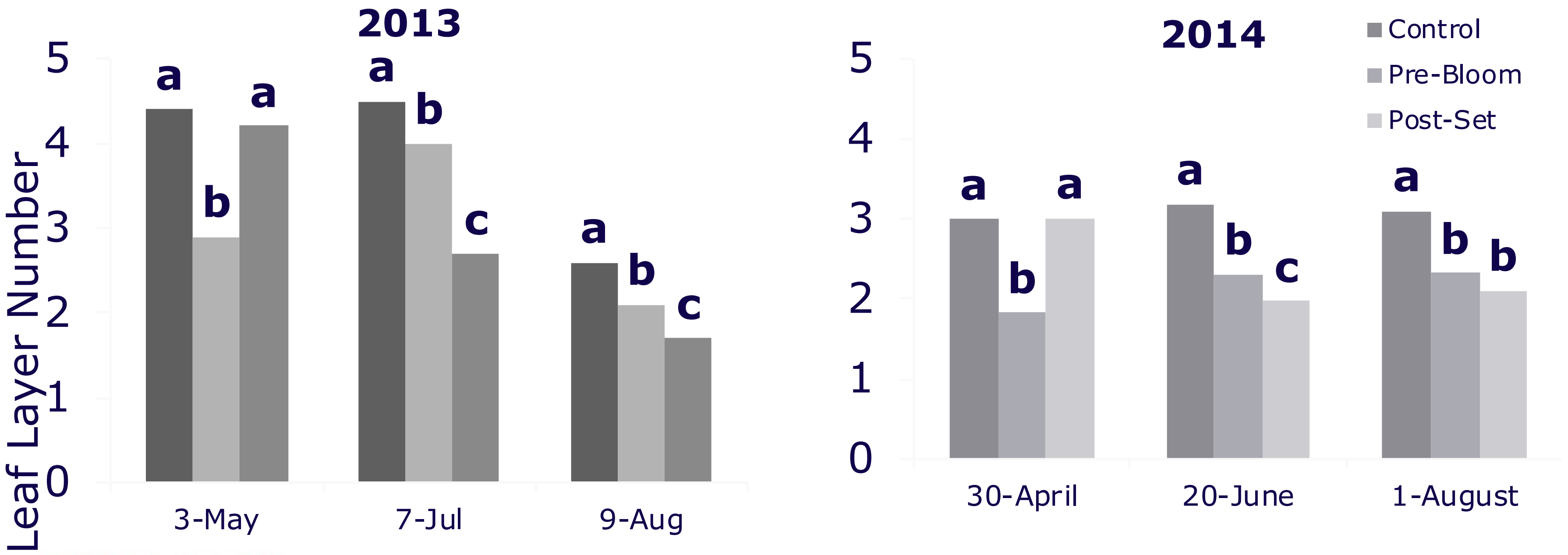
Irrigation Treatment Difference: 0.48 ML/ha

Mid-day leaf water potential

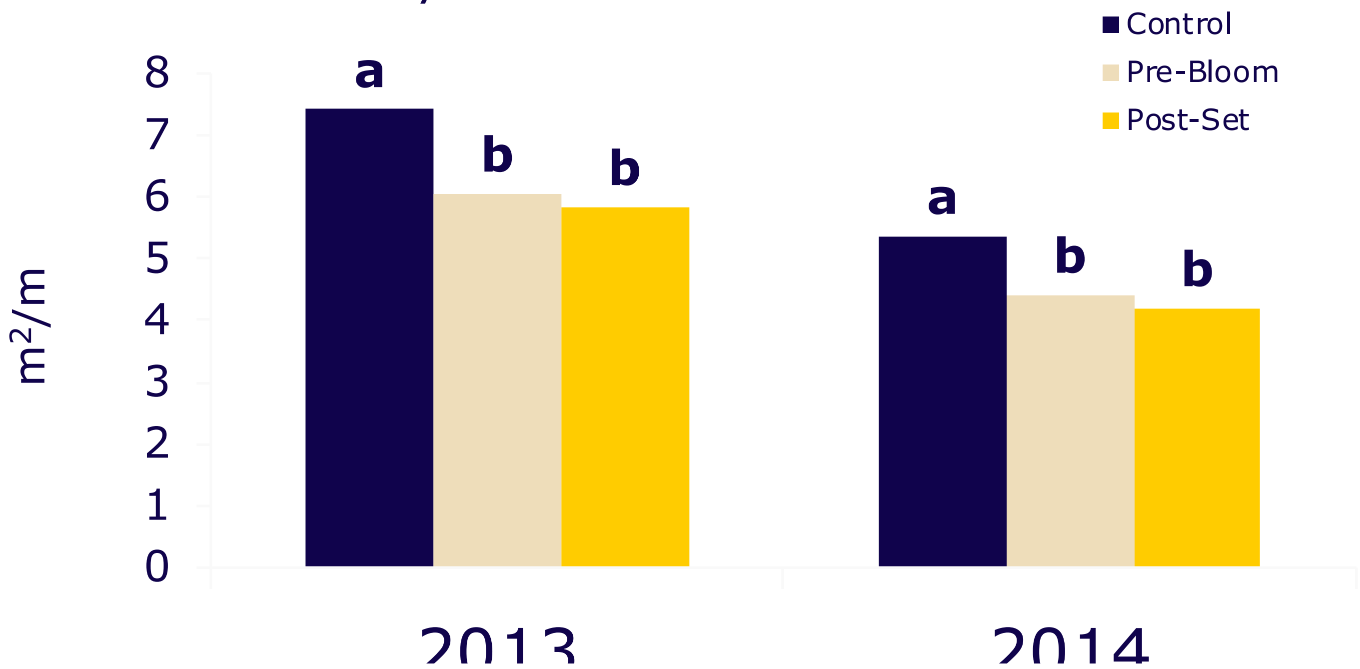




Leaf Layer Number



Functional Leaf Area/m



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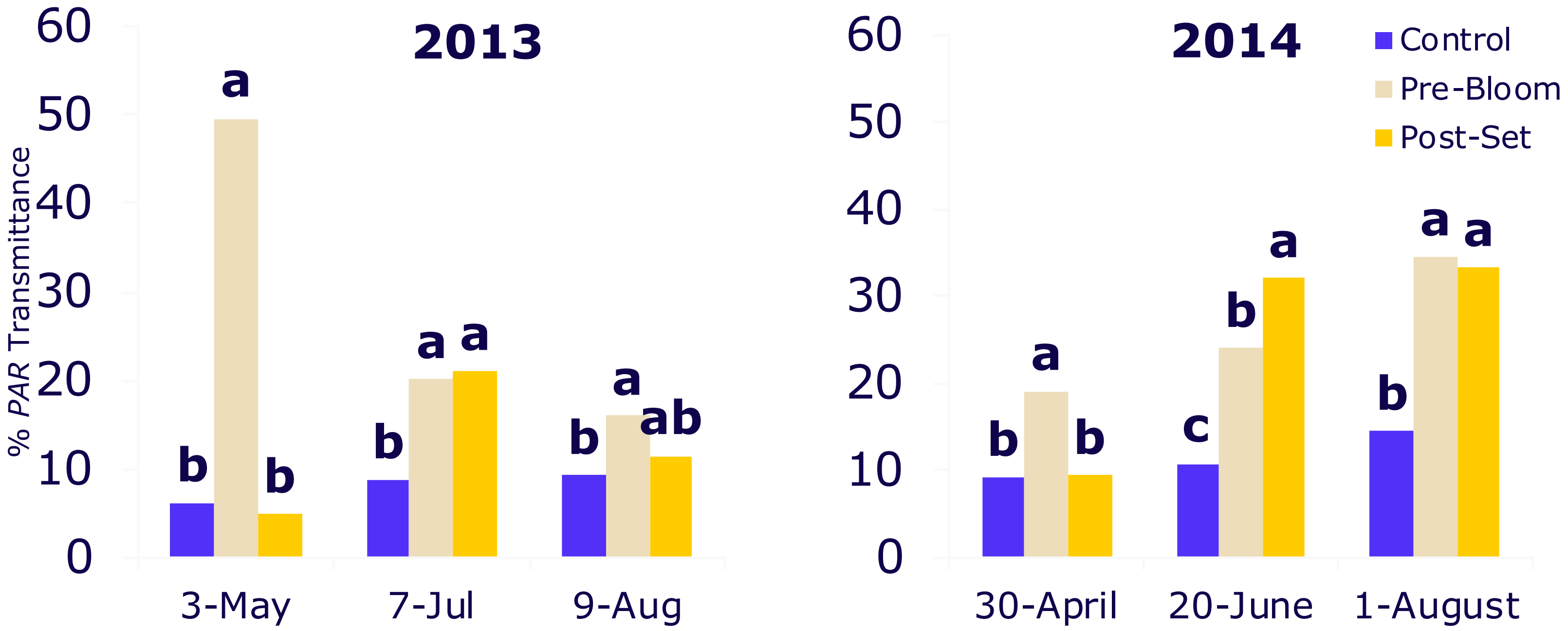
Mechanical Severity – approx. 20% reduction in leaf area

Light Transmittance



Vegetative Compensation Response

- critical factor in determining lasting effects of improved microclimate and yield status
- response dependent on severity, timing, and frequency of LR

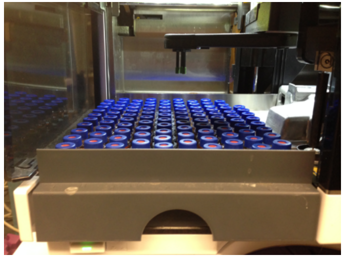
- Pre-Bloom
  - recovery response observed but incomplete
    - mechanical blower effect on incipient and lateral shoot tips
    - positive effects of defoliation long lived

- Post-fruit set
  - in 2013 vines re-filled soon after defoliation
  - in 2014 recovery occurred but remained more open
    - due to cane pulling as observed in previous studies

Yield components

	Berry mass (g)	Berry skin mass (mg)	Yield (kg/m)
		2013	
Leaf removal			
Control	1.36[a] a	55.0 a	6.64
Pre-bloom	1.27 b	51.7 a	6.34
Post-fruit set	1.28 b	45.0 b	6.78
Pr>F	0.0216	0.002	0.4996
ET_c fraction			
SDI	1.34 a	51.3	6.86
RDI	1.26 b	47.8	6.31
Pr>F	0.0068	0.5103	0.0748
LR × ET_c fraction	0.9004	0.9074	0.8684
		2014	
Leaf removal			
Control	1.09	45.3 a	6.17 a
Pre-bloom	1.07	42.9 ab	6.10 a
Post-fruit set	1.11	39.5 b	4.46 b
Pr>F	0.5314	0.031	0.0016
ET_c fraction			
SDI	1.14 a	42.7	6.08 a
RDI	1.04 b	42.3	5.27 b
Pr>F	0.0021	0.6963	0.0003
LR × ET_c fraction	0.4878	0.5892	0.0053

Chemical Composition



Fruit Composition

	TSS (%)	Juice pH	TA (g/L)
Leaf removal		2013	
Control	24.6 a	3.57	5.26
Pre-bloom	24.7 a	3.59	4.78
Post-fruit set	24.0 b	3.58	5.06
Pr>F	0.0171	ns	ns
Deficit irrigation			
SDI	24.2 b	3.59	5.04
RDI	24.7 a	3.57	5.02
Pr>F	0.0206	ns	ns
Leaf removal		2014	
Control	24.3	3.60	4.83
Pre-bloom	24.1	3.62	4.66
Post-fruit set	24.2	3.64	4.69
Pr>F	ns	ns	ns
Deficit irrigation			
SDI	23.9 b	3.63	4.83
RDI	24.5 a	3.61	4.62
Pr>F	0.0199	ns	ns

Effects of leaf removal and applied water on flavonoid concentration of grape skins

	On Berry Weight Basis (mg/kg)				On per Berry Basis (mg/berry)			
	C	EC	Total skin flavonols	Total skin anthocyanins	C	EC	Total skin flavonols	Total skin anthocyanins
2013								
Leaf removal								
Control	103 b	89 b	218.23b	2066.4 b	0.0209 b	0.0280	0.2405 b	4.5162 b
Pre-bloom	196 a	169 a	375.82a	2763.9 a	0.0335 a	0.0334	0.3456 a	6.0095 a
Post-fruit set	144 ab	120 b	302.56a	2381.5ab	0.0242ab	0.0238	0.2676 b	4.4101 b
p value[a]	0.0016	0.0007	0.001	0.0055	0.0852	0.2918	0.002	0.0388
Applied water								
SDI	136	116	284.92	2284.7	0.0294	0.0323	0.2849	5.1259
RDI	155	128	312.82	2527.2	0.0230	0.0245	0.2842	4.8313
p value[a]	0.3607	0.4465	0.3974	0.319	0.1811	0.1171	0.9770	0.5997
LR × applied water	0.2725	0.5666	0.9541	0.1267	0.7089	0.3322	0.3999	0.079
2014								
Leaf removal								
Control	141 b	149 b	350.93b	1554.1 b	0.0207 a	0.0536	0.1570 b	2.7655 a
Pre-bloom	160 ab	166 ab	432.96a	2135.3 a	0.0198ab	0.0627	0.1726ab	2.4290 b
Post-fruit set	186 a	184 a	477.45a	2044.9 a	0.0169 b	0.0520	0.1938 a	2.8352 a
p value[a]	0.0255	0.0481	0.0035	0.0014	0.0891	0.1271	0.0661	0.0199
Applied water								
SDI	157	160	415.01	1902.1	0.0203	0.0630 a	0.1799	2.6304
RDI	172	175	427.41	2012.6	0.0178	0.0490 b	0.1692	2.7261
p value[a]	0.3704	0.2079	0.7496	0.1093	0.0845	0.0031	0.4008	0.3937
LR × applied water	0.9114	0.8767	0.306	0.2871	0.2285	0.6796	0.6236	0.3512

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Effects of leaf removal and applied water on proanthocyanidin composition and polymerization of grape skins

	% mol proportion				
	EGC	C	EC	ECG	mDP
			2013		
Leaf removal					
Control	40.2 b	1.7 ab	55.8 a	2.3	14.1ab
Pre-bloom	42.1 b	1.8 a	54.1 b	2	13.9 b
Post-fruit set	42.3 a	1.6 b	54.6 ab	1.5	15.9a
p value[a]	0.0005	0.0139	0.0004	0.1033	0.0172
Applied water					
SDI	41.5	1.8 a	54.8	1.86	14.1
RDI	41.5	1.6 b	54.8	2.03	15.1
p value[a]	0.8146	0.0049	0.7119	0.5167	0.0854
LR × applied water	0.8669	0.8098	0.8172	0.9073	0.4905
			2014		
Leaf removal					
Control	48.5	1.5	44.1 b	3.6	20.2 a
Pre-bloom	49.8	1.4	45.4 ab	3.3	17.9 b
Post-fruit set	50.8	1	47.1 a	3.3	18.6 a
p value[a]	0.1010	0.3414	0.0234	0.0646	0.0454
Applied water					
SDI	49.1	1.5	46	3.4	18.4
RDI	50.3	1.2	45	3.5	19.4
p value[a]	0.9677	0.1825	0.2666	0.9678	0.2326
LR × applied water	0.5429	0.9475	0.4502	0.6678	0.9236

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Proanthocyanidin concentration, hydroxylation and conversion yield

	Skin				Seed		
	Total PAs (Phloro) (mg/L)	Total PAs (IRP) (mg/L)	Tri-OH (mg/L)	Conversion Yield (%)	Total PAs (Phloro) (mg/L)	Total PAs (IRP) (mg/L)	Conversion Yield (%)
2013							
Leaf removal							
Control	426.4 b	1797.1	164.5 b	24.9 b	302.7	4862.6	6.4 a
Pre-bloom	409.1 b	2082.4	165.2 b	20.6 c	295.0	4883.6	6.0ab
Post-fruit set	577.1 a	2099.9	234.9 a	28.3 a	265.7	4941.3	5.4 b
p value[a]	0.0004	0.1001	0.0005	0.0001	0.2161	0.9912	0.0664
Applied water							
SDI	466.7	2062.2	186.3	23.6 b	302.5	4907.3	6.2
RDI	475.0	1924.0	190.0	25.6 a	273.1	4884.4	5.7
p value[a]	0.8060	0.2016	0.8146	0.0427	0.1172	0.6945	0.0769
LR × applied water	0.8453	0.8696	0.8669	0.3087	0.2366	0.3839	0.1605
2014							
Leaf removal							
Control	264.4ab	1067.2	127.6	32.4	228.4 b	7317.2	3.0
Pre-bloom	240.6 b	1038.0	112.7	24.6	268.79 a	7606.5	3.3
Post-fruit set	278.0 a	1064.5	131.9	36.1	247.44ab	7835.3	3.3
p value[a]	0.0566	0.8276	0.1010	0.4241	0.1611	0.3745	0.1874
Applied water							
SDI	265.7	1092.7	123.8	30.1	237.9 b	7682.5	3.1
RDI	257.5	1019.5	124.3	32.0	258.5 a	7490.2	3.3
p value[a]	0.5396	0.3602	0.9677	0.9284	0.0588	0.6407	0.0875

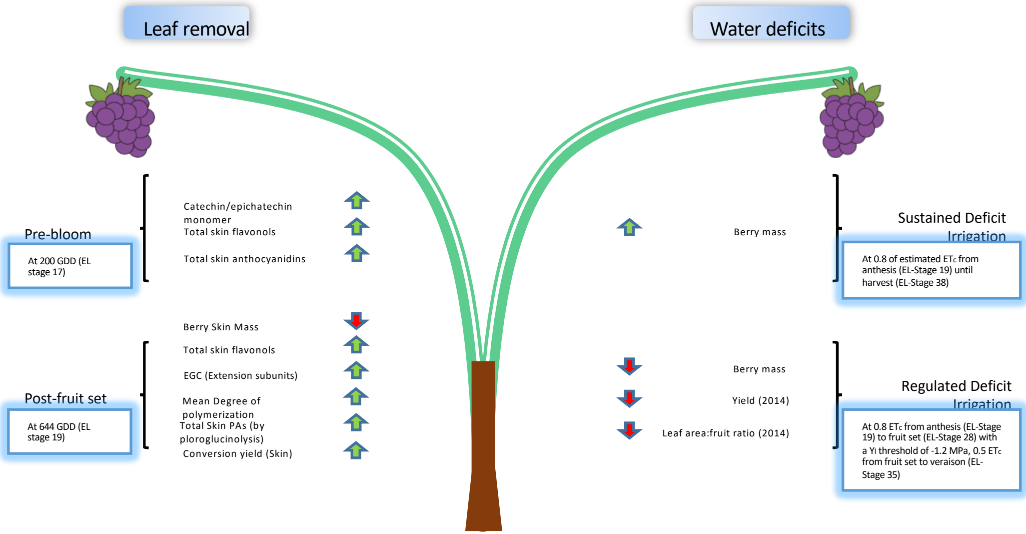
Labor operations costs…..

Table 6 Effects of mechanical leaf removal and fractions of crop evapotranspiration application on labor operations cost of canopy management and cost of producing total skin anthocyanins per hectare in northern San Joaquin Valley of California (n = 4).

	Pruning cost ($/ha)	Leaf removal cost ($/ha)	Irrigation applied (ML/ha)	Irrigation water cost ($/ha)	TSA production[a] (g/ha)	TSA unit cost ($/g)
2013						
Control + SDI	748	0	2.37	950	1,086 c[b]	1.56 a
Control + RDI	748	0	2.03	827	1,718 b	0.92 bc
Prebloom + SDI	748	30	2.37	950	1,976 a	0.87 c
Prebloom + RDI	748	30	2.03	827	1,958 a	0.82 c
Post fruit-set + SDI	748	30	2.37	950	1,589 b	1.09 b
Post fruit-set + RDI	748	30	2.03	827	1,799 ab	0.89 c
Pr > *F*	–	–	–	–	0.0001	0.0001
2014						
Control + SDI	748	0	3.08	1,235	1,079 c	1.84 a
Control + RDI	748	0	2.60	1,029	1,261 b	1.41 b
Prebloom + SDI	748	30	3.08	1,235	1,657 a	1.21 c
Prebloom + RDI	748	30	2.60	1,029	1,552 a	1.16 c
Post fruit-set + SDI	748	30	3.08	1,235	1,062 c	1.90 a
Post fruit-set + RDI	748	30	2.60	1,029	1,181 b	1.53 b
Pr > *F*	–	–	–	–	0.0001	0.0001

[a]TSA: total skin anthocyanin (g) produced per hectare.
[b]Columns followed by a different letter are significantly different according to Tukey's HSD test at *Pr* > *F* 0.05.

Cook et al. 2015



Leaf removal
Water deficits
Pre-bloom
At 200 GDD (EL stage 17)
Catechin/epichatechin monomer
Total skin flavonols
Total skin anthocyanidins
Berry Skin Mass
Post-fruit set
At 644 GDD (EL stage 19)
Total skin flavonols
EGC (Extension subunits)
Mean Degree of polymerization
Total Skin PAs (by ploroglucinolysis)
Conversion yield (Skin)
Berry mass
Sustained Deficit Irrigation
At 0.8 of estimated ETc from anthesis (EL-Stage 19) until harvest (EL-Stage 38)
Berry mass
Yield (2014)
Leaf area:fruit ratio (2014)
Regulated Deficit Irrigation
At 0.8 ETc from anthesis (EL-Stage 19) to fruit set (EL-Stage 28) with a Yl threshold of -1.2 MPa, 0.5 ETc from fruit set to veraison (EL-Stage 35)

Yu et al. 2016

Summary

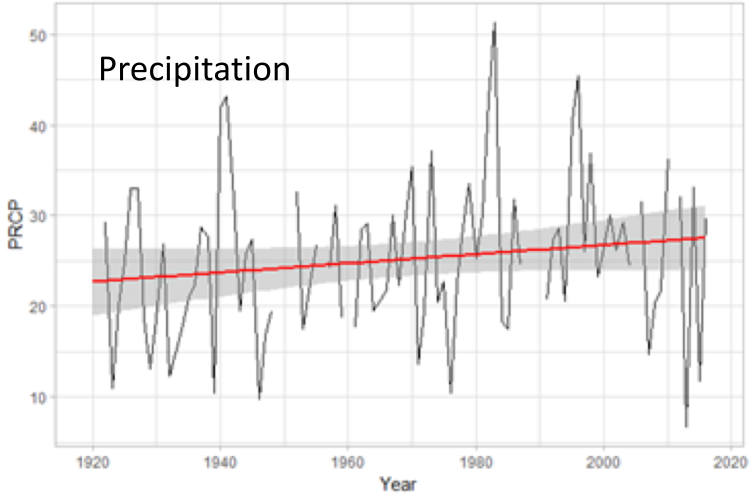
- **Pre-Bloom Leaf Removal**
  - allowed increased light filtration earlier in season
  - canopy open throughout season to 20% ambient PAR
  - promoted skin tissue formation
  - Less skin PA concentration
  - Less mole proportion of EGC subunits
  - Less mDP
  - Less PA conversion yield

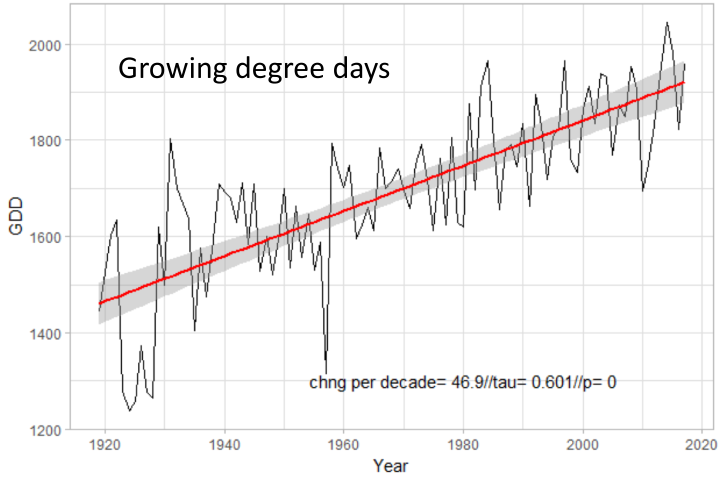
- **Post-Set Leaf Removal**
  - often performed poorly, seemingly better in 2014 but loss of yield
  - sudden increase in light and temperature detrimental to phenolic biosynthesis
  - Greater tannin concentration
  - Greater mole proportion of EGC subnits
  - Greater mDP
  - Greater PA conversion yield

PERSPECTIVES

A shifting climate in California's North Coast AVAs

- Little to no cloud cover
- Intermittent heat spikes
- A general warming trend
- No increase in precipitation supply

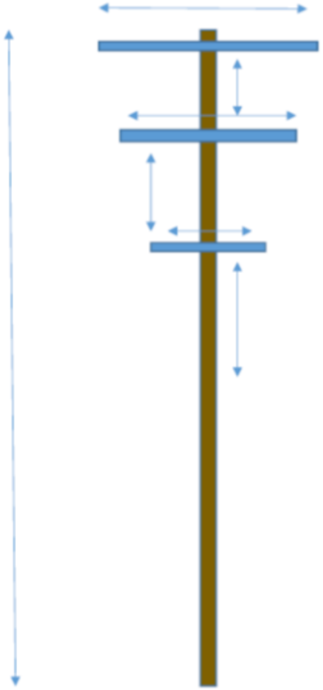


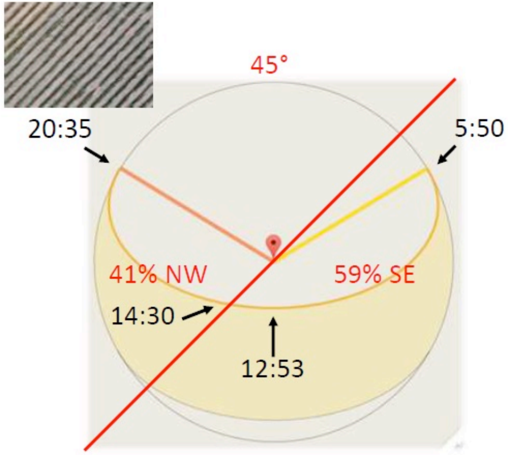


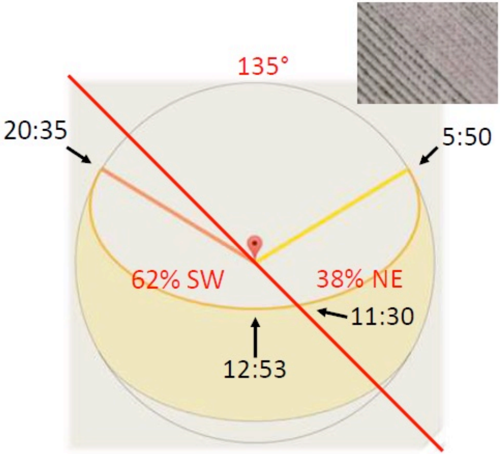
UCDAVIS

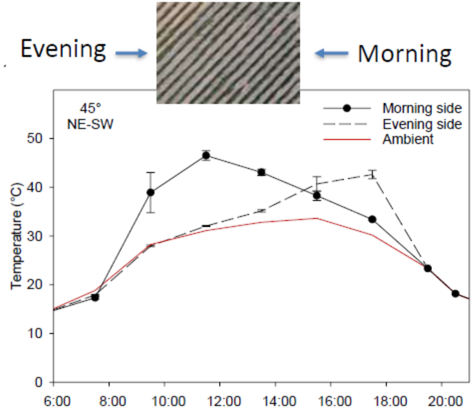
Shift towards positioned and sprawling systems

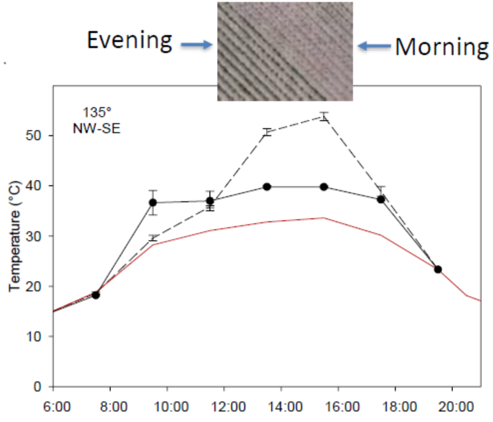
The UCDavis30 Trellis









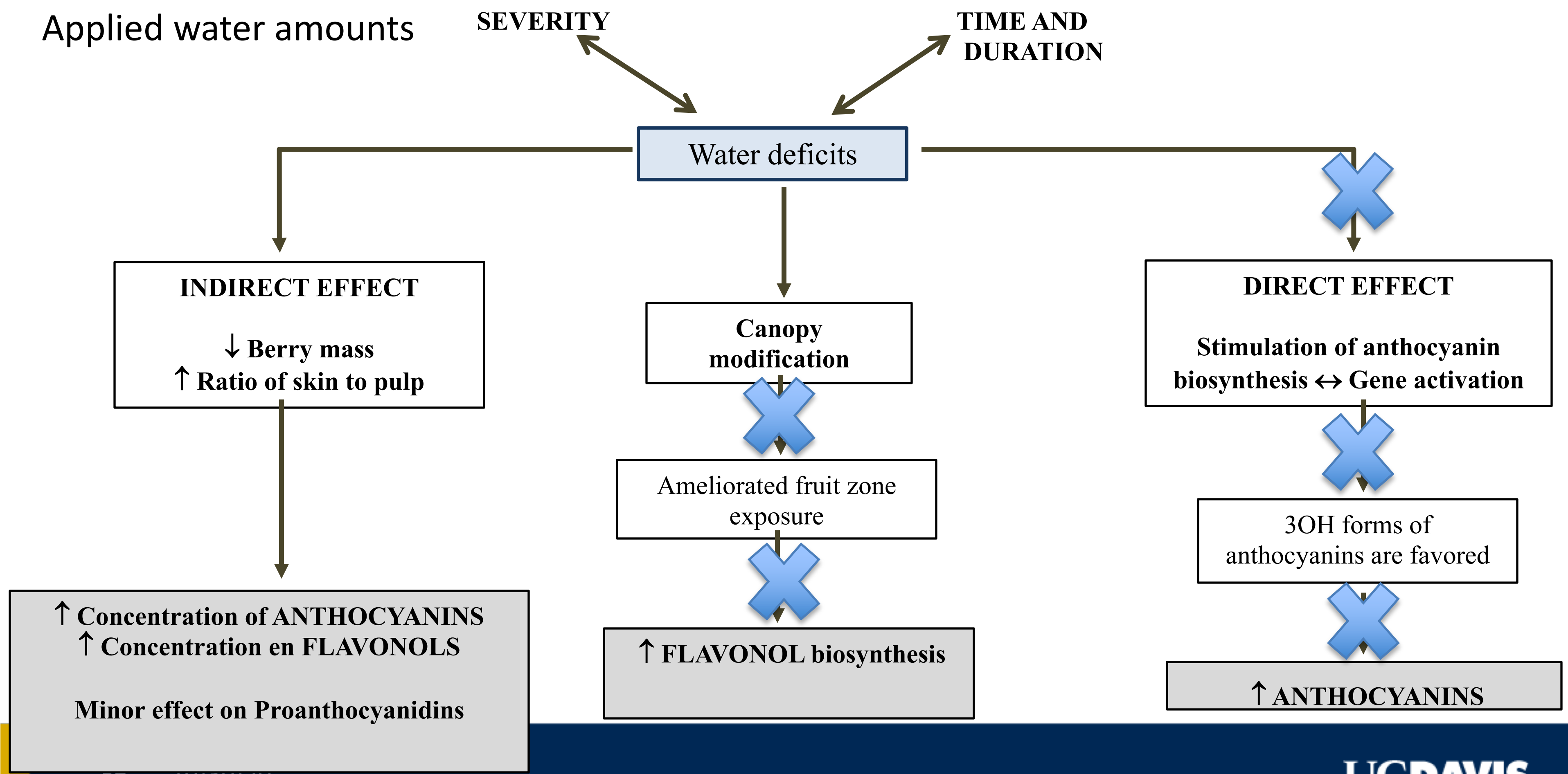


UCDAVIS

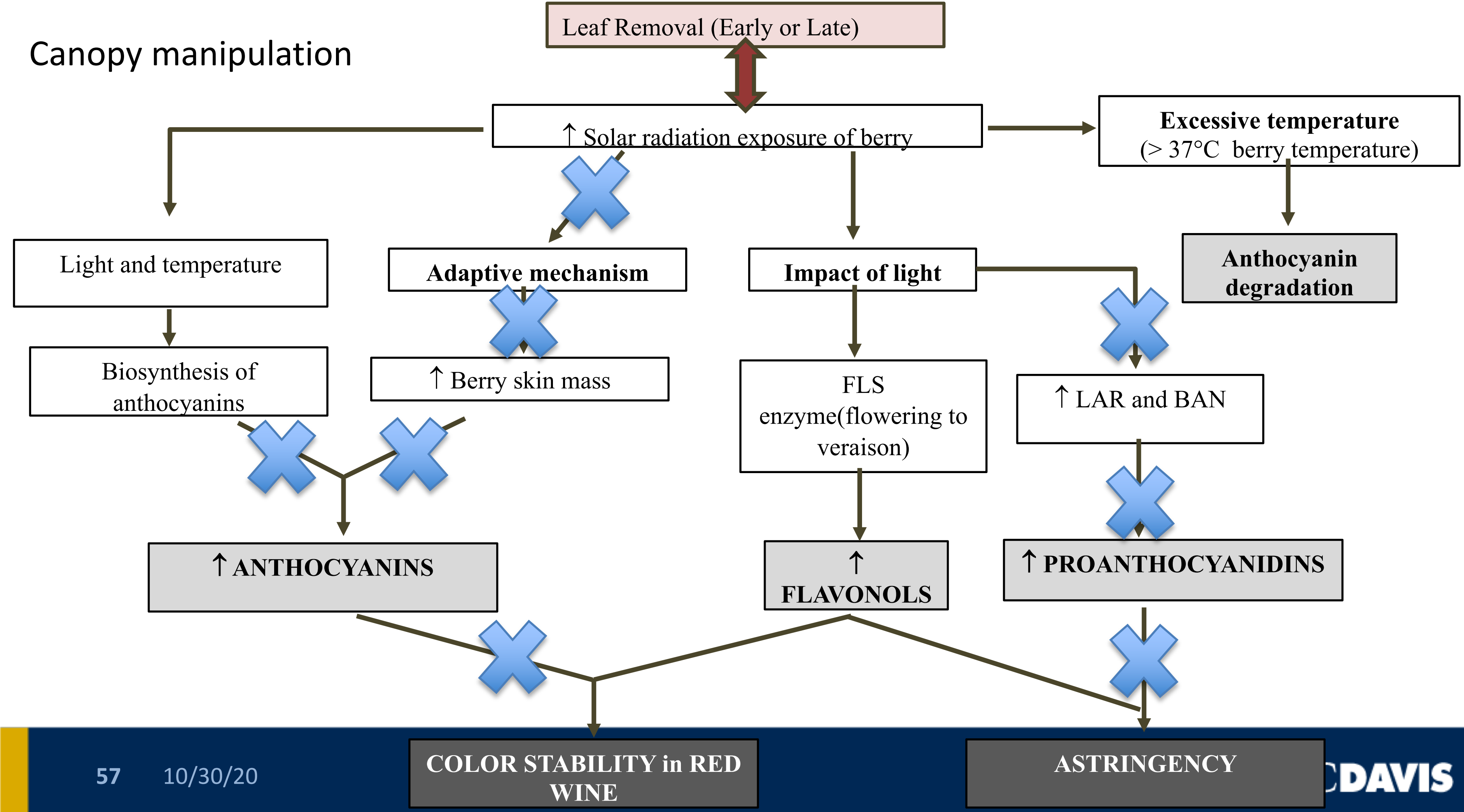
Primary metabolism summary North Coast

- Leaf removal timing
    - No effect on
        - Water status
        - Net gas exchange
        - Components of yield
            - No effect on fruit set
        - Primary metabolites
- Applied water amounts
    - Significant effect on
        - Water status
        - Net gas exchange
        - Components of yield
        - Primary metabolites
            - Only TSS

Applied water amounts



Canopy manipulation



Conclusions

- Cluster microclimate on the North Coast without leaf removal already optimized
- Clear skies, long periods with minimal precipitation coupled with irrigation restriction have stronger effect on primary and secondary metabolism then canopy manipulation (*e.g.* shoot or leaf removal)
    - An optimal ET replacement is 50%-60% ETc using sustained deficits.
- Although not as impactful, there seems to be interest from producers to understand the impact of leaf removal practices on berry physiology

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