Maximizing yields and grape quality with limited water

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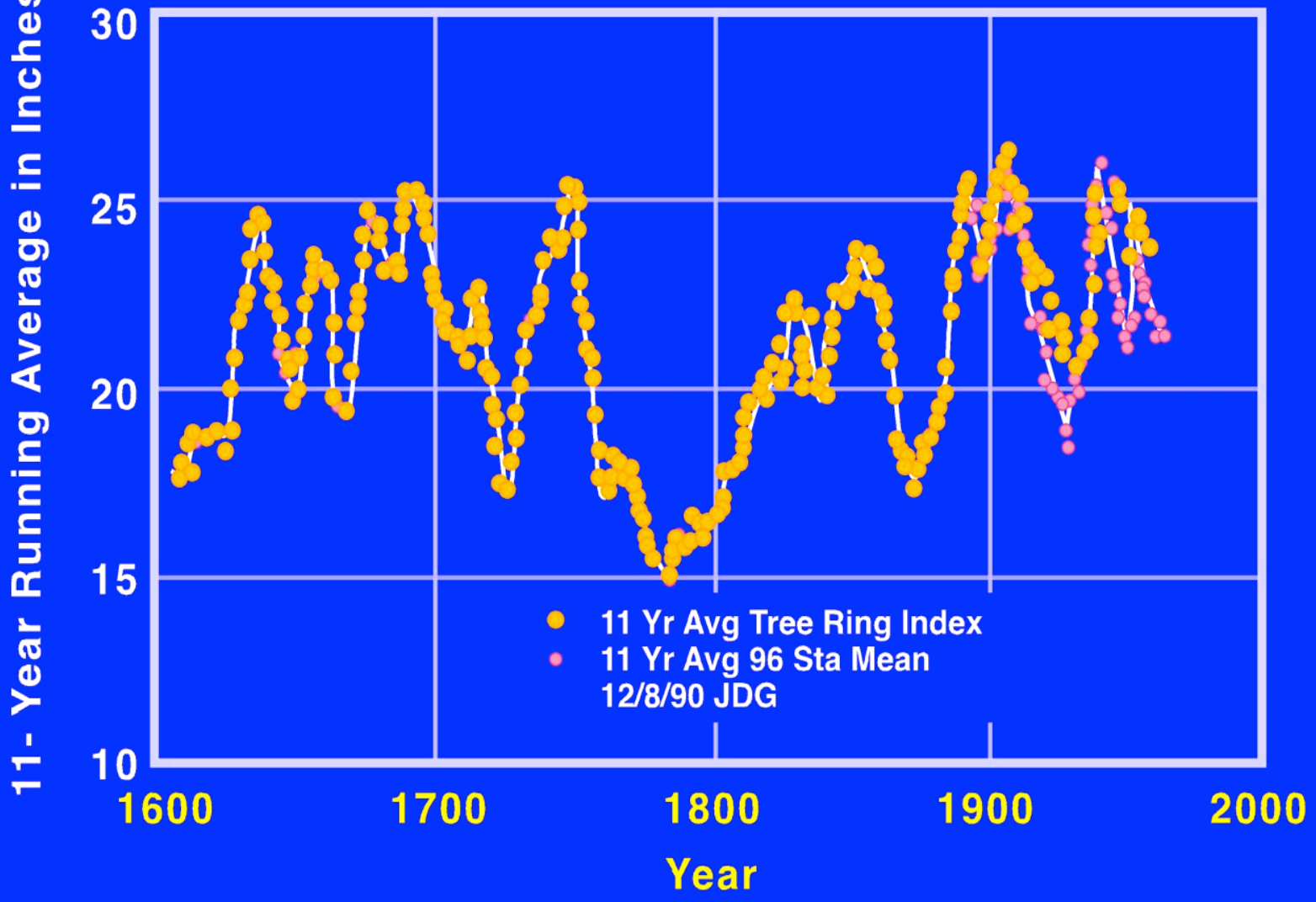
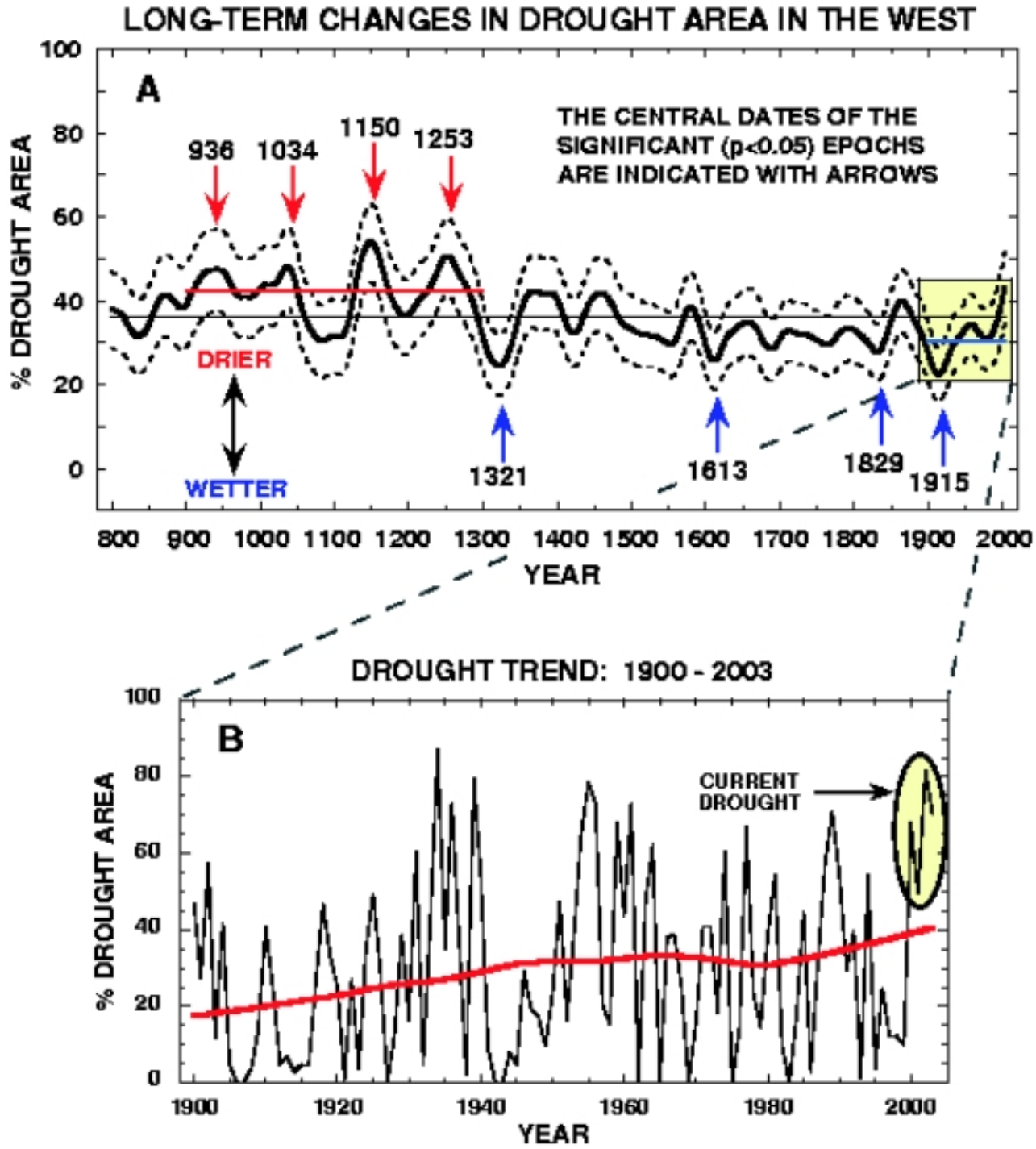
California Rainfall Trends Since 1600



Tree data from Pritts and Geoffrey, DWR July 1980


LONG-TERM CHANGES IN DROUGHT AREA IN THE WEST
A
THE CENTRAL DATES OF THE SIGNIFICANT (p<0.05) EPOCHS ARE INDICATED WITH ARROWS
936
1034
1150
1253
DRIER
WETTER
1321
1613
1829
1915
% DROUGHT AREA
YEAR
DROUGHT TREND: 1900 - 2003
B
CURRENT DROUGHT
% DROUGHT AREA
YEAR

Historic monthly rainfall (inches) at four locations in California.

	---------- Location ----------			
Month	Sonoma	Oakville	Fresno	Paso
Jan.	6.26	8.57	2.13	3.48
Feb.	5.23	5.45	1.89	3.06
Mar.	4.18	4.27	1.93	2.49
Apr.	1.82	1.73	1.03	1.01
May	0.80	0.46	0.37	0.36
Jun.	0.23	0.19	0.14	0.06
Jul.	0.03	0.06	0.01	0.02
Aug.	0.09	0.07	0.01	0.06
Sept.	0.34	0.38	0.16	0.18
Oct.	1.63	1.70	0.51	0.59
Nov.	3.94	3.77	1.13	1.38
Dec.	5.22	5.83	1.59	2.54
Total	29.8	32.5	10.9	15.2

Sonoma: 1893 – 2007
Oakville: 1906 – 1981
Fresno: 1948 – 2007
Paso Robles:
1894 - 2007

Rainfall (mm/inches) at ten locations in California.
(historical values at those locations)

	Rainfall (1 Nov. 2013 – 11 Feb., 2014)	
Location	mm	inches
Windsor	275	10.8 (15.4)
Oakville	240	9.4 (18.2)
Carneros	183	7.2
Lodi (west)	102	4.0
Salinas	55	2.2
King City	20	0.8
Parlier	48	1.9 (4.8)
Paso Robles	34	1.3 (7.4)
San Luis Obispo	73	2.9
Temecula	18	0.7

Irrigation management and Vineyard Sustainability

- Maintain productivity over time
- Maximize fruit quality
- Increase vineyard water use efficiency
- Minimize/maximize soil water depletion (function of soil type and rooting depth, cover crop management)
- Some of the above factors will be a function of location in California and price of grapes

Irrigation management and Vineyard Sustainability

- Install water meters either at the pump or down individual rows (know how much you've applied throughout the season and total amount)
- Make sure drip irrigation system maintained
- Know what ET of your vineyard(s) might be
- Use a means to assess vineyard soil water or vine water status (most methods to monitor vine and soil water status are highly correlated with one another)

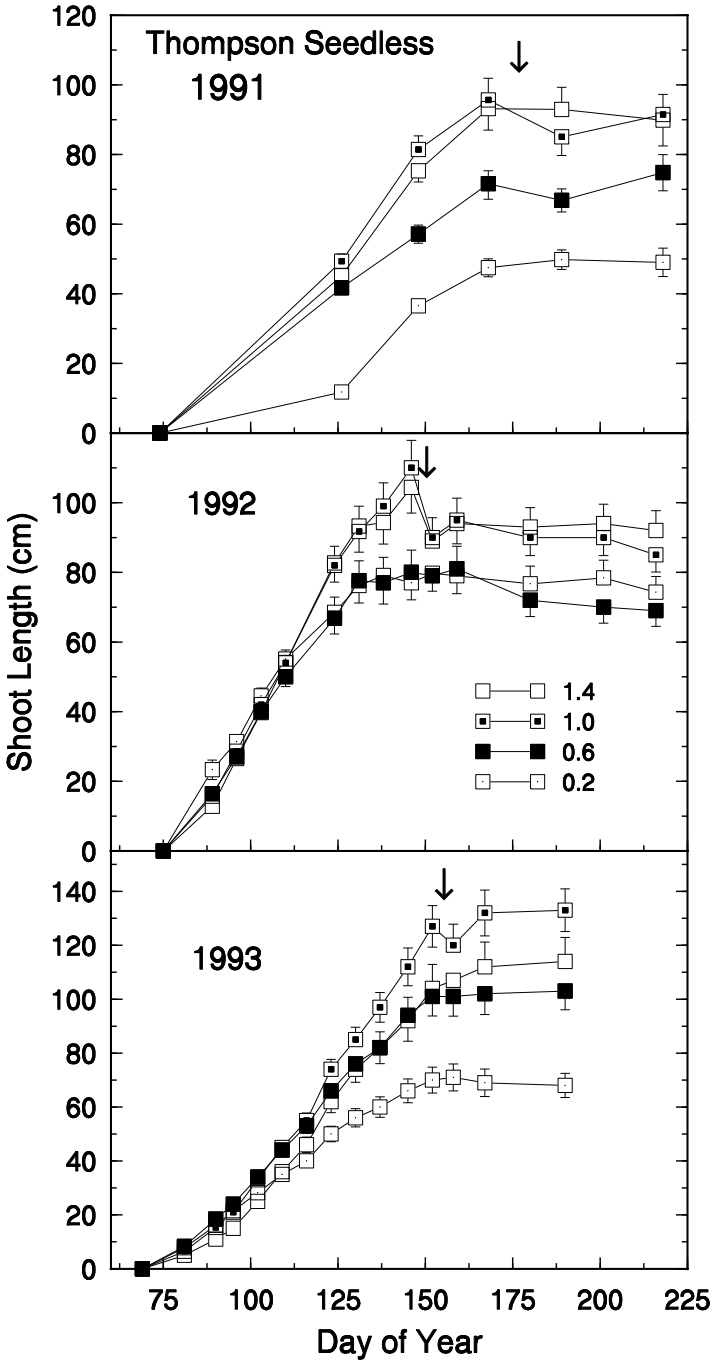
Question:

If rainfall is inadequate to refill the soil profile should one apply water prior to budbreak and/or very early in the growing season?

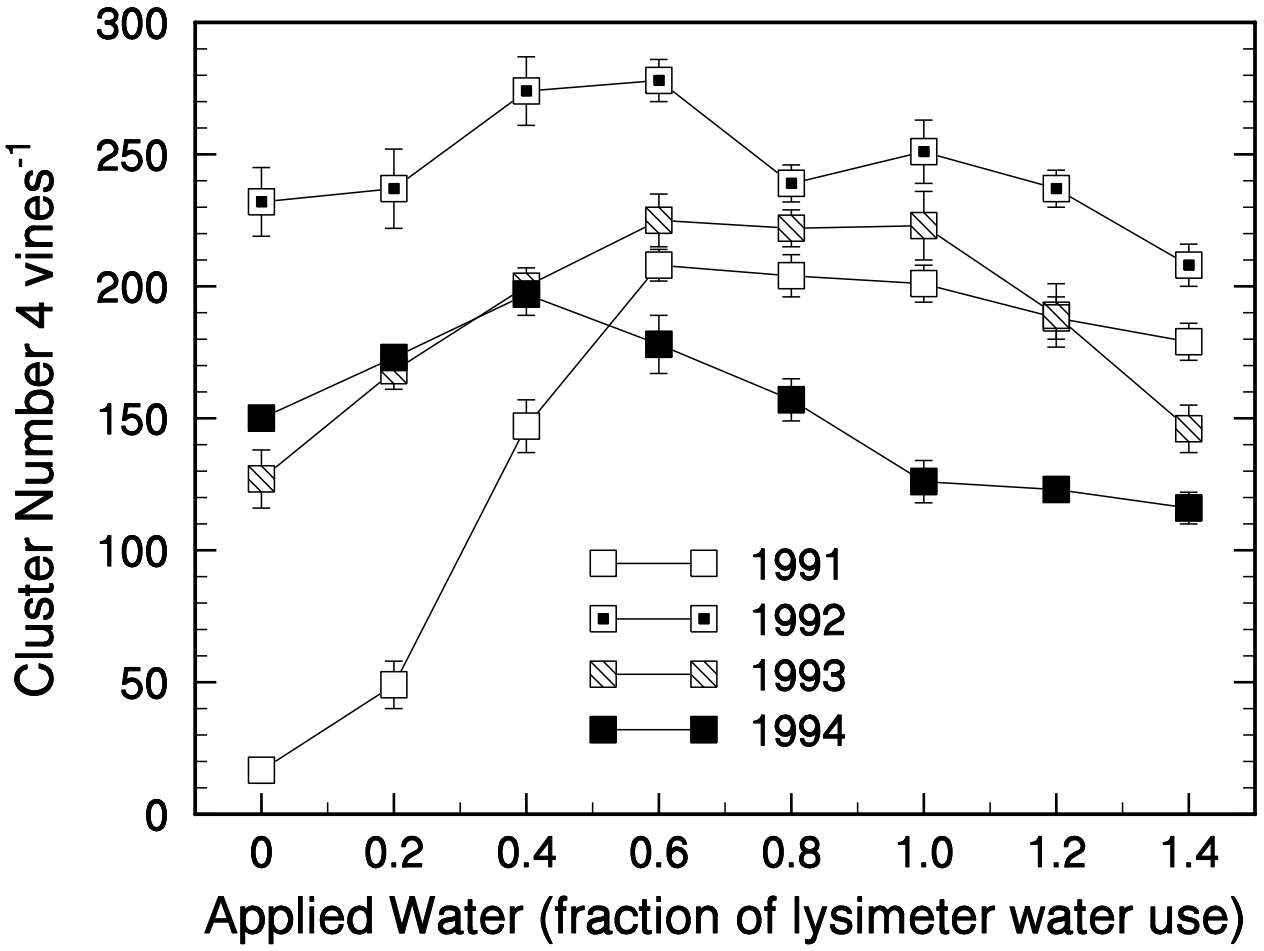
Answer:

A very dry soil can delay shoot growth once budbreak has occurred. I am of the opinion that the application of irrigation water should occur just prior to or at budbreak if so needed. The amount will be dependent upon the rooting depth, water holding capacity of the soil and the amount of deficit in the soil profile.

Seasonal growth of shoots as a function of day of year and irrigation treatment (applied water at various fractions of ET_c)



The number of clusters per vine counted when shoots were approximately 30 cm in length within the 0.6 m cross-arm trellis sub-plot of each irrigation treatment. The data from 1994 is presented since it represents the effects of the previous year's (1993) treatments on bud fruitfulness. The bars represent one SE.



Question:

How much does rainfall contribute to the water requirements of the vineyard?

Answer:

The evaporation of water from the soil after a rainfall event can approach ET_o for up to three days (~ 5 mm per day determined with a weighing lysimeter early in the spring). Most researchers assume that 50% of the rainfall is effective (depending upon a few more factors). Therefore, if you receive 25 mm (1 inch) of rain, you can assume ½ of that is available for the grapevines.

Soil water balance can be calculated as follows:

$$P + I + W - ET_c - R - D = \pm \Delta SWC$$

where P is precipitation, I is irrigation amount, W is the contribution of a water table via upward capillary flow, ET_c is vineyard ET, R is surface runoff, D is drainage and ΔSWC is the change in soil water content between measurement dates. Effective daily rainfall:

Effective rainfall (mm) = (rainfall amount – 6.35) x 0.8

(Prichard et al., 2004)

Williams, AJEV, 2014 (in press) has found this to be reliable.

How much water is lost from the soil profile during a winter with low rainfall amounts?

- Thompson Seedless grapevines were irrigated at full ET_c during the 2013 season at the Kearney Ag Center.
- Irrigation was terminated 11 November.
- Soil water content on 12 November, 2013, was 15.16 % vol./vol.
- Soil water content on 19 March, 2014, was 15.44% vol./vol.
- Between those dates we received 73 mm (~ 3 in.) of rainfall (22.7 mm or < 1.0 in. effective rainfall).

The effect of the previous season's (2002) irrigation amount on the current season's midday leaf water potential. The vines in the irrigation trial were irrigated for the first time the weekend of May 30th. Vines in the cooperator's vineyard had been irrigated three times in 2003.

			Previous Season's Irrigation ----- Amount (% of ET_c) -----		
Date (2003)	Growth Stage	Cooperator's vines	120%	80%	40%
		---------- (MPa) ----------			
5/13	Before bloom	-0.58 a	-0.70 b	-0.72 b	-0.82 c
5/22	50% bloom	-0.77 a	-0.88 b	-0.89 b	-0.96 c
5/28	100% bloom	-0.76 a	-1.04 b	-1.08 b	-1.18 c
6/2	Berry Set	-0.83 a	-0.98 b	-1.02 b	-1.12 c
6/5	1-3 mm dia.	-0.84 a	-0.94 b	-1.01 c	-1.17 d

The effect of irrigation amounts on shaded area cast on the ground at solar noon on June 6th, 2003, in a Merlot vineyard located in Madera County. The cooperator's vines had been irrigated several times prior to those in the trial.

Coop. Vines	1.2 ET_c	0.8 ET_c	0.4 ET_c
------- Shaded Area (m^2 $vine^{-1}$) -------			
2.98	2.77	2.20	1.84
± 0.08	± 0.15	± 0.02	± 0.03
-------- % of Cooperator's vines --------			
100	93	74	62

Factors affecting vineyard water use (per land area).

- Evaporative demand (ET_o)
- Seasonal growth of the vine
- Ultimate canopy size (trellis type)
- Spacing between rows
- Amount of water in the soil profile
- Presence of a cover crop

The following equation can be used to calculate vine water requirements:

$$ET_c = ET_o \times K_c$$

where ET_c = vineyard evapotranspiration, ET_o = reference evapotranspiration and K_c = crop coefficient. The above equation will give water requirements in inches or mm (one acre inch = ~ 27,500 gallons per acre) (one mm covering one hectare = 10,000 L)

$$ET_c = ET_o \times K_c$$

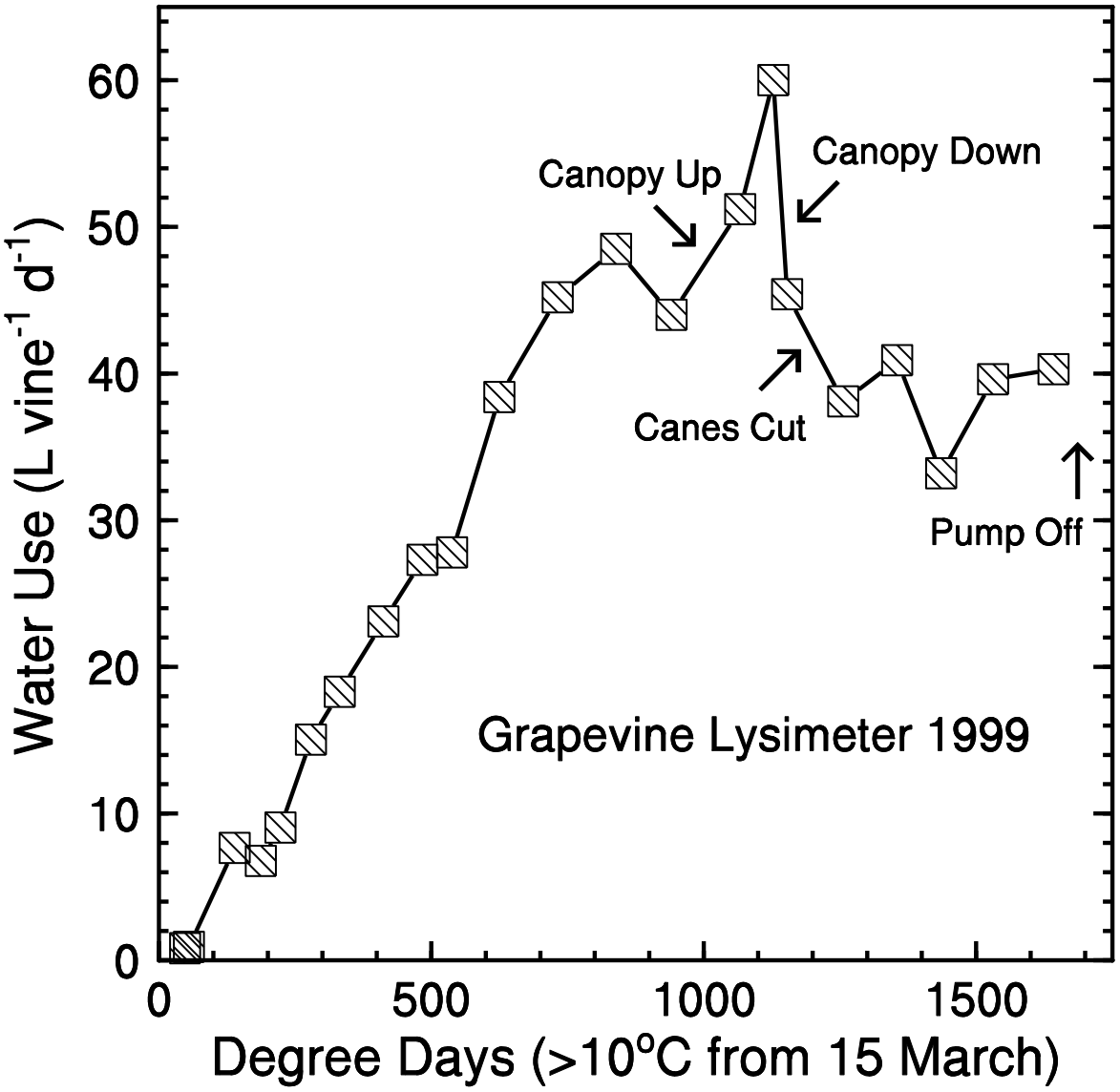
In the above equation, "The K_c value relates to ET of a disease-free, crop grown in large fields under optimum soil water and fertility conditions and achieving full production potential under the given growing environment"

Doorenbos and Pruitt, 1977

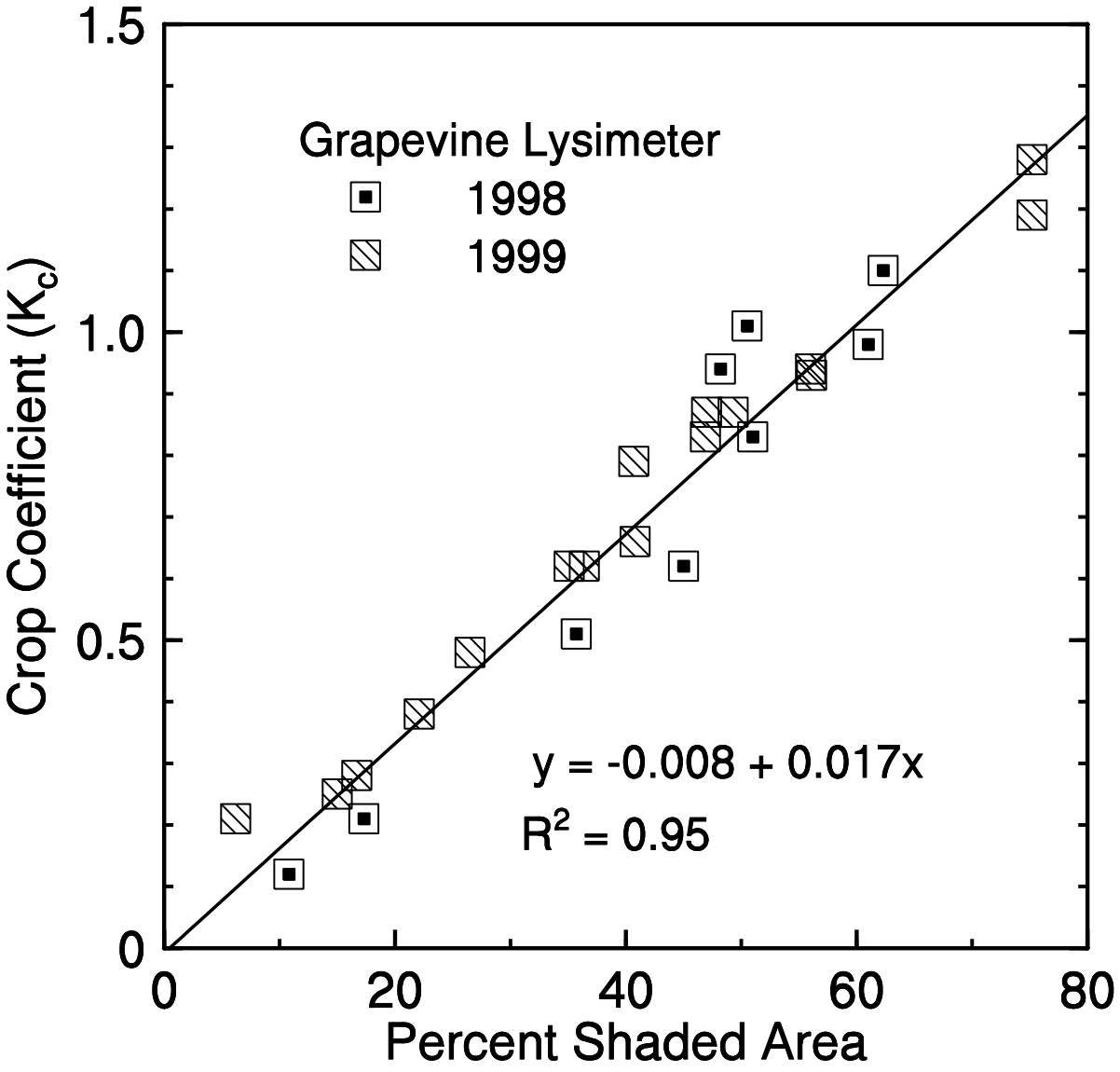
Reliable crop coefficients should take the following into account:

- Seasonal growth of the grapevines (growth is a function of degree-days)
- Final canopy size, which is a function of trellis design
- Row spacing (the closer the row spacing the greater the water use per acre)

Data from this slide illustrates that it is the amount of light intercepted by the canopy, not the total leaf area per vine that determines ET_c. (Williams and Ayars (2005) Agric. For. Meteor. 132:201-211)



Williams and Ayars (2005) Agric. For. Meteor. 132:201-211.



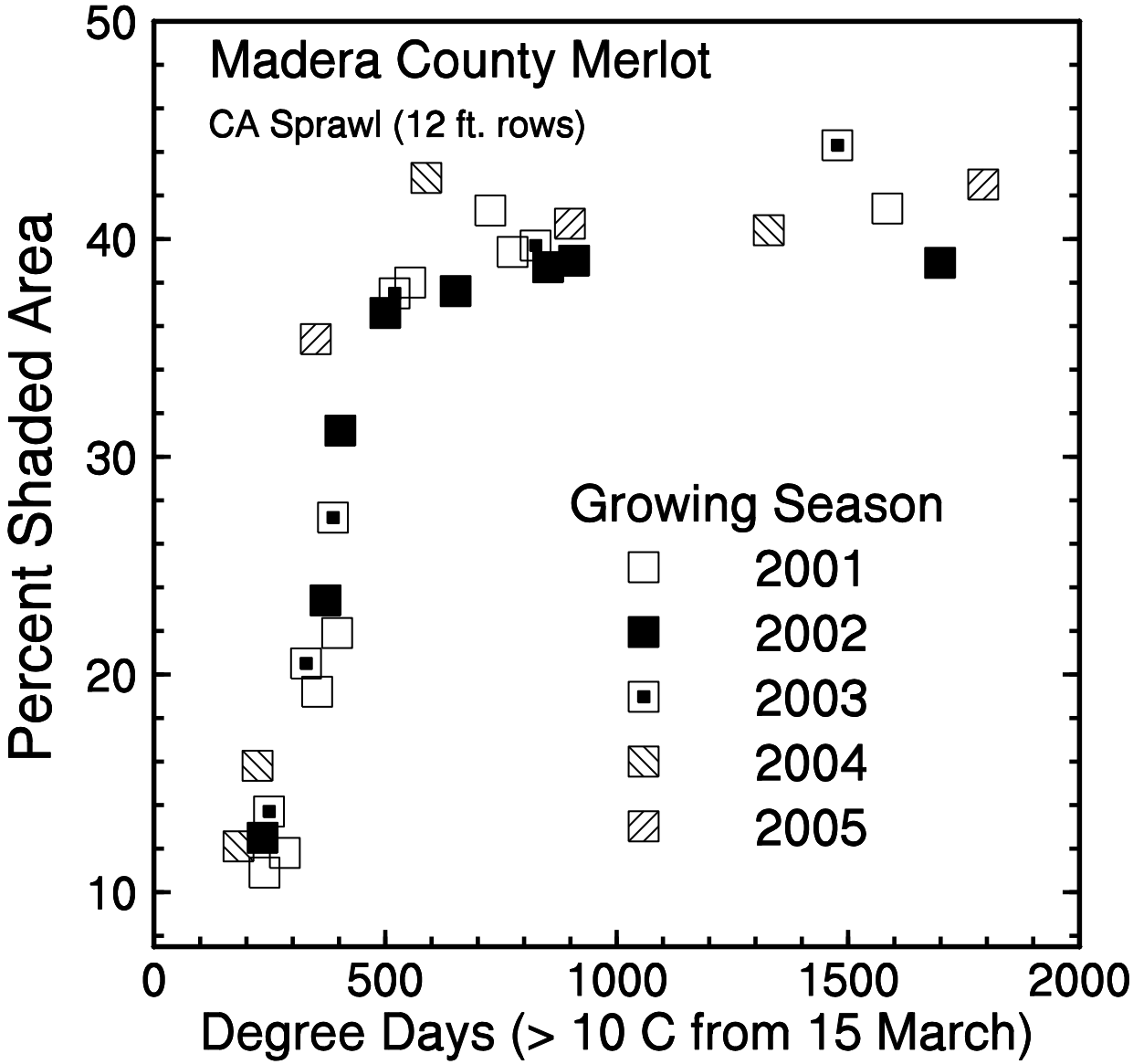
Other estimates of K_cs using ground cover

- Ayars et al. (2003) Irrig. Sci. 22, 187–194. The estimated slope would be 0.0159. (peach trees with weighing lysimeter)
- Stevens and Harvey (1996). Aust. J. Grape Wine Res. 2, 155–162. The estimated slope would be 0.018. (Colombard using water balance)
- Picón-Toro et al. (2012) Irrig. Sci. 30:419-432; K_c = 0.07 + 0.02x; R^2 = 0.88) (weighing lysimeter)
- López-Urrea et al. (2012) Agric. Water Man. 112:13-20; K_c = -0.024 + 0.017x; R^2 = 0.99 in 2009 and -0.088 + 0.017x; R^2 = 0.97 in 2007) (weighing lysimeter)
- Ferreira et al. (2012) Irrig. Sci. 30:433-447; K_c = 0.076 + 0.019x.

"It can be concluded that measuring canopy cover is a reliable approach to estimate K_{cb} values in grapevines. The use of growing degree-days should improve the precision of the estimate by removing year to year variation in crop development."
López-Urrea et al. (2012) Agric. Water Man. 112:13-20.

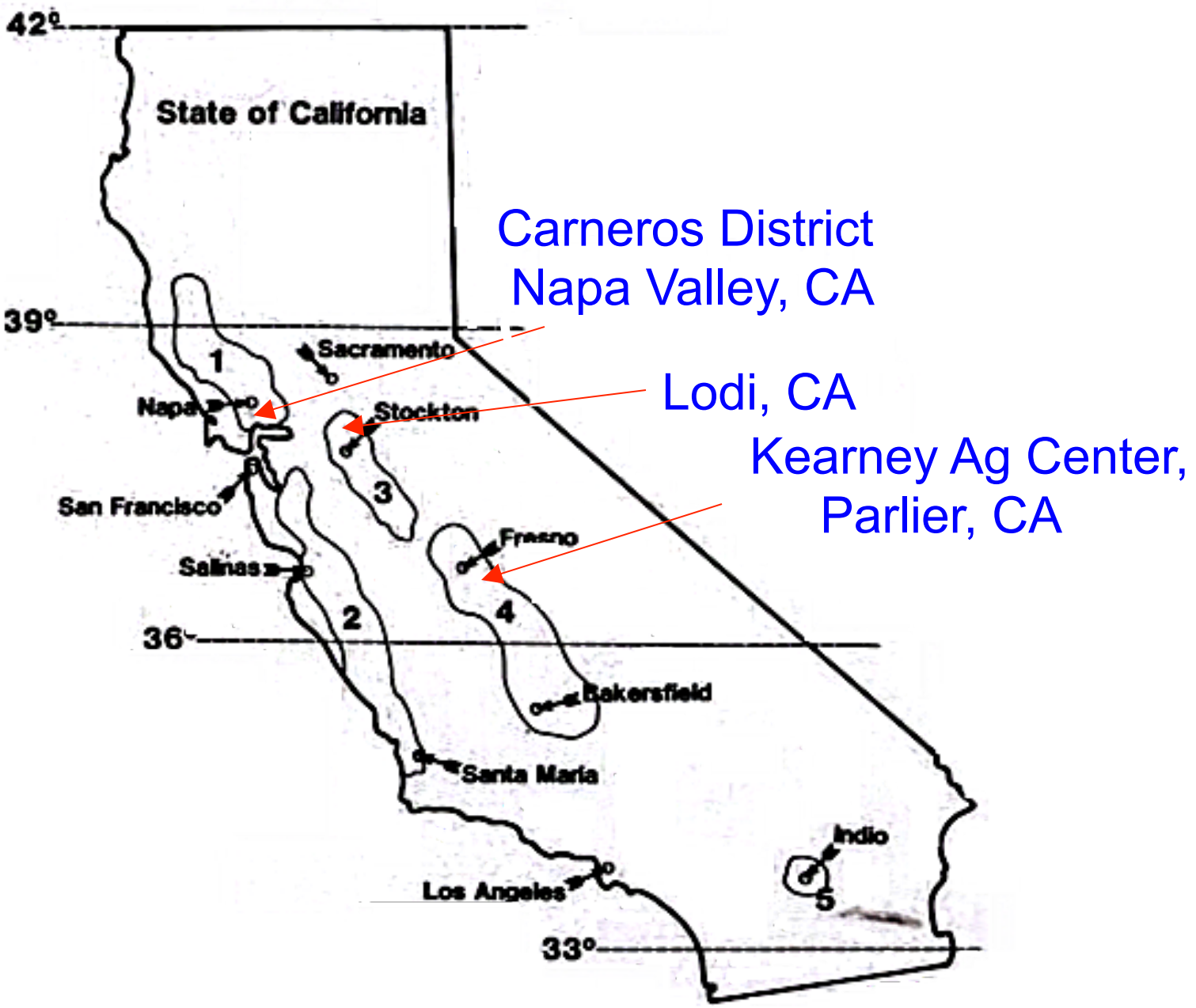
The above had been advocated in earlier papers by Williams et al. (2003) Irrig. Sci. 22:11-18 and Williams and Ayars (2005) Agric. For. Meteor. 132:201-211.

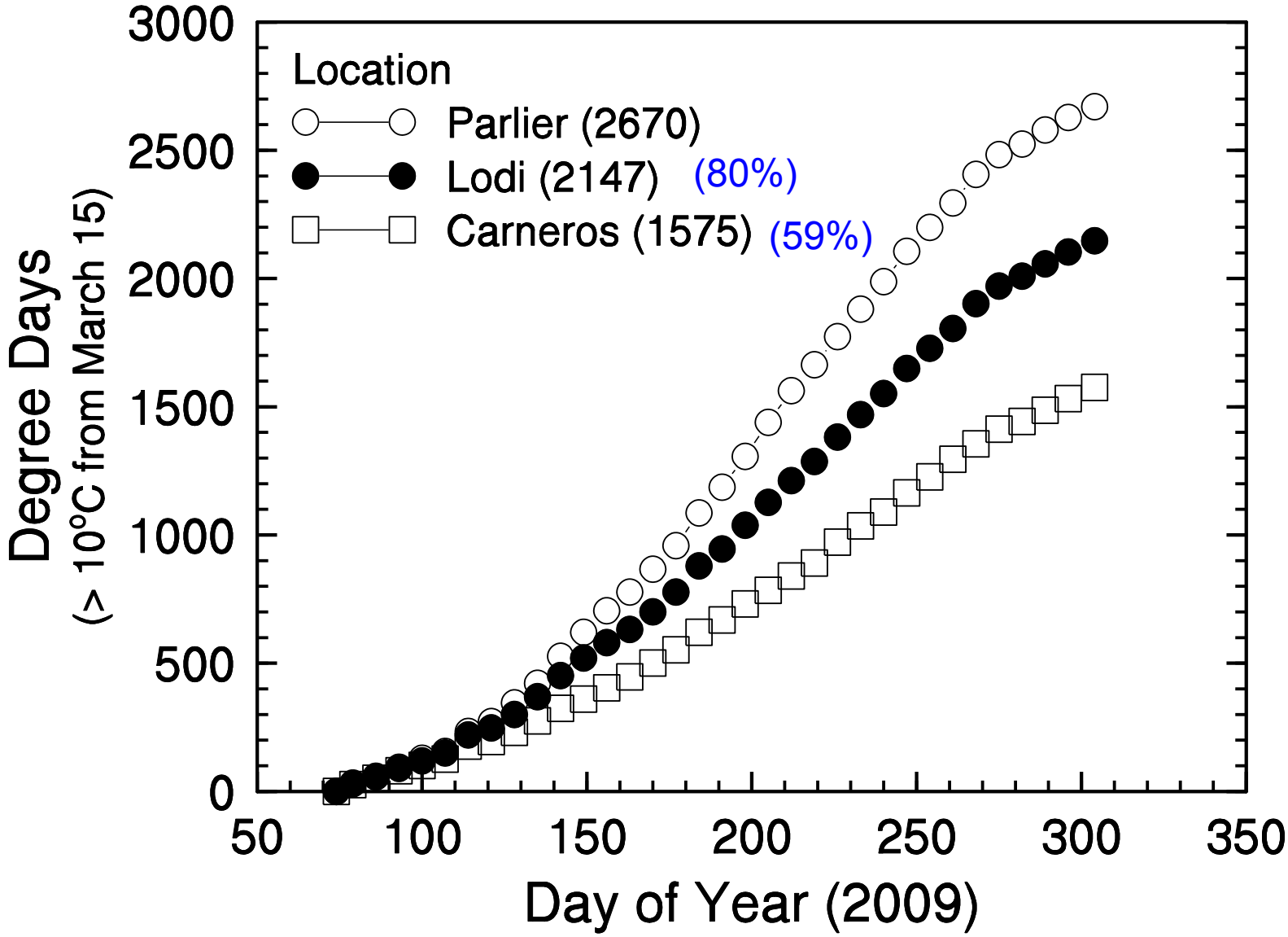
Williams (2012) Irrig. Sci. 30:363-375

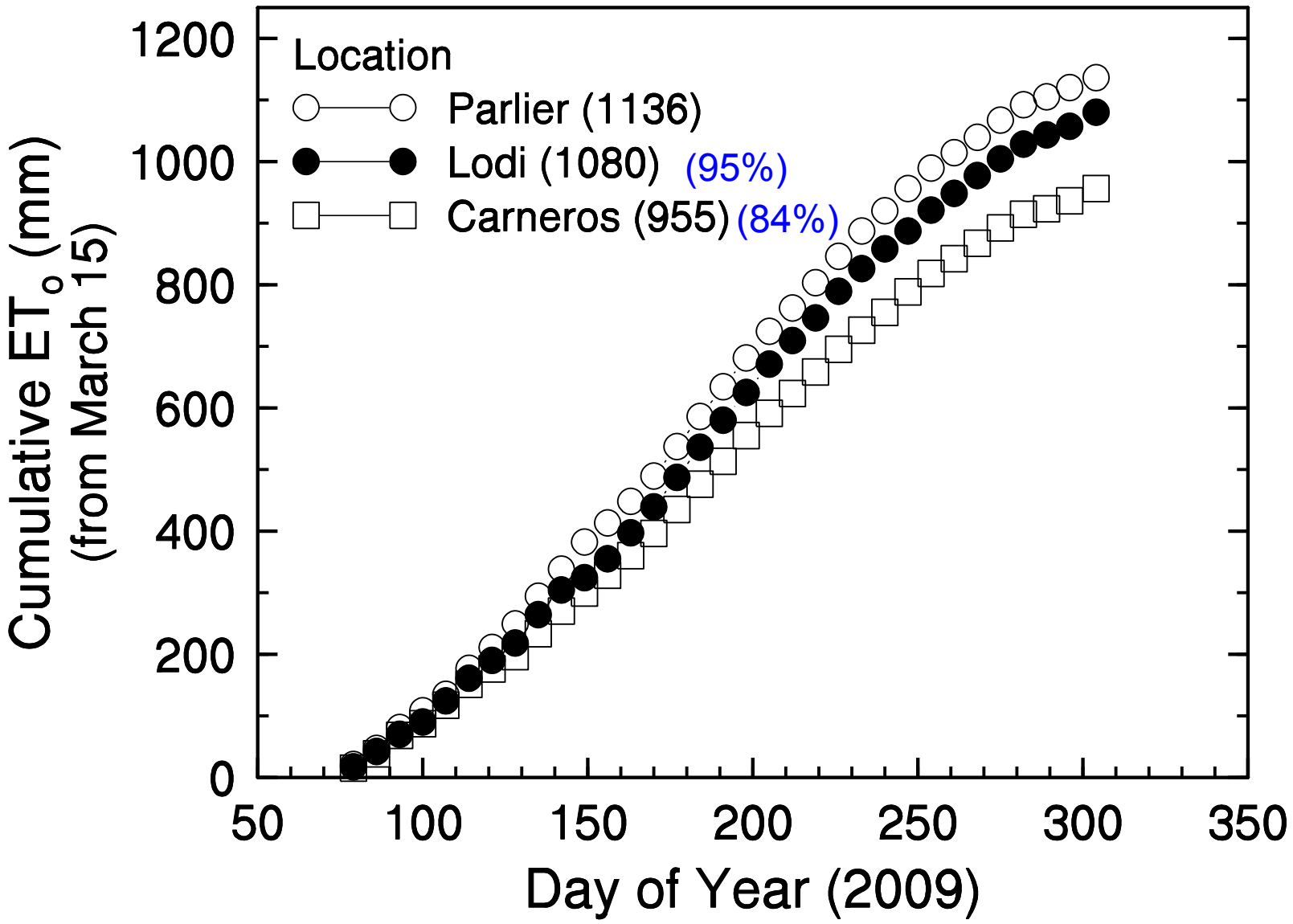


Question: How much is estimated vineyard ET affected by location in California?

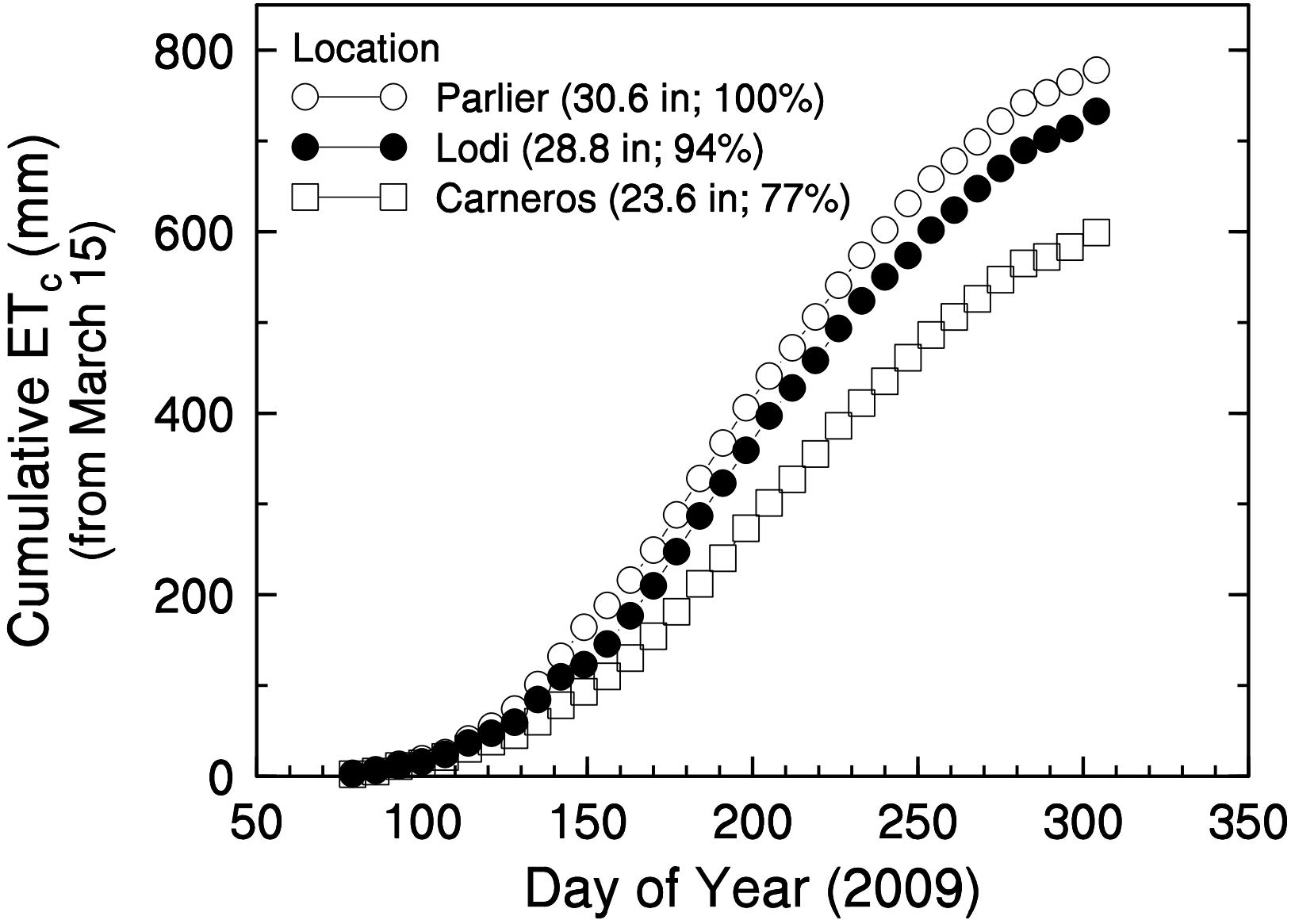
- Grapevine water use was estimated at three locations in California using weather data obtained from the particular locale.
- The vines were assumed to be trained as a CA sprawl and row spacing was 11 feet.
- The crop coefficient at each location was estimated using degree days (> 10^{o}C) from March 15th.


42°
State of California
39°
Sacramento
1
Napa
Stockton
3
San Francisco
Fresno
Salinas
2
4
36°
Bakersfield
Santa Maria
Indio
5
Los Angeles
33°
Carneros District
Napa Valley, CA
Lodi, CA
Kearney Ag Center,
Parlier, CA


Location
Parlier (2670)
Lodi (2147) (80%)
Carneros (1575) (59%)
Degree Days
(> 10°C from March 15)
Day of Year (2009)
0
500
1000
1500
2000
2500
3000
50
100
150
200
250
300
350


Location
Parlier (1136)
Lodi (1080) (95%)
Carneros (955) (84%)
Cumulative ETo (mm)
(from March 15)
Day of Year (2009)
0
200
400
600
800
1000
1200
50
100
150
200
250
300
350

Row spacing was 12 ft.

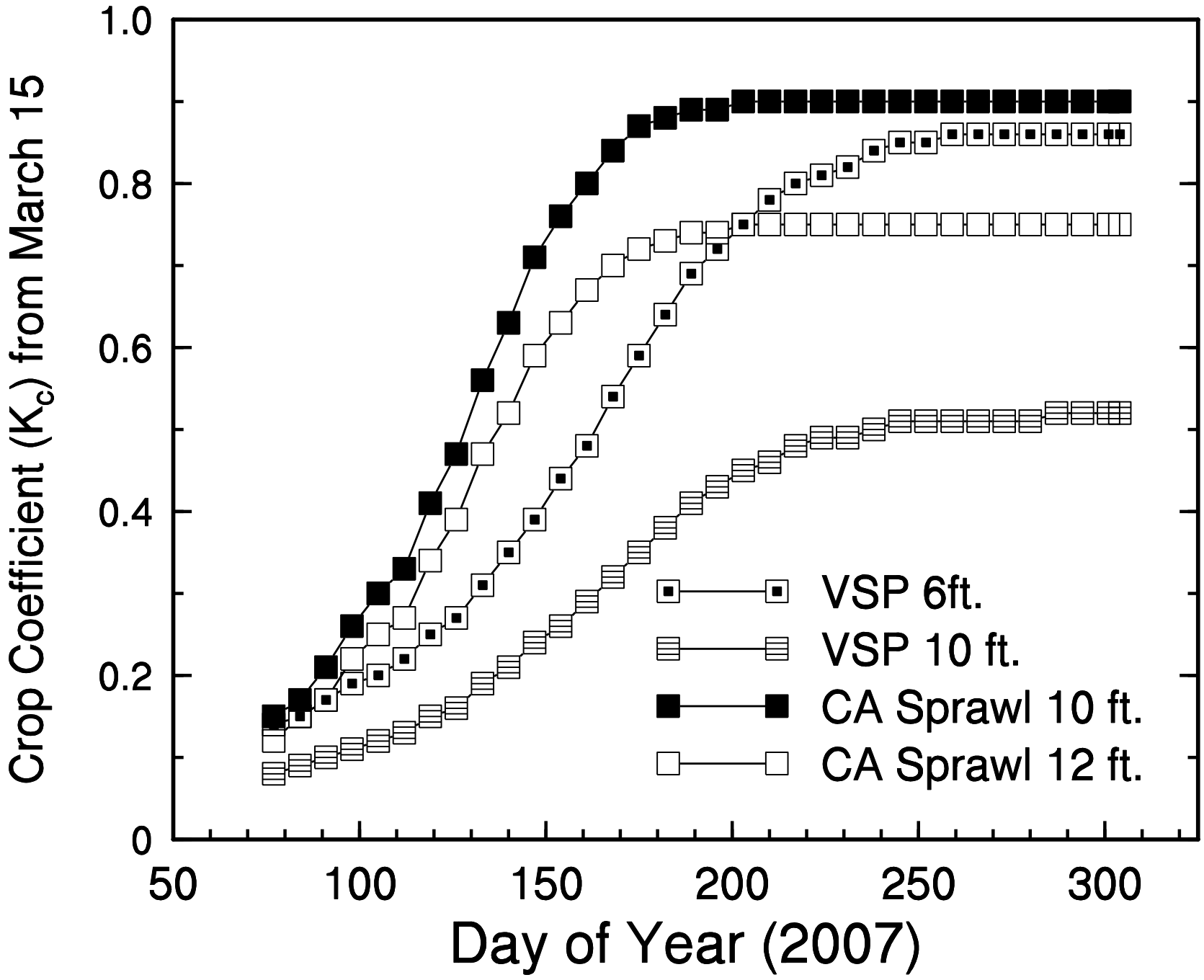


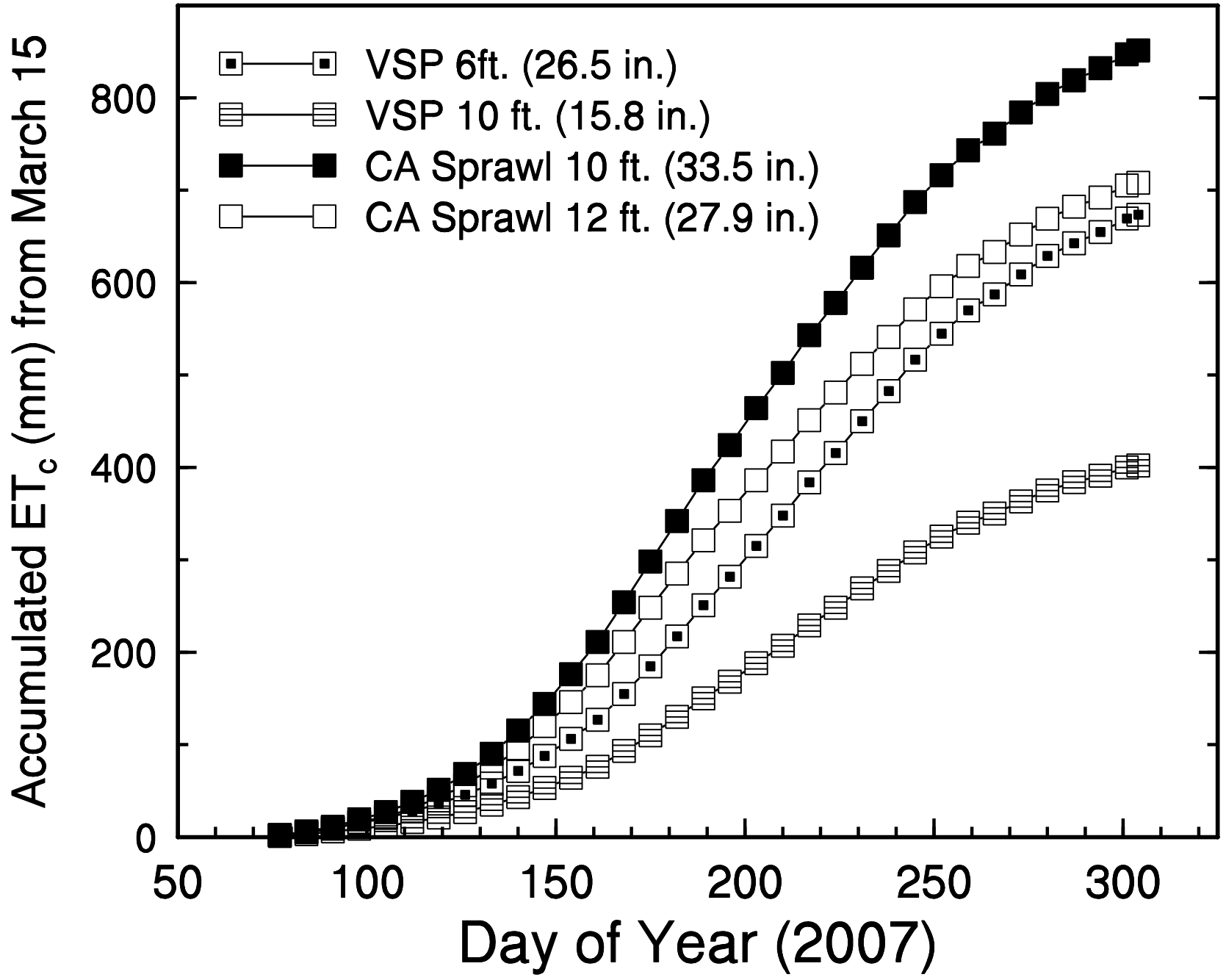
How does trellis/training system and row spacing affect estimated vineyard ET?

- Grapevine water use was estimated using weather data from the Lodi West CIMIS station.
- The two canopy types were a CA sprawl and vertically shoot positioned (VSP) trellis.
- The row spacings were 10 and 12 feet for the CA sprawl and 6 and 10 feet for the VSP.
- The seasonal crop coefficients used were those for a CA sprawl and VSP at the designated row spacings.

The equations for the crop coefficients were:

- K_c (VSP / 6 ft) = $0.87/(1 + e^{(-(x - 525)/301)})$
- K_c (VSP/10 ft) = $0.52/(1 + e^{(-(x - 525)/301)})$
- K_c (CaS/10 ft) = $0.90/(1 + e^{(-(x - 275)/150)})$
- K_c (CaS/12 ft) = $0.75/(1 + e^{(-(x - 275)/150)})$
- x = degree days (base of 10^{o}C) from 3/15
- e = 2.71828

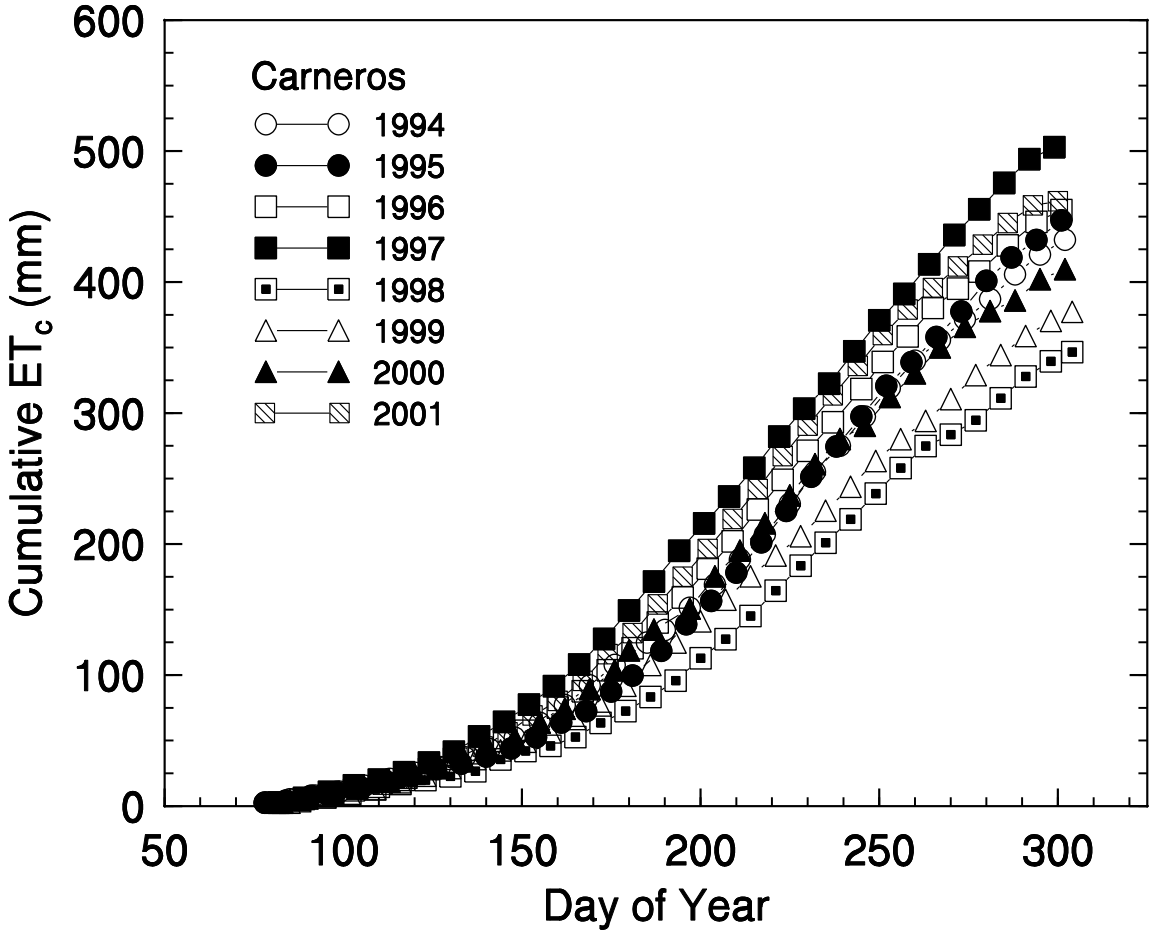

Crop Coefficient (K_c) from March 15
1.0
0.8
0.6
0.4
0.2
0
50
100
150
200
250
300
Day of Year (2007)
VSP 6ft.
VSP 10 ft.
CA Sprawl 10 ft.
CA Sprawl 12 ft.


VSP 6ft. (26.5 in.)
VSP 10 ft. (15.8 in.)
CA Sprawl 10 ft. (33.5 in.)
CA Sprawl 12 ft. (27.9 in.)
Accumulated ET$_c$ (mm) from March 15
0
200
400
600
800
50
100
150
200
250
300
Day of Year (2007)

Question: How much is estimated vineyard ET affected by year?

- Grapevine water use was estimated at one location across several years.
- Water use was estimated for Chardonnay grapevines on a 2.13 m row spacing.
- The trellis was a VSP.

Estimated ET_c across 8 growing seasons for a Chardonnay vineyard in the Carneros district of Napa Valley. The high was 502 mm (1997) and the low was 346 mm (1998). The row spacing was 2.13 m and the trellis was a VSP. (1 inch = 25.4 mm)



Question: How much is estimated vineyard ET affected by year? Conclusions:

- The lowest value of estimated ET_c (1998) was only 69% that of the greatest (1997).
- ET_o from 1998 was 83% that from 1997.
- The accumulation of DDs from 1998 were 81% that from 1997.
- The difference in ET_c between the two years were due to a combination of differences in ET_o and DDs. The differences in DDs affected the K_c.

What other factors affect vineyard water use?

- Cover crop – I’ve found that a cover crop grown at the KARE Center used 40% more water across the growing season (BB → July 1) than a clean cultivated treatment.
- I’m of the opinion that a cover crop probably uses water equivalent to ET_o (with absolute amount dependent upon its surface coverage).

Soil type:

Do vineyards on lighter soils require more water once irrigations commence?

Answer:

ET of the vineyard is driven by evaporative demand and canopy development. Assuming that soil water is not limiting, ET of two vineyards on different soil types will be the same as would their irrigation requirements. If the water applied to the lighter soil is lost below the rootzone, then irrigation requirements will be greater. One means to overcome this is to schedule irrigations at a higher frequency with lowered amounts.

Question: How much water do non-irrigated vines use?

Water balance in a Carneros Chardonnay vineyard from 1999. Vine and row spacings were 5 and 7 ft., respectively.

	Irrigation Treatment (fraction of ET_c)		
	0.0	0.5	1.0
	---------- (inches) ----------		
Soil water depletion	9.8*	7.8	6.1
Applied water	----	5.8	11.6
Total H_2O	9.8	13.6	17.7

* 9.8 inches is equivalent to 213 gallons per vine.

Water balance in a Thompson Seedless vineyard from 1990 - 1993. Vine and row spacings were 2.15 and 3.51 m, Respectively (7.05 x 11.51 ft.)

	Irrigation Treatment (fraction of ET_c)		
	0.2	0.6	1.0
	---------- (inches) ----------		
Soil water depletion	6.1	5.2	4.8
Applied water	4.9	13.3	21.9
Total H_2O	11.0	18.5	26.7

11 inches is equivalent to 558 gallons per vine.

In 1991, the 0.2 and 0.6 treatments used132 and 97 mm of water, respectively from the soil profile.(5.2 and 3.8 inches).Other years the 0.2 treatment used from3.8 to 7.5 inches. The greatest amount of water depleted in this soil type, sandy loam, with no irrigation was ~ 8 inches.

Rainfall (mm/inches) at ten locations in California.
(historical values at those locations)

	Rainfall (1 Nov. 2013 – 11 Feb., 2014)	
Location	mm	inches
Windsor	275	10.8 (15.4)
Oakville	240	9.4 (18.2)
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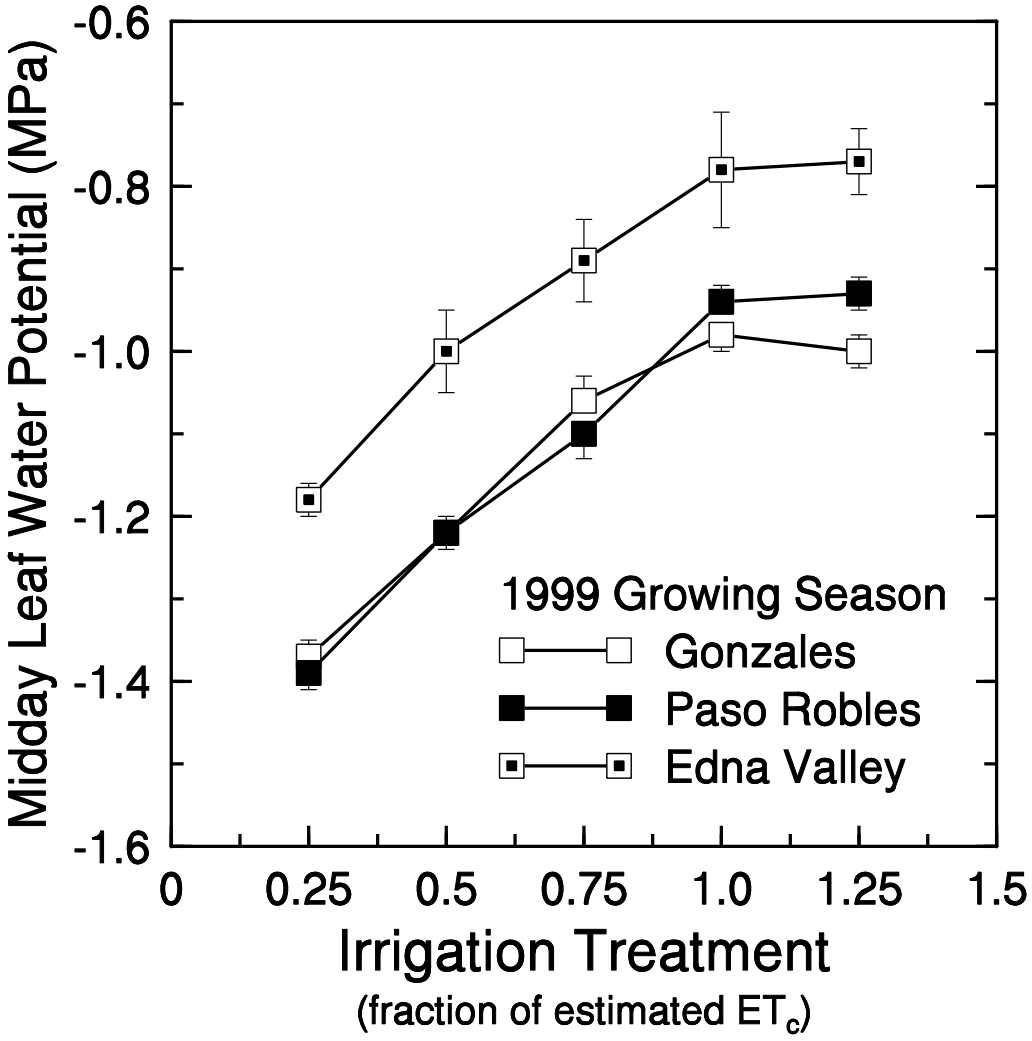
Lodi (west)	102	4.0
Salinas	55	2.2
King City	20	0.8
Parlier	48	1.9 (4.8)
Paso Robles	34	1.3 (7.4)
San Luis Obispo	73	2.9
Temecula	18	0.7

What percentage of ET_c is E or soil evaporation?

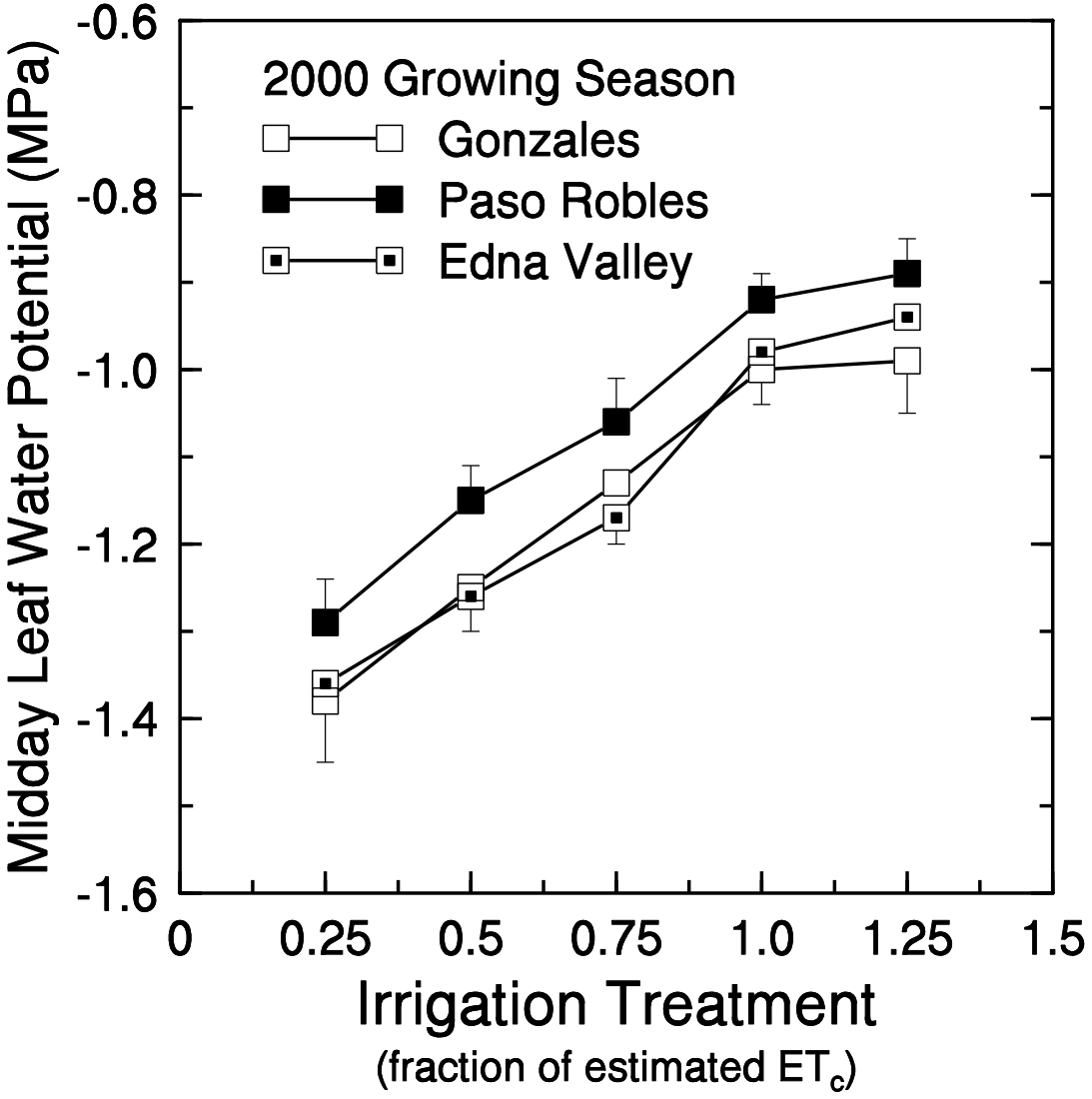
- Lysimeter's soil surface was covered with plastic numerous times during the 2009 growing season (6 June to 14 Sept.).
- Grapevine water use was reduced ~ 11% when the soil was covered with plastic compared to bare soil (5.64 vs. 6.36 mm/ day).
- The K_c was reduced from an average of 1.07 to 0.93 (13% reduction) over the 100 day period mid-season.

How does one use the calculation of vineyard ET_c to assist in a deficit irrigation management strategy?

Leaf water potential was measured at different locations, using different cultivars as a function of applied water amounts at various fractions of estimated ET_c.

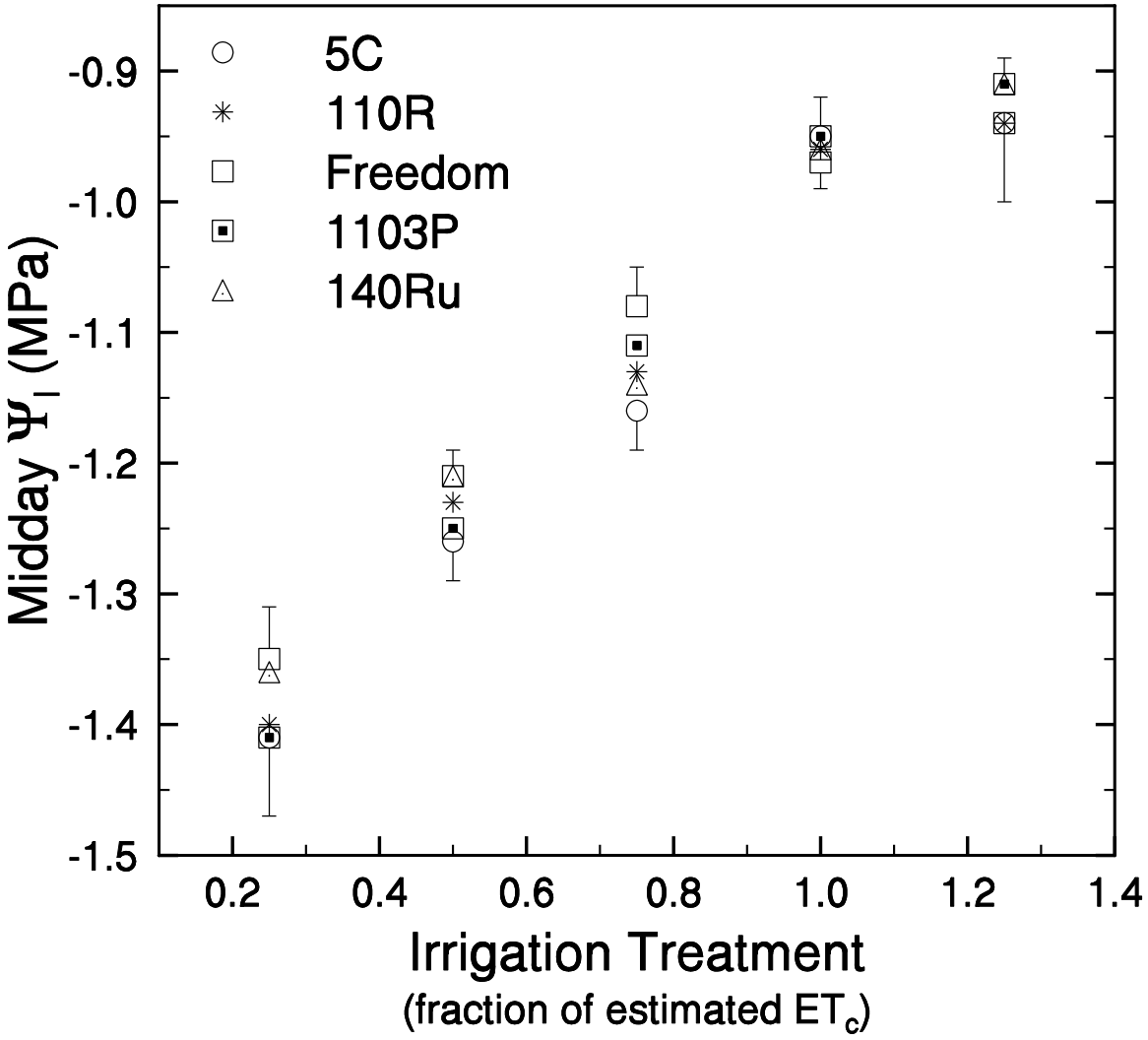


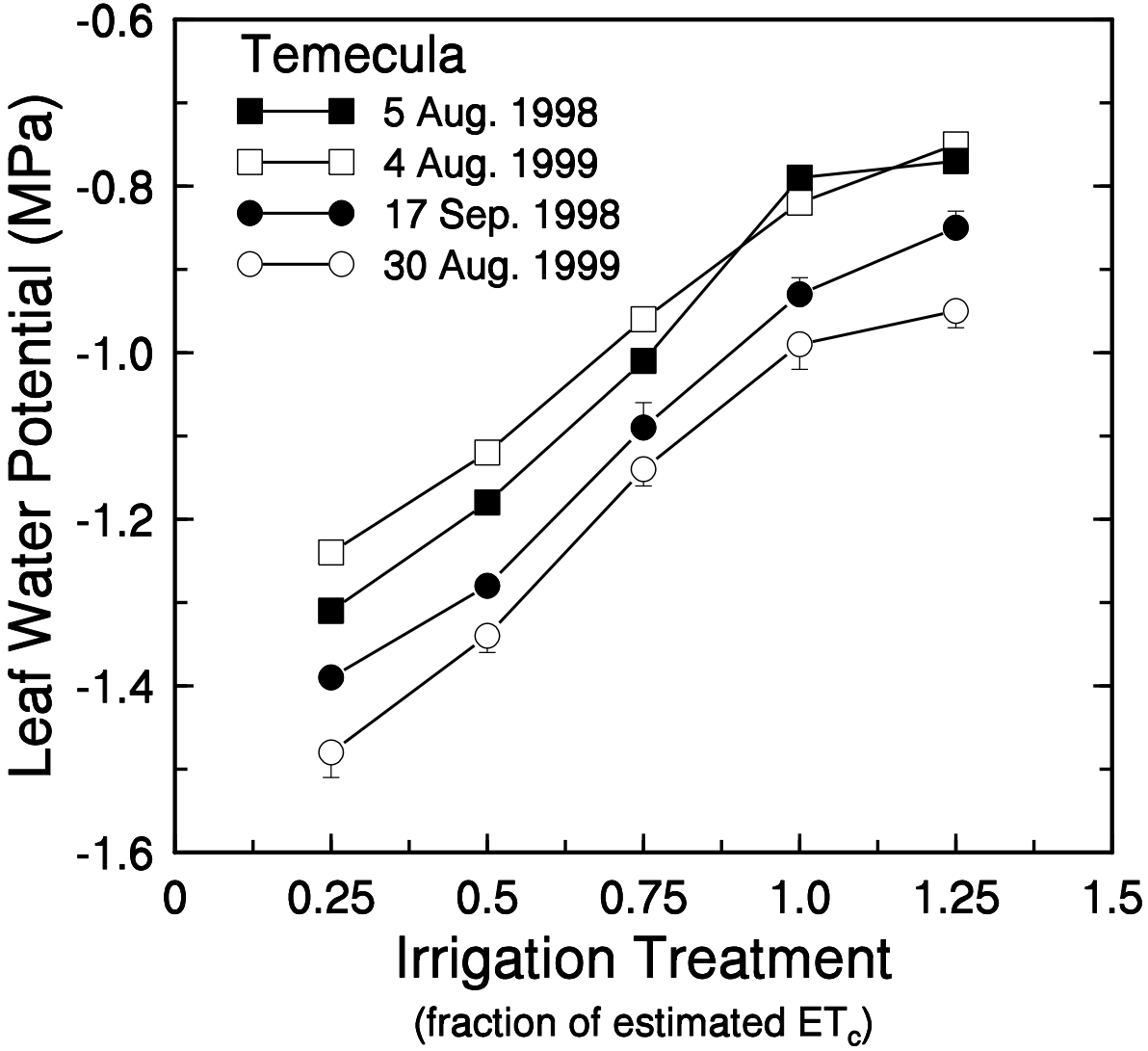
Midday Ψ_l as a function of applied water amounts on the last measurement date in 1999. It had been foggy the morning measurements were taken in Edna Valley.



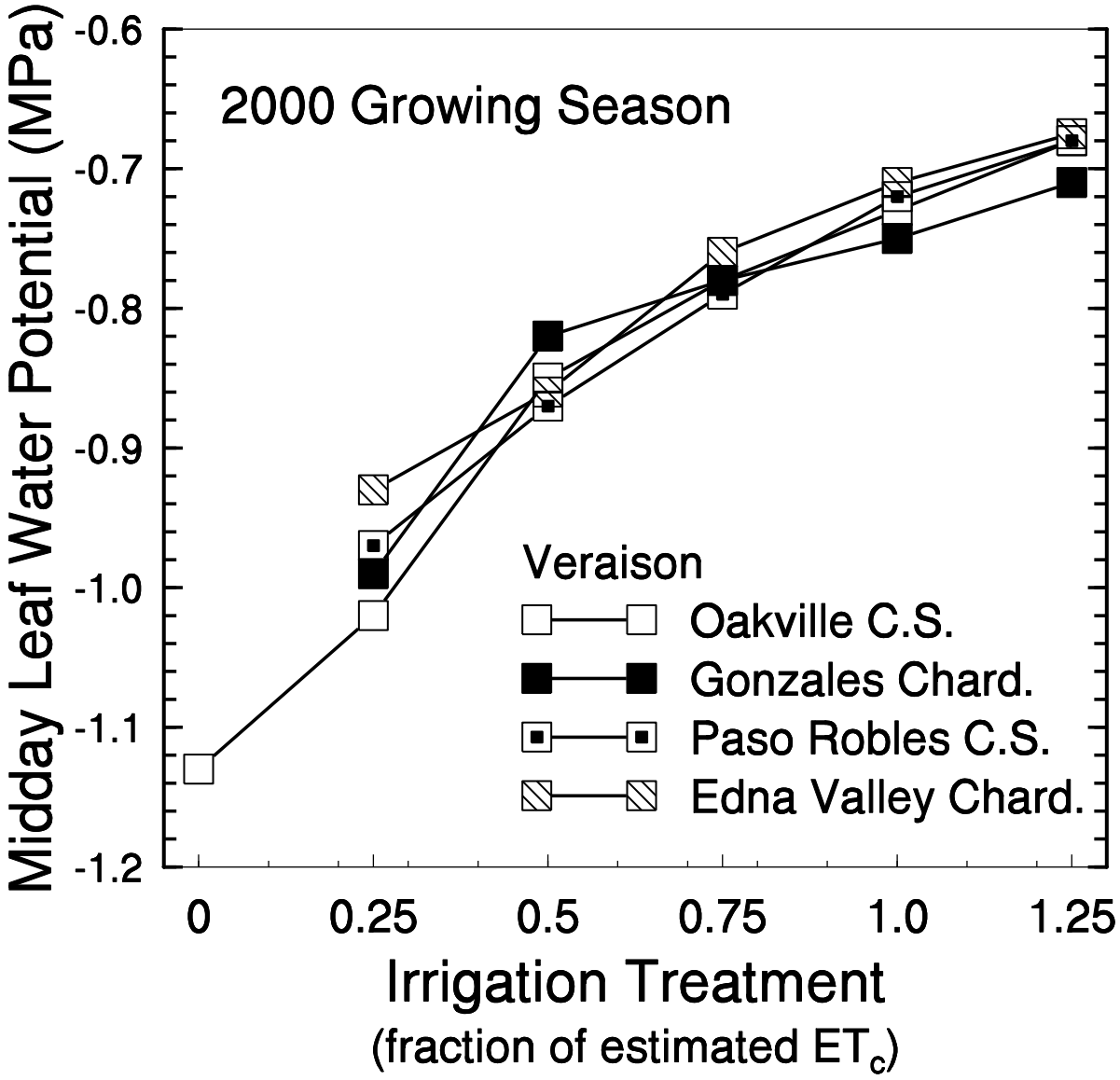
Midday Ψ_l as a function of applied water amounts on the last measurement date in 2000. It had been foggy the morning measurements were taken in Paso Robles.

Midday Ψ_l of Cabernet Sauvignon as a function of applied water amounts on the last measurement date across five years. Vines were grown at Paso Robles and on five different rootstocks.





Midday Ψ_l of Chardonnay as a function of applied water amounts close to harvest in 1998 and 1999.



Midday Ψ_l as a function of applied water amounts at veraison in 2000 (July). Values are averaged across rootstocks.

How does seasonal water use vary as a function of phenology?

Water use of Thompson Seedless grapevines grown in a weighing lysimeter from March 15th until the ~ date of bloom and veraison and the harvest date and the end of the season (Oct. 31). One inch = 25.4 mm.

Year	Date of Bloom	ET_c to Bloom	Date of Veraison	ET_c to Veraison	Date of Harvest	ET_c to Harvest	ET_c all Season
		(mm)		(mm)		(mm)	(mm)
1991	5/25	99	7/8	354	9/22	743	866
1992	5/5	78	6/22	298	9/4	704	811
1993	5/9	81	7/2	321	9/21	803	857
		---------- ET_c as a percent of season long ET_c ----------					
1991		11.5		41		86	100
1992		9.6		37		87	100
1993		9.5		37		94	100

ET_c ranged from 32 to 34 inches across years

Water use of Chardonnay grapevines up to various phenological stages as a function of the seasonal total.

- Vines were grown in the Carneros District of Napa Valley,(Region I to II). (VSP trellis, 7 ft. rows)
- Mean seasonal ET_o and DDs from April 1 to Oct. were 1009 mm and 1480, respectively.
- Mean seasonal water use from April 1 to the end of October was 429 mm (~ 17 inches) (8 yr. mean) .
- April 1 to anthesis: 10% of seasonal use
- April 1 to veraison: 38% of seasonal use
- April 1 to harvest: 78% of seasonal use

Water use of Merlot grapevines grown in Madera County from March 15th until the ~ date of bloom and veraison and the harvest date and the end of the season (Oct. 31). (CA sprawl, 12 ft. rows) One inch = 25.4 mm.

Year	Date of Bloom	ET_c to Bloom	Date of Veraison	ET_c to Veraison	Date of Harvest	ET_c to Harvest	ET_c all Season
		(mm)		(mm)		(mm)	(mm)
2001	5/16	81	7/28	397	9/4	579	729
2002	5/16	51	7/26	389	9/10	576	708
2003	5/22	79	7/24	382	9/19-27	620	713
2004	5/20	98	7/15	394	8/25-9/7	616	760
2005	5/24	55	7/19	300	9/16	554	663
		-------- ET_c as a percent of Seasonal Estimated ET_c ------					
		10%		52%		82%	715

715 mm = 28.1 inches

Water use of red wine cultivars up to various phenological stages as a function of the seasonal total.

- Vines were grown at the Kearney Ag Center, (Region V). (CA sprawl, 10 ft. rows)
- ET_o and DDs from 15 March to 31 Oct. were 1189 mm and 2754, respectively.
- Mean seasonal water use from 15 March to the end of October was 825 mm (32.4 in).
- 15 Mar. to anthesis: 10% of seasonal use
- 15 Mar. to veraison: 48% of seasonal use
- 15 Mar. to harvest: 78% of seasonal use

Response of grape yield to applied water amounts at various locations in California.

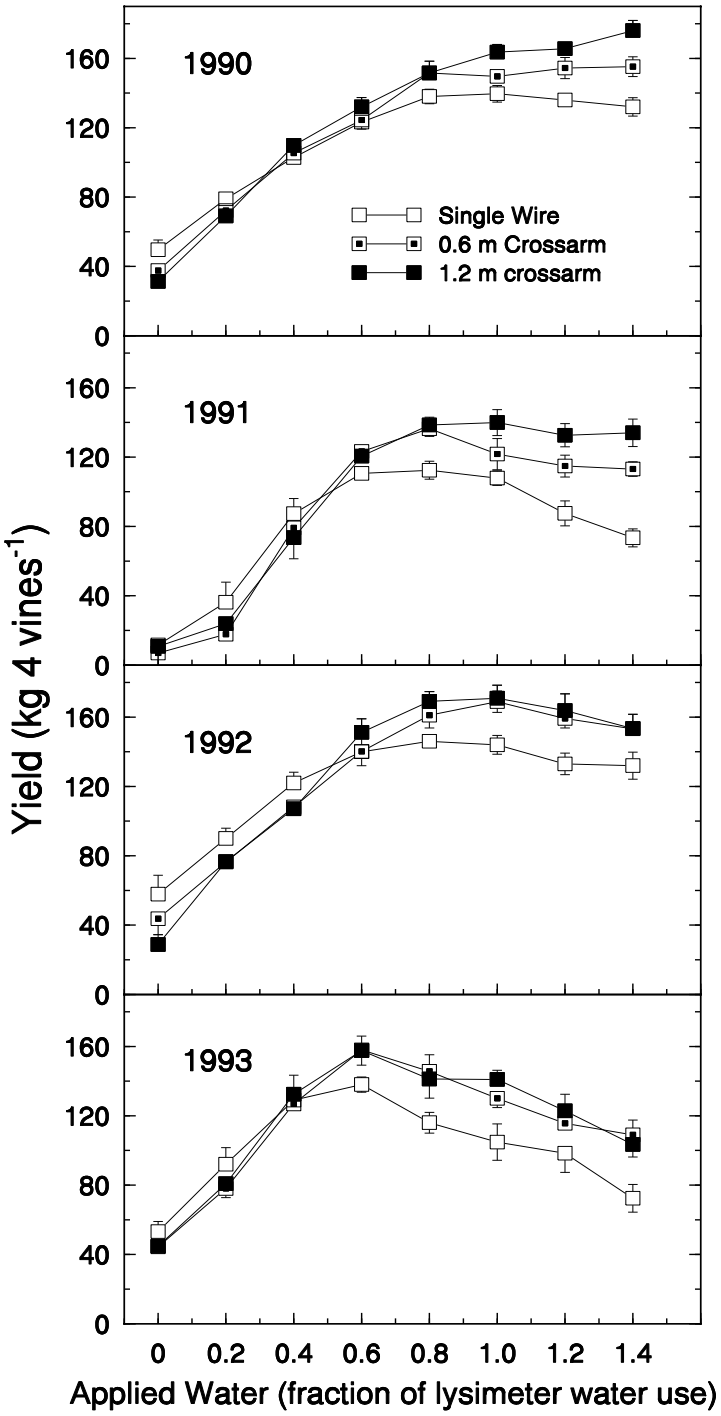
Sustained Deficit Irrigation (SDI)

- The practice of purposely deficit irrigating beginning with the first irrigation of the season and irrigating such throughout the remainder of the growing season. SDI is based upon knowing what full ET for the vineyard is and then irrigating at a particular fraction of full ET – Larry E. Williams

Yield of Thompson Seedless grapevines as a function of irrigation and trellis treatments measured each year of the study. There were 1326 vines per hectare. Individual data points within the figure multiplied by 0.331 are equivalent to metric tons per hectare.

Full ET_c ranged from 32-34 in.

Fruit quality vs. yield in hot region: clusters will generally desiccate on the vine in a hot region with no or low amounts of applied water, especially if fruit exposed to direct solar radiation.



Madera irrigation and canopy management study: specifics

- Three irrigation amounts: 0.4, 0.8 and 1.2 times estimated ET_c.
- Three canopy treatments (leaf removal in the fruiting zone at berry set or veraison or no leaf removal).
- Vine and row spacing was 7 x 12 ft.
- Vines were trained to a bilateral cordon at a height of 48 inches.
- There was no crossarm (CA sprawl).
- The first irrigation of the season did not take place until a midday leaf water potential of –1.0 MPa was measured

ET_o, ET_c, rainfall and applied water amounts in a Merlot vineyard in Madera County.

Year	ET_o	Est. ET_c	Irrigation Treatment 0.4	0.8	1.2	Rainfall (mm) Before	After
	-- (mm) --		App. H_2O (% of ET_c)			15 March	
2001	1261	729	33	64	92	137 (5.4 in)	40 (1.6 in)
2002	1257	708	34	65	92	174 (6.9 in)	42 (1.6 in)
2003	1241	714	31	63	94	183 (7.2 in)	42 (1.6 in)
2004	1289	760	36	69	103	161 (6.3 in)	2 (0.1 in)
2005	1204	663	41	78	124	191 (7.5 in)	83 (3.3 in)

Mean ET_o = 49 inches; mean estimated ET_c = 28 inches

The effect of irrigation amount and year on berry weight of Merlot grown in Madera County.

	Irrigation Treatment			Ave. Effect
Year	**0.4**	**0.8**	**1.2**	Year
	Berry weight (g 100 berries^{-1})			
2001	**135** (93%)	**144** (99%)	**145**	**141**
2002	**120** (78%)	**147** (95%)	**154**	**143**
2003	**128** (70%)	**176** (96%)	**183**	**163**
2004	**129** (81%)	**152** (95%)	**160**	**147**
2005	**148** (85%)	**165** (94%)	**175**	**162**
	132 (81%)	**157** (96%)	**163**	

There was a significant effect of irrigation amount and year on berry weight but no interaction (n = 75). Values in parentheses are % of the 1.2 treatment.

The effect of irrigation amount and year on yield of Merlot grown in Madera County.

Year	-------- Irrigation Treatment -------- 0.4	0.8	1.2	Ave. Effect Year
	---------- (tons / acre) ----------			
2001	**7.4** (88%)	**8.4** (99%)	**8.4**	**8.0**
2002	**8.5** (69%)	**11.2** (90%)	**12.4**	**10.7**
2003	**5.3** (51%)	**8.4** (82%)	**10.3**	**8.5**
2004	**5.7** (70%)	**7.1** (87%)	**8.2**	**7.0**
2005	**6.5** (55%)	**9.7** (82%)	**11.9**	**9.4**
	6.7 (66%)	**9.0** (88%)	**10.2**	

Applied water for the 0.4 and 0.8 treatments were 35 (9.8 in) and 68% (19 in) of estimated ET_c (28 in).

Interaction of trellis/training type and applied water amounts on Cabernet Sauvignon productivity and wine quality.

Trellis/training type has been shown to affect the productivity, berry composition and wine quality of wine grapes. A study was conducted to examine the interaction of various applied water amounts on Cabernet Sauvignon trained to a VSP and Scott Henry Trellis in the Livermore Valley.

The effects of irrigation amounts and trellis/training systems on berry weight and soluble solids of Cabernet Sauvignon grown in Livermore Valley sampled on September 11, 2002.

Trellis System	-Irrigation Treatment (Fraction of Estimated ET_c)- 0.375	0.56	0.75	1.12	Ave. Effect Trellis
	---------- (g 150^{-1} berries) ----------				
VSP	125	143	151	158	144
SH	113	129	141	148	133
Irr. Effect	119	136	146	154	
	$LSD_{0.05}$	Irr. = 4.9	Trellis = 3.5	Interaction = ns	
	---------- (^{o}Brix) ----------				
VSP	24.1	24.2	24.0	23.5	23.9
SH	24.0	23.6	23.3	22.9	23.4
Irr. Effect	24.0	23.9	23.6	23.2	
	$LSD_{0.05}$	Irr. = 0.26	Trellis = 0.18	Interaction = ns	

The effects of irrigation amounts and trellis/training systems on anthoycanin content per area berry skin and yield of Cabernet Sauvignon grown in Livermore Valley during the 2002 growing season.

Trellis System	-Irrigation Treatment (Fraction of estimated ET_c)- 0.375	0.56	0.75	1.12	Ave. Effect Trellis
	---------- (Anthos. mg cm^{-2}) ----------				
VSP	0.92	0.87	0.87	0.82	
SH	0.91	0.87	0.83	0.79	
Irr. Effect	0.92	0.87	0.85	0.81	
	$LSD_{0.05}$ Irr. = 0.09 Trellis = ns Interaction = ns				
	---------- Yield (kg 4^{-1} vines) [tons $acre^{-1}$] ----------				
VSP	11.9 [3.95]	12.4 [4.11]	15.3 [5.08]	16.9 [5.61]	14.1
SH	12.2 [4.05]	14.9 [4.95]	16.3 [5.41]	21.0 [6.99]	16.1
Irr. Effect	12.0	13.6	15.8	18.9	
	$LSD_{0.05}$ Irr. = 1.64 Trellis = 1.16 Interaction = ns				

The effects of trellis/training type and irrigation amount on chemical components and Index rating by Enologix® of wine made from Cabernet Sauvignon. The vines, grown at Livermore, were harvested in **2002**.

Irrig. amount	Index	Total Phenol.	Tannins	Free Anthos	Total Anthos	Complex Anthos
VSP		---------- (mg L^{-1}) ----------				
0.375	0.61	1805	783	285	456	140
0.56	0.61	1889	806	247	401	140
0.75	0.41	1882	873	258	403	123
1.12	0.41	1835	808	259	421	122
Scott/Henry						
0.375	0.61	1912	869	290	453	147
0.56	0.61	1865	812	290	441	143
0.75	0.41	1839	785	262	399	122
1.12	0.41	1902	860	242	396	122

Livermore: 2002

Trellis: VSP vs. Scott Henry

Irrigation: 0.37, 0.56, 0.75, 1.12 of ET_c

Sensory analysis of the wines at UC-Davis indicated no significant differences among treatments except VSP and SH at 1.12 of ET_c

Effect of applied water amounts on yield of Chardonnay grown in the Temecula Valley.

Frequency of application:
5 days per week
Quad cordons on 12 ft. rows.

The effect of irrigation amounts on vegetative growth and yield of Chardonnay grapevines grown in Temecula Valley. Water use was calculated weekly and irrigated 5 days per week. All treatments were irrigated at the same frequency.

	Irrigation treatment (fraction of est. ET_c)				
	0.25	0.5	0.75	1.0	1.25
	----- % of the 1.0 irrigation treatment -----				
Pr. Wt. (98)	71	85	94	100	110
Yield (98)	104	92	90	100	103
Yield (99)	85	87	104	100	87

Effect of applied water amounts on yield of Chardonnay and Cabernet Sauvignon grown in Napa Valley.

Frequency of application:
1 to 2 days per week

The effect of irrigation amount, cultivar and year on productivity of grapevines grown in Napa County. (both used VSP trellis, Chardonnay was on 2.13 m row and Cabernet Sauvignon on 1.83 m row, vines irrigated 1 - 2 times per week)

Location/	---------- Irrigation Treatment (fraction of estimated ET_c) --------					
Year	0.0	0.25	0.5	0.75	1.0	1.5
Carneros	---------- Yield (% of maximum or t/acre) ----------					
1998	88%	---	95%	---	7.88	---
1999	74%	---	95%	---	6.59	---
2000	49%	---	84%	---	8.10	---
2001	49%	---	83%	---	7.30	---
Oakville						
1998	62%	76%	99%	93%	89%	6.41
1999	70%	86%	99%	100%	119%	4.32
2000	74%	73%	93%	116%	94%	6.01
2001	50%	85%	114%	110%	108%	5.08

Oakville 1998:

Sensory analysis of the wines at UC-Davis indicated no significant differences among irrigation treatments (wine was not made with fruit from 1.5 irrigation treatment).

Oakville 1999

Irrigation	Mondavi	NCVRG*	
Treatment	Panel	-------- Preference --------	
	(Ranking)	Most	Least
0	4th	4	6
0.25	1st	3	0
0.5	3rd	3	5
0.75	5th	3	9
1.0	1st	8	3

* North Coast Viticulture Research Group

Oakville 2000

Irrigation Treatment	Mondavi Panel	Mondavi Winemakers	NCVRG
	---------- (Ranking) ----------		
0	2nd	4th	1st
0.25	4th	2nd	2nd
0.5	5th	4th	4th
0.75	1st	1st	3rd
1.0	2nd	3rd	5th

Meridian winery (Paso Robles) irrigation/rootstock trial

Cabernet Sauvignon grafted onto five rootstocks (5C, 110R, Freedom, 140 Ru and 1103P) were used in the study. Irrigation treatments were various fractions (0.25,0.5,0.75,1.0 and1.25) of estimated ET_c. The trellis was a VSP and vine and row spacings were 6 x 10 ft (1.83 x 3.05 m)

Rainfall (inches) at Paso Robles from 1997 - 2008.

Year	Nov - Mar	Apr – Sept	October	Total
1997	9.7	0	0	9.7
1998	18.1	3.4	0.3	21.8
1999	5.0	1.2	0	6.2
2000	9.0	1.5	1.0	11.5
2001	13.0	0.7	0.1	13.8
2002	5.9	0.2	0	6.1
2003	7.7	2.7	0.3	10.7
2004	8.4	0	3.9	12.3
2005	15.0	1.5	0	16.5
2006	9.3	3.1	0.6	13.0

Applied water as a percentage of estimated ET_c from 1998 to 2001 at Meridian Winery.

	Irrigation treatment (fraction of estimated ET_c)				
Year	0.25	0.5	0.75	1.0	1.25
	Applied H_2O (% of seasonal estimated ET_c)				
1997	--	--	--	--	--
1998	18	41	64	86	105
1999	19	43	67	91	111
2000	18	40	63	86	104
2001	18	40	63	85	104
	18	41	64	87	106
	---------- Mean applied H_2O (inches) ----------				
97 gal/vine →	2.6	5.9	9.3	12.6	15.4

ET_o was 44 inches, estimated ET_c was 14.5 inches.

The effect of applied water amounts and rootstock on Berry weight of Cabernet Sauvignon at Meridian Winery from 1997 to 2001.

	--------- Irrigation Treatment (fraction of estimated (ET_c) ---------					Ave. Eff.
Rootstock	**0.25**	**0.5**	**0.75**	**1.0**	**1.25**	**Rtstck**
	---------- Berry weight (g 100 berries^{-1}) ----------					
5C	111	122	129	133	143	128 b
110R	112	120	132	139	145	130 b
Freedom	115	122	134	147	151	134 ab
140Ru	116	133	142	146	153	138 a
1103P	119	124	132	146	144	133 ab
Ave. Irr. Eff.	115 d	124 c	134 b	142 a	147 a	

The effect of applied water amounts and rootstock on yield of Cabernet Sauvignon at Meridian Winery from 1997 to 2001. (Greatest yield ~ 8.1 tons/acre; lowest yield ~ 4.1 tons/acre)

	---- Irrigation Treatment (fraction of estimated (ET_c)----					Ave. Eff.
Rootstock	**0.25**	**0.5**	**0.75**	**1.0**	**1.25**	**Rootstock**
	---------- Yield (kg 3 vines^{-1}) ----------					
5C	**15.9** 66	**18.9** 78	**22.1** 91	**22.5** 93	**24.2**	**20.7**
110R	**17.0** 62	**19.5** 71	**25.4** 93	**26.2** 96	**27.4**	**23.1**
Freedom	**15.5** 54	**19.4** 67	**22.9** 79	**25.8** 89	**28.9**	**22.5**
140Ru	**20.2** 70	**19.8** 69	**23.7** 82	**24.9** 86	**28.9**	**23.5**
1103P	**18.6** 60	**21.2** 73	**25.2** 83	**27.5** 91	**30.3**	**24.6**
Ave. Eff. Irr.	**17.4** 62	**19.8** 71	**23.9** 86	**25.1** 90	**27.9**	

$LSD_{0.05}$ Irrigation = 1.6 Rootstock = 1.5 Interaction = ns

Values in this color represent % of the highest yield of each rootstock at a particular irrigation treatment.

Wine maker comments:

We’re disappointed in the study since we found no differences in wine sensory characteristics among the treatments (irrigation or rootstock).

Regulated Deficit Irrigation (RDI)

- The practice of purposely creating water deficits during specific times of the season primarily to save water while minimizing or eliminating negative impacts on yield or crop revenue – David Goldhamer

Paso Robles Irrigation Strategies: 2002 - 2006

- SuDI – Sustained Deficit Irrigation at 0.375, 0.56 and 0.75 of estimated ET_c (control was 1.12 of ET_c)
- PRD – Partial Rootzone Drying: (sides alternated every 2 weeks)
- RDI – S to V: deficit irrigation at fraction of ET_c from set to veraison, then 1.12 ET_c from veraison to harvest.
- RDI – V to H: irrigation at 1.12 ET_c from set to veraison and then deficit irrigation at fraction of ET_c from veraison to harvest.
- Dry Down: water applied every two weeks (approximately 24 gallons per vine)

Rainfall (inches) at Paso Robles from 1997 - 2008.

Year	Nov - Mar	Apr – Sept	October	Total
1997	9.7	0	0	9.7
1998	18.1	3.4	0.3	21.8
1999	5.0	1.2	0	6.2
2000	9.0	1.5	1.0	11.5
2001	13.0	0.7	0.1	13.8
2002	5.9	0.2	0	6.1
2003	7.7	2.7	0.3	10.7
2004	8.4	0	3.9	12.3
2005	15.0	1.5	0	16.5
2006	9.3	3.1	0.6	13.0
2007	3.5	0.4	0.6	4.5
2008	5.3	---	---	---

Applied water as a percentage of estimated ET_c from 2002 to 2006 in a study at J. Lohr winery.

	Irrigation treatment (fraction of estimated ET_c)			
Year	0.375	0.56	0.75	1.12
	Applied H_2O (% of seasonal estimated ET_c)			
2002	30	40	60	80
2003	24	36	48	72
2004	30	46	61	85
2005	22	33	44	66
2006	25	38	50	75
	26	39	53	76
	---------- Mean applied H_2O (inches) ----------			
176 gallons →	4.7	7.0	9.5	13.6

Estimated ET_c was 18.1 inches.

The effects of irrigation treatment and year on berry wt. of Cabernet Sauvignon grown near Paso Robles. There was a significant interaction between irrigation treatment and year.

Irrigation Treatment	Berry wt. (g 100 berries^{-1})	Year	Berry wt. (g 100 berries^{-1})
SuDI 0.375	87 f	2002	91 c
SuDI 0.56	97 de	2003	90 c
SuDI 0.75	109 b	2004	100 b
FI 1.12	116 a	2005	111 a
S-V 0.375	97 d	2006	112 a
S-V 0.56	104 c	Rain	Before/After 4/1
V-H 0.375	99 d	2004	213 / 0 mm
V-H 0.56	104 c	2005	381 / 38 mm
DD	93 e	2006	237 / 79 mm

The effects of irrigation treatment and year on yield of Cabernet Sauvignon grown near Paso Robles. There was no significant interaction between irrigation treatment and year.

Irrigation Treatment	Yield (kg 4 vines^{-1})		Yield (kg 4 vines^{-1})
SuDI 0.375	31.6 c 72%	2002	38.9 b 7.76
SuDI 0.56	33.4 c 77%	2003	29.3 d 5.85
SuDI 0.75	39.0 ab 90%	2004	24.3 e 4.85
FI 1.12	43.4 a	2005	52.4 a 10.5
S-V 0.375	33.6 bc	2006	34.9 c 6.97
S-V 0.56	41.2 a	Rain	Before/After 4/1
V-H 0.375	33.5 bc	2004	213 / 0 mm
V-H 0.56	35.3 bc	2005	381 / 38 mm
DD	33.9 bc 78%	2006	237 / 79 mm

Effects of cultivar and irrigation treatments on yield of vines grown in the San Joaquin Valley.

- Seventeen red, wine cultivars grown at the KARE Center.
- All grafted onto 1103P.
- Irrigation treatments consisted of 1.) full ET_c from 1st irrigation to veraison and then no applied water, 2.) applied water at 50% of ET_c season long and 3.) no applied water to veraison and then applied water at 50% of ET_c up to harvest.

Berry weight at veraison. I → NI - Full ET to veraison, no water after that; 0.5 ET all season; NI → 0.5 – no water to veraison, 0.5 ET after that (2012).

Cultivar	Irrigation Treatment			
	I → Ni	0.5 ET_c	NI → 0.5	Cv. Mean
	(g $berry^{-1}$)			
Cabernet Sauvignon	0.84	0.76	0.49	0.70
Cinsaut	2.29	1.69	0.84	1.67
Durif	1.15	0.95	0.57	0.89
Freisa	1.53	1.11	0.71	1.12
Grenache noir	1.41	1.28	0.72	1.13
Malbec	1.32	1.11	0.74	1.06
Montepulciano	1.67	1.35	0.74	1.29
Petit Verdot	0.75	0.71	0.44	0.63
Refosco	1.33	1.15	0.74	1.07
Sauzao	1.41	1.15	0.69	1.09
Syrah	1.37	1.14	0.71	1.07
Tannat	0.84	0.71	0.51	0.71
Tempranillo	1.40	1.12	0.59	1.08
Tinta Amarella	1.29	1.11	0.68	1.05
Tinta Madeira	1.20	1.07	0.68	0.98
Touriga Nacional	1.16	0.95	0.62	0.94
Irr. Trt. Mean	1.24 a	1.04 b	0.64 c	
Irr. Trt. Mean (Ψ_l, MPa)	-0.97 ± 0.03	-1.18 ± 0.02	-1.54 ± 0.05	

Berry weight at harvest. I → NI - Full ET to veraison, no water after that; 0.5 ET all season;NI → 0.5 – no water to veraison, 0.5 ET after that (2012).

Cultivar	Irrigation Treatment				
	I → Ni	0.5 ET_c	NI → 0.5	Cv. Mean	1.0 ET_c
	(g $berry^{-1}$)				
Cabernet Sauv.	1.08	1.18	0.89	1.05	1.58
Cinsaut	2.86	2.67	1.64	2.39	3.05
Durif	1.24	1.29	0.75	1.08	1.81
Freisa	0.97	1.16	0.84	0.99	1.75
Grenache noir	1.63	1.61	0.96	1.38	1.93
Malbec	1.30	1.52	1.26	1.37	1.81
Montepulciano	1.83	1.93	1.49	1.75	2.23
Petit Verdot	1.05	1.13	0.85	1.01	1.51
Refosco	1.53	1.69	1.16	1.45	2.00
Sauzao	1.23	1.40	1.10	1.25	1.90
Syrah	1.23	1.36	0.93	1.17	1.98
Tannat	1.05	1.24	0.95	1.08	1.32
Tempranillo	1.60	1.81	1.29	1.56	1.96
Tinta Amarella	1.79	1.70	1.05	1.51	1.76
Tinta Madeira	1.46	1.46	1.10	1.33	1.81
Touriga Nacional	1.27	1.32	1.04	1.21	1.73
Irr. Trt. Mean	1.44 b	1.52 a	1.08 c		1.89
Irr. Trt. (% 1.0 ET_c)	76%	81%	57%		
Irr. Trt. Mean (Ψ_l, MPa)	-1.61	-1.35	-1.35		-0.99 ± 0.03

Brix, berry weight and yield data from 2012 averaged across 16 red, wine cultivars.

	Irrigation treatment			
Parameter	**I → Ni**	**0.5 ET_c**	**Ni → I**	**1.0 ET_c**
Brix	**24.6 a**	**24.0 b**	**22.3 c**	**23.8**
Berry wt.		**(g berry^{-1})**		
Veraison	**1.24**	**1.04**	**0.64**	**---**
Harvest	**1.44**	**1.52**	**1.08**	**1.89**
		(kg vine^{-1})		
Yield	**11.7**	**11.9**	**7.2**	**14.4**
% 1.0 ET_c	**82%**	**83%**	**50%**	**---**

Brix, berry weight , titratable acidity (TA) and yield data from 2013 averaged across 17 red, wine cultivars.

	Irrigation treatment			
Parameter	**I → Ni**	**0.5 ET_c**	**Ni → I**	**1.0 ET_c**
Berry wt.	---------- (g $berry^{-1}$) ----------			
Veraison	**1.78**	**1.46**	**0.91**	**---**
Harvest	**1.63**	**1.58**	**1. 23**	**---**
SS (Brix)	**24.5**	**24.1**	**24.0**	**---**
TA (g L^{-1})	**5.66**	**4.43**	**4.31**	**---**
	---------- (kg $vine^{-1}$) ----------			
Yield	**13.3**	**12.3**	**8.1**	**---**
				BB → Har.
Applied H_2O (mm)	397	347 - 457	173 - 279	619
Applied H_2O (in.)	15.6	13.7 – 18.0	6.8 – 11.0	27.2

Final thoughts:

- Row spacing and trellis type are the predominant factors determining potential vineyard water use. Generalizations made concerning season-long average, applied water amounts as a function of location in California and possible reductions in those amounts without causing a loss in vineyard productivity should be viewed with caution. This is why estimates of vineyard ET are important.

Other considerations:

- To disk or not to disk, that is the question.
- Use of extraneous ground covers (mulches or plastics)
- Should some crop be removed early in the season?
- Are other standard management practices affected by water shortage?
- How are invertebrate pest populations affected by water shortage?

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