Overview of vineyard irrigation management and the use of soil monitoring techniques to understand soil moisture dynamics

Larry E. Williams

Dept. Viticulture and Enology

UC-Davis and

Kearney Agricultural Research and Extension Center

9240 S. Riverbend Ave.

Parlier, CA 93648

lewilliams@ucanr.edu

Irrigation management and Vineyard Sustainability

- Maintain productivity over time
- Maximize fruit quality
- Increase vineyard water use efficiency (WUE) (in general, if the vineyard is irrigated any reduction in applied water will increase WUE).
- 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

Goal of irrigation management

- Your goal should be to grow vines with a uniform degree and pattern of water stress every season (the degree of stress determined by the grower).
- To do this, you need to adjust irrigation timing and amounts to take into account unique growing conditions in any given season.
- Weather (evaporative demand and temperature) is the variable component that exerts the most influence on irrigation requirements during the season.

Definitions

- Transpiration – evaporation of water that has passed through a plant
- Crop evapotranspiration (ET_c) – the total process of water transfer to the atmosphere by a specific crop (i.e. grapevines) to include soil evaporation
- Reference ET (ET_o) – a measure of the evaporative demand in a region (can be obtained from CIMIS)
- Leaf water potential – a measure of the water status of plants (units expressed in bars or megapascals (MPa), 10 bars = 1.0 MPa)

California Sustainable Winegrowing Alliance

Performance Metrics and the California Sustainable Winegrowing Program:

"You can't manage what you don't measure"

Irrigation management and Vineyard Sustainability

- Know what total ET of your vineyard(s) might be and ET as a function of phenology.
- 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.
- 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).
- Was water applied for frost protection? If so, how much?

Within the drip line water meter.

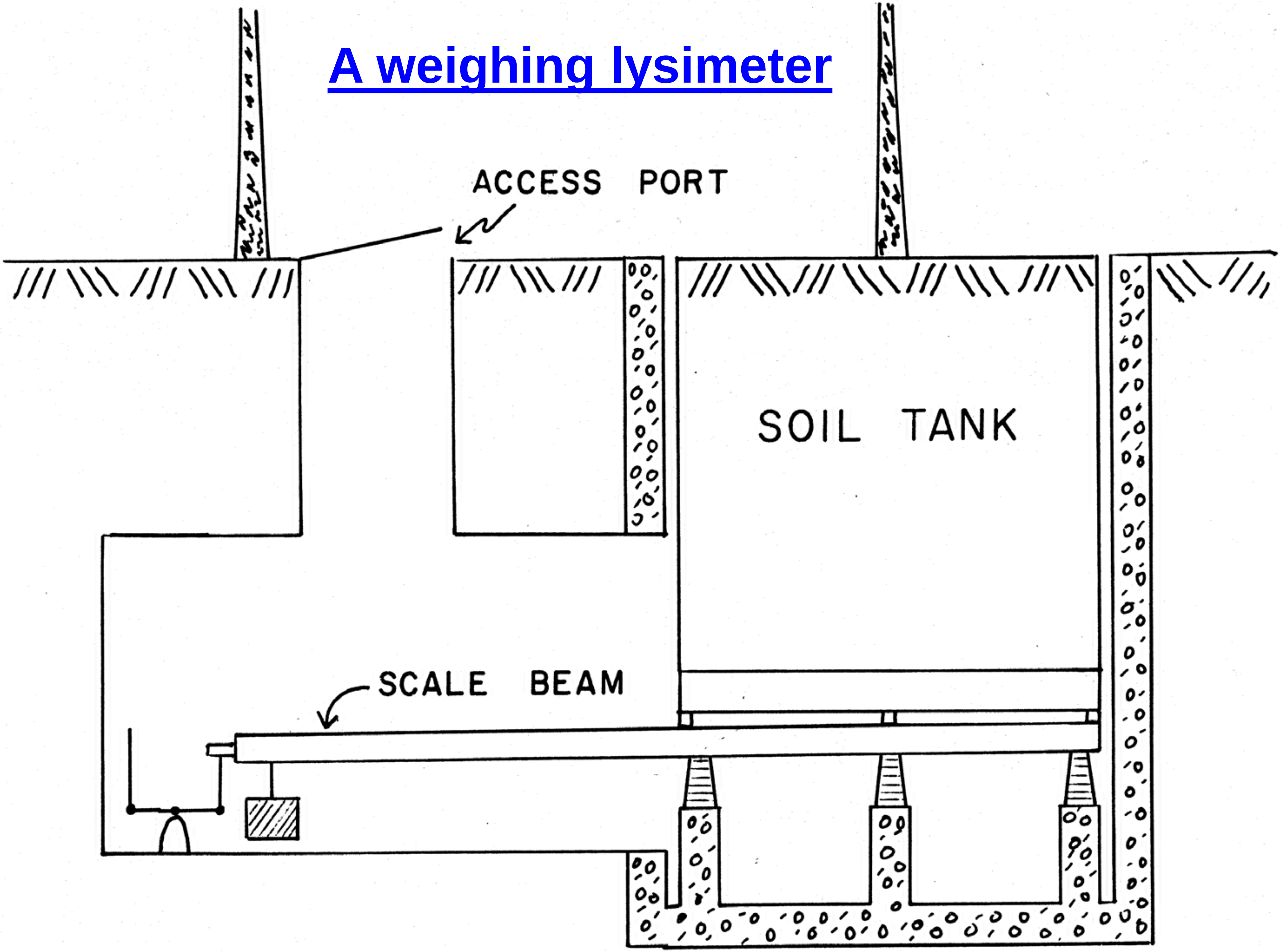
Important irrigation management decisions

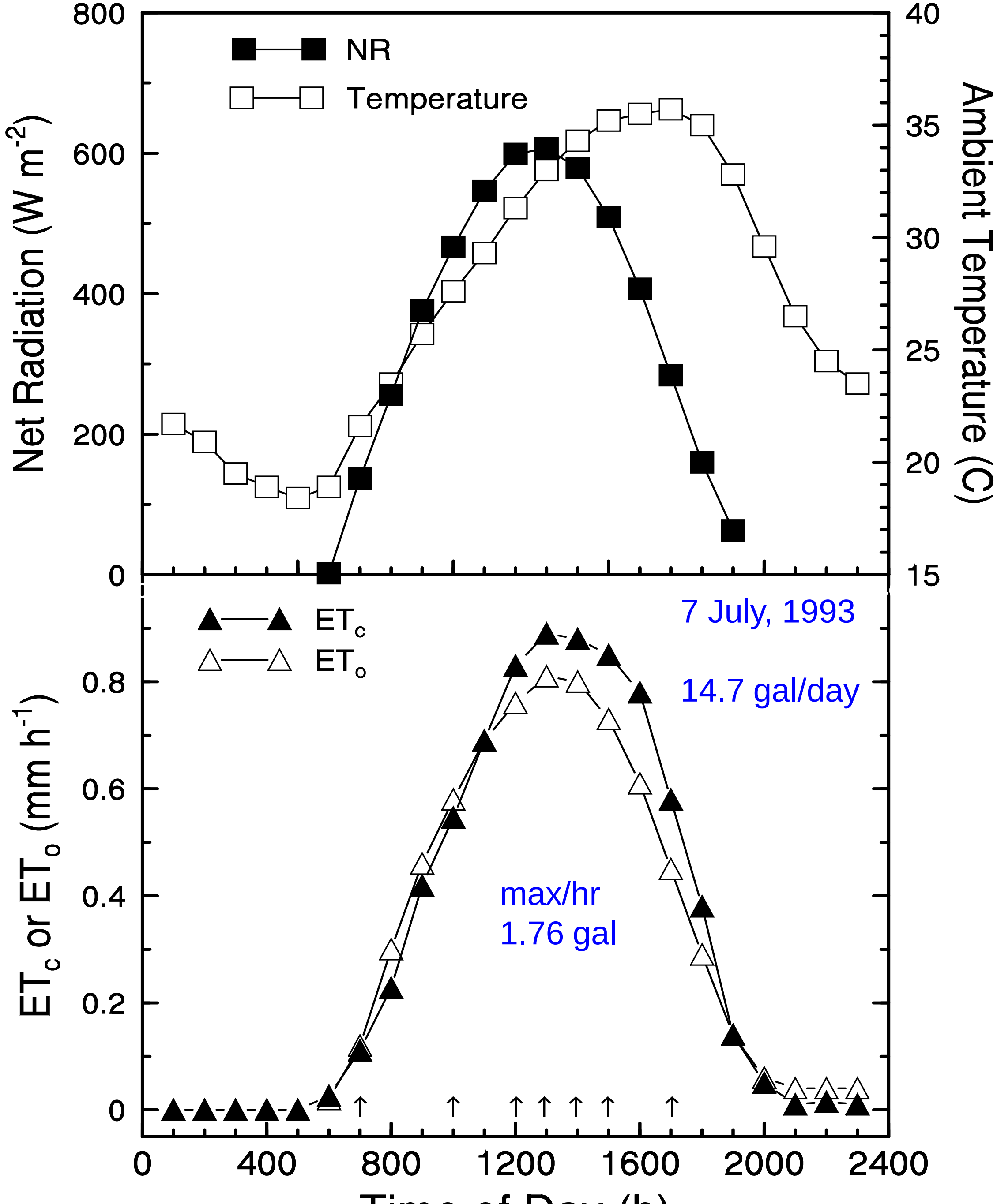
- When should one initiate irrigations at the beginning of the season?
- How much water should one apply?
- How does the design of your irrigation system affect the ability to irrigate your vineyards?
- Are there deficit irrigation practices to minimize production loss and maximize fruit quality?

Environmental Factors Affecting ET

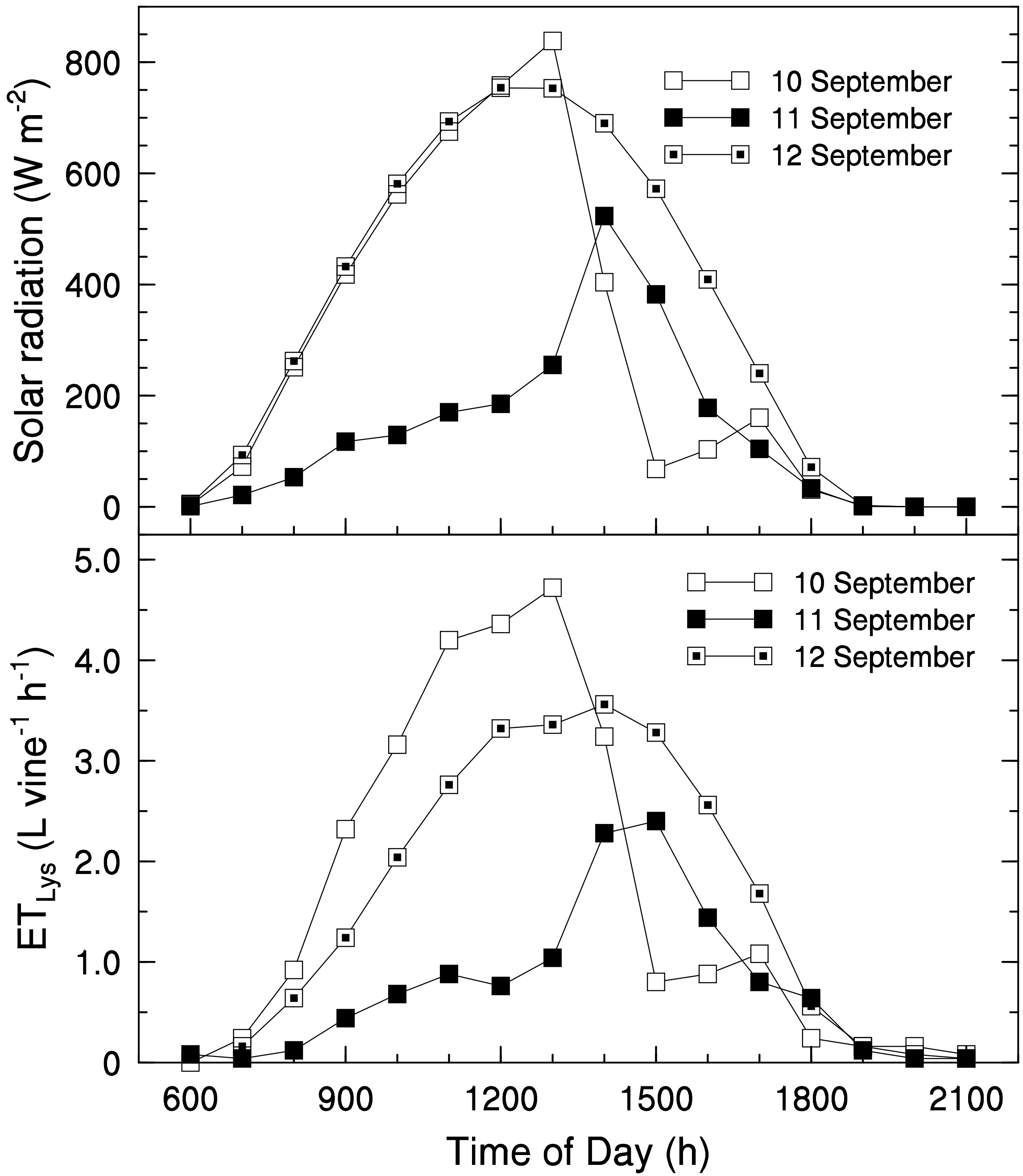
- Light is required to open stomata on plants
- As Net Radiation increases, ET increases
- As the VPD increases, ET increases
- As wind increases, ET increases (high winds reduce ET)
- High ambient temperatures may up-regulate stomatal conductance (i.e. grapevine transpiration may increase due to high temperatures).
- As water in the soil profile decreases, ET decreases.

A weighing lysimeter



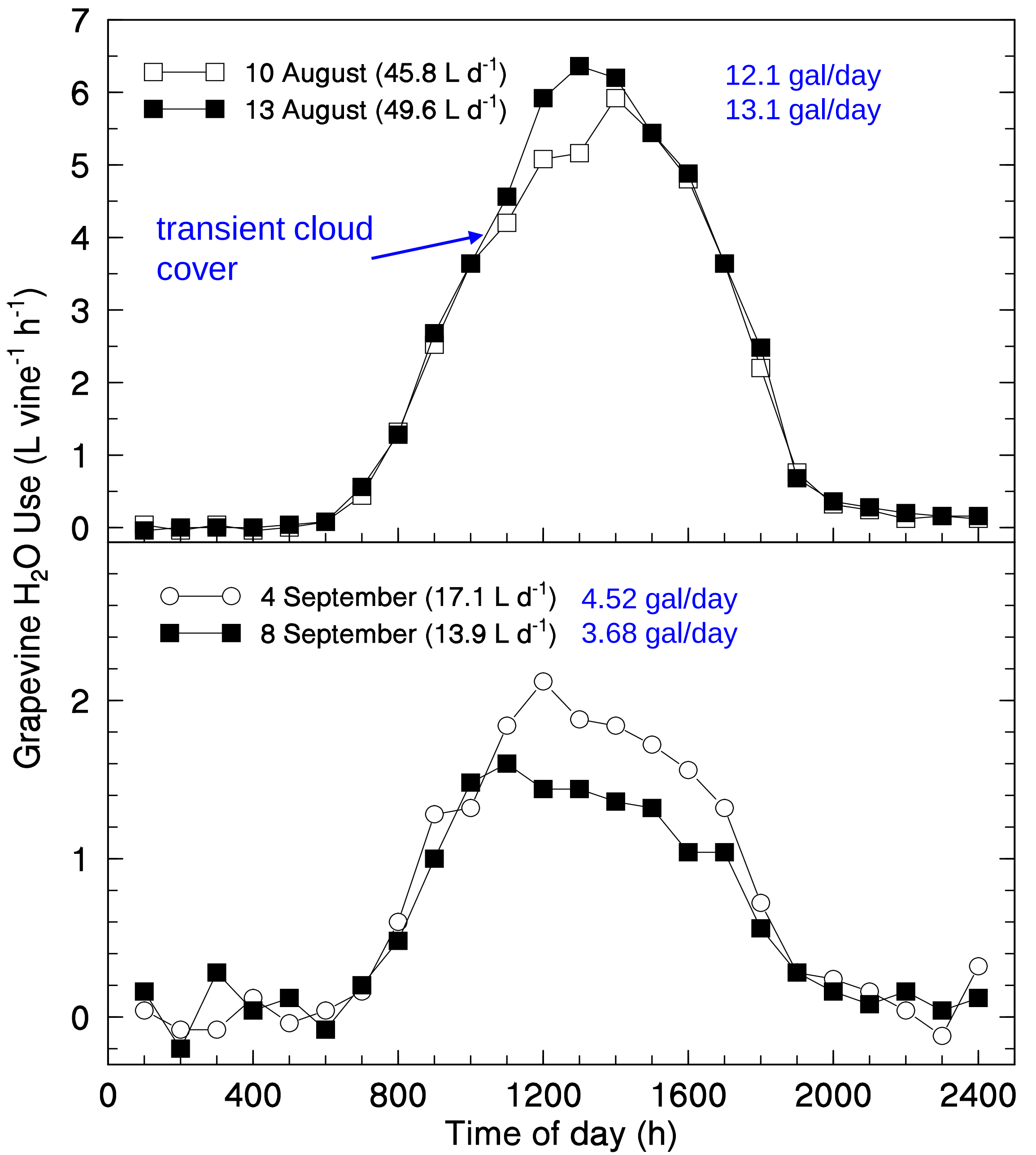


NR
Temperature
Net Radiation (W m-2)
Ambient Temperature (C)
ETc
ETo
7 July, 1993
14.7 gal/day
max/hr
1.76 gal
ETc or ETo (mm h-1)
Time of Day (h)



Solar radiation (W m^{-2})
800
600
400
200
0
10 September
11 September
12 September
ET$_{Lys}$ (L vine^{-1} h^{-1})
5.0
4.0
3.0
2.0
1.0
0
10 September
11 September
12 September
600
900
1200
1500
1800
2100
Time of Day (h)

Soil water deficits reduce ET.



What percentage of ET_c is due to vine transpiration? How much water is lost via soil evaporation?

Vine water use, measured with the weighing lysimeter, was compared when the soil surface was covered with two layers of thick plastic versus no plastic on the soil surface. This was done over several years under high frequency drip irrigation at 100% of ET_c.

Lysimeter covered with plastic to minimize soil water evaporation.

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.

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

Possible 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.

Question: How much rainfall during the winter months contribute to the water requirements of a vineyard in the San Joaquin Valley?

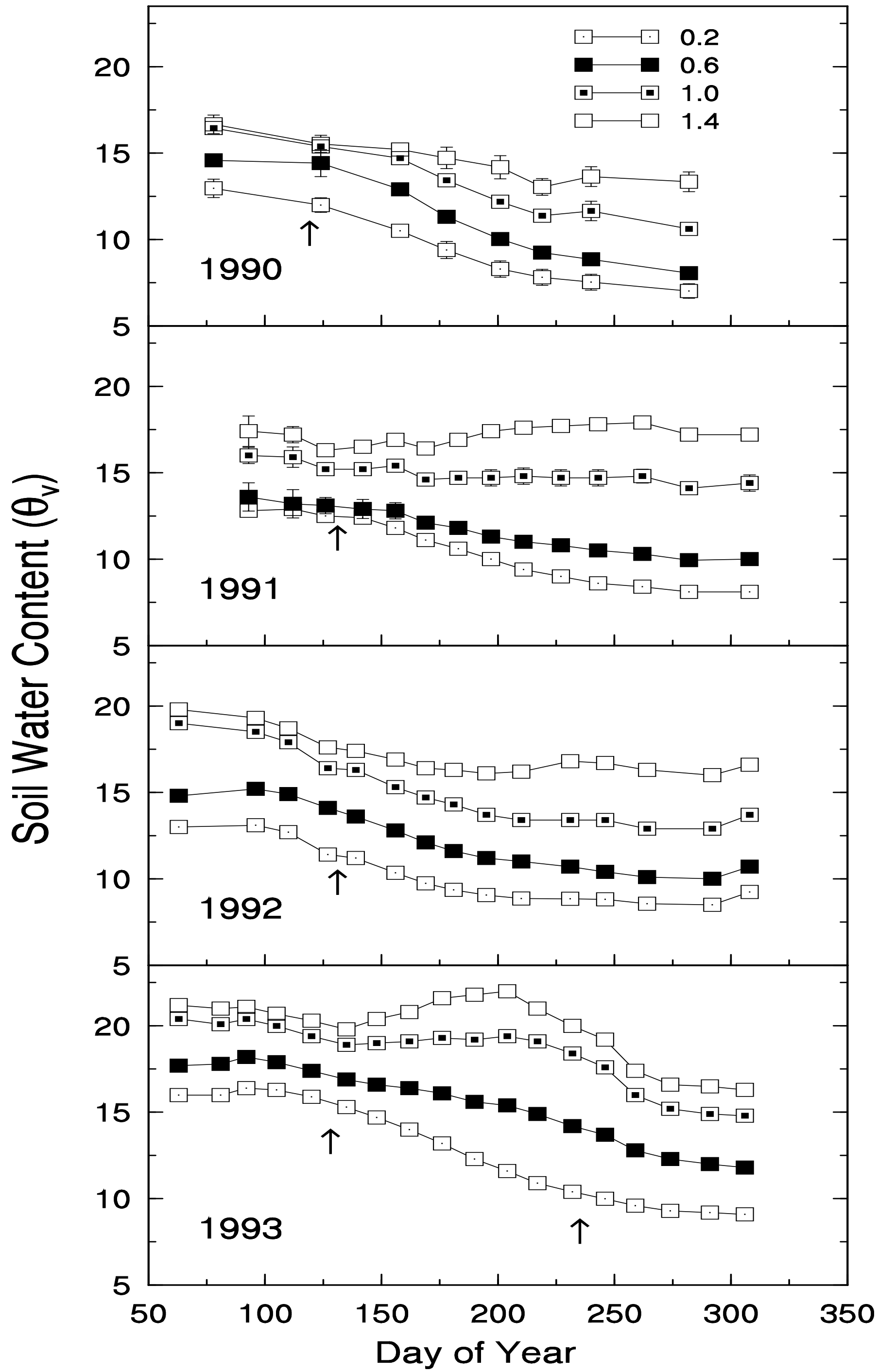
- Thompson Seedless grapevines were irrigated at full ET_c during the 2013 season at the Kearney Ag Center.
- Irrigation was terminated 11 November and soil water content on 12 November was 15.16 % vol./vol.
- Soil water content on 19 March, 2014, was 15.44% vol./vol. The change was equivalent to ~ 23 mm.
- Between those dates we received 73 mm (~ 3 in.) of rainfall. Therefore, 22.7 mm or < 1.0 in. was effective rainfall.
- ET_o was 200 mm (7.9 in.) during that period.

Soil water content as a function of irrigation treatment in a Thompson Seedless vineyard

Rainfall dormancy:
11/90 → BB/91 = 162 mm
11/91 → BB/92 = 241 mm
11/92 → BB/93 = 350 mm

Δ Soil water content
11/90 → BB/91= 150 mm
11/91 → BB/92 = 138 mm
11/92 → BB/93 = 198 mm
11/93 → BB/94 = 61 mm

Upward arrows indicate date irrigation commenced each year.



Rainfall amounts and the change in soil water content from 1 November to budbreak the following year in a vineyard at the Kearney Agricultural Research and Extension Center near Parlier. The soil was a Hanford fine sandy soil. Soil water content was measured to a depth of 2.9 m in plots irrigated at 0.2, 0.6, 1.0 and 1.4 times vine water use.

Rainfall during dormancy:

11/90 → BB/91 = 162 mm

11/91 → BB/92 = 241 mm

11/92 → BB/93 = 350 mm

11/93 → BB/94 = 165 mm

11/94 → BB/95 = 447 mm

Available soil water at field capacity was estimated to be 400 mm.

Δ Soil water content:

11/90 → BB/91= 150 mm (93%)

11/91 → BB/92 = 138 mm (57%)

11/92 → BB/93 = 198 mm (57%)

11/93 → BB/94 = 61 mm (37%)

11/94 → BB/95 = 181 mm (40%)

Determination of Evapotranspiration and Crop Coefficients for a Chardonnay Vineyard Located in a Cool Climate

Williams (2014, Amer. J. Enol. Vitic. 65: 159-168)

- Chardonnay vineyard in **Carneros** (VSP trellis, vine and row spacings 5 x 7 ft., respectively) on two rootstocks.
- The soil was a clay (51% clay, 36% silt, and 13% sand) and of uniform texture to a depth of 2.7 m. The soil bulk density was also uniform with depth and averaged 1.4 g cm^3.
- Irrigation treatments were applied water amounts at various fraction of estimated ET_c (0.25, 0.5, 0.75, 1.0 and 1.25 for 4 years and 0, 0.5 and 1.0 for 4 years)
- Irrigations commenced when midday leaf water potential was -1.0 to -1.1 MPa (-10 to -11 bars).
- Soil water content was measured close to budbreak through the latter part of October (every 2 weeks) for the first six years.
- Six access tubes per site to a depth of 3 m (10 ft.) with three sites per irrigation treatment/rootstock).
- Across years the soil water content was at field capacity (~38% v/v) each spring regardless the irrigation treatment the year before.

Soil water balance can be calculated as follows:

$$P + I + W - ET_c - R - D = \underline{+} \Delta SWC$$

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 (in.) = (rainfall amount – 0.25) x 0.8

(Prichard et al., 2004)

Williams (2014, Amer. J. Enol. Vitic. 65: 159-168) has found this to be reliable for rainfall during the growing season.

What is available to a grower for assisting in vineyard irrigation management? (deciding to start or when and how much to irrigate)

"We have devices in the vineyards that tell us the exact soil moisture, so we only water when we need to." (LEW comment: perhaps)

"While traditional methods such as soil tensiometers, pressure chambers and neutron probes are some the best tools available, they only provide part of the picture and do not accurately reflect how a vine is doing. The scatter plot for neutron probe information can be very wide, and what does that really tell you about the vine." (LEW comment: I've found all techniques are highly correlated with one another)

"Vine water status is valuable information, but leaf water potential can sometimes be misleading." (LEW comment: Not if measured correctly)

(California Sustainable Winegrowing Alliance)

How do agricultural and production practices relate to performance metrics and sustainability?

Many sustainable agriculture initiatives to date, including the SWP, focus on documenting, tracking, and improving practices used on the farm or by subsequent operations along the supply chain. Although improvements in practices presumably result in beneficial environmental, social, and/or economic outcomes, precise impacts must be determined by measurement. **For example, the knowledge of the water holding capacity of the vineyard and the monitoring of evapotranspiration and plant water status may support irrigation decisions, but the impact of these practices on water use is only known if the total amount of applied water is also measured.** Understanding the interdependence of practices and performance metrics is crucial to making and validating improvement in sustainable agriculture. Practices impact metrics and metrics inform practices; understanding and quantifying this relationship is important for continuous improvement.

Deciding when to start irrigating

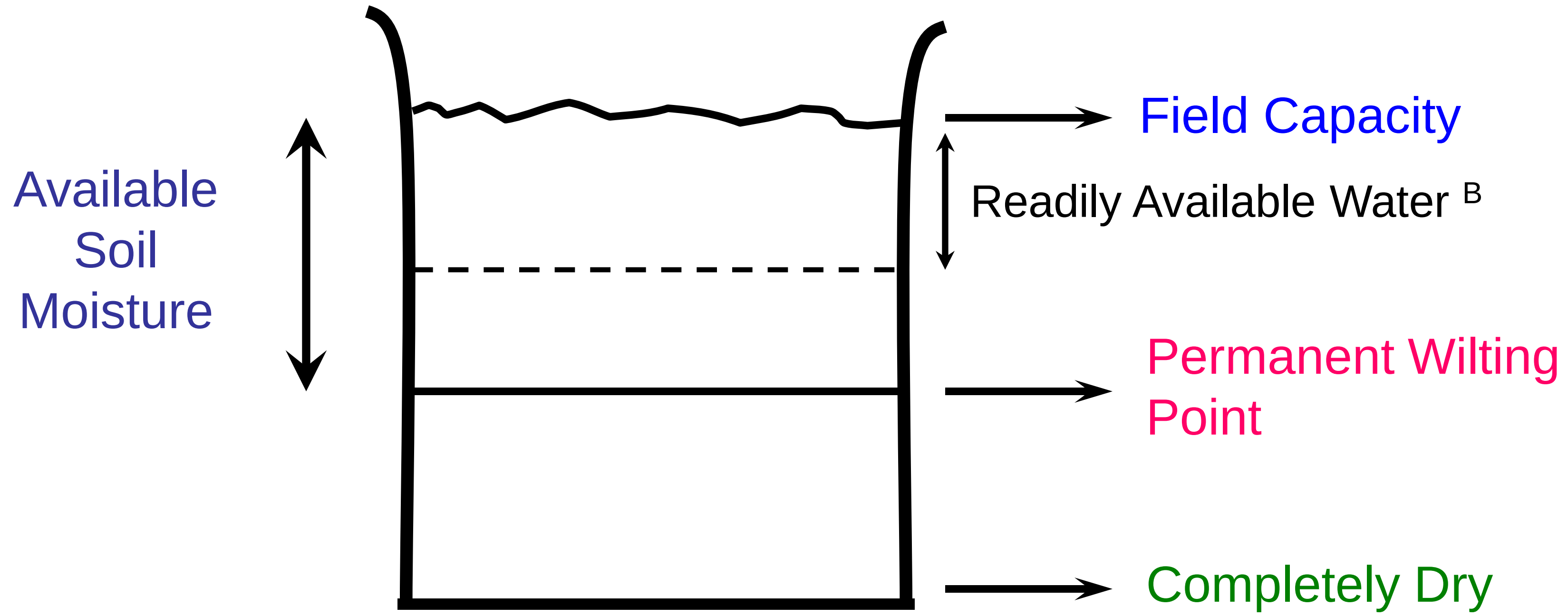
There are several methods: **a.)** measuring the depletion of water in the soil profile to a pre-determined value with a neutron probe (or other such technique), **b.)** water budgeting, i.e. calculating vineyard water use and subtracting that from the amount of water in the profile (this requires knowledge of the water holding capacity of the soil and effective rooting depth) and **c.)** using a plant based method such as measuring leaf water potential. All three methods could be used with low volume or surface irrigation.

a.) depletion of water in soil profile

What information is needed to determine when to start irrigating?

- An estimate of the amount of water available in the soil profile (this can be determined with a neutron probe, capacitance sensors, tensiometers, etc.) or knowledge of soil type
- Rooting depth of the vines in your vineyard (a good estimate is ~ 1.2 to 1.5 m (4 to 5 feet) <u>but water extraction may take place at greater depths.</u>
- An irrigation event would take place once a pre-determined value of soil water was depleted.

Illustration of Soil Moisture Terms [A]



[A] At soil saturation the beaker would be full or overflowing.

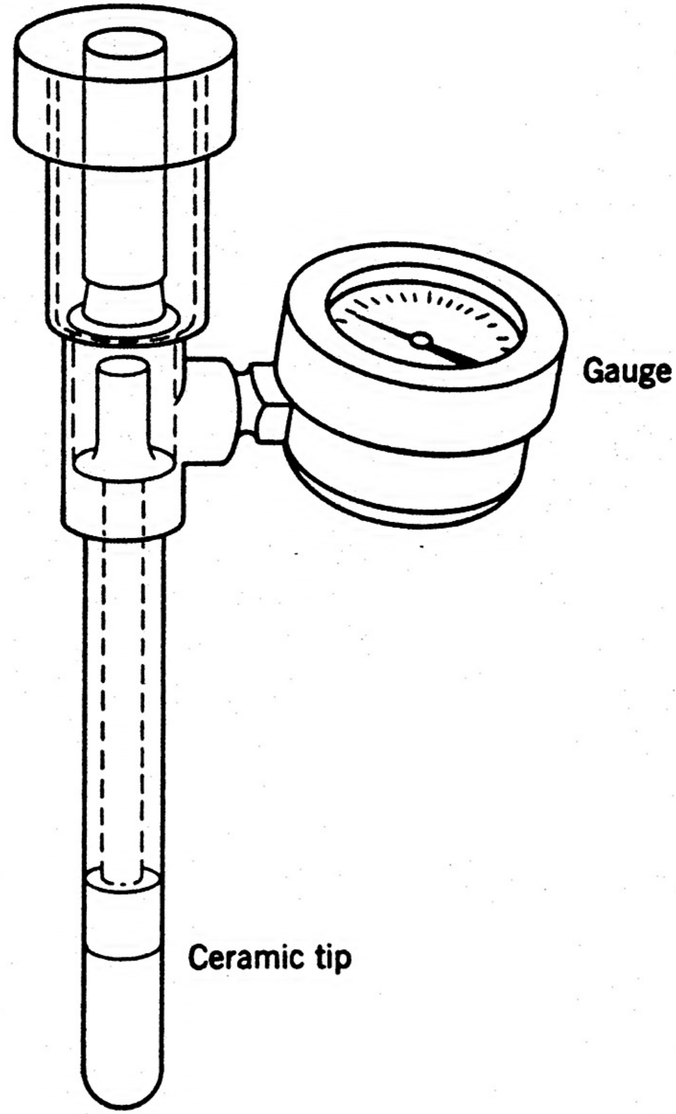
[B] Readily available water is considered to be ~50% of the available soil moisture.

Measurement of Soil Moisture

- There are various means to measure the amount of water in the soil profile or a measure of its tension.
- Tensiometer – measures the attraction of soil to its water. Soil-water suction or tension is a measure of the soil's matric potential.
- Gravimetric – taking a known volume of soil and weighing it first and then taking its dry weight.
- Neutron probe, capacitance sensors, TDR – are used to measure soil volumetric water content (θ_v) .

Tensiometer:

It is used to measure soil moisture tension (Ψ_m)



In use since 1978, the patented WATERMARK sensor is a solid-state electrical resistance sensing device that is used to measure soil water tension. As the tension changes with water content the resistance changes as well. That resistance can be measured using the WATERMARK Sensor.

The sensor consists of a pair of highly corrosion resistant electrodes that are imbedded within a granular matrix. A current is applied to the WATERMARK to obtain a resistance value. The WATERMARK Meter or Monitor correlates the resistance to centibars (cb) or kilopascals (kPa) of soil water tension.

The WATERMARK is designed to be a permanent sensor, placed in the soil to be monitored and "read" as often as necessary with a portable or stationary device. Internally installed gypsum provides some buffering for the effect of salinity levels normally found in irrigated agricultural crops and landscapes.

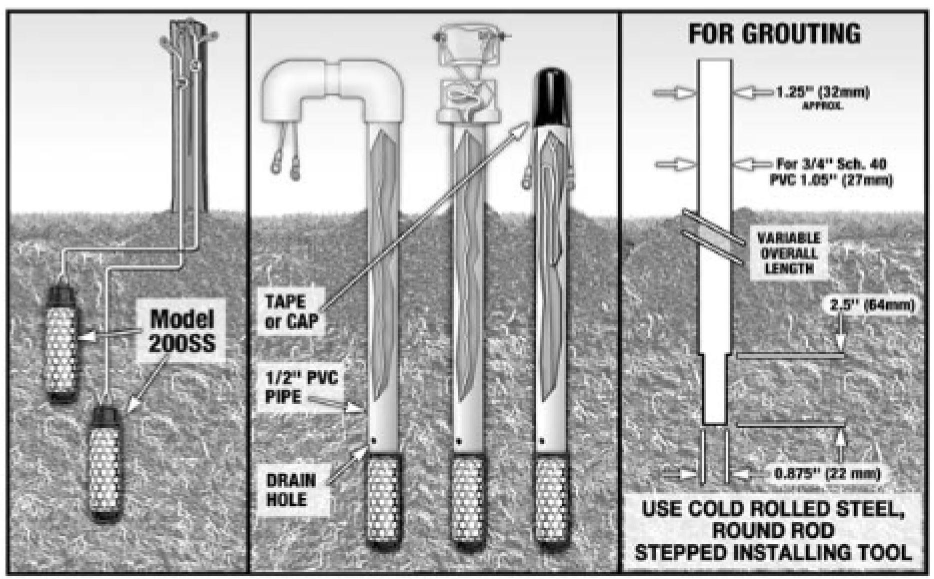
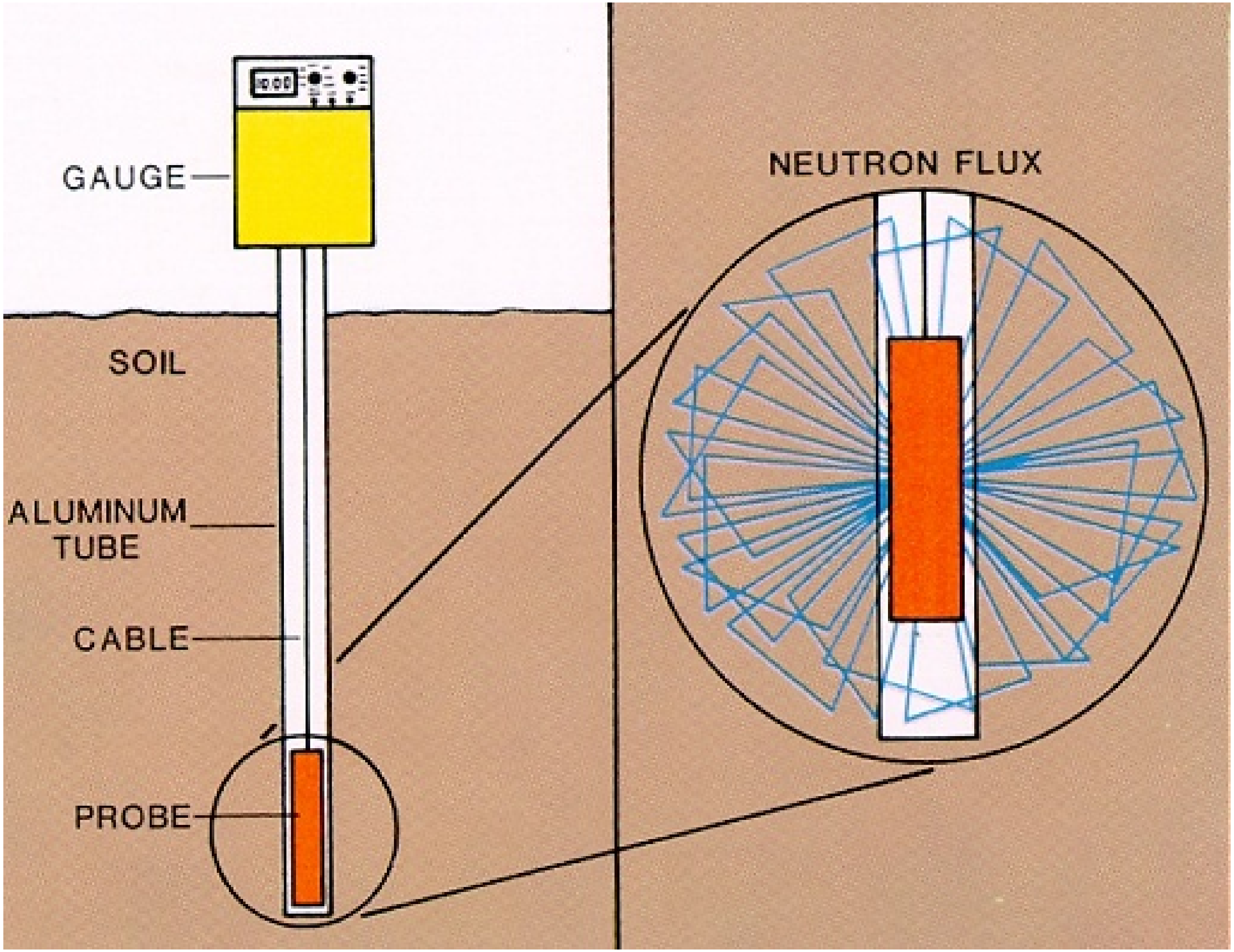


Figure 1 Figure 2 Figure 3

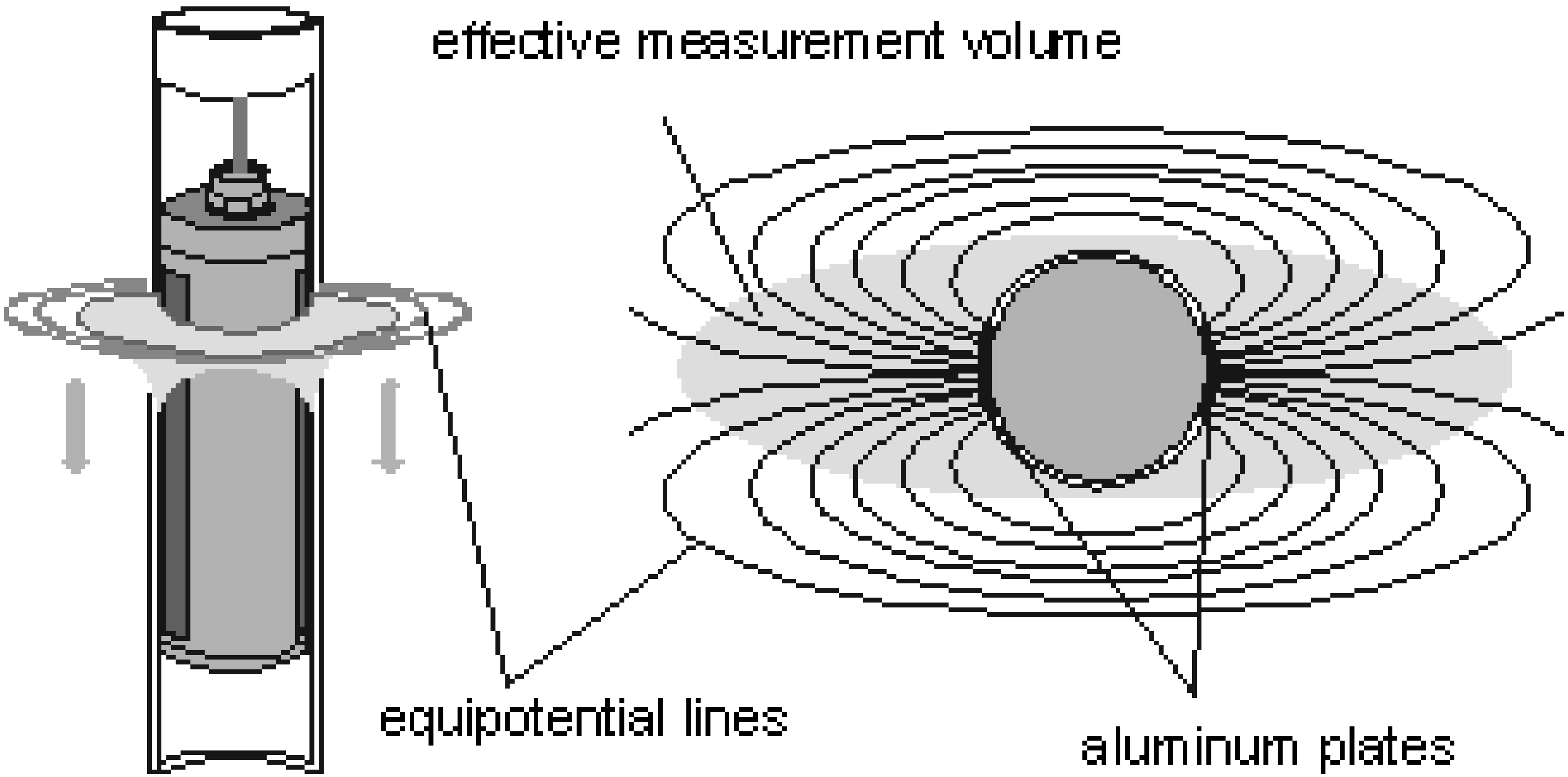
Neutron Probe: used to measure soil water content



A capacitance sensor used to measure soil moisture content. The sensors on this strip will remain in the same tube, it will not be moved. These types of sensors measure the soils ability to transmit electromagnetic waves. They are also called di-electric sensors.

TDR – Time Domain Reflectometry

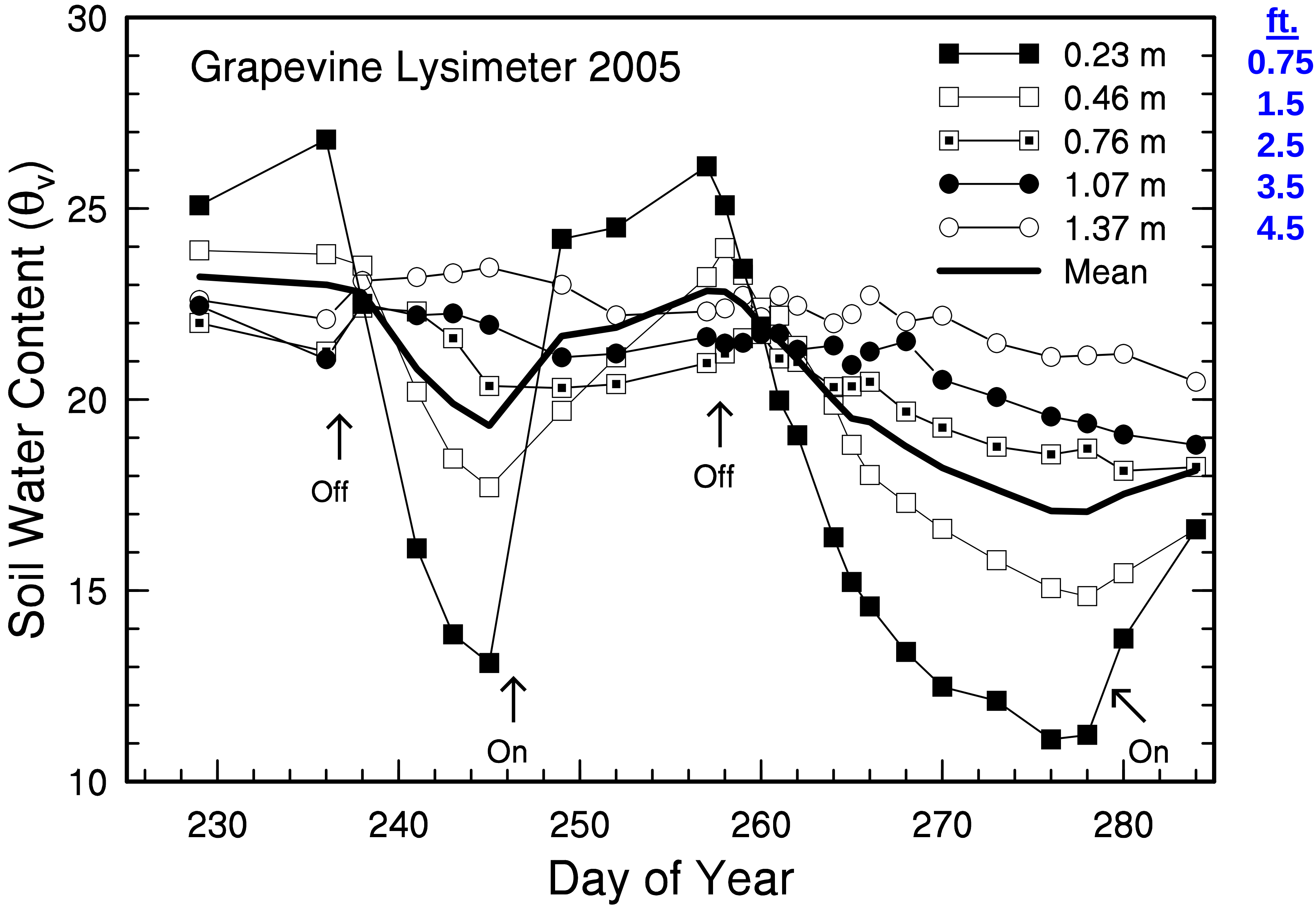
It is another of the di-electric sensors measuring volumetric water content in the soil.

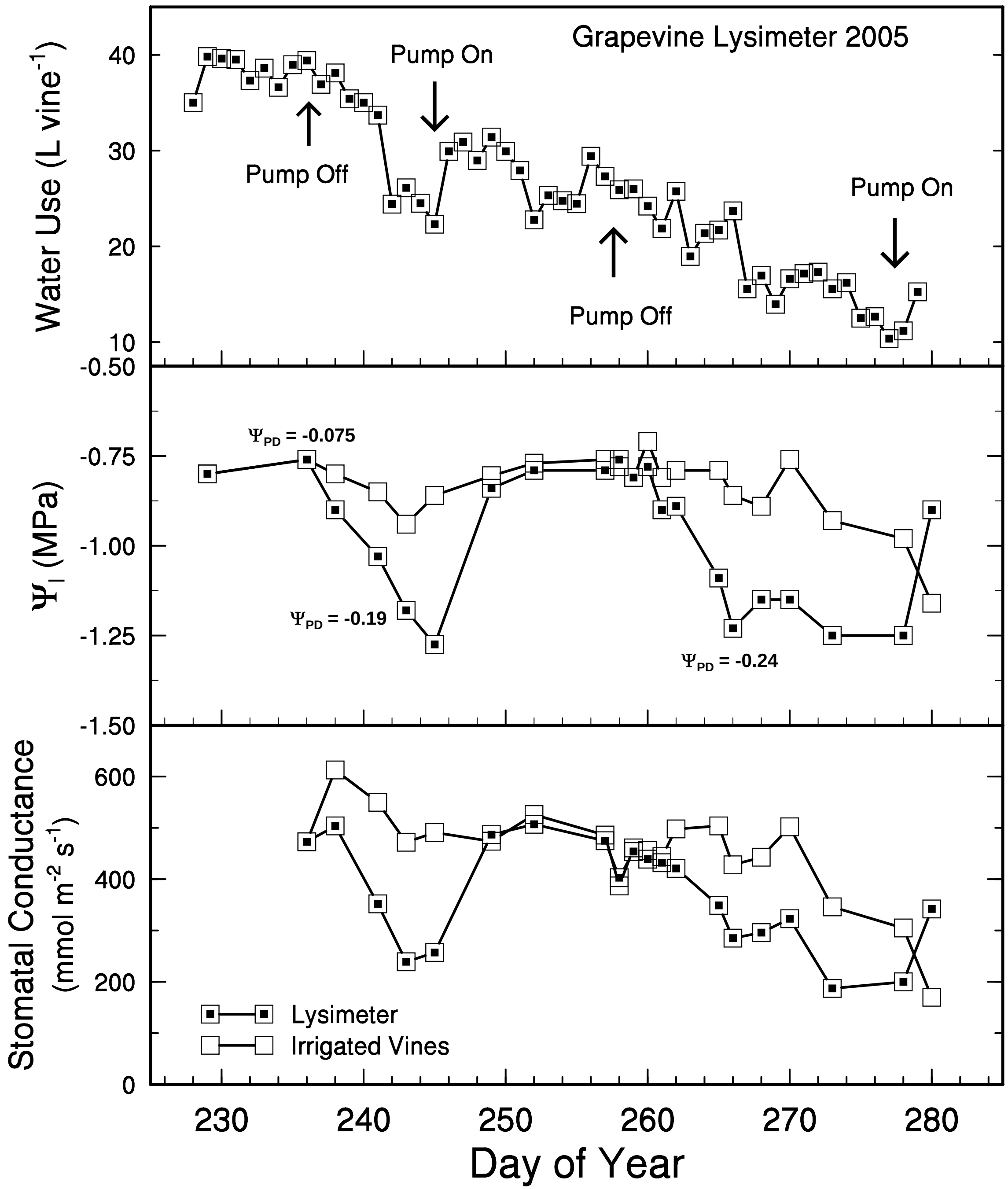


Where should one place the access tubes, tensiometers or other such devices to measure soil water content or matric potential?


Access tubes

Soil water content measured with access tubes directly beneath the emitters as a function of depth inside the weighing lysimeter.

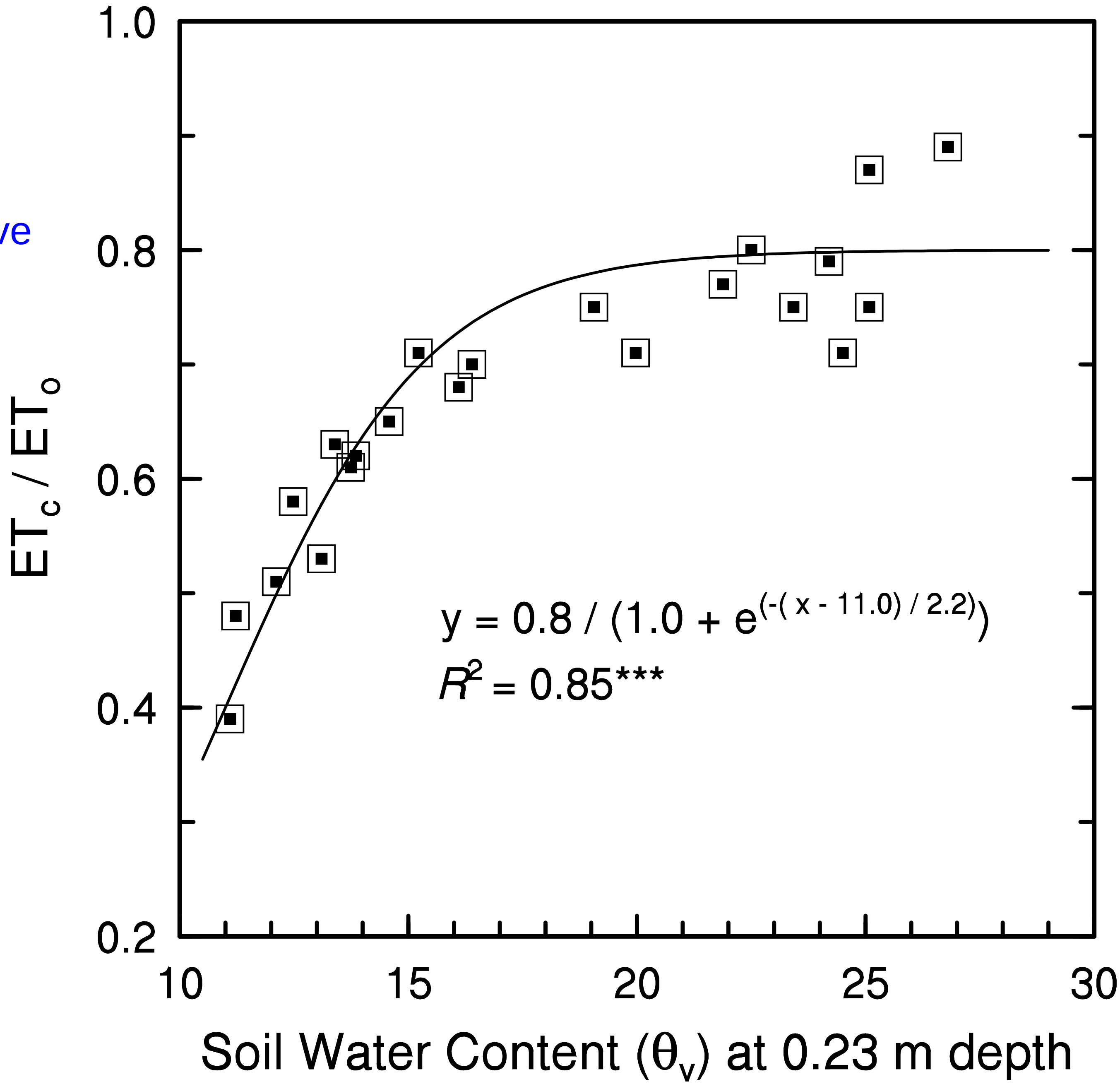




Grapevine Lysimeter 2005
Pump On
Pump Off
Pump Off
Pump On
Water Use (L vine-1)
40
30
20
10
-0.50
-0.75
-1.00
-1.25
-1.50
ΨPD = -0.075
ΨPD = -0.19
ΨPD = -0.24
Ψl (MPa)
Stomatal Conductance (mmol m-2 s-1)
600
400
200
0
Lysimeter
Irrigated Vines
230
240
250
260
270
280
Day of Year

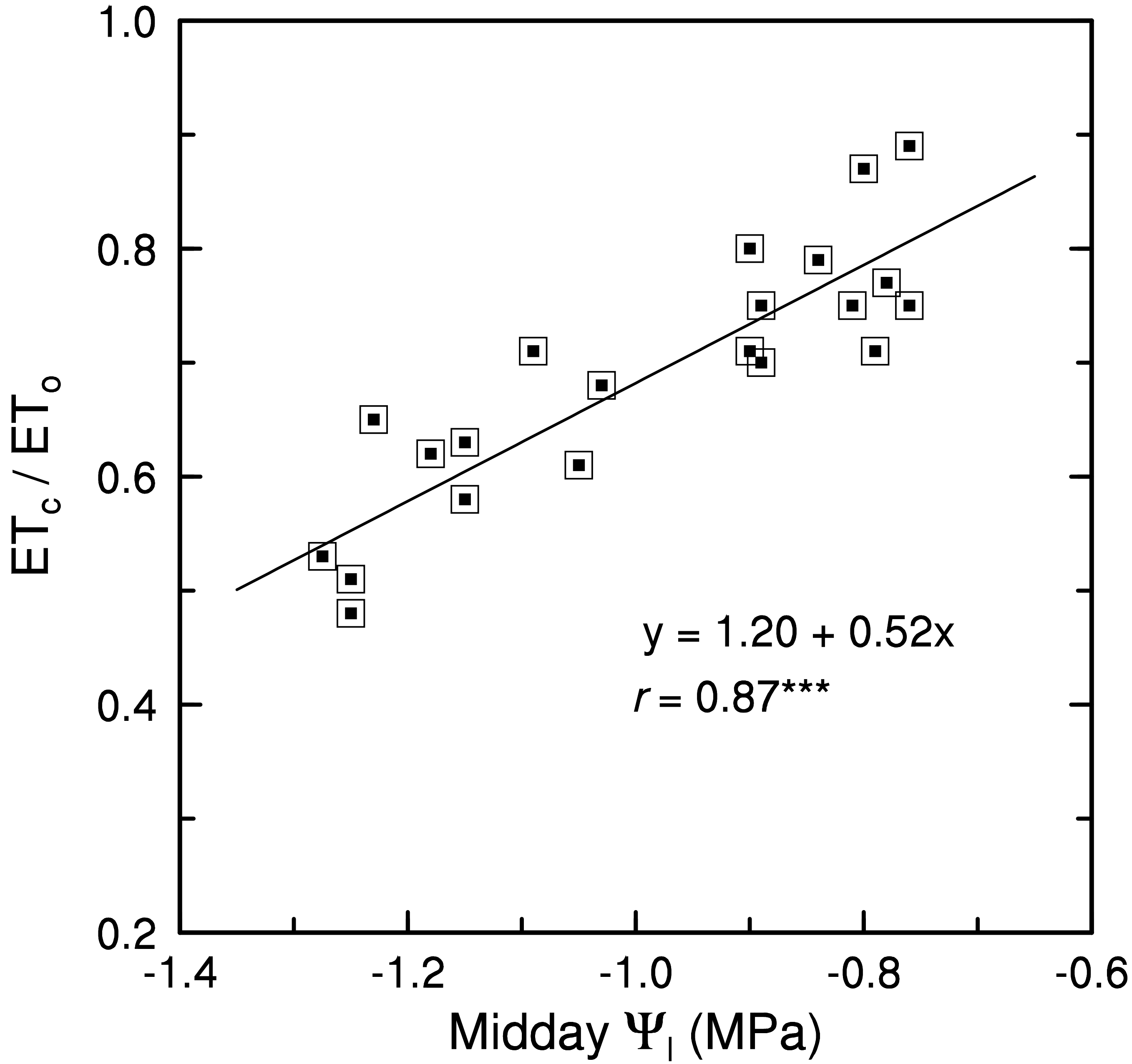
Thompson Seedless data

Grapevine water use (ET_c) is normalized dividing by evaporative demand (ET_o).

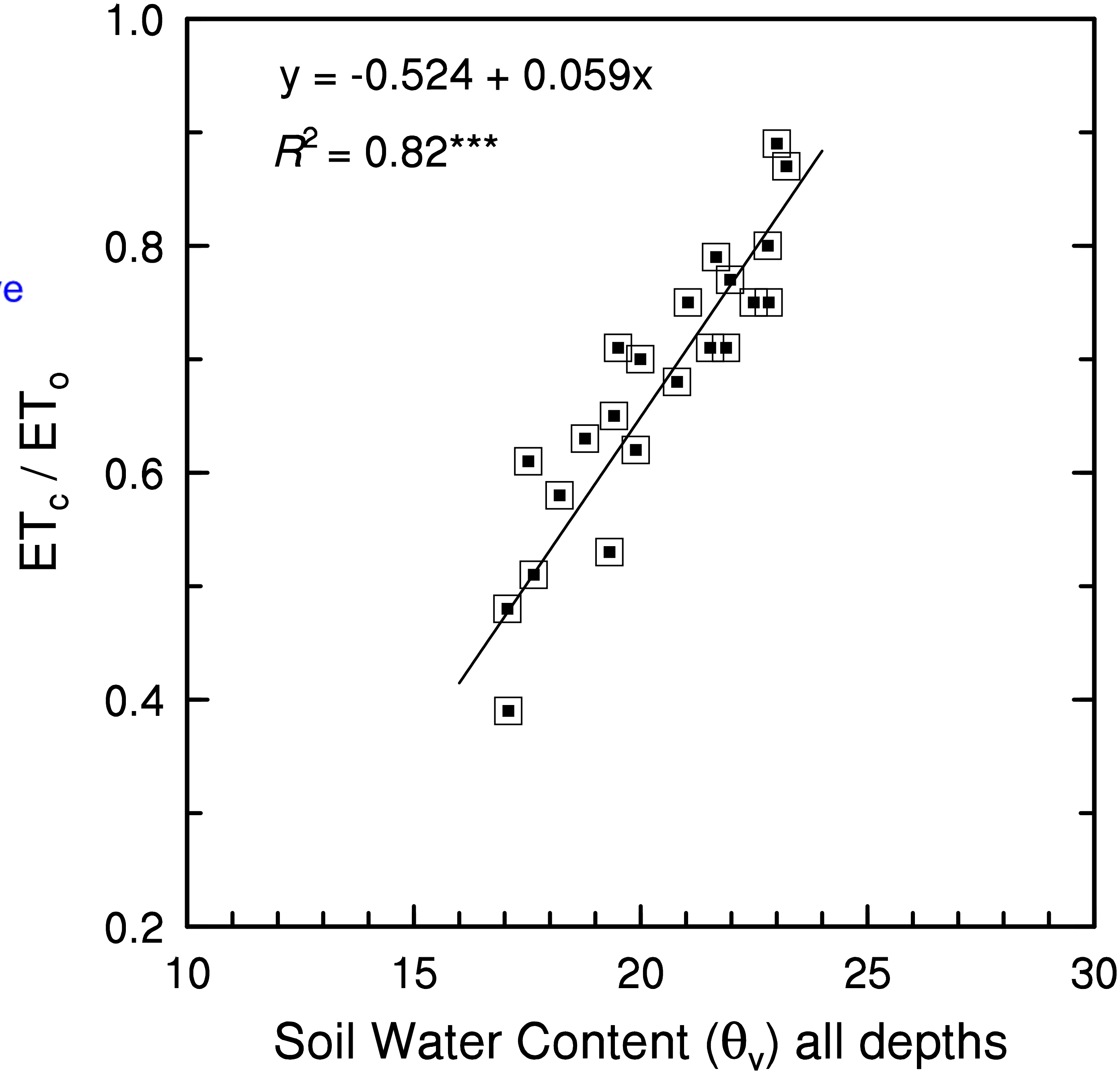


0.23 m = 9 in.

Thompson Seedless data



Grapevine water use (ET_c) is normalized dividing by evaporative demand (ET_o).



A study from Australia and data from a weighing lysimeter in California indicate that once SWC drops below field-capacity, grapevine water use will decrease.

Stevens and Harvey, 1996. Soil water depletion rates under large grapevines. Austral. J. Wine Grape Res. 2:155-162.

Williams et al., 2012. Midday measurements of leaf water potential and stomatal conductance are highly correlated with daily water use of Thompson Seedless grapevines. Irrig. Sci. 30:201-212.

Does the depletion of water in the soil profile as measured with the two access tubes equal water lost as measured with the lysimeter?

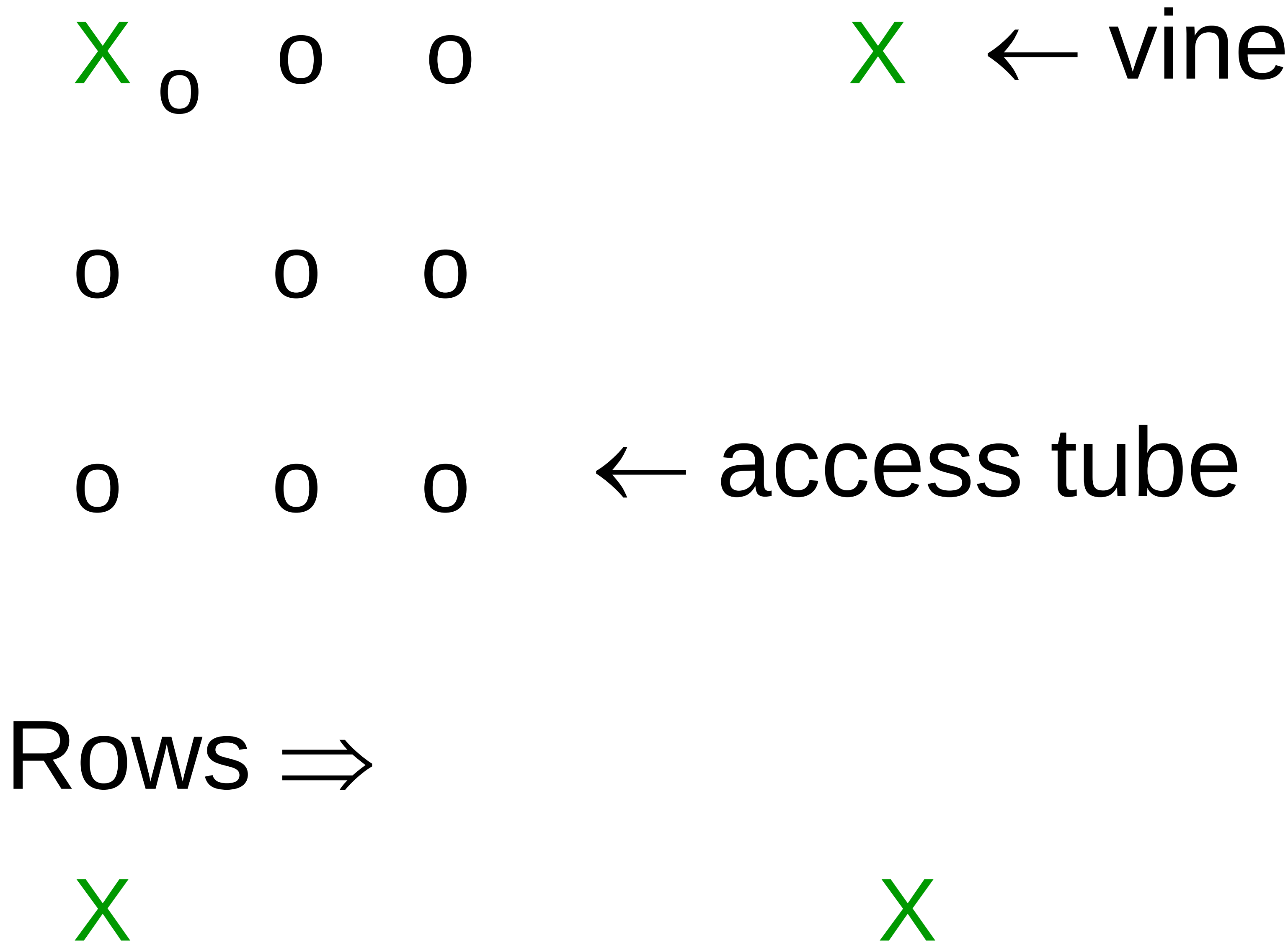
A comparison was made assuming that the amount of water depleted in the soil profile measured with a neutron probe in the two access tubes was similar to that of the entire soil volume of the lysimeter.


Access tubes

Comparison between measured water use of Thompson Seedless vines in a weighing lysimeter (Lys) and calculated water use via soil water depletion. Soil water depletion was measured with a neutron probe (NP) using two access tubes directly beneath the drip line down to a depth of 1.67 m.

		-------- Water Use (L d^{-1}) --------		
Calendar Dates	# days	Lysimeter	Neutron Probe	NP / Lys
8/16 – 8/21	6	40.6	na	na
8/23 – 9/2	10	33.7	22.1	0.66
9/3 – 9/9	7	24.4	19.2	0.79
9/10 – 9/16	7	15.9	3.4	0.21
9/17 – 9/24	8	15.6	6.0	0.38

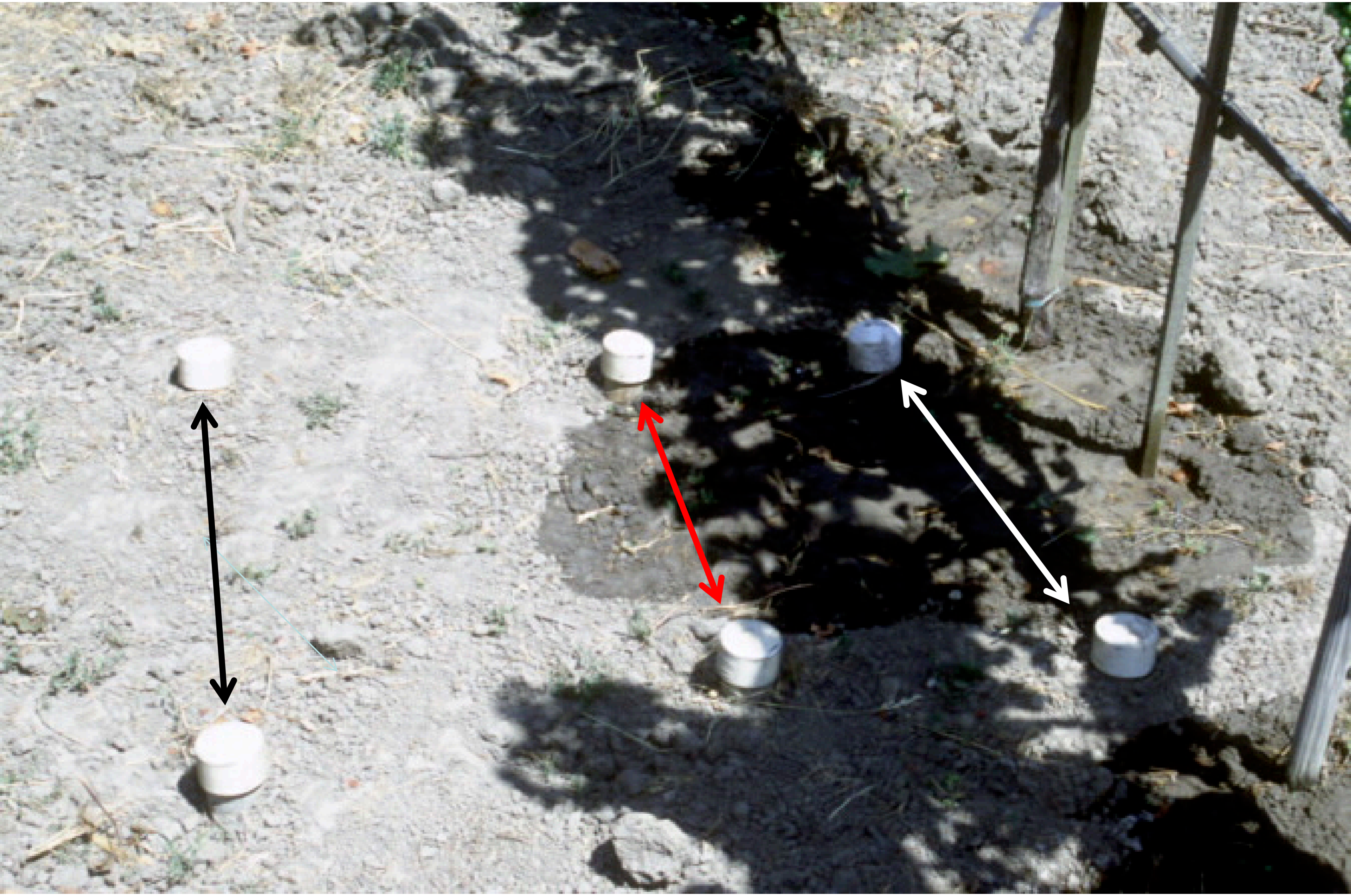
Based upon the above data, one could not obtain an accurate depletion of water in the soil profile utilizing an access tube directly beneath the drip line. You need to measure soil water out to the middle of the row.



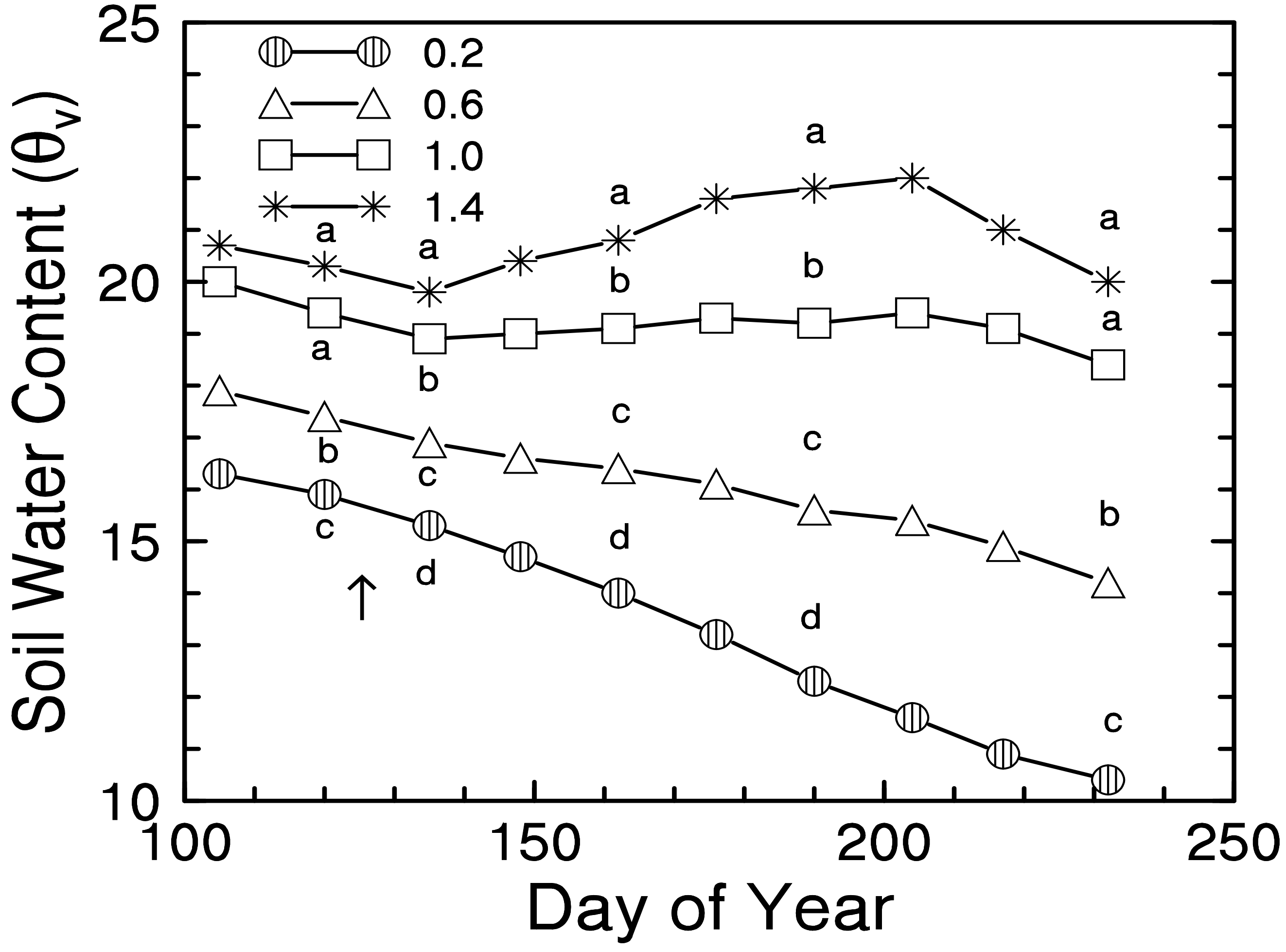
This is the tube arrangement I use for experimental purposes.
The number of tubes per site may differ due to vine and row spacing.

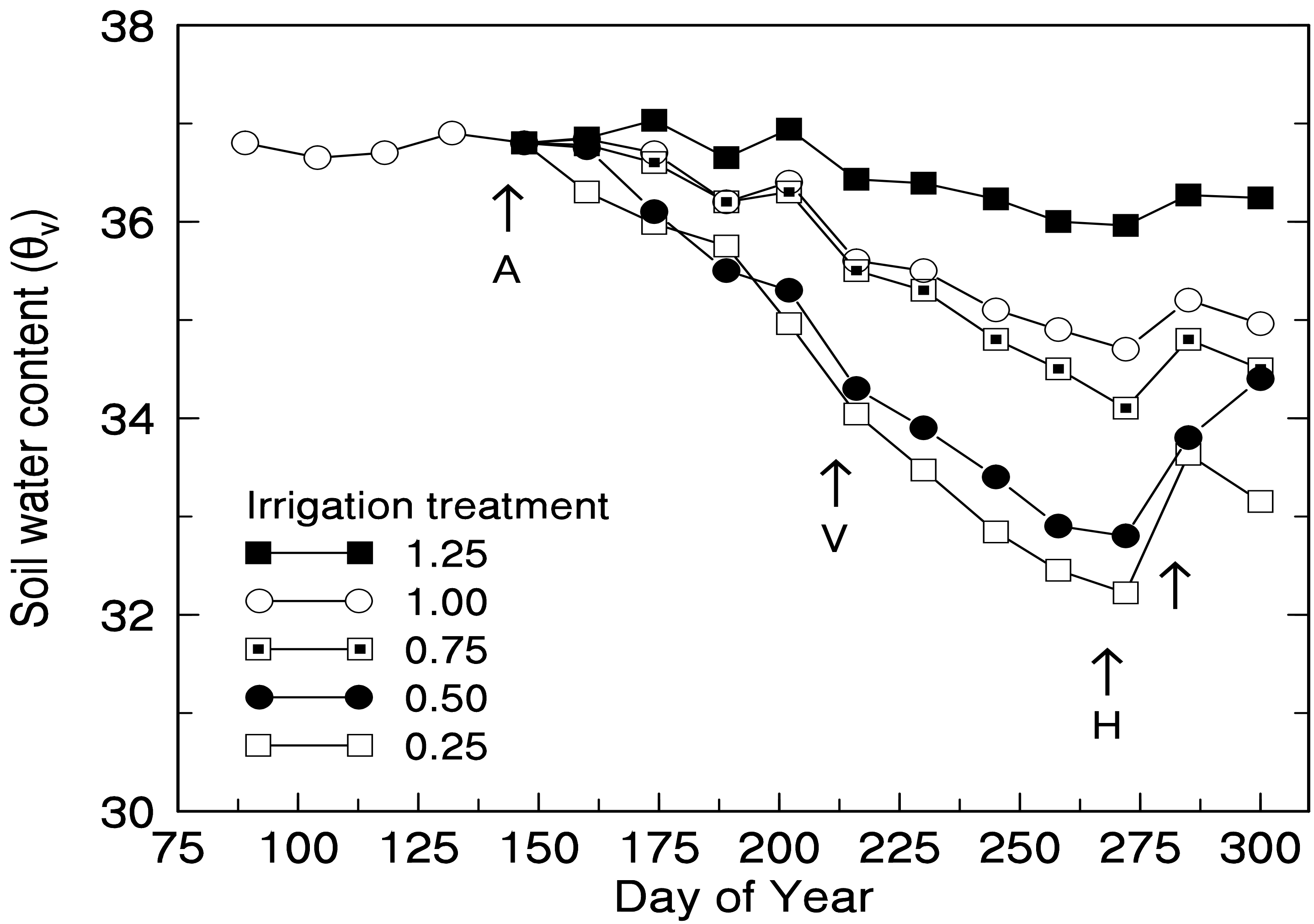
Access tube arrangement for Thompson Seedless vines with 2.15 m between vines and 3.51 m between rows. Tube depth is 3 m with nine tubes per site.

Access tube arrangement for Chardonnay vines with 1.52 m between vines and 2.13 m between rows. Tube depth is 3 m with six tubes per site.



Vines were irrigated with applied water amounts at 0.2, 0.6, 1.0 and 1.4 of measured ET_{c}. The arrow indicates when irrigation commenced.





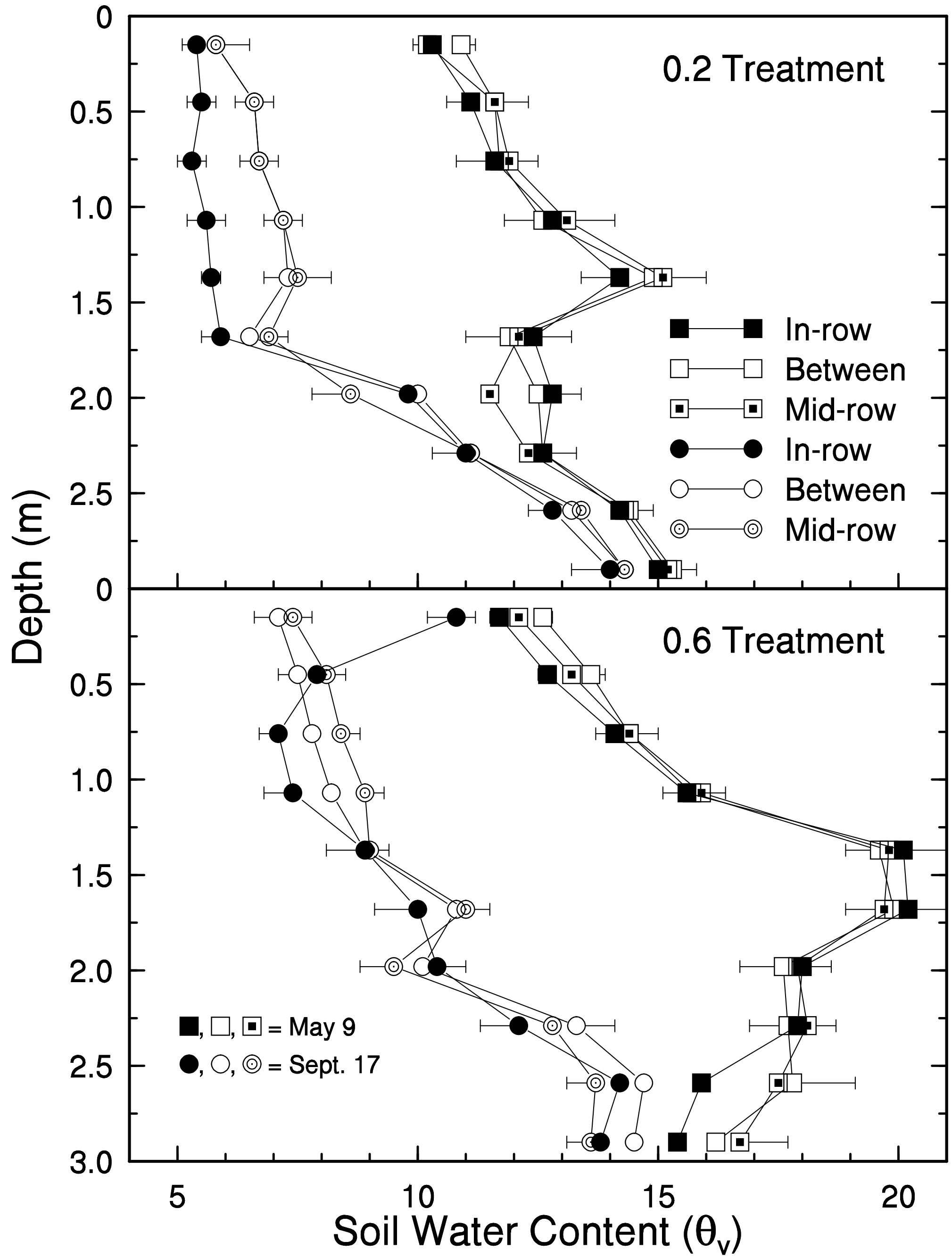
Soil water content during the growing season in a Chardonnay Vineyard. The vines were irrigated at 1.25, 1.0, 0.75, 0.5 and 0.25 of estimated ET_c. The arrows indicate the approximate dates of anthesis (A), veraison (V) and harvest (H). The last arrow denotes a rainfall event (~ 29 mm).

Question: How deep in the soil profile do grapevines use water and is soil water content related to measures of vine water status?

Access tube arrangement for Thompson Seedless vines with 2.15 m between vines and 3.51 m between rows. Tube depth is 3 m with nine tubes per site.

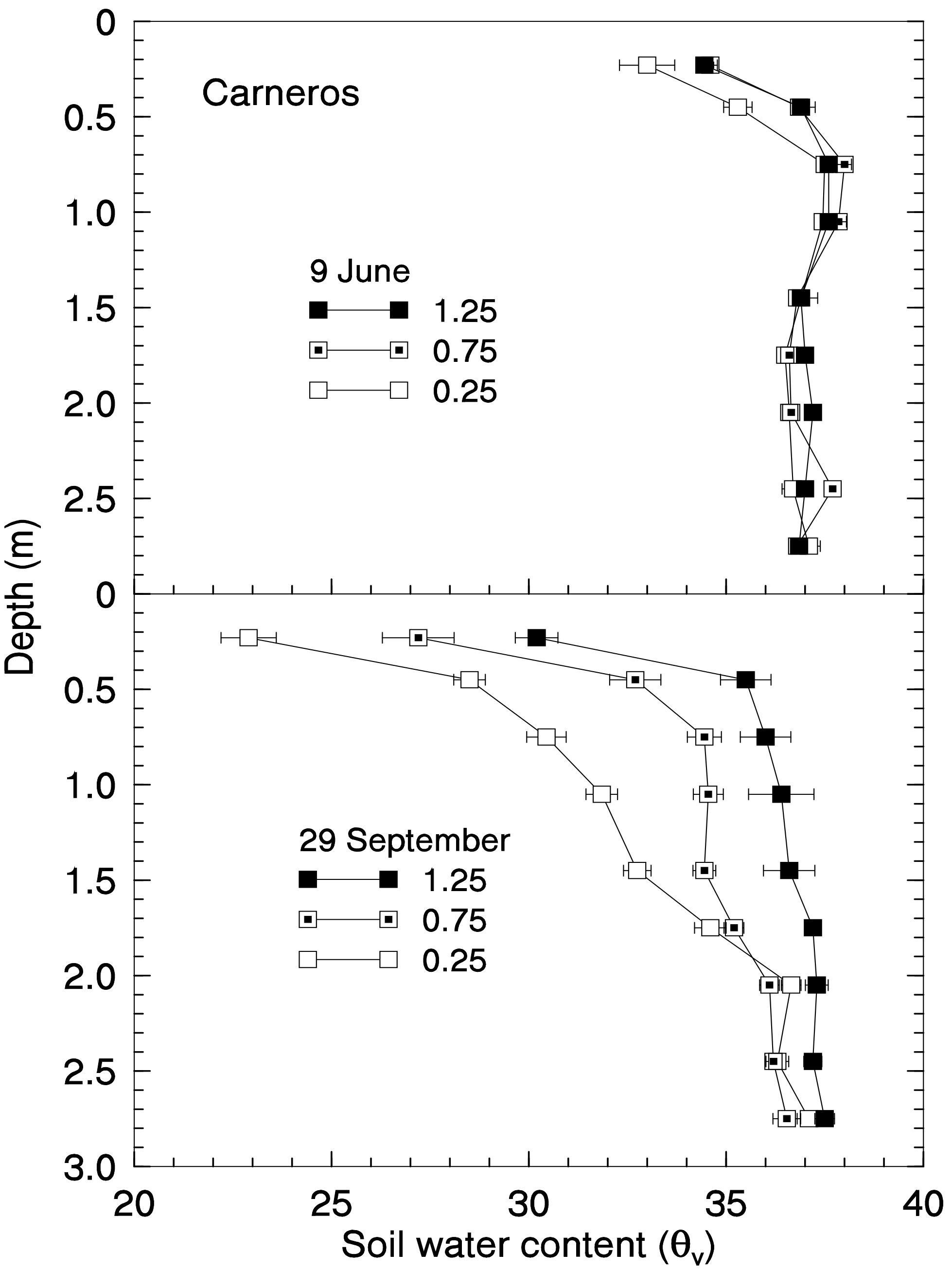
Kearney Ag Center

(vines were drip irrigated multiple times daily at the fraction of measured ET_c given in the graph)



Chardonnay Vineyard Carneros:

(vines were drip irrigated one to two times a week)



Comments on root distribution and measured soil water content

- The majority of roots were located in the top 1 m of soil profile and 1 m out from the vine into the middle of the row.
- Soil water was depleted in the deficit irrigated treatments to a depth of 3 m and out to the middle of the row.
- No one access tube or any particular depth was representative of the mean SWC of all nine access tubes.

c.) Monitoring Vine Water Status:

Currently, many individuals and consultants in California are measuring vine water status (leaf water potential) with a pressure chamber to aid in irrigation management.

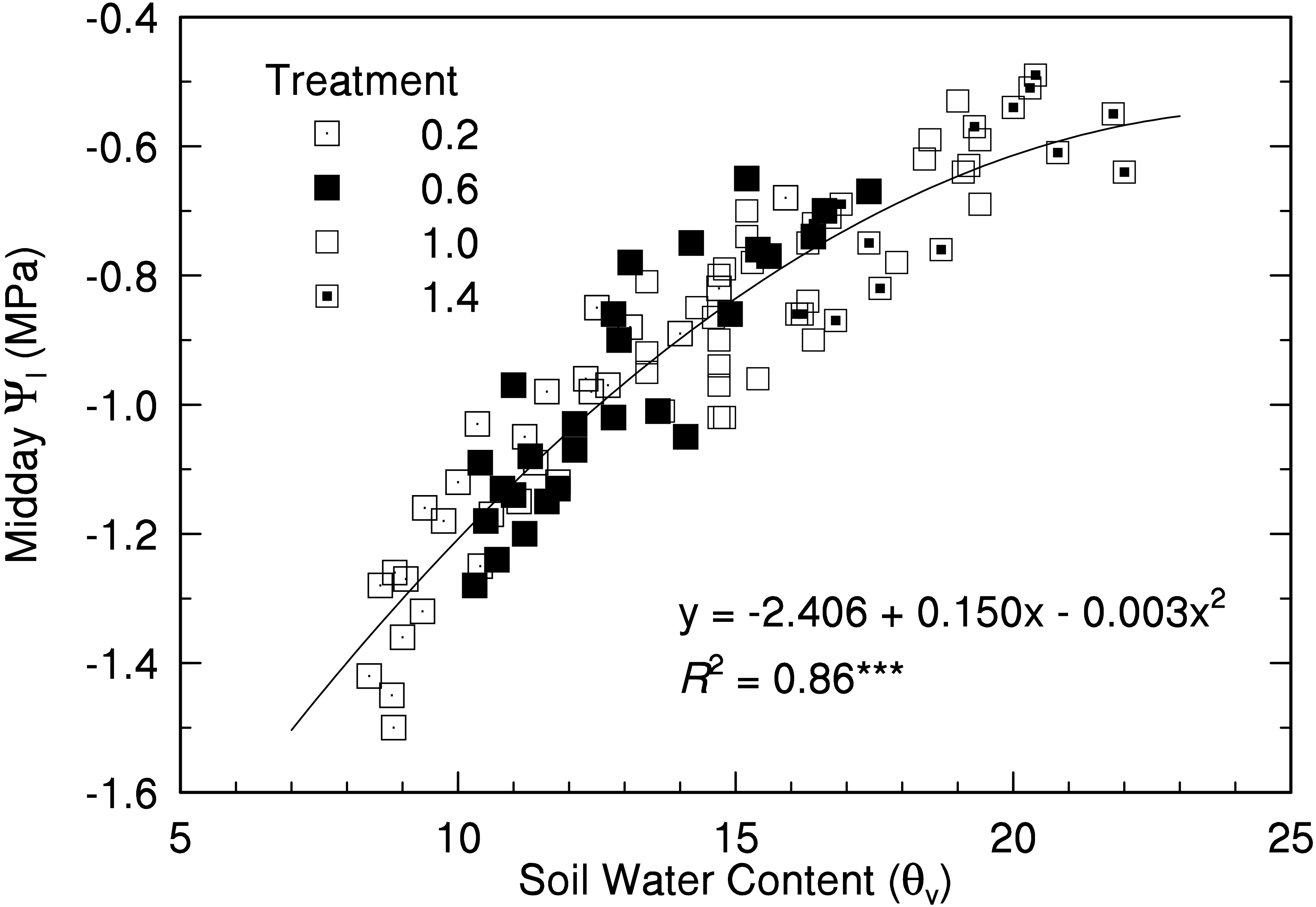
Therefore, the technique used by these growers to measure vine water status is important and may be dependent upon the type and frequency of irrigation, particularly the use of pre-dawn leaf water potential (Ψ_{PD}).

c.) Measuring vine water status with a pressure chamber

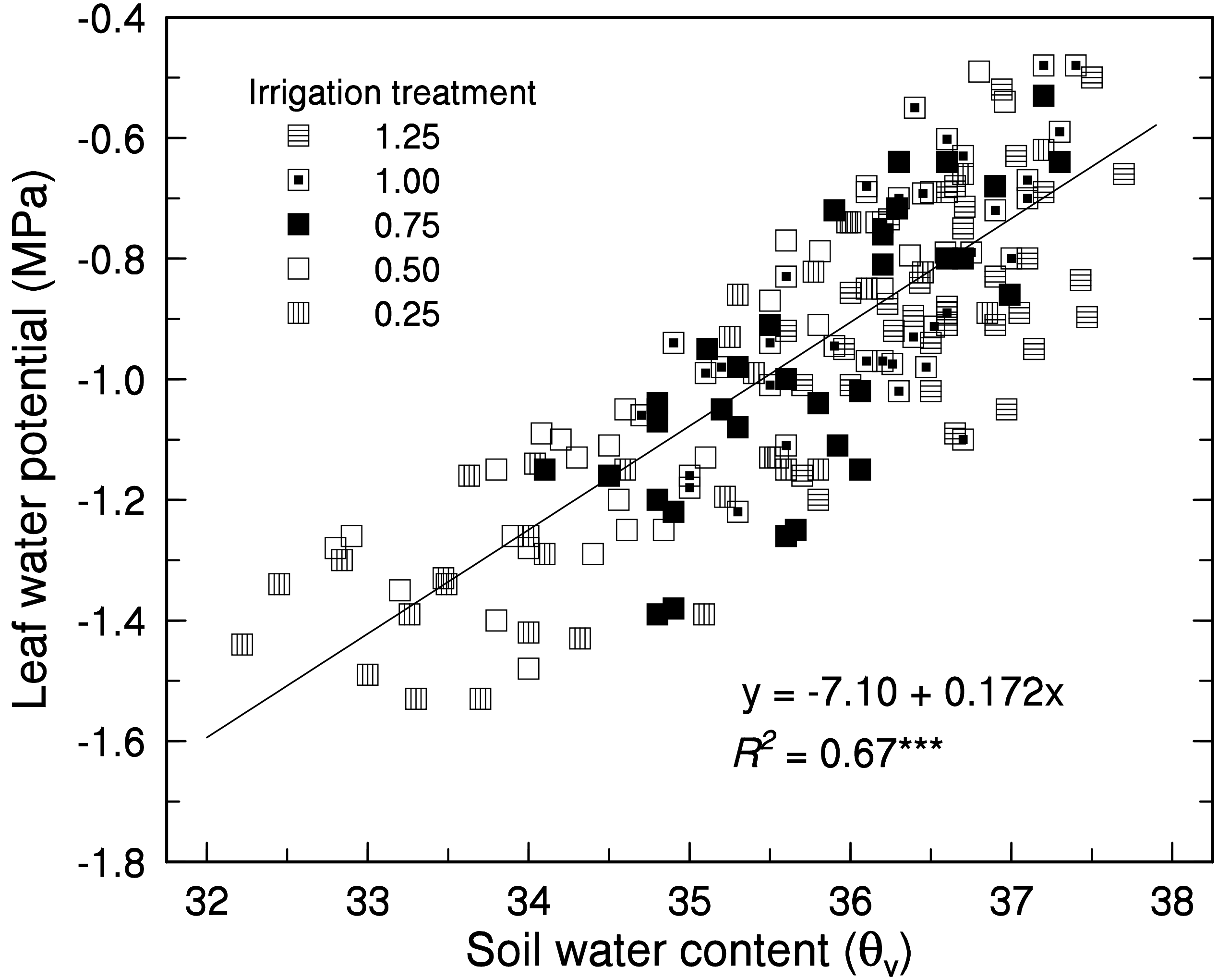
- Pre-dawn leaf water potential - measurements taken prior to sunrise
- Midday leaf water potential - measurements taken when minimum daily would be recorded
- Stem water potential – leaf blade placed in a plastic bag covered with aluminum foil 30 to 60 minutes prior to measurement [assume leaf comes into equilibrium with that of the stem] and measurements taken at daily minimum

Plant based measurements of water status should reflect the amount of water available in the soil profile (Higgs and Jones, 1990; Jones 1990).

Thompson Seedless data



Chardonnay data



Relationships among predawn (Ψ_{PD}), midday leaf (Ψ_l), and midday stem (Ψ_{stem}) water potentials and mean soil matric potential (Ψ_π) of a Hanford fine sandy loam.

- $\Psi_{PD} = -0.059 + 0.94x$ (R^2 = 0.56 ***)
- Midday $\Psi_l = -0.476 + 5.72x$ (R^2 = 0.88 ***)
- Midday $\Psi_{stem} = -0.126 + 6.85x$ (R^2 = 0.83 ***)

- X in the above equations is soil matric potential

b.) Water budgeting

Estimates of vineyard water use and the amount of water available in the soil profile are needed when utilizing the water budgeting method to determine when to start irrigating the vineyard. Once the irrigation season begins, this method can be used to determine the intervals between irrigations and the amount of water to apply for flood or furrow irrigated vines.

Factors affecting vineyard water use (per land area).

- Evaporative demand
- Seasonal growth of the vine
  (function of temperature, i.e. degree days)
- Ultimate canopy size (trellis type)
- Spacing between rows
- Amount of water in the soil profile

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

$$ET_c = ET_o \times K_c$$

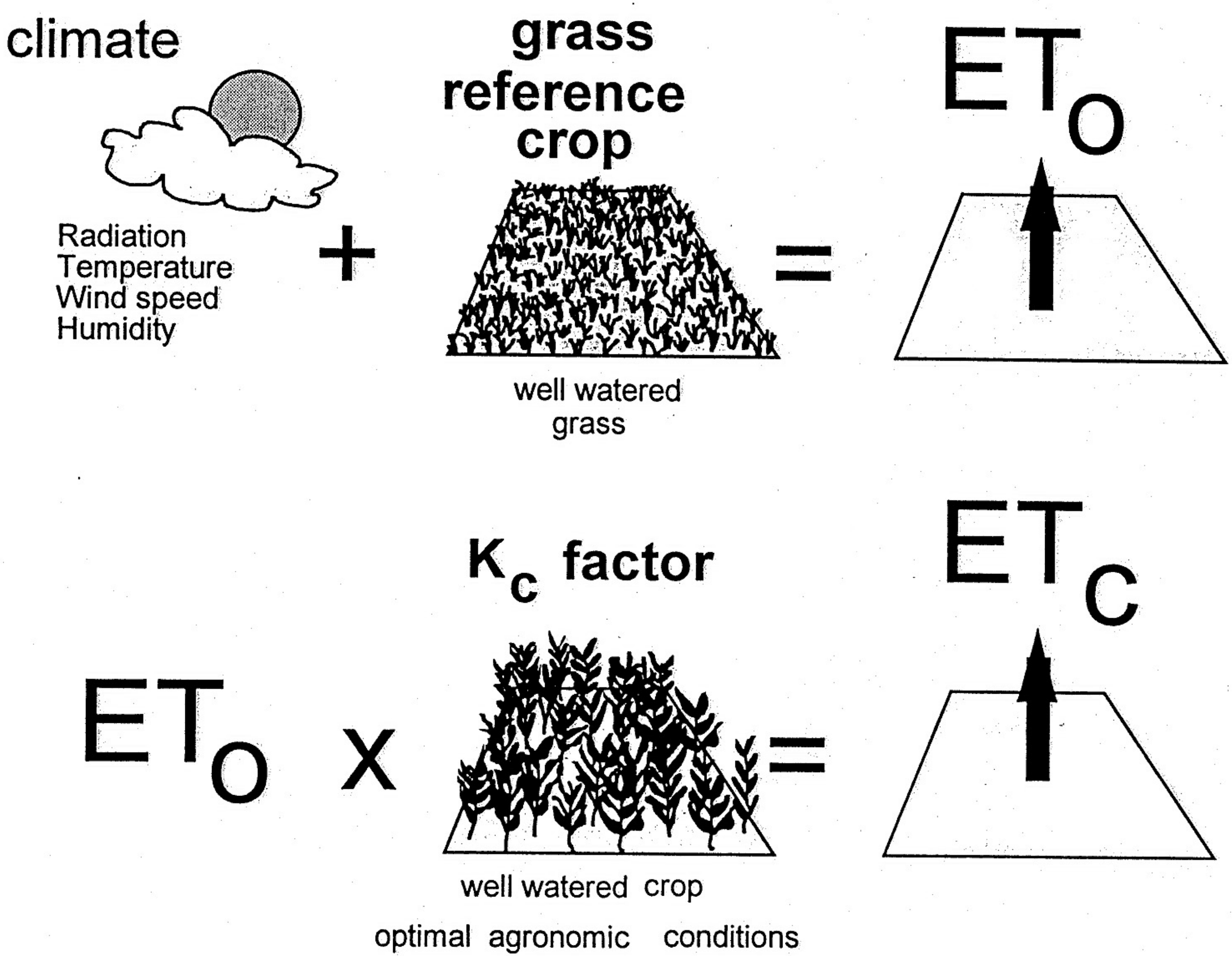
where ET_c = vineyard evapotranspiration, ET_o = reference evapotranspiration and K_c = crop coefficient. The above equation will give water requirements in inches (one acre inch = ~ 27,500 gallons per acre [43,560 ft^2]) (one mm covering one hectare = 10,000 L)

Evaporative Demand

- It is a function of net radiation, vapor pressure deficit and wind.
- Reference evapotranspiration (ET_o) is used as a measure of evaporative demand.
- ET_o can be obtained from a CIMIS weather station or by other means.

Crop Coefficient (K_c)

- The fraction of water used by a specific crop compared to that of ET_o at a given location
- $K_c = ET_c / ET_o$
- The K_c depends upon stage of crop development, degree of cover, crop height and canopy resistance.


climate
Radiation
Temperature
Wind speed
Humidity
+
grass reference crop
well watered grass
=
ET_O
ET_O X
K_c factor
well watered crop
optimal agronomic conditions
=
ET_C

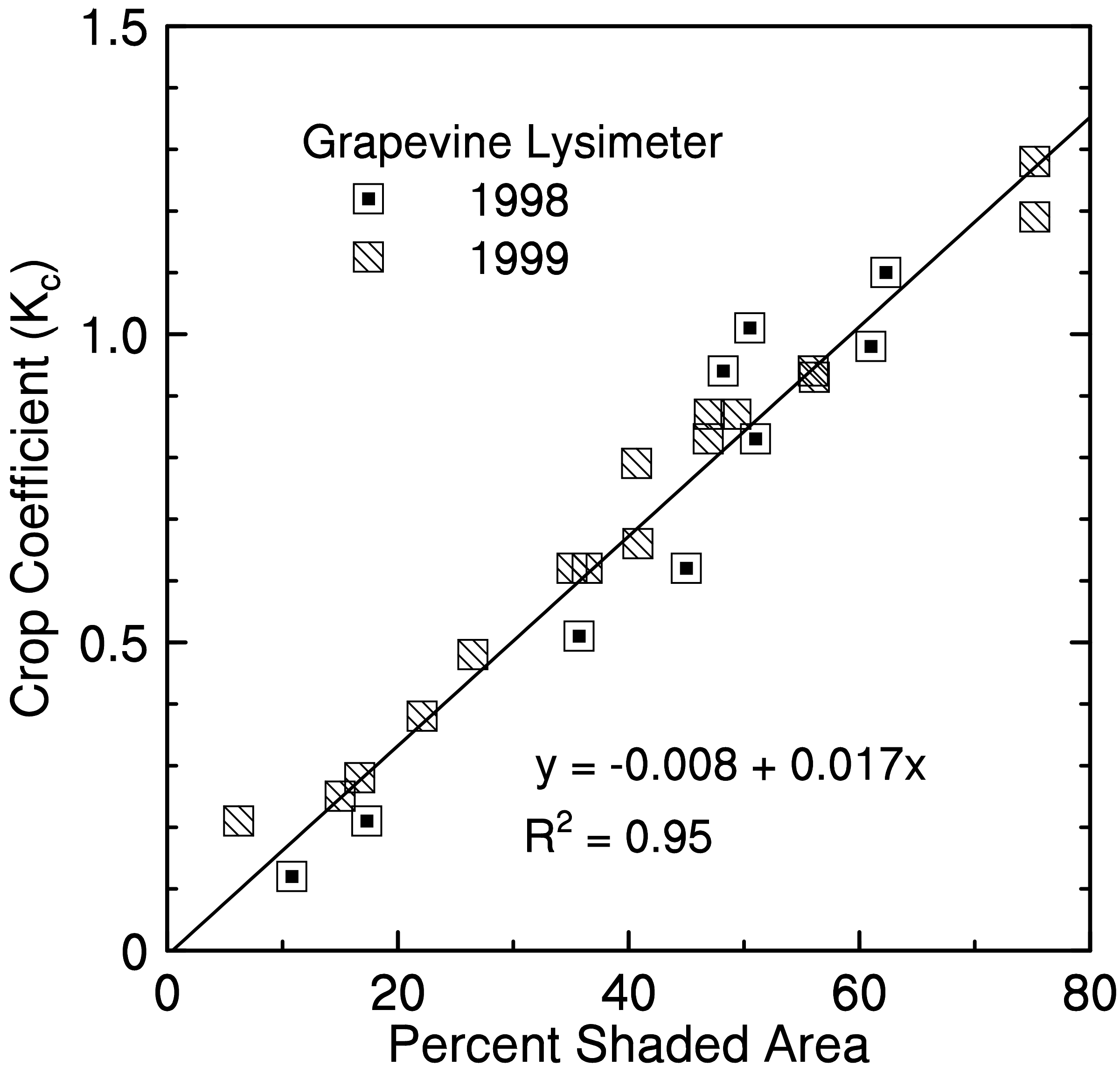
$ET_c = ET_o \times K_c$

- The above equation predicts ET_c under standard conditions. This represents conditions where no limitations are placed on crop growth or ET due to water shortage, crop density, or disease, weed, insect or salinity pressures.

Reliable crop coefficients should take the following into account:

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

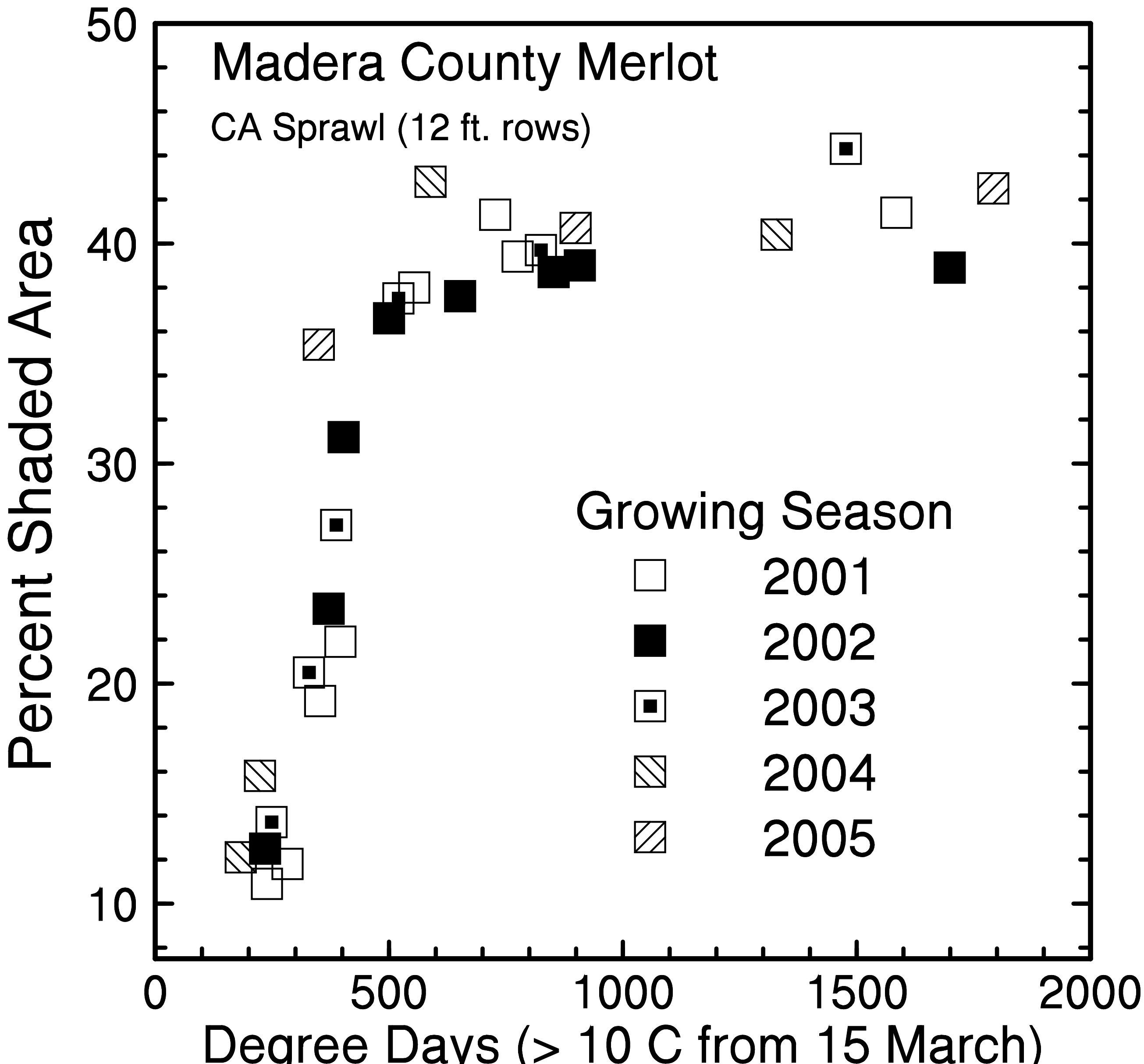
Technique I used for estimating crop coefficients (K_c) for vineyards.

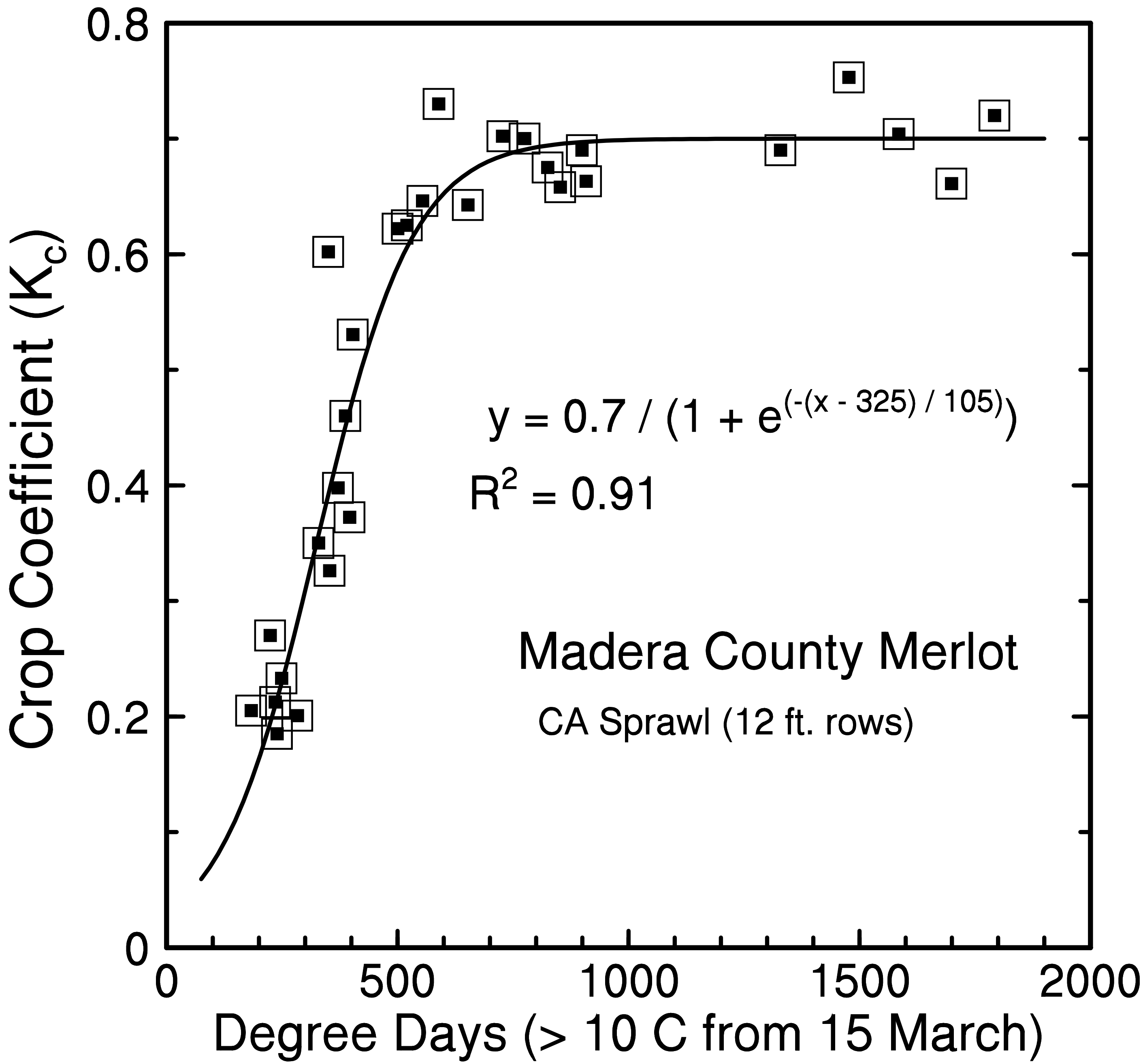


Williams and Ayars (2005) Agric. For. Meteor. 132:201-211.

Other estimates of K_cs using ground cover

- Ayars et al. (2003) Irrig. Sci. 22, 187–194. The estimated slope would be 0.016. (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; $K_c = 0.076 + 0.019x$.


Madera County Merlot
CA Sprawl (12 ft. rows)
Growing Season
2001
2002
2003
2004
2005
Percent Shaded Area
Degree Days (> 10 C from 15 March)
10
20
30
40
50
0
500
1000
1500
2000



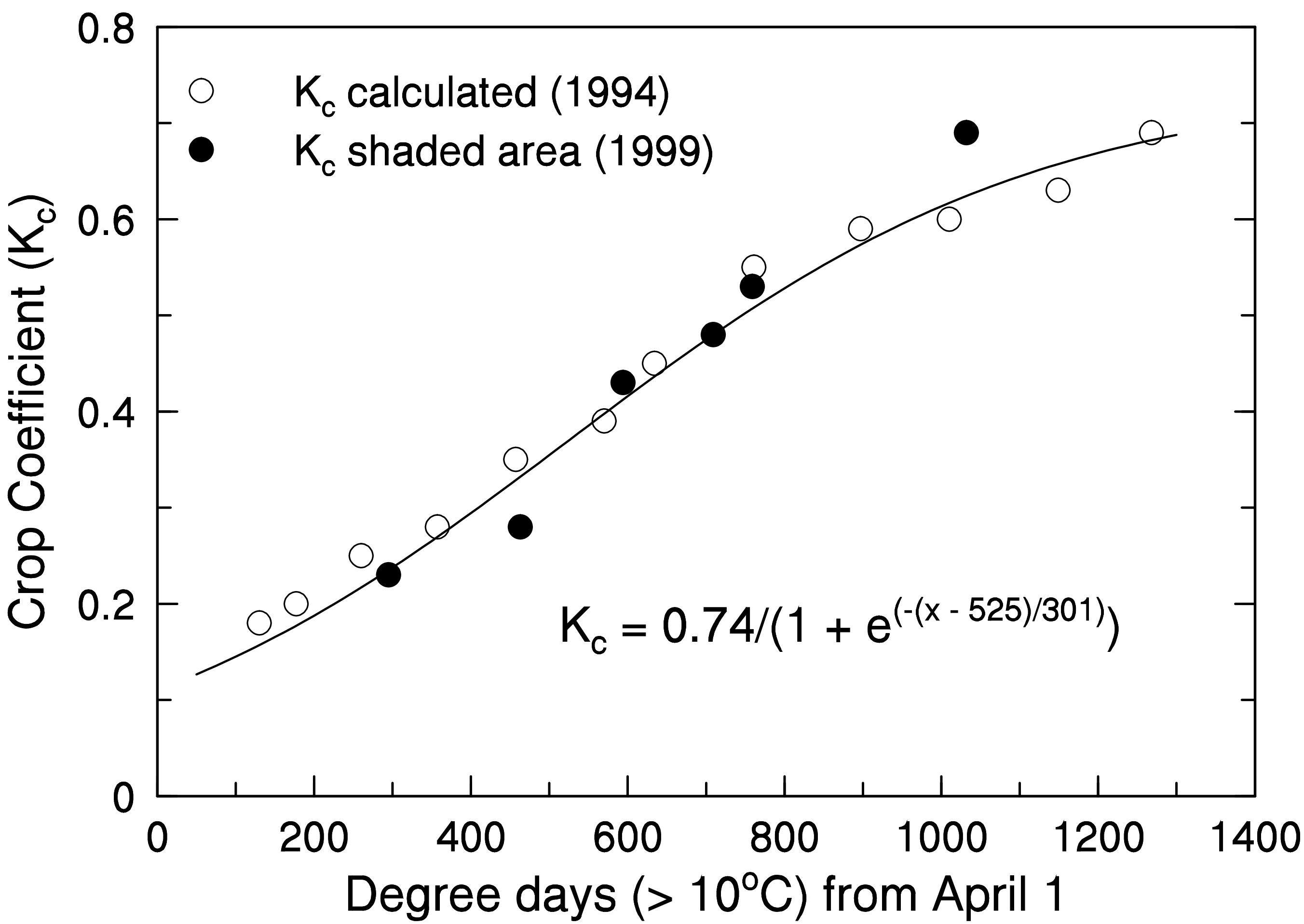
Max K_c:
11 ft row = 0.76
10 ft row = 0.84

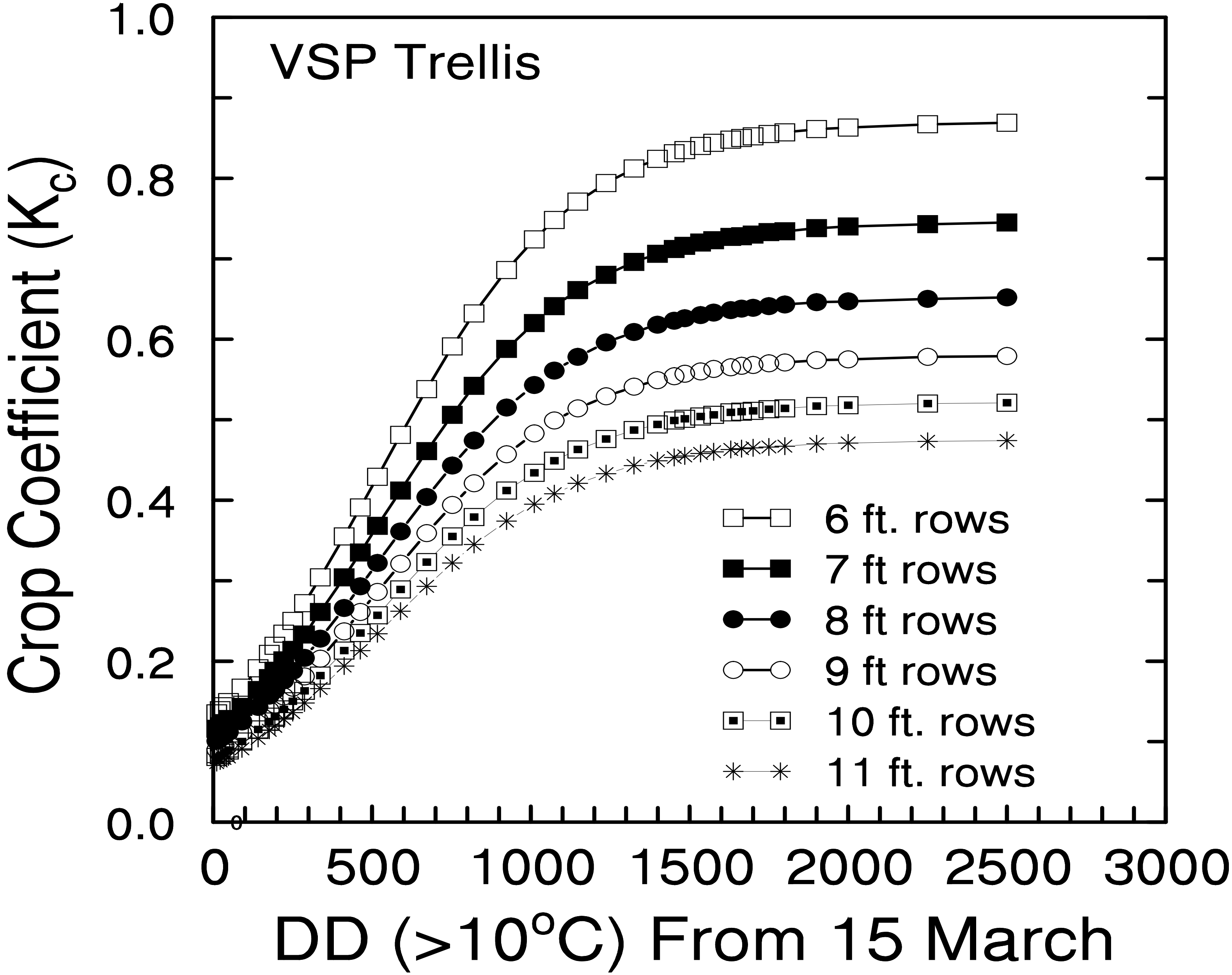
"It can be concluded that measuring canopy cover is a reliable approach to estimate K_c values in grapevines. The use of growing degree-days should improve the precision of the estimate by removing year to year variation in crop development."

López-Urrea et al. (2012) Agric. Water Man. 112:13-20.

The above has 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.

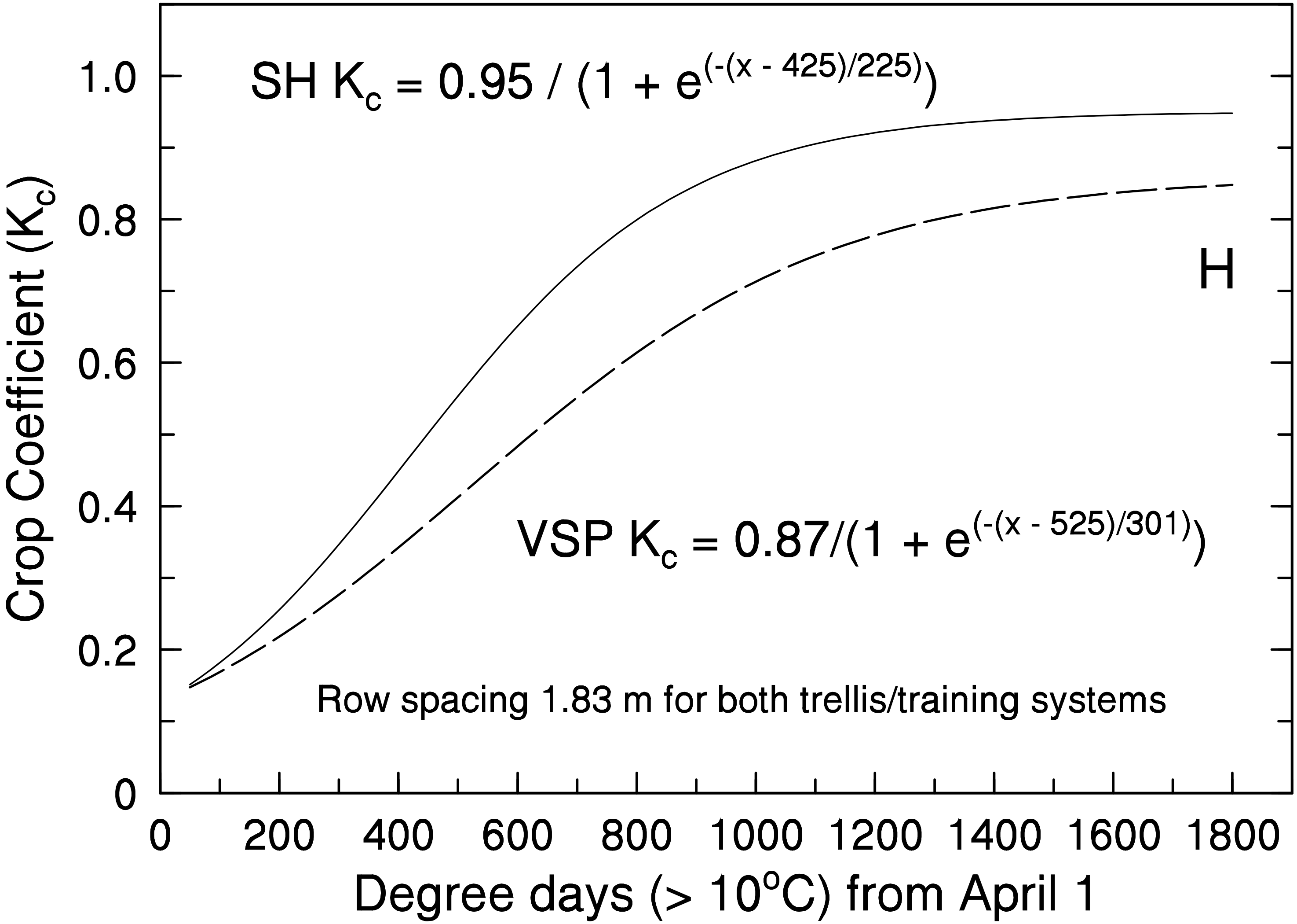
Seasonal crop coefficient developed in Carneros using the soil water budget method for VSP trained Chardonnay vines in 1994 on a 2.13 m row spacing. The black circles represent K_cs calculated from shaded area. Note that the maximum K_c is 0.74. The line represents a regression through the data points from 1994.



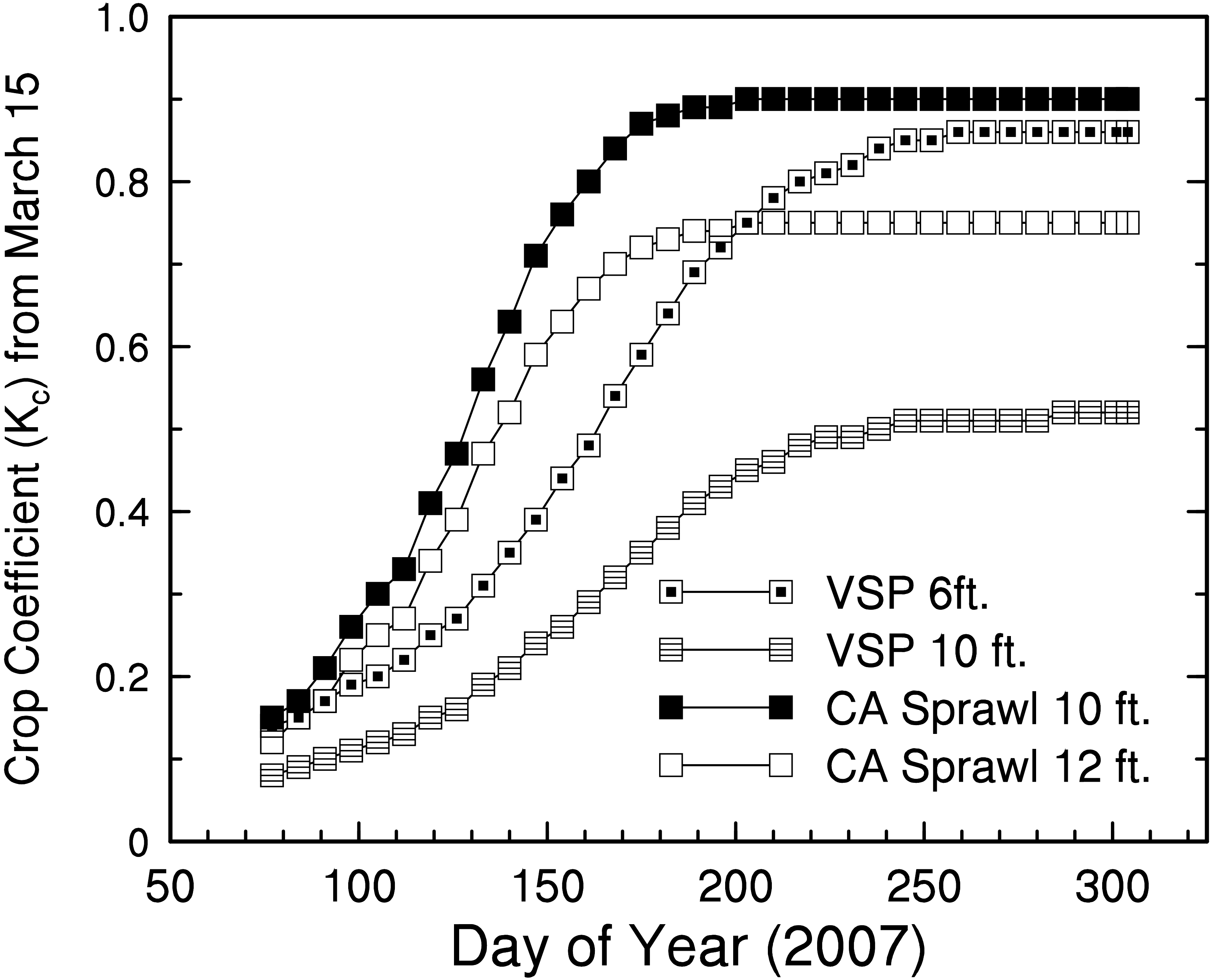

VSP Trellis
Crop Coefficient (K_c)
1.0
0.8
0.6
0.4
0.2
0.0
0
500
1000
1500
2000
2500
3000
DD (>10^{o}C) From 15 March
6 ft. rows
7 ft rows
8 ft rows
9 ft rows
10 ft. rows
11 ft. rows

Several canopy types in Viticulture

Scott-Henry (SH) and VSP trellises



1.83 m = 6 ft.



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

How much water is used by vines as a function of phenology throughout the growing season?

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
		10		38		89	

ET_c ranged from 32 to 34 inches across years

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). 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 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

What is the relationship between vineyard ET_c (or applied water amounts) and productivity?

Water use of Chardonnay grapevines as a function of irrigation treatment and year.

Year (rain)	Irrigation Treatment	Yield	Soil H_2O	Applied H_2O	ET_c
		t/acre	(mm)	(mm)	(mm) (in)
1994	0.25	7.08	141	86	227 (8.94 in)
(10.0 in)	0.5	7.44	105	155	260 (10.2 in)
	0.75	9.04	71	236	307 (12.1 in)
	1.0	7.79	54	302	356 (14.0 in)
	1.25	8.06	23	378	401 (15.8 in)
1995	0.25	9.26	139	163	322 (12.7 in)
(35.1 in)	0.5	9.44	126	226	352 (13.9 in)
	0.75	10.2	103	257	360 (14.2 in)
	1.0	9.62	98	312	410 (16.1 in)
	1.25	9.97	54	356	410 (16.1 in)
1996	0.25	4.94	129	115	244 (9.61 in)
(24.4 in)	0.5	4.76	77	191	268 (10.6 in)
	0.75	5.11	71	282	353 (13.9 in)
	1.0	5.11	51	352	403 (15.9 in)
	1.25	5.52	14	482	496 (19.5 in)
1997	0.25	9.12	132	134	266 (10.5 in)
(22.1 in)	0.5	9.93	127	205	332 (13.1 in)
	0.75	9.40	75	312	387 (15.2 in)
	1.0	9.89	52	471	523 (20.6 in)
	1.25	11.2	40	514	554 (21.8 in)

ET_c of Chardonnay grapevines as a function of irrigation treatment and year. The separation of ET_c into water derived from the soil and that applied is also given.

Year (rain)	Irrigation Treatment	Yield (t/acre)	Soil H_2O (mm)	Applied H_2O (mm)	ET_c (mm)
1998 (35.5 in)	0	6.99	260	0	260 (10.2 in)
	0.5	7.52	201	105	306 (12.0 in)
	1.0	7.88	165	232	397 (15.6 in)
1999 (19.3 in)	0	4.85 b	249	0	249 (9.80 in)
	0.5	6.23 a	198	147	345 (13.6 in)
	1.0	6.59 a	155	294	449 (17.7 in)
2000 (19.6 in)	0	3.96 c	--	--	--
	0.5	6.81 b	--	153	-
	1.0	8.14 a	--	298	-
2001 (12.8 in)	0	3.56 c	--	--	--
	0.5	6.06 b	--	165	-
	1.0	7.31 a	--	320	-

260 mm = 841 l/vine (222 gal./vine) (vine x row = 5’ x 7’)

ET_c of Thompson Seedless grapevines as a function of irrigation treatment and year. The separation of ET_c into water derived from the soil and that applied is also given.

Year (rain)	Irrigation Treatment	Yield (t/acre)	Soil H_2O (mm)	Applied H_2O (mm)	ET_c (mm)
1990 (8.9 in)	0.2	10.8 c	167	99	266 (10.5 in)
	0.6	18.6 b	180	237	417 (16.4 in)
	1.0	22.2 a	158	416	574 (22.6 in)
1991 (10.3 in)	0.2	3.8 c	132	134	266 (10.5 in)
	0.6	13.1 b	97	383	480 (18.9 in)
	1.0	18.2 a	41	632	673 (26.5 in)
1992 (10.7 in)	0.2	11.9 b	132	112	244 (9.61 in)
	0.6	21.2 a	101	304	405 (15.9 in)
	1.0	23.8 a	161	477	638 (25.1 in)
1993 (15.9 in)	0.2	12.3 c	190	149	339 (13.3 in)
	0.6	22.3 a	150	432	582 (22.9 in)
	1.0	18.5 b	131	698	829 (32.6 in)

266 mm = 2000 l/vine (531 gal./vine) (vine x row = 2.15 x 3.51 m [~7x11.5 ft.])

The effect of irrigation amount, cultivar and year on productivity of grapevines grown in Napa County. Values in parentheses (in green) to the right of yield are percent of the 1.0 and 1.5 irrigation amount treatments at Carneros and Oakville, respectively. The values (in pink) to the right of the 1.0 and 1.5 irrigation treatments at Carneros and Oakville, respectively, are yields in tons per acre.

Location/ Year	Irrigation Treatment (fraction of estimated ET_c)					
	0.0	0.25	0.5	0.75	1.0	1.5
Carneros	Yield (kg 3 vines^{-1})					
1998	15.2 (88)	---	16.5 (95)	---	17.3 (7.9)	---
1999	10.6 (74)	---	13.7 (95)	---	14.4 (6.6)	---
2000	8.7 (49)	---	14.9 (84)	---	17.8 (8.1)	---
2001	7.8 (49)	---	13.2 (83)	---	15.9 (7.3)	---
Oakville						
1998	4.83 (62)	5.93 (76)	7.71 (99)	7.24 (93)	6.93 (89)	7.79 (6.4)
1999	3.66 (70)	4.50 (86)	5.15 (99)	5.24 (100)	6.21 (119)	5.22 (4.3)
2000	5.27 (74)	5.20 (73)	6.61 (93)	8.30 (116)	6.67 (94)	7.31 (6.0)
2001	3.11 (50)	5.26 (85)	7.08 (114)	6.86 (110)	6.68 (108)	6.21 (5.1)

Oakville vine and row spacings are 1 m and 6 ft., respectively.

Goal of irrigation management

- Your goal should be to grow vines with a uniform degree and pattern of water stress every season (the degree of stress determined by the grower).
- To do this, you need to adjust irrigation timing and amounts to take into account unique growing conditions in any given season.
- Weather (evaporative demand and temperature) is the variable component that exerts the most influence on irrigation requirements during the season.

Seasonal precipitation, degree days (DDs) from 1 April and reference ET (ET_o) and estimated ET_c (1 April to 1 Nov.) of a Chardonnay vineyard in Carneros. (vine x row is 5' x 7')

Year	Seasonal Precipitation Nov - Mar	Seasonal Precipitation From 1 Apr	DDs	ET_o	Estimated ET_c
	---------- (mm) ----------		(> 10 C)	---------- (mm) ---------	
1994	192 (7.6 in)	61 (2.4 in)	1408	1067	432 (17.0 in)
1995	843 (33.2 in)	47 (1.9 in)	1522	1032	447 (17.6 in)
1996	480 (18.9 in)	139 (5.5 in)	1548	1009	455 (17.9 in)
1997	522 (20.6 in)	38 (1.5 in)	1675	1066	503 (19.8 in)
1998	819 (32.2 in)	85 (3.3 in)	1369	885	346 (13.6 in)
1999	436 (17.2 in)	53 (2.1 in)	1357	988	378 (14.9 in)
2000	427 (16.8 in)	72 (2.8 in)	1446	975	410 (16.1 in)
2001	308 (12.1 in)	19 (0.7 in)	1519	1057	462 (18.2 in)
				1009	429 (16.9 in)

Available water to a depth of 2.75 m was estimated to be 275 mm (10.8 in) in this vineyard.

ET_c of 429 mm (16.9 in) is equivalent to 1390 L/vine or 368 gal/vine in this vineyard.

Things you can do to assist in irrigation management.

- Get an estimate of ET for your vineyard(s).
- Collect degree days from budbreak each year and determine DDs as a function of phenological events.
- Download ET_o data from closest CIMIS station (or other means).
- Download rainfall amounts/events.
- Measure applied water amounts and record as a function of time (DDs).
- Using the above develop an irrigation coefficient.