Vineyard Irrigation

Principles, Practices, and Consequences

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Vineyard Irrigation

- The act of supplying or controlling water to the vineyard

Main Purpose:
Produce quality fruit

Vine Irrigation Strategies

- Full potential water use
- Withhold irrigation
  - Severity
    - Moderate vine water deficits
    - Severe vine water deficits
  - Timing
    - Early season
    - Mid season
    - Late season

Deficit Irrigation

- Supplying vines with less irrigation water than they can use.
  - Causing reduced soil moisture availability
  - Causing vine water stress

Purpose: Produce Quality Fruit

Vineyard Irrigation: Principles, Practices and Consequences

- Vine Water relations
- Vine Water use
- Vine Water deficits
  - Effects on fruit quality/yield
- How to develop a strategy to achieve consistent results
- When to begin irrigation
- How much to apply
- How to evaluate the strategy

Stress Threshold
Regulated Deficit Irrigation

- Measure plant stress
- Ability to estimate full potential vine water use
- Micro-irrigation System

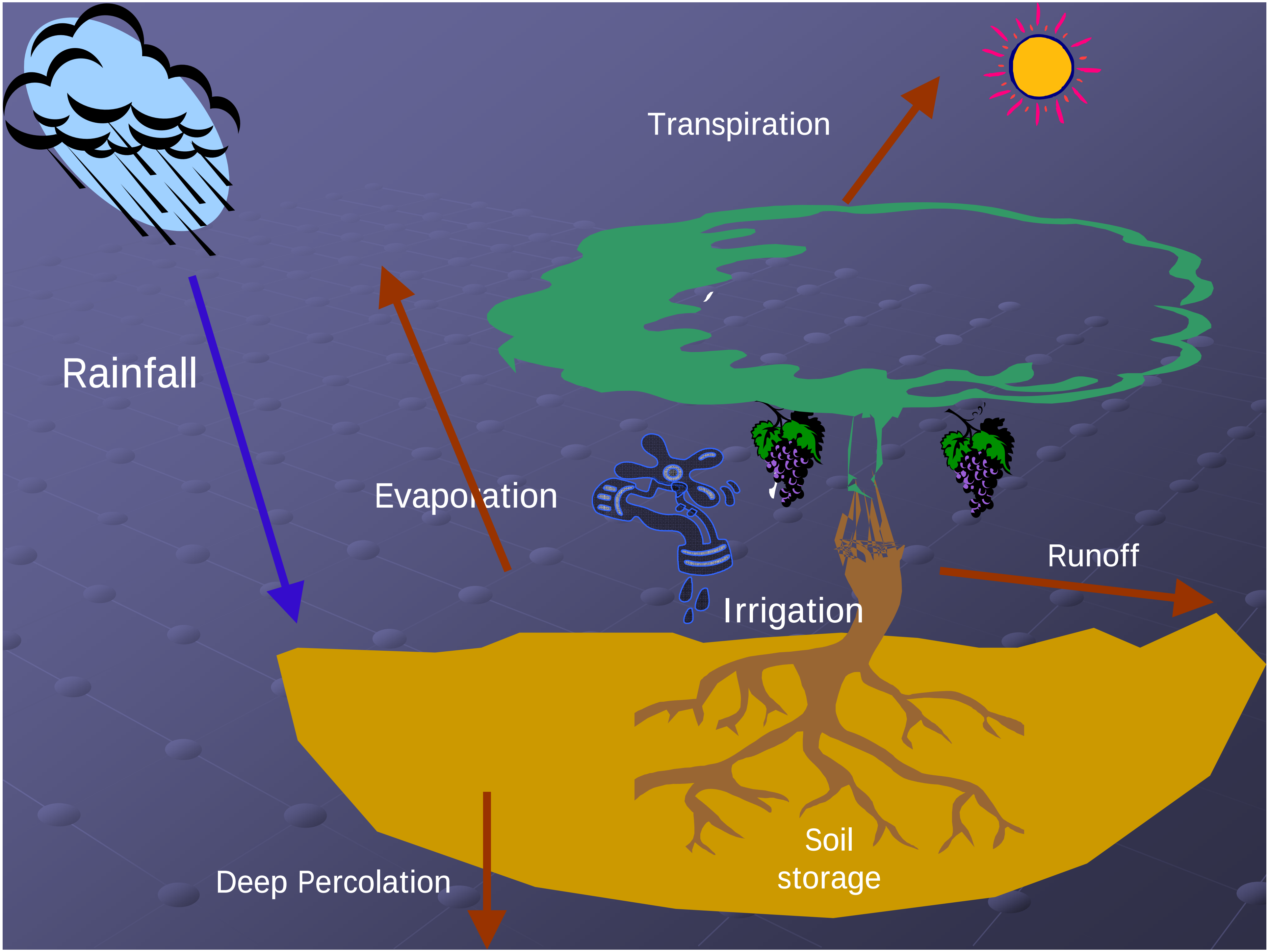
Simple Volumetric Model

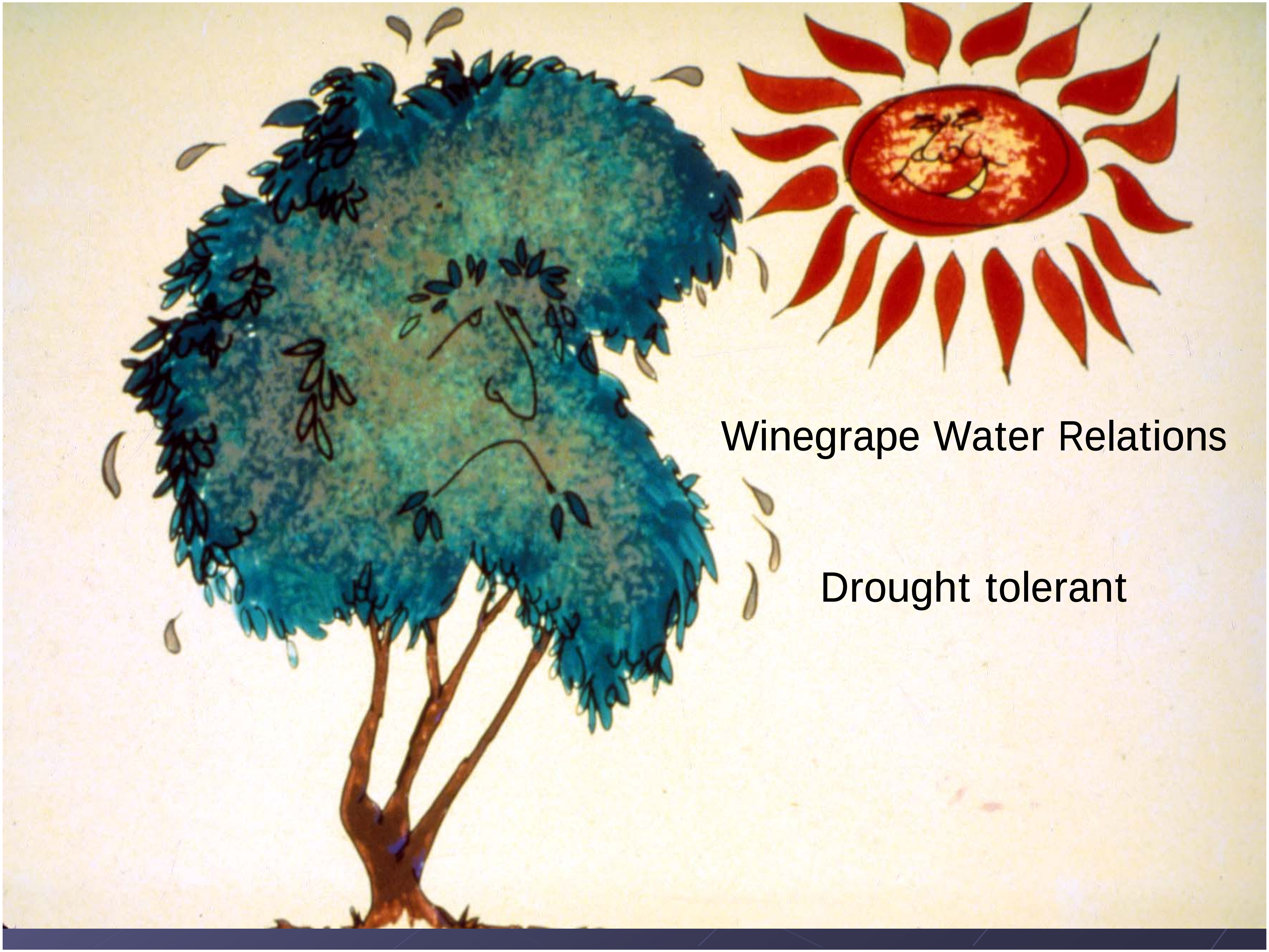
Soil Stored Moisture
In- season Effective Rainfall
Irrigation

=

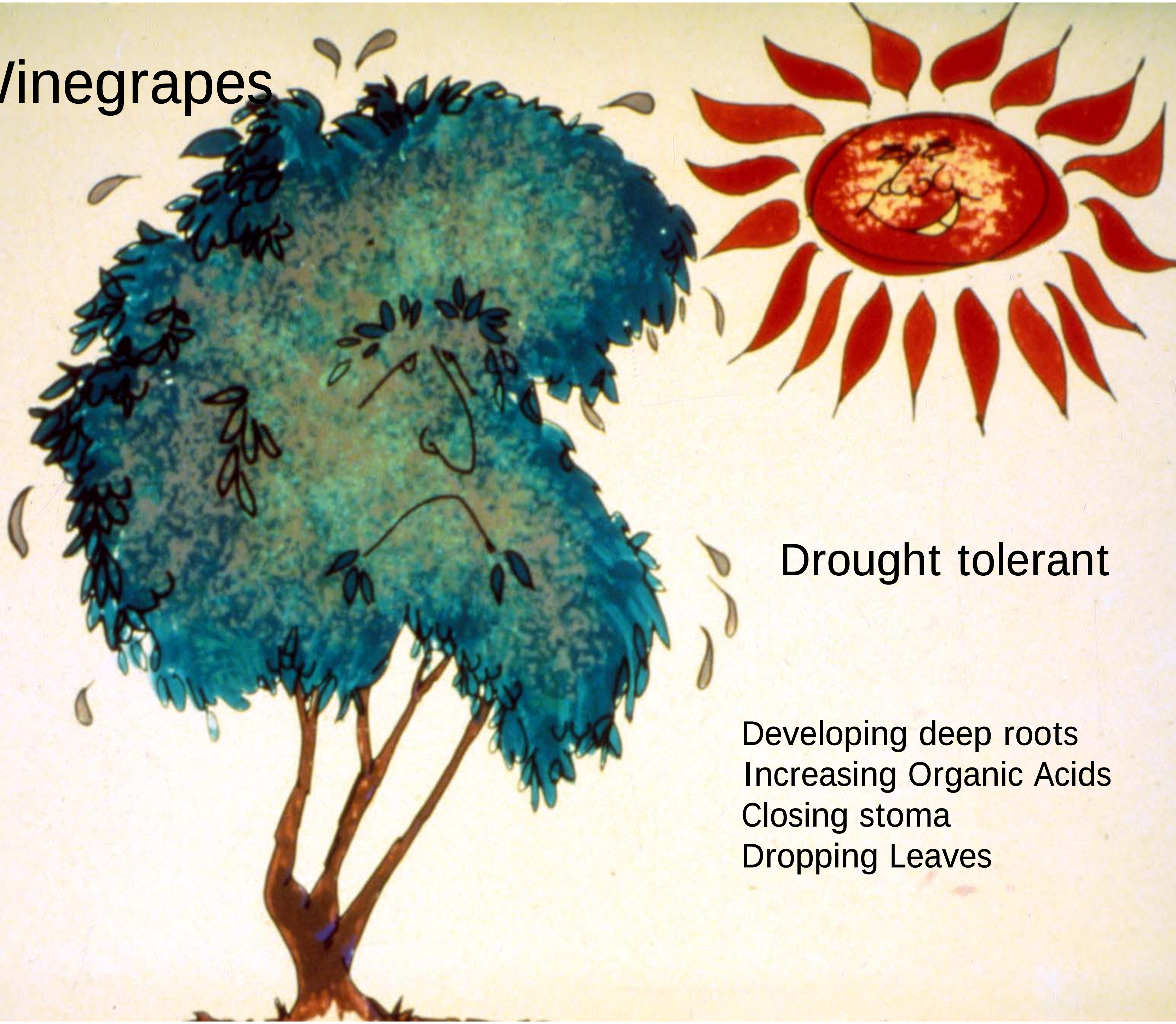
Vine Water Use

Evaporation
Transpiration


Transpiration
Rainfall
Evaporation
Runoff
Irrigation
Soil
storage
Deep Percolation

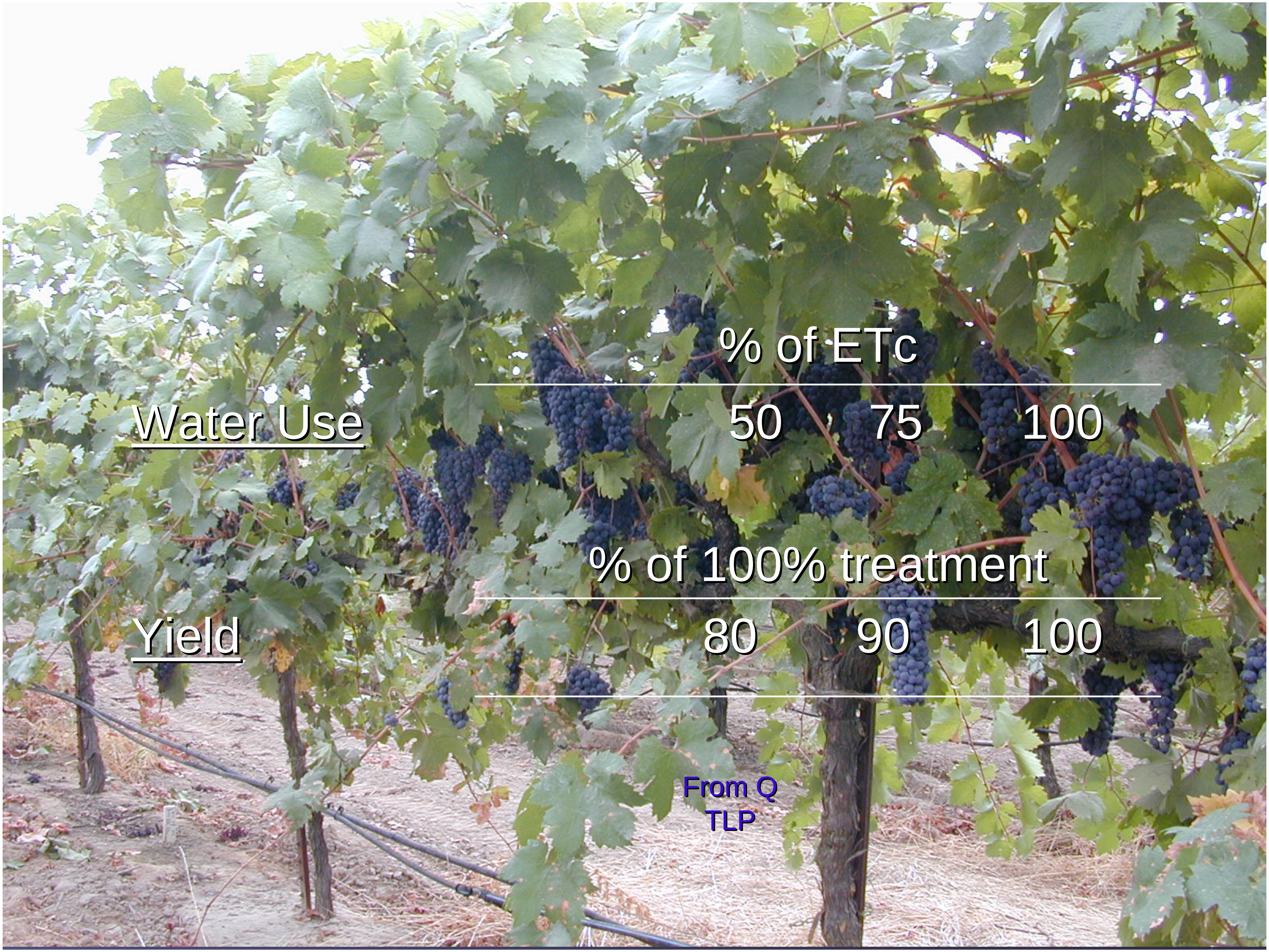

Winegrape Water Relations
Drought tolerant

Winegrapes



Drought tolerant

Developing deep roots
Increasing Organic Acids
Closing stoma
Dropping Leaves



	% of ETc		
Water Use	50	75	100
	% of 100% treatment		
Yield	80	90	100

From Q TLP

Physiological Role of Water in Vines

- Solvent--carrier for nutrients/gases
- Reactant in chemical reactions
  - Photosynthesis
- Support
  - Turgor/Growth
- Transpirational Cooling

Water Use

- 80-90% of tissue weight

- Transpiration

  Loss of water to the atmosphere

  90 % of uptake lost

1v=15-30 min

T=2º/min

Transpiration

Water movement

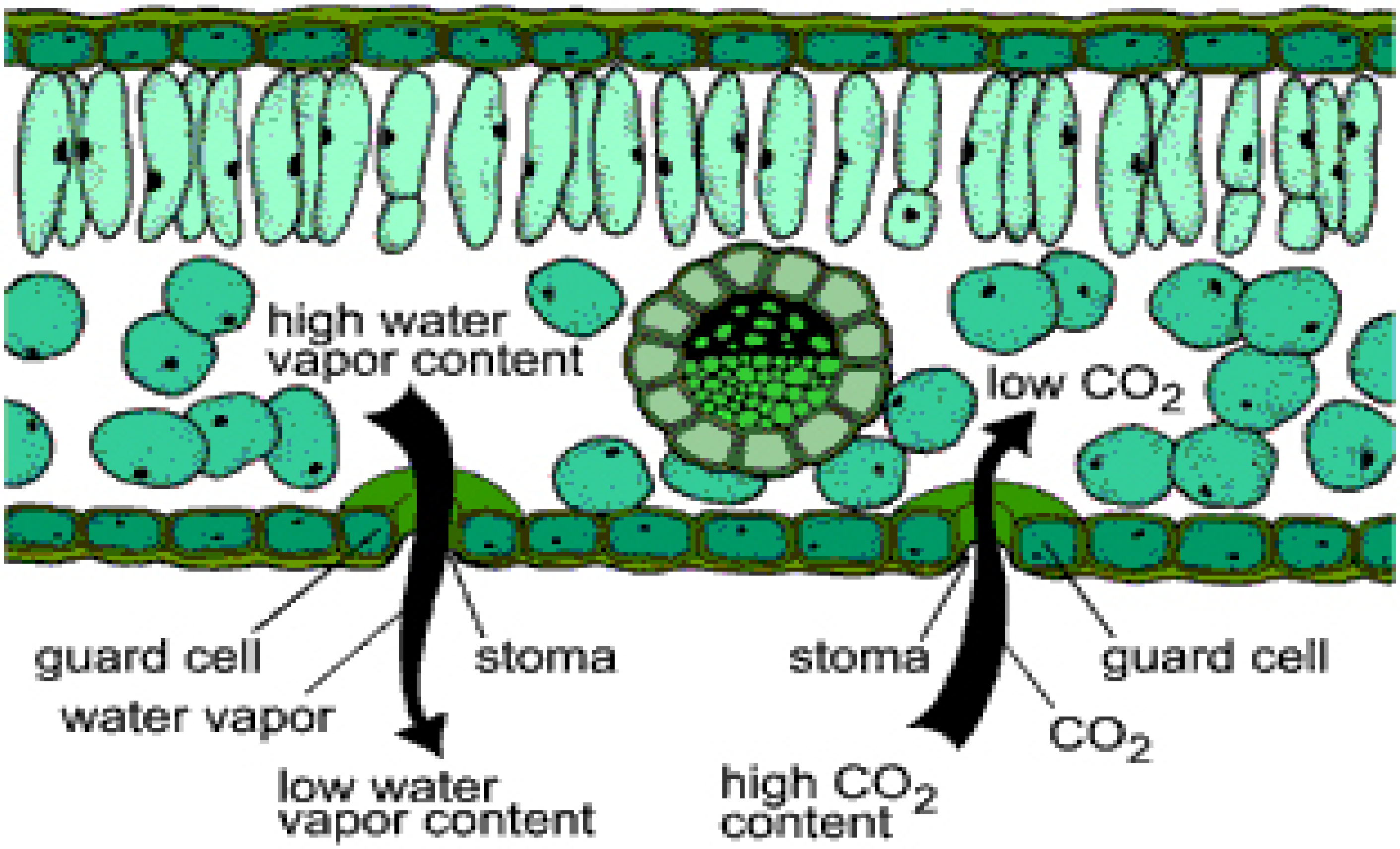


Figure 25. Stomata open to allow carbon dioxide (CO_2) to enter a leaf and water vapor to leave.

Photosynthesis

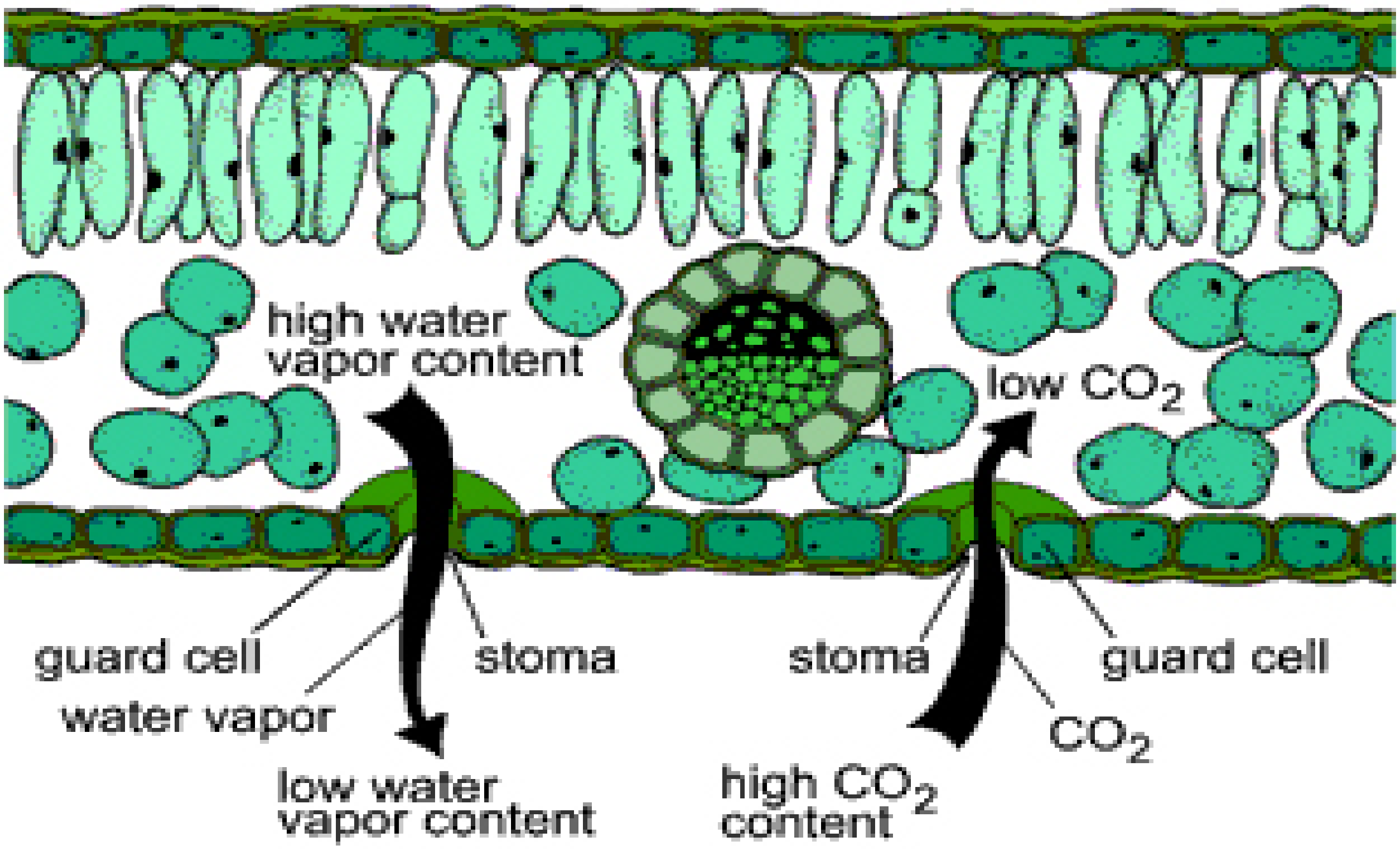
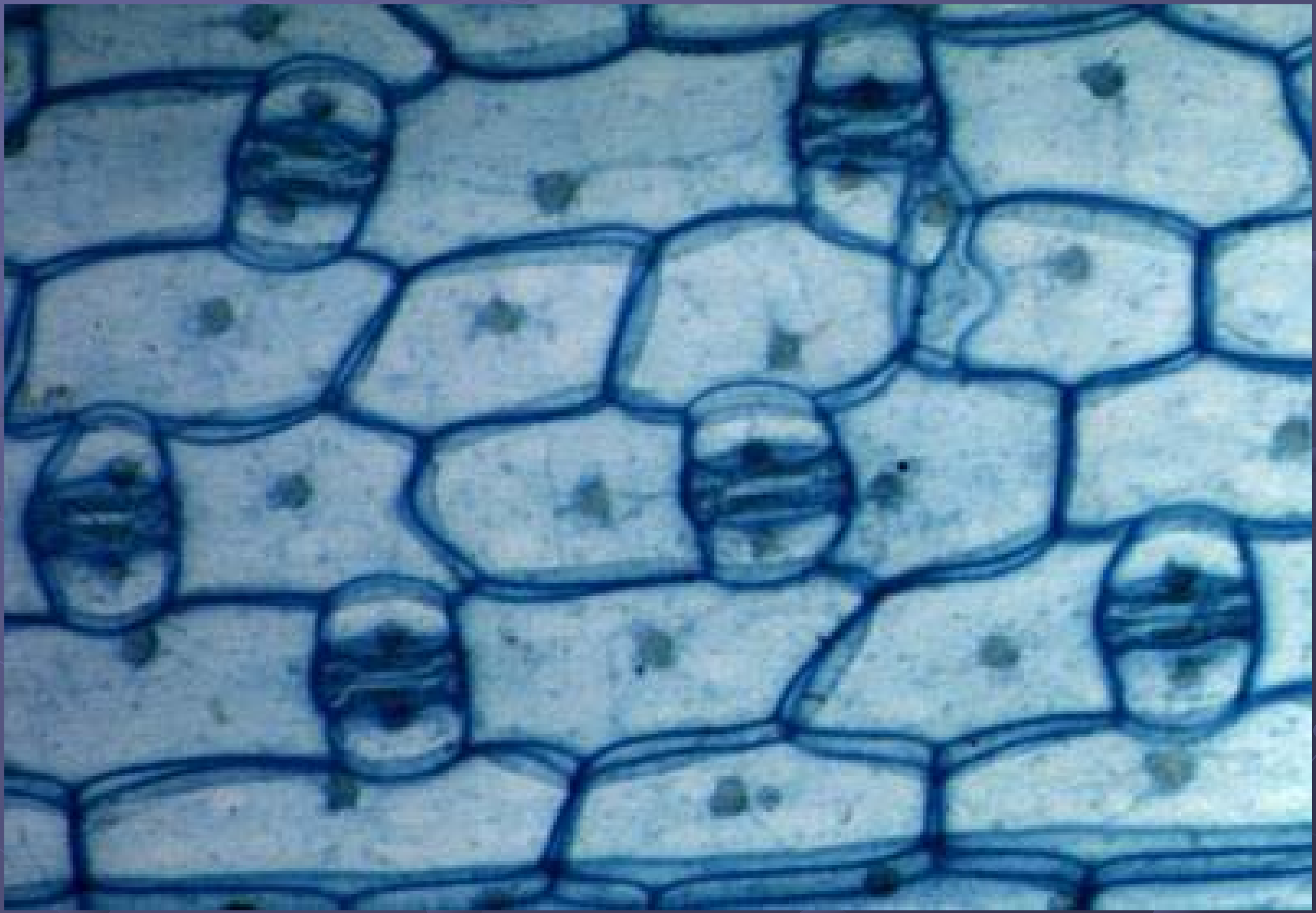


Figure 25. Stomata open to allow carbon dioxide (CO_2) to enter a leaf and water vapor to leave.

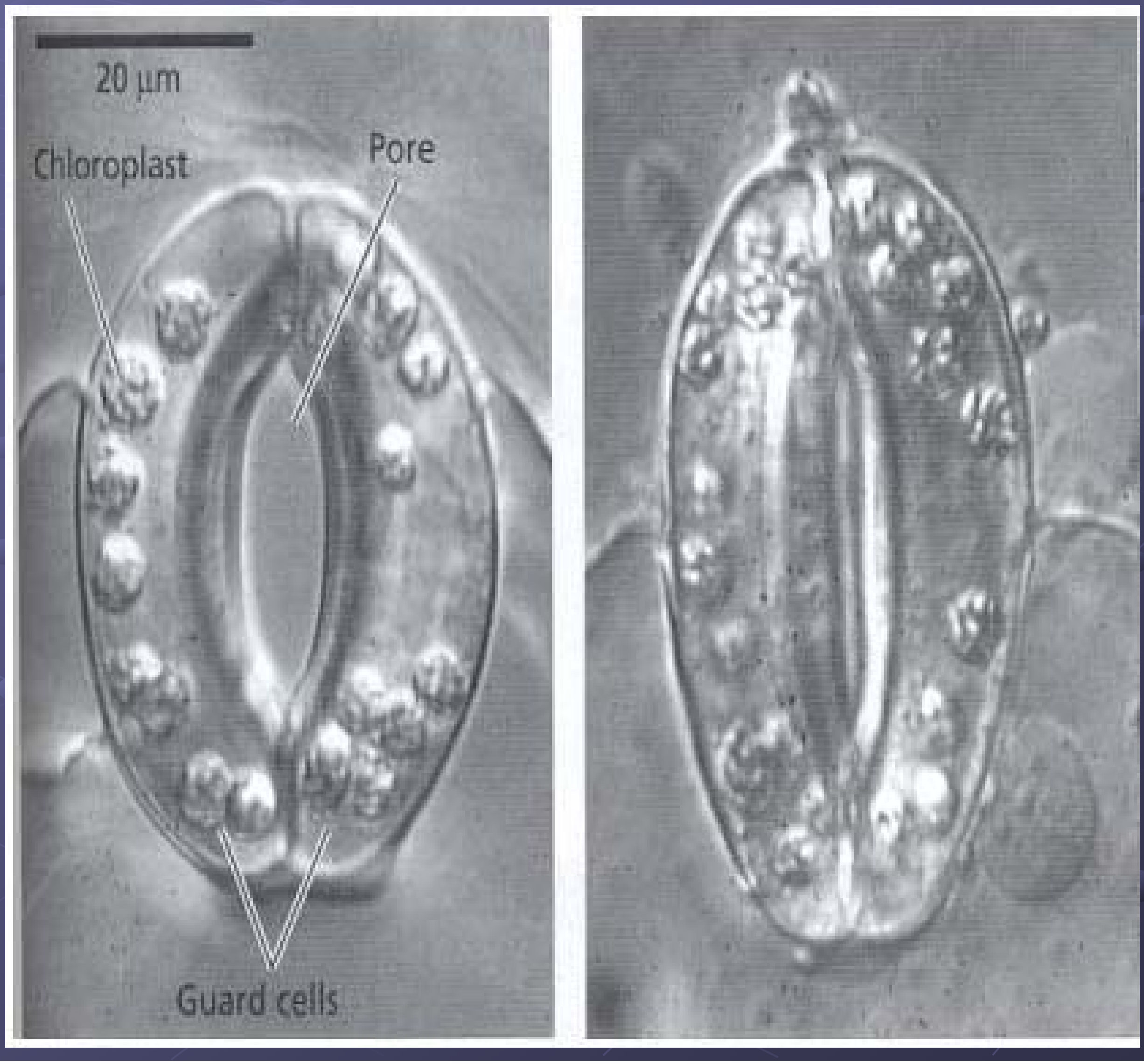
Stomata

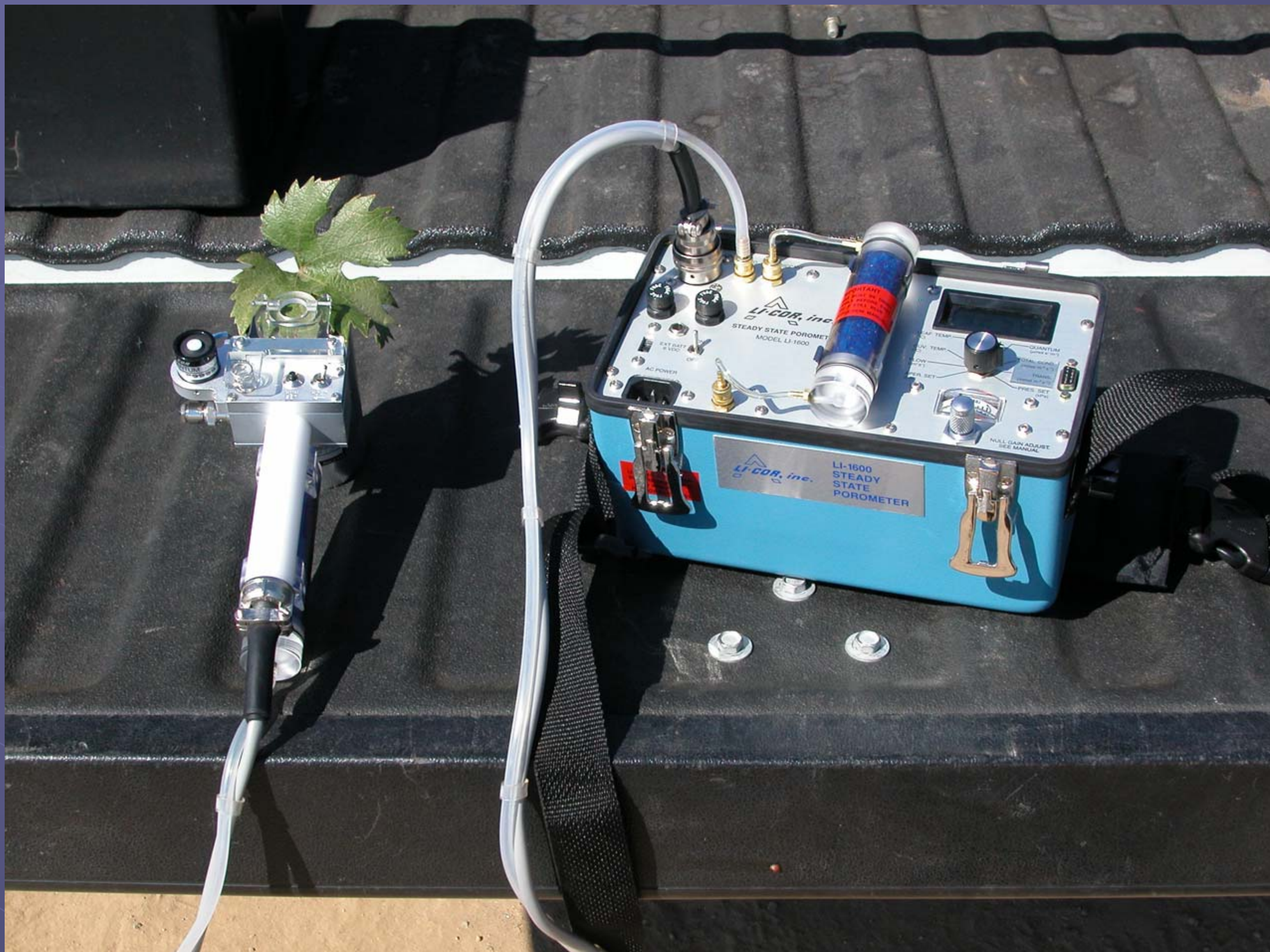
Normally open in the light



Stomata

CO_2 in Water vapor out




LI-COR, inc.
STEADY STATE POROMETER
MODEL LI-1600
LI-COR, inc.
LI-1600
STEADY
STATE
POROMETER

RTANT
UST BE DRIED
BEFORE EACH
STILL BLUE
TION MANUAL
LEAF TEMP. (°C)
REL. HUM. (%)
QUANTUM (µmol s-1 m-2)
CUV. TEMP. (°C)
TOTAL COND. (mmol m-2 s-1)
TRANS. (mmol m-2 s-1)
FLOW (cm3 s-1)
APER. SET (cm2)
PRES. SET (kPa)
NULL ADJ
NULL GAIN ADJUST.
SEE MANUAL

How do Stoma Open

1. The light at dawn is the signal that is recognized by a receptor on the guard cell.
2. The receptor signals the guard cell’s plasma membrane to start pumping protons (H^+) out of the guard cell. This loss of positive charge creates a negative charge in the cell.
3. Potassium ions (K^+) enter the guard cell through channels in the membrane

How do Stoma Open

- As the potassium ions accumulate in the guard cell, the osmotic pressure is increased.
- Higher osmotic pressure attracts water to enter the guard cell increasing turgor
- The pressure causes the shape of the guard cells to change and a pore is formed, allowing gas exchange

How do Stoma Close

- When water uptake is exceeded by transpiration, stoma will close because there will not be enough water to create pressure in the guard cells.
- Abscisic acid hormone causes Cl^{-} and Organic acids to be pumped out of the cell reducing osmotic pressure and tugor.
- This response helps the plant conserve water.

Guard Cells

Time	Osmotic Pressure, lb/in2
7 A.M.	212
11 A.M.	456
5 P.M.	272
12 midnight	191

- Other lower epidermal cells 150 constant

Stomatal Index

- Stoma Number : All Cells

High

late in the Permian period (275–290 million years ago)
in the Pleistocene epoch (1–8 million years ago).

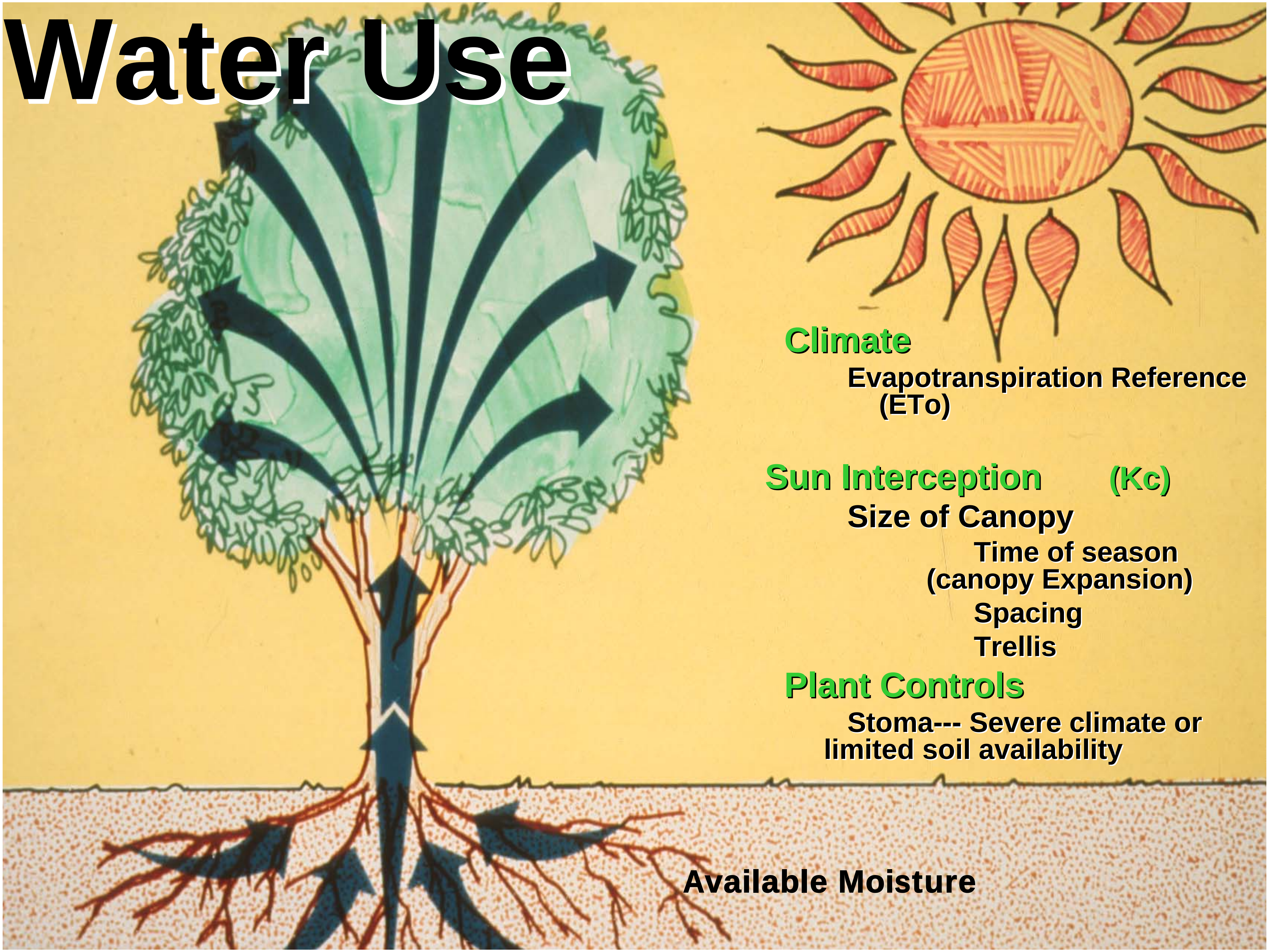
Both these periods are known from geological evidence to have been times of **low** levels of atmospheric carbon dioxide and ice ages

Low

During the Cretaceous period, a time of high CO_2 levels and warm climate.

Vine Water Use and Status

Water Use



Climate

Evapotranspiration Reference (ETo)

Sun Interception (Kc)

Size of Canopy

Time of season (canopy Expansion)

Spacing

Trellis

Plant Controls

Stoma--- Severe climate or limited soil availability

Available Moisture

Climate (ETo)

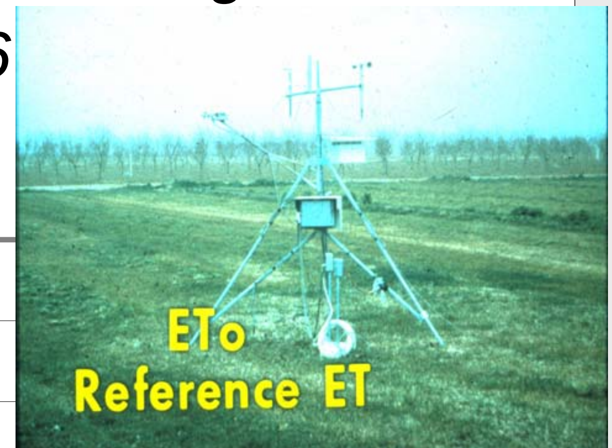
Light intensity
Air temperature
Humidity
Wind speed

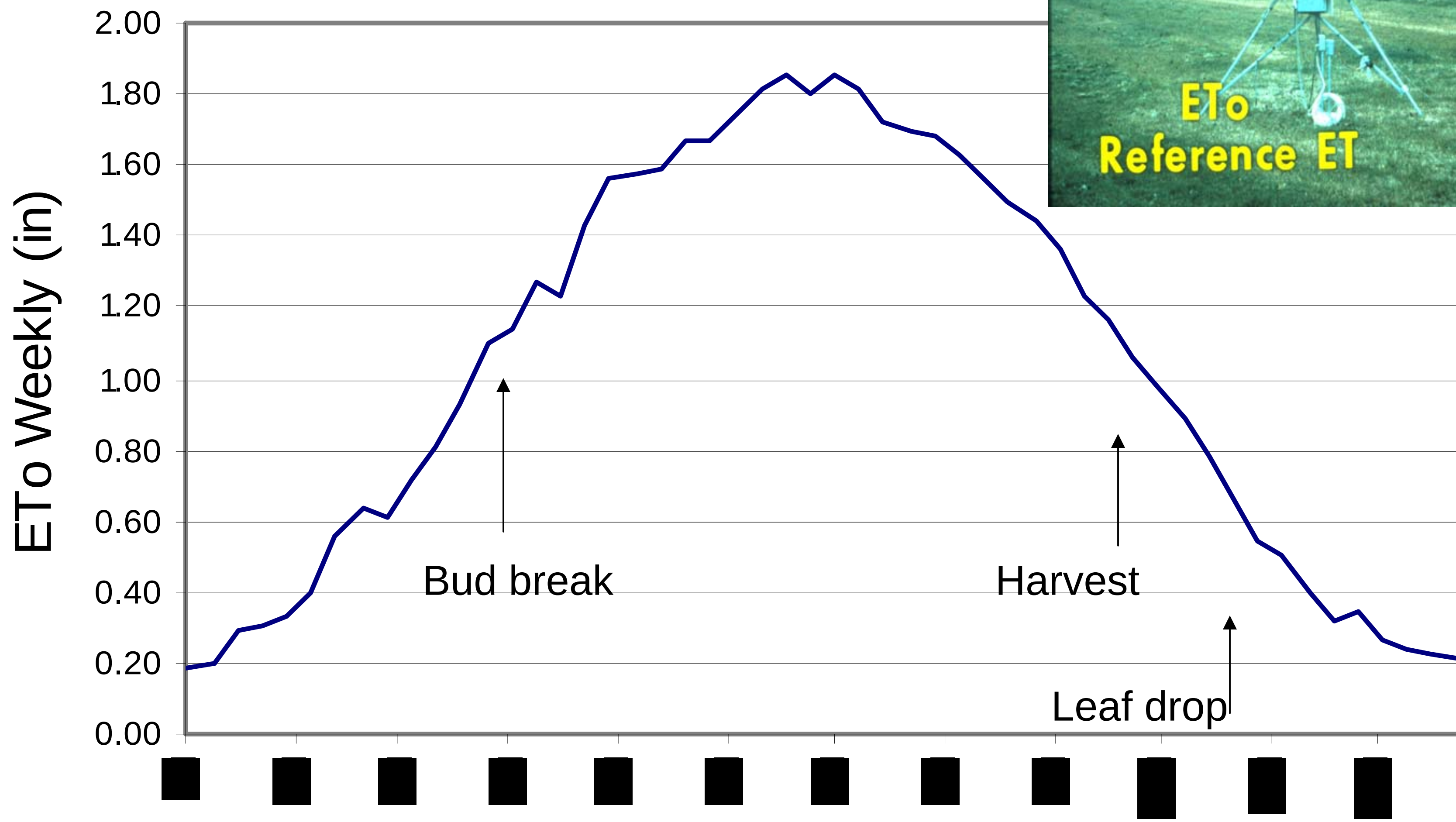
What is the volume of irrigation water required to produce high quality fruit ?

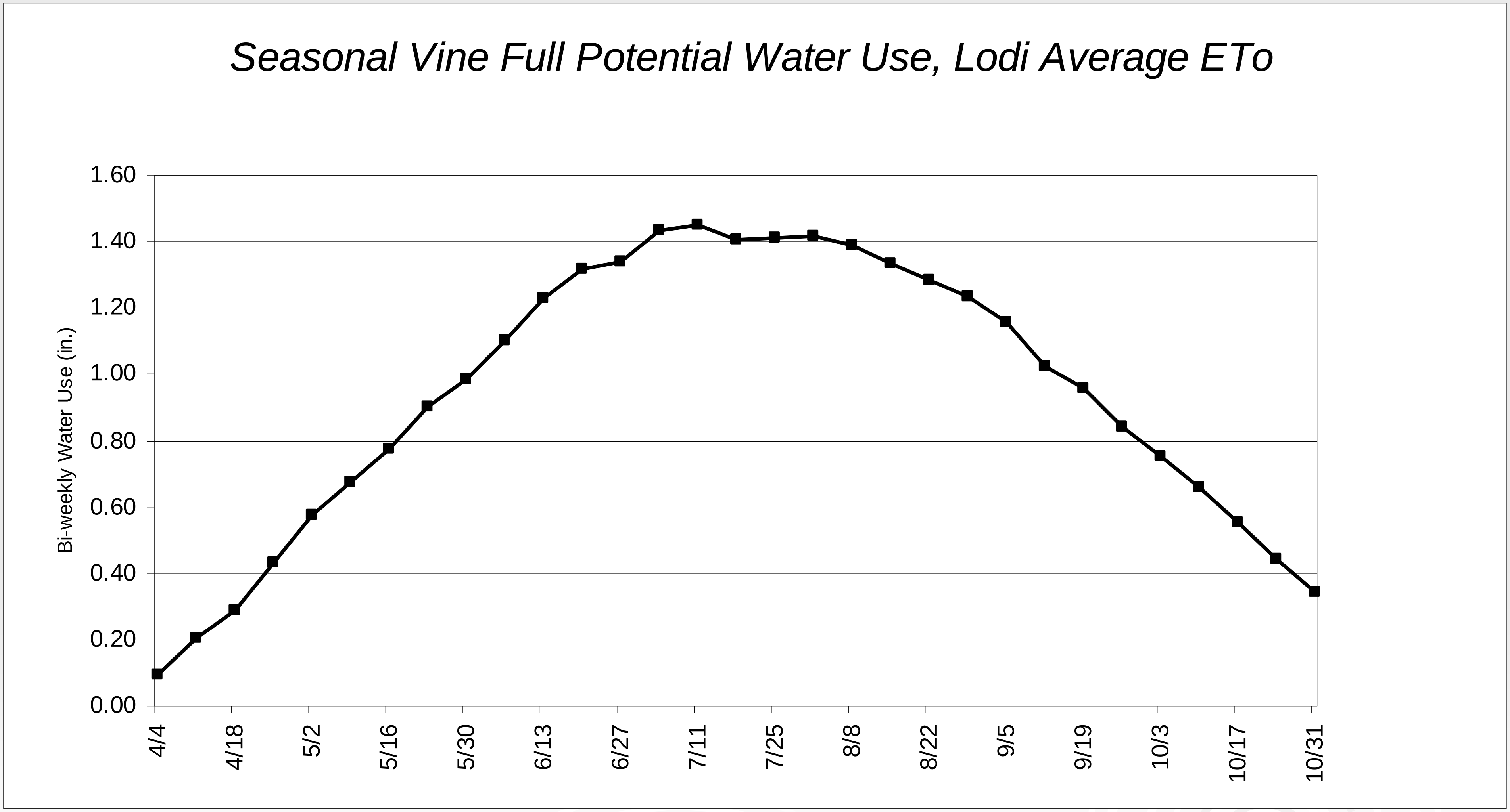
It varies:

- Canopy size
- Soil resource (available soil moisture storage)
- Climate (demand)

Figure D-1. Lodi Eto, 1984 - 2003 Average
Stations # 42 and # 166



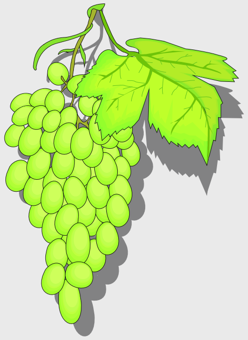




Seasonal Vine Full Potential Water Use, Lodi Average ETo
Bi-weekly Water Use (in.)
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
4/4
4/18
5/2
5/16
5/30
6/13
6/27
7/11
7/25
8/8
8/22
9/5
9/19
10/3
10/17
10/31


Full Potential water Use

Balance Vegetative / Reproductive Structure



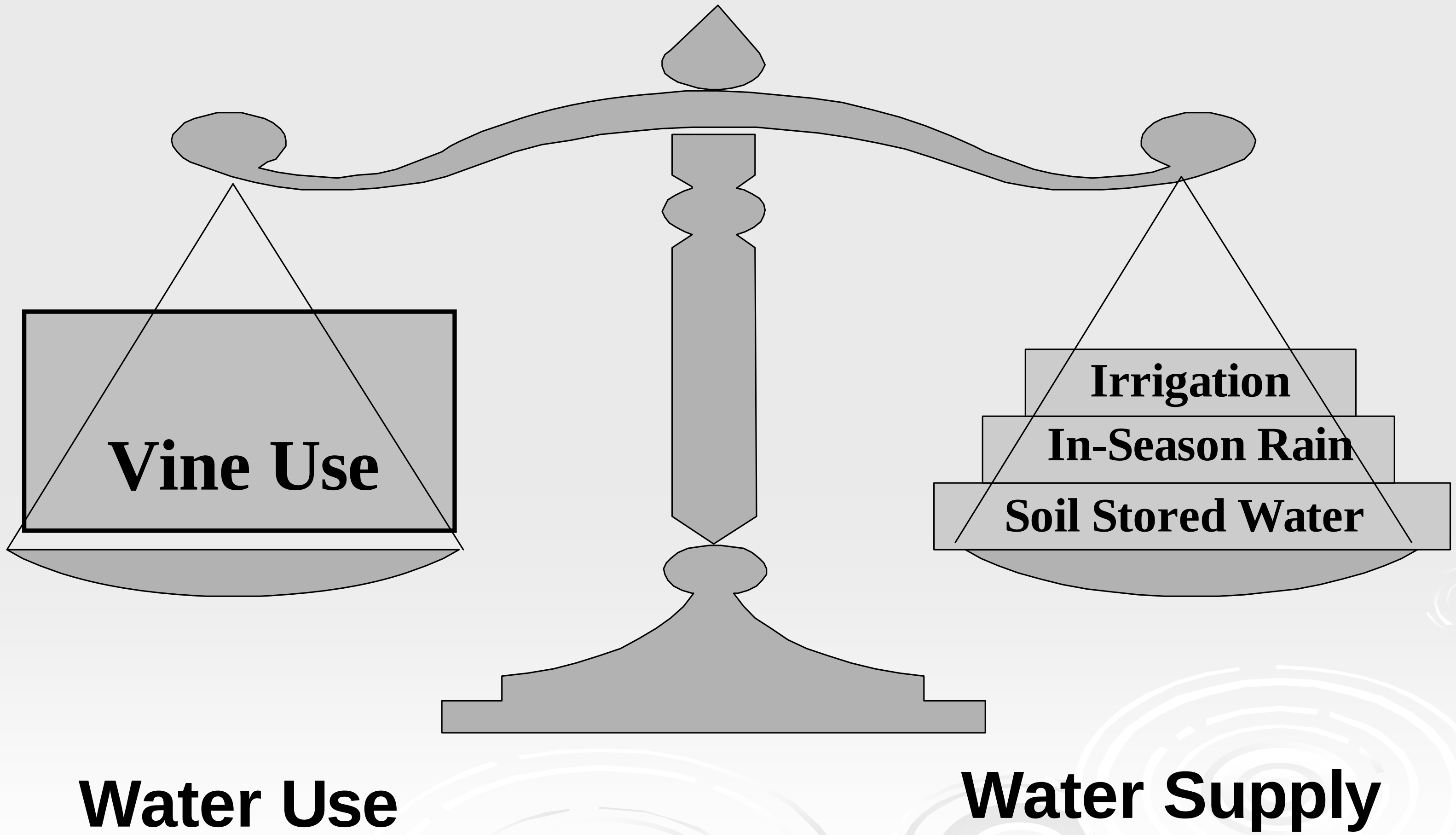
Irrigation Management Philosophy

Controlled water deficits

can improve fruit quality

with little effect on yield

Irrigation Scheduling



Vine Water Stress

- Caused by reduced soil water availability
- Increasing canopy size
- Increasingly hot, dry climatic condition
- Longer days

Vine Water Stress

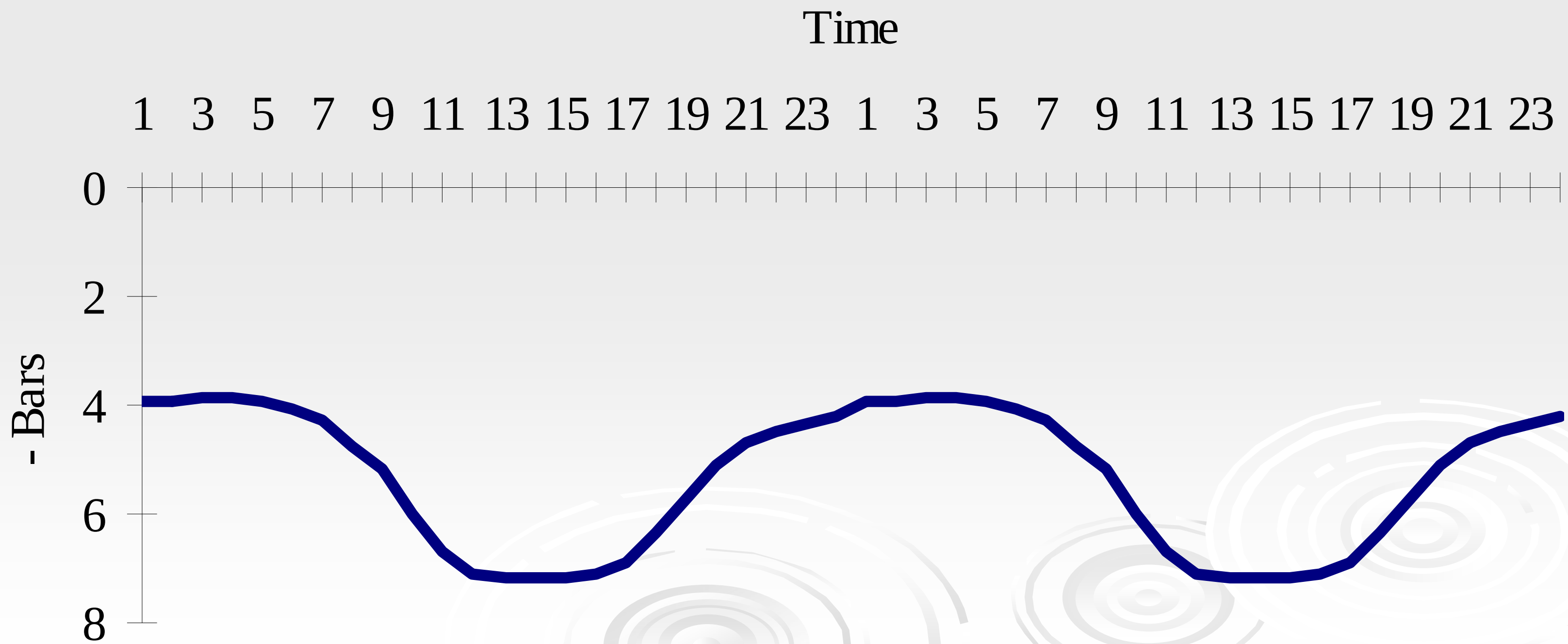
Without irrigation:

- Stress occurs later in:
  - Deep root zones
  - Heavier soils
  - Cooler climate areas

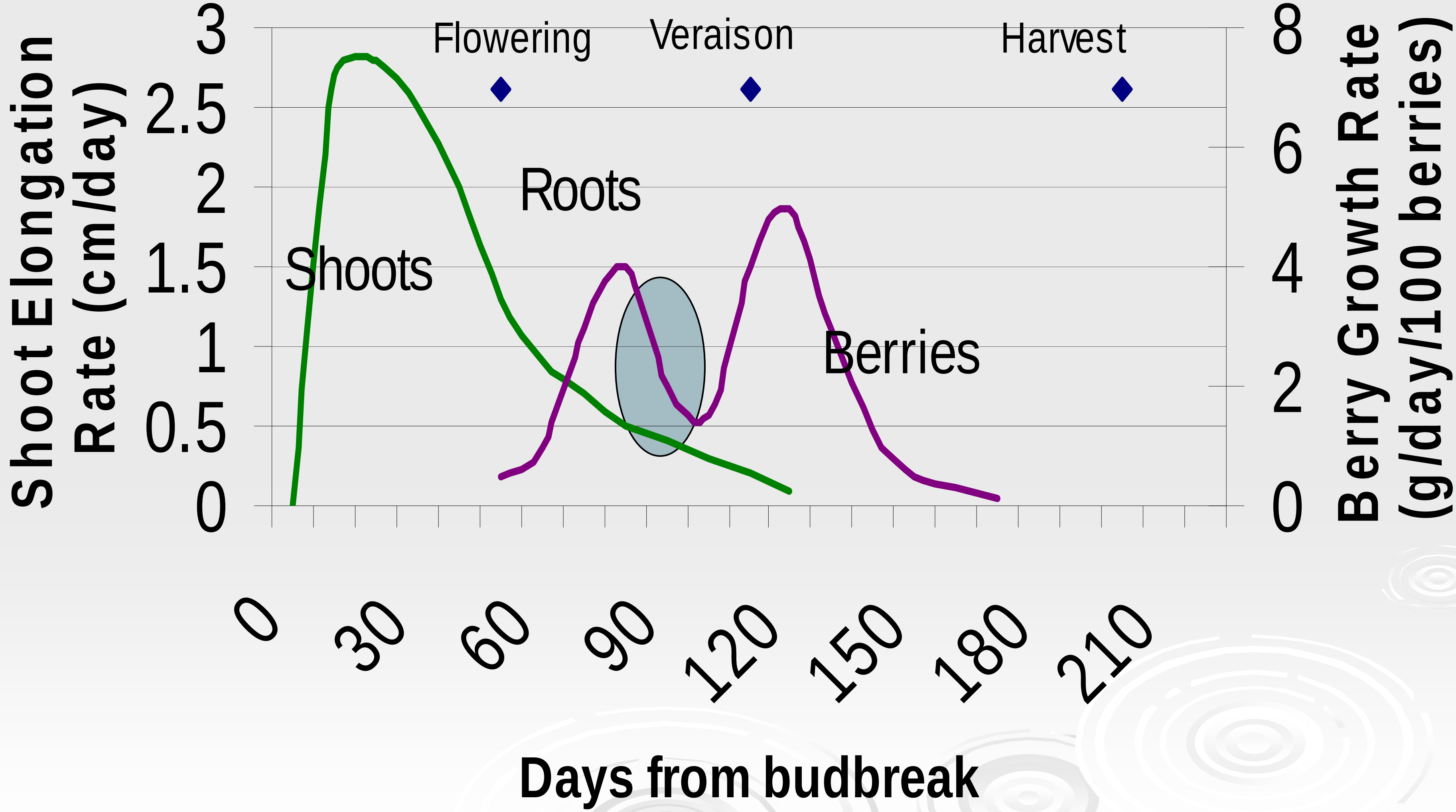
Vine Water Stress

- Measured as midday leaf water potential
  - Using a pressure chamber
    - aka pressure bomb

Diurnal Leaf Water Potential



Shoot, Root, and Berry Growth Rate



Most soils provide adequate water for stage I:

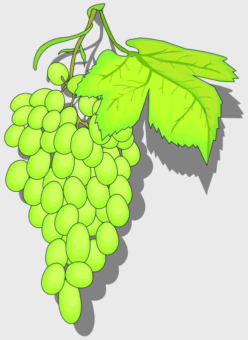
- Basic shoot growth
- Root growth
- Berry cell division

Water deficits in Stage II

- Leading up to veraison
  - Reduce main shoot growth
  - Reduce the number and length of lateral shoots
- Limiting shoot growth to near 1 meter provides adequate leaf area and allows diffuse light into the fruiting area
  - 0.8-1.2 m^2/kg fruit– single canopy
  - 0.5-0.8 m^2/kg fruit– divided canopy

Water deficits in Stage III

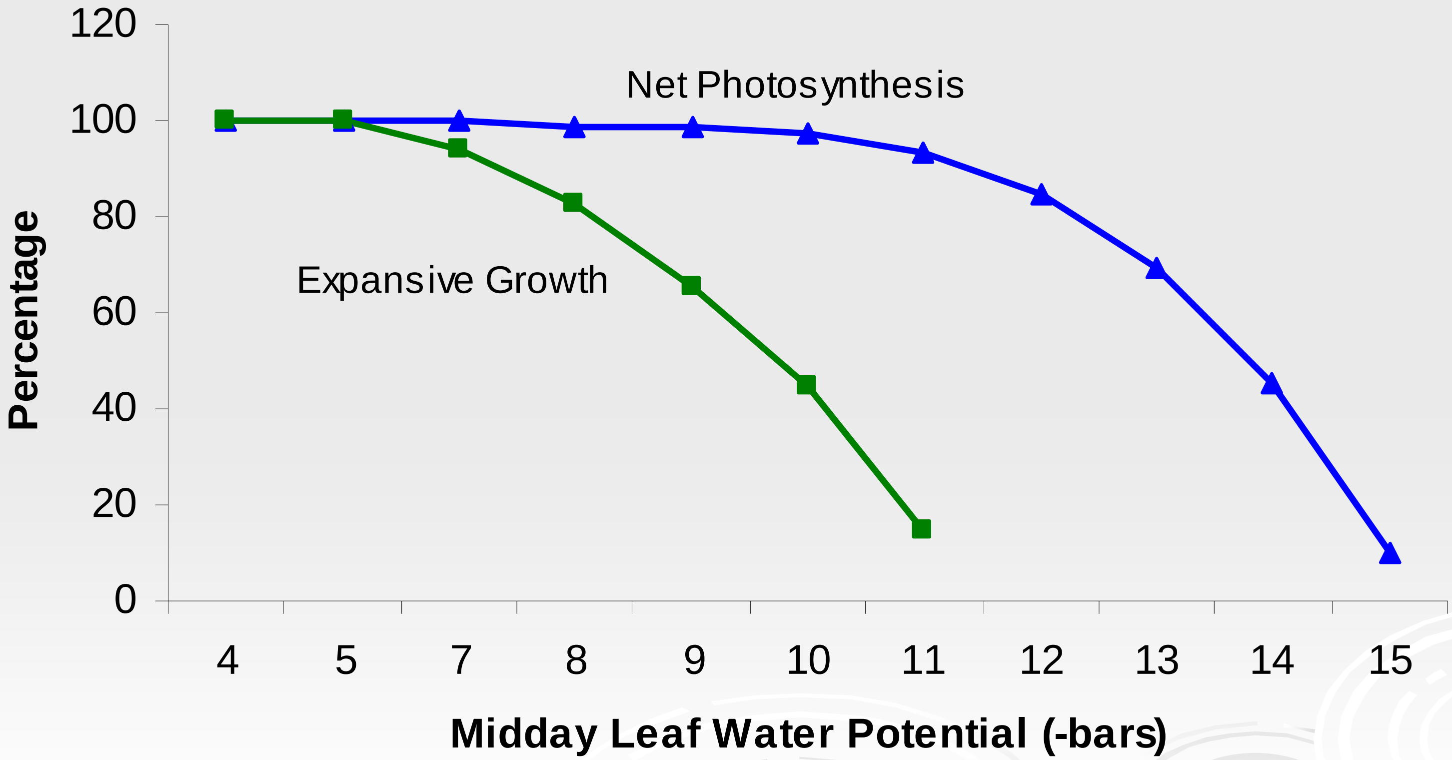
- Continued moderate deficits
  - Prevent resumption of main and lateral shoot growth
  - Provide water to maintain photosynthetic capacity
  - Increases diffuse light into fruit
- Irrigate post harvest



Moderate Water Deficits

- Reduce vegetative growth
  - Shoot length
  - No. of lateral shoots
- Increase light in canopy
- Remove lower leaves

Relative Rate vs. Leaf Water Potential



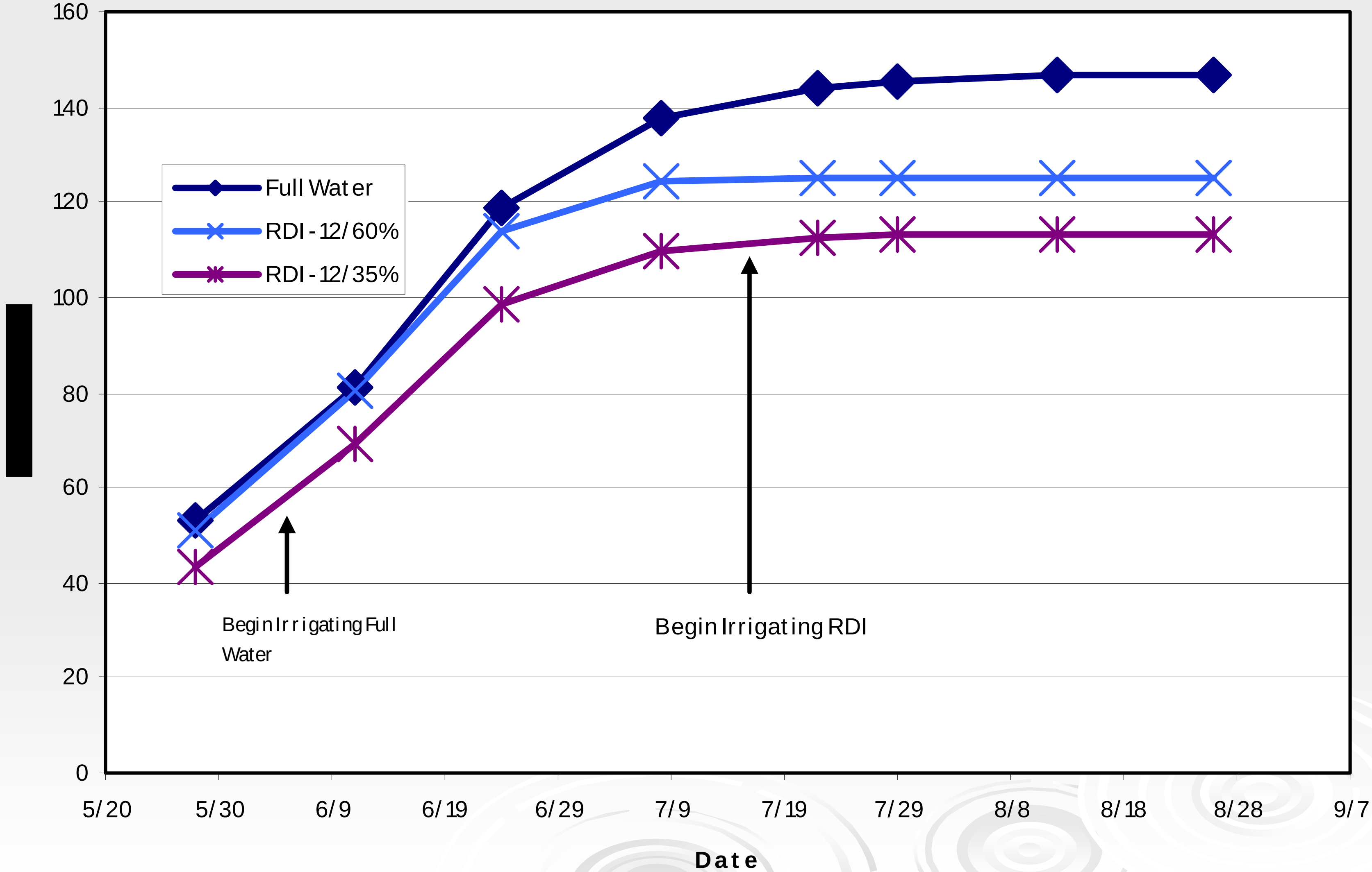
Deficit Effects on Vine and Fruit

- Beneficial or Harmful

- Depending on the severity and timing of the deficit

Moderate Water Deficits
Open canopy– diffused light

Figure E-1. Shoot Length of Full Irrigation and Deficit Treatments
Hopland Cabernet 1999



Syrah 2006 Canopy Measurements

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

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


Severe Deficit
Loss of Leaf Cover

Timing of Water Deficits

- Early season
  - bud break through set
- Mid season
  - set through veraison
- Late season
  - veraison through harvest
- Postharvest

Deficit Irrigation Syrah @ Harvest

Stress Threshold
Regulated Deficit Irrigation

Requirements

- Measure plant stress
- Ability to estimate full potential vine water Use
- Micro-irrigation System
    - Uniformly
    - Small water volumes
    - Frequently

Surface Irrigation

Quality Goals

- Titratable acidity
- Tartaric/Malic ratio
- pH
- Potassium

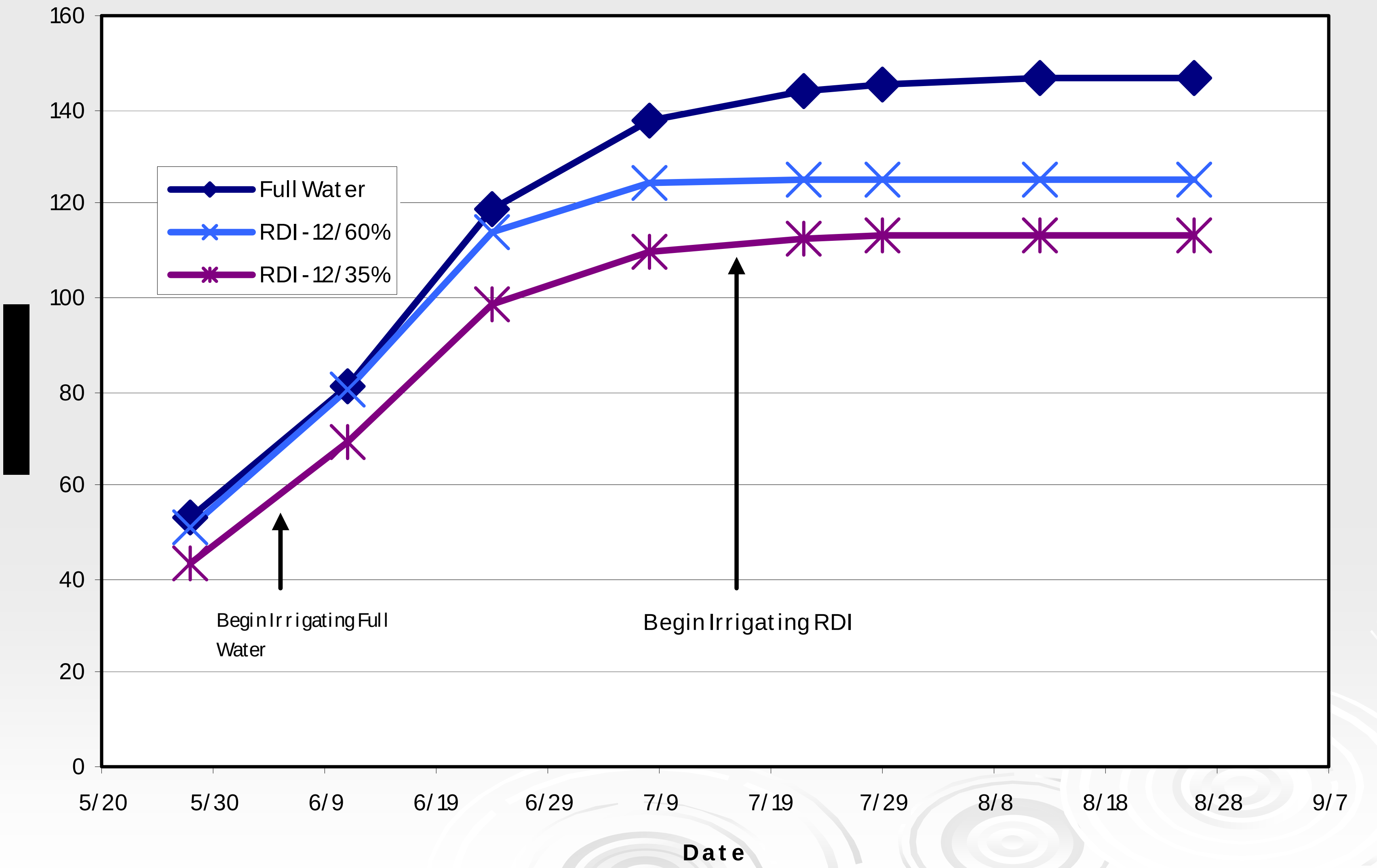
Extractable

- Color

Extractable

- Character

Figure E-1. Shoot Length of Full Irrigation and Deficit Treatments
Hopland Cabernet 1999



Lodi Cabernet Sauvignon Light at fruiting level and wine analysis Treatments as a percentage of full potential water use with pre or post veraison deficits					
	Cumulative Light	Absorbance		Color Hue	Phenolics (Abs 280 nm)
		420 nm	520 nm		
T1 (100%)	1.32 d	0.162 d	0.169 f	0.962 a	29.9 c
T2 (70%, post ver)	2.19 cd	0.227 bc	0.289 bc	0.789 bc	36.6 abc
T3 (70%, Pre ver)	1.70 cd	0.226 bc	0.268 bcd	0.847 b	33.1 cde
T4 (50%Post ver)	4.00 bc	0.295 a	0.373 a	0.790 bc	39.3 a
T5 (50%Pre ver)	3.20 cd	0.250 ab	0.335 ab	0.745 c	38.2 ab

Prichard and Verdegaal 1988

Table E-1. Hopland 1998 Cabernet Sauvignon Must Analysis

	^{0}Brix	pH	Titratable Acidity (gm/L)	Malate (mg/L)
T1 (100)	23.0	3.37	6.68	3555
T2 (-14/60)	23.1	3.49	4.94	2528
T3 (-14/35)	22.4	3.51	5.39	1450
T4 (-12/60)	23.2	3.43	6.04	2645
T5 (-12/35)	23.0	3.50	5.97	1808
P=	0.4788	0.4152	0.0004	0.0001

Treatments: T1 (100) = full potential water use
T2-T5 = Leaf water potential at irrigation start / RDI %

Lundquist, Smith and Prichard

com

. Lodi Merlot 2000	
Treatment (Threshold/RDI%)	Must Malic Acid Concentration(g/L)
Full potential	3.83
-13/60%	1.92
-13/35%	1.45
-15/60%	1.27
-15/35%	1.14

Prichard and Verdegaal 1996

Table E-2. Skin phenolics and Anthrocyanins in Cabernet Franc		
Treatment	Skin Phenolics mg/cm2	Skin Anthrocyanins mg/cm2
Control (grower std)	0.46	0.51
Early Deficit (pre-veraison)	0.56	0.61
Late Deficit (post veraison)	0.52	0.59
Continual Deficit (pre & post veraison)	0.57	0.65

Matthews and Anderson, 1988

. Yield and Yield Components
2006 Syrah, Galt

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

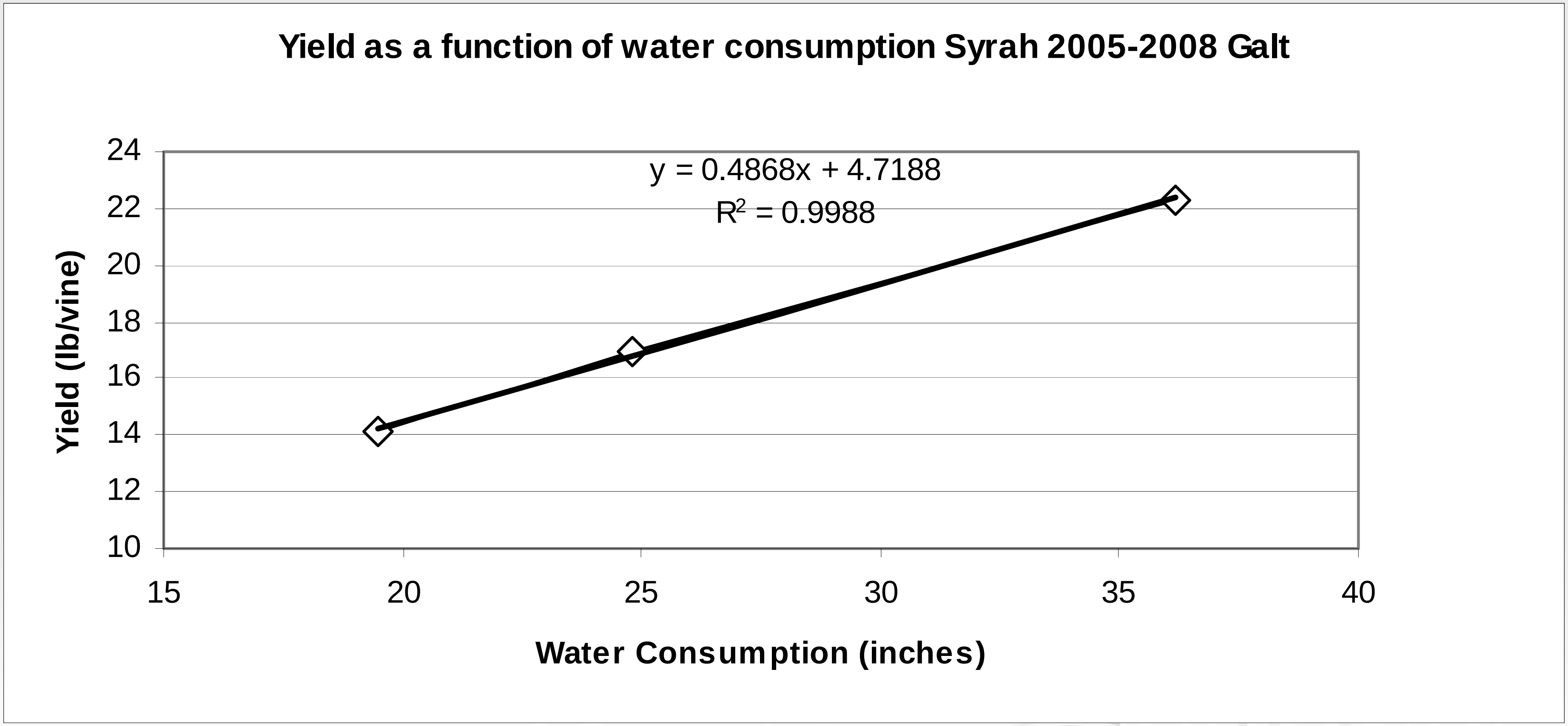
[a] *Different letters in the same column indicate significant differences as indicated by the stated p value using Duncan's means separation test*

Prichard, Verdegaal, and Ingels

Hopland Cabernet

	Yield	Berry wt.	Fruit Load	Cluster No.	Cluster wt.
	(kg/vine)	(gm/berry)	(Berries/vine)	(Clust./vine)	(gm/cluster)
Treatment Averages					
T1 (100)	12.6	1.12	12188	89	150
T2 (-1.4/60)	9.7	0.93	11179	83.8	126
T3 (-1.4/35)	9.1	0.91	11394	83.7	117
T4 (-1.2/60)	10	0.95	11460	82.3	132
T5 (-1.2/35)	9.6	0.92	11658	84.2	116
T6 (-1.2/35-60)	9.7	0.93	11592	83.7	119
Treatment p=	0.0006	0.0001	0.522	0.1968	0.0004

Response to increased irrigation is linear



Deficit Irrigation (white grape)

	% of ETc			
Variable	**25**	**50**	**75**	**100**
	% of 100% treatment			
Berry Size	**84**	**93**	**97**	**100**

From LE Williams

Cabernet Deficit Irrigation

	% of ETc		
Variable	50	75	100
	% of 100% treatment		
Berry Size	80	90	100

From
TLP

Developing a Deficit Irrigation Strategy

Types of deficit strategies

- Irrigate early season with decreasing portion of full vine water use as the season progresses
- Irrigate at a portion of full vine water use beginning early season
- Wait to irrigate until water deficits have curbed vegetative growth then irrigate with a portion of full vine water use

Stress Threshold Regulated Deficit Irrigation

- Wait to irrigate until water deficits have curbed vegetative growth then irrigate with a portion of full vine water use

Regulated Deficit Irrigation (RDI)

- Supplying vines with less irrigation water than they can use.
- Causing reduced soil moisture availability
- Causing vine water stress
  - Constant reduction (start early with a % reduction) ETc * RDI% = volume
  - Variable RDI % over irrigation season

Stress Threshold Regulated Deficit Irrigation

- Wait to irrigate until water deficits have curbed vegetative growth then irrigate with a portion of full vine water use

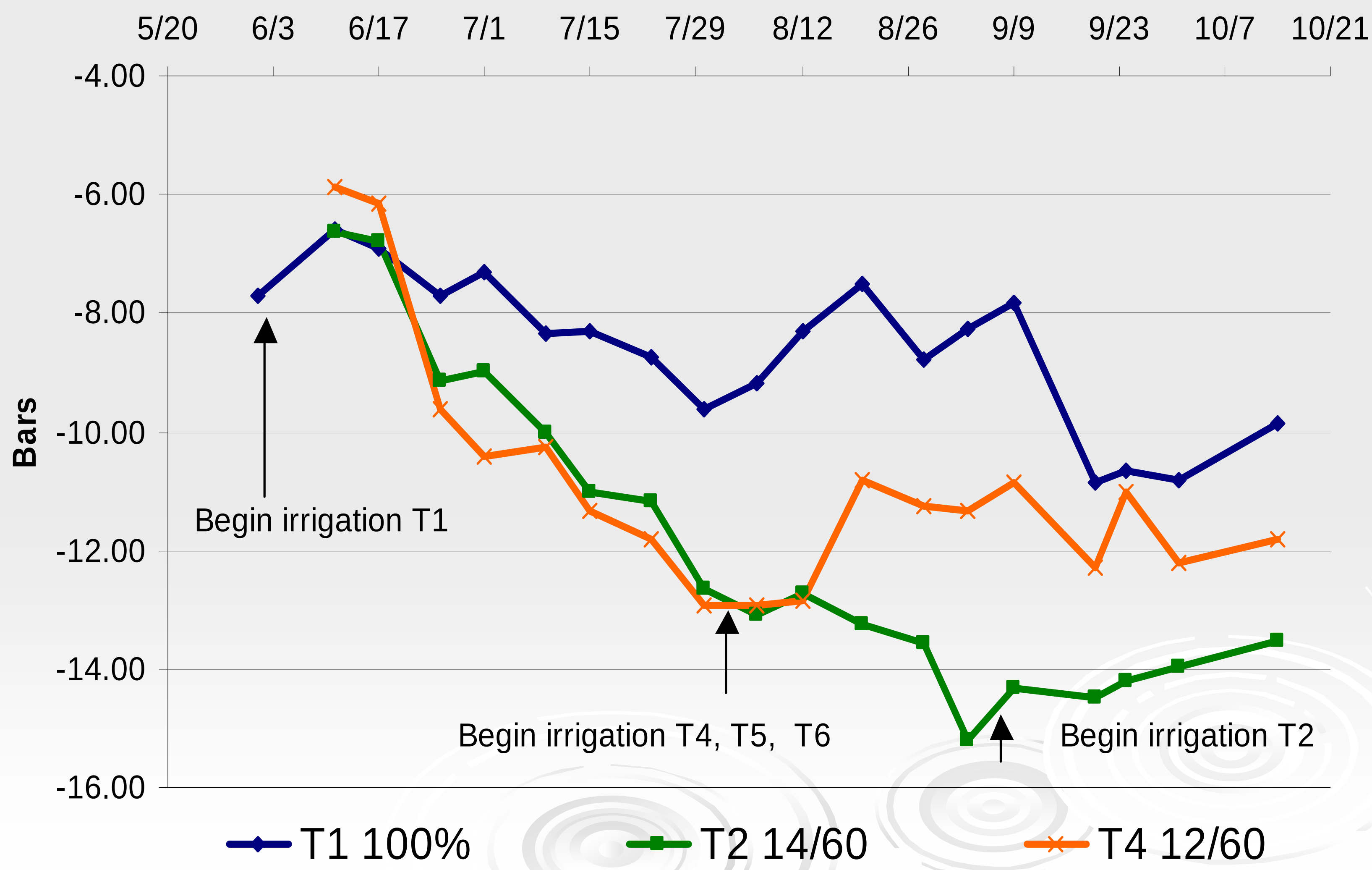
Table F-2. Levels of winegrape water deficits measured by mid-day leaf water potential		
1	less than -10 Bars	no stress
2	-10 to -12 Bars	mild stress
3	-12 to -14 Bars	moderate stress
4	-14 to -16 Bars	high stress
5	above -16 Bars	severe stress

Selecting an Appropriate Stress Threshold and RDI

- Research
- Experience

- Select conservative levels of both and monitor results
  - Evaluate your current practice to any new strategy

Mid-day Leaf Water Potential Hopland Cabernet 2000



Selecting a Stress Threshold

Vigor

Variety

Climate

Goal

Stress Thresholds

- Red Varieties
  - Tolerate (and benefit) more severe deficits
    - -13 to -15 bars
  - Benefit (quality) more from more sever deficits
    - Curb vegetative growth and open up canopy

- White Varieties
  - Do no benefit by more sever deficits\
    - Only severe enough to curb vegetative growth

RDI %

- Conservative RDI’s are near 50% or more of full vine water use.

- Risky RDI’s are 35 and below

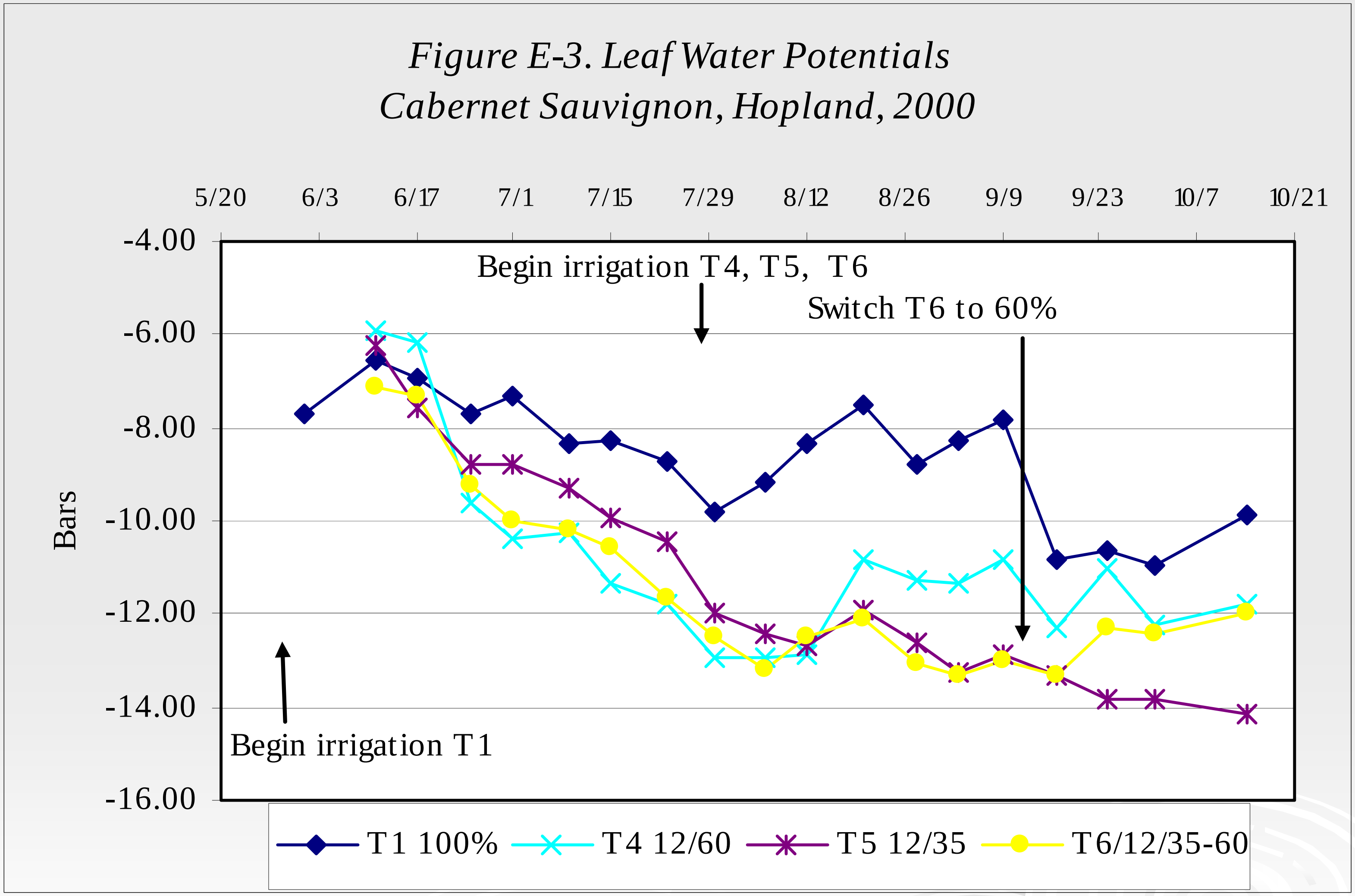
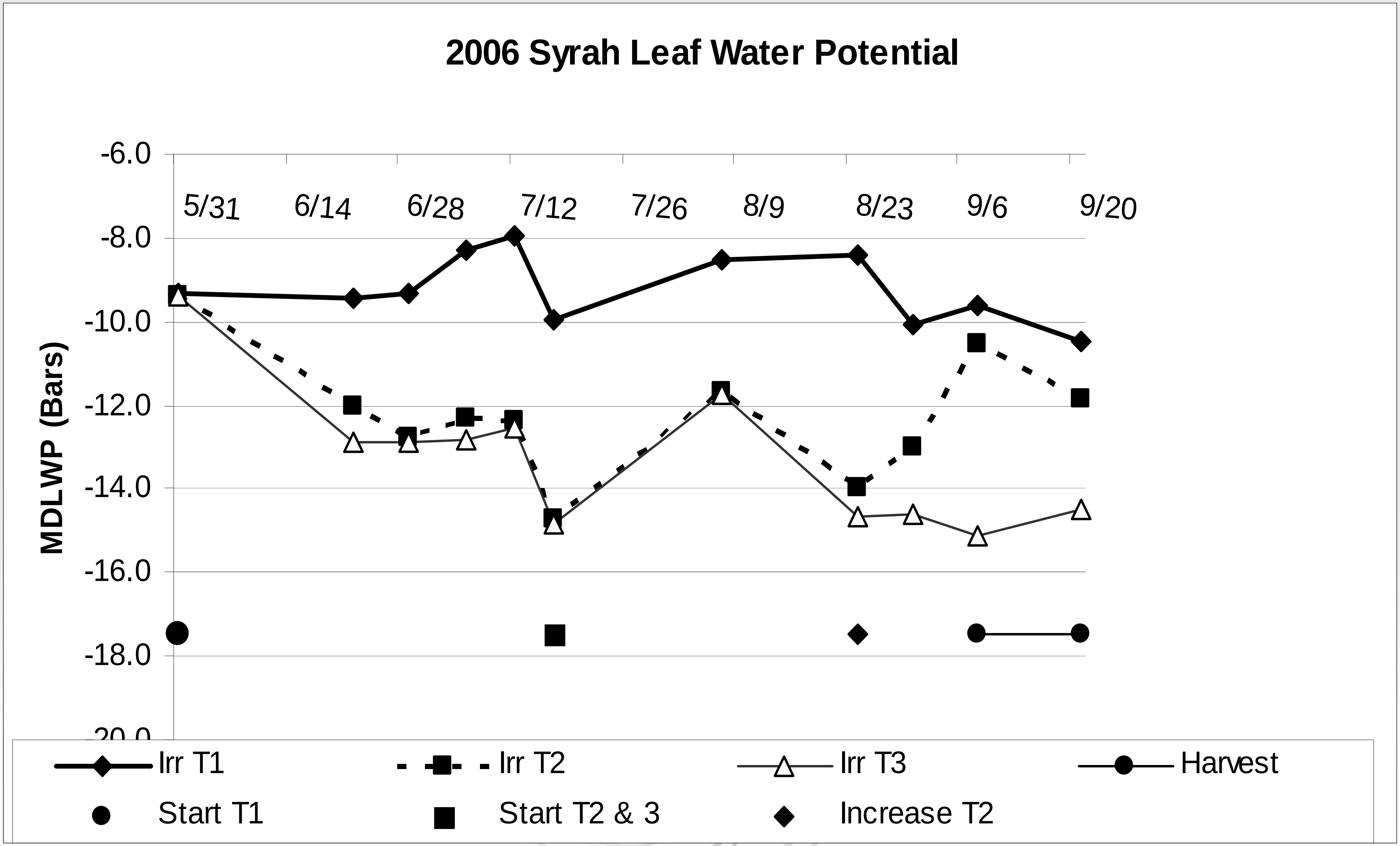


Figure E-3. Leaf Water Potentials
Cabernet Sauvignon, Hopland, 2000
5/20
6/3
6/17
7/1
7/15
7/29
8/12
8/26
9/9
9/23
10/7
10/21
-4.00
-6.00
-8.00
-10.00
-12.00
-14.00
-16.00
Bars
Begin irrigation T4, T5, T6
Switch T6 to 60%
Begin irrigation T1
T1 100%
T4 12/60
T5 12/35
T6/12/35-60

Sensitivity to High Stress Threshold and Low RDI's

- White varieties — Most sensitive
- Merlot
- Cabernet
- Syrah
- Zinfandel — Least Sensitive

Variable RDI 50-100% at 19 Brix



Irrigation of Quality Winegrapes

- Determine
  - When
  - How much
- Achieve a predictable response

When to begin Irrigation

- Shoot Tip Rating

Tip Ratings

1 Tendrils longer than tip

2 Tendrils even with tip

3 Tendrils behind tip

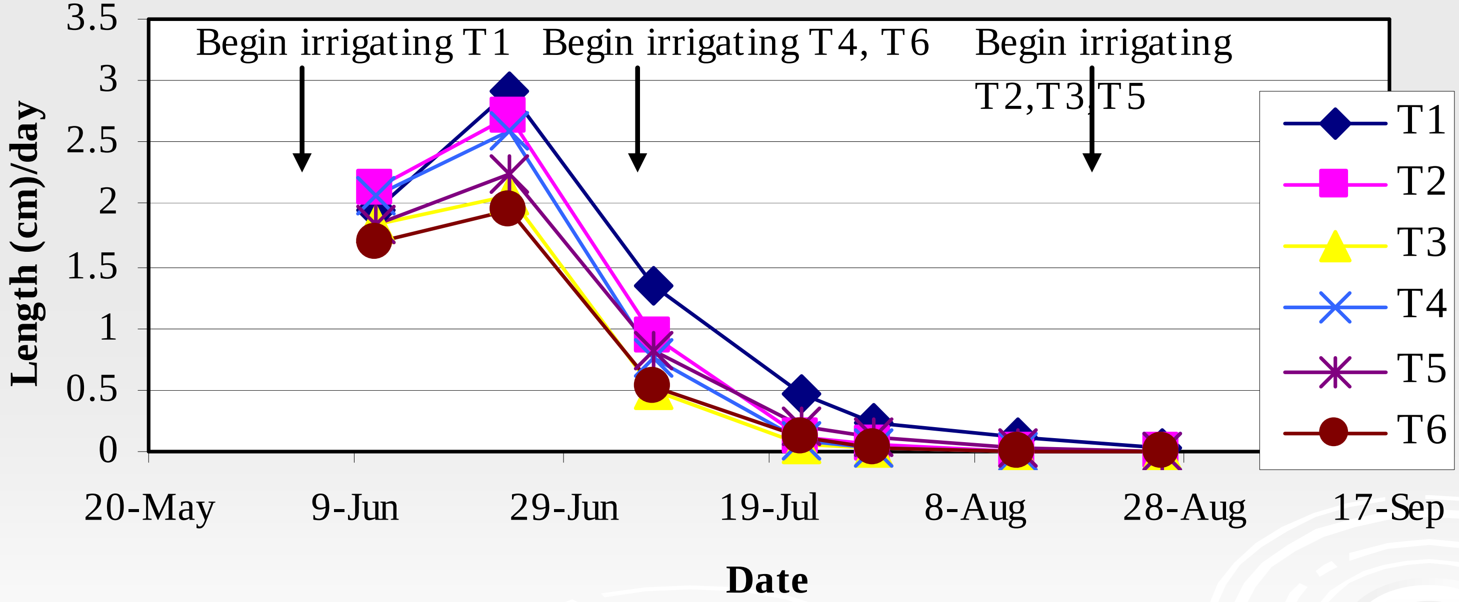
4 Tendrils yellow/withering

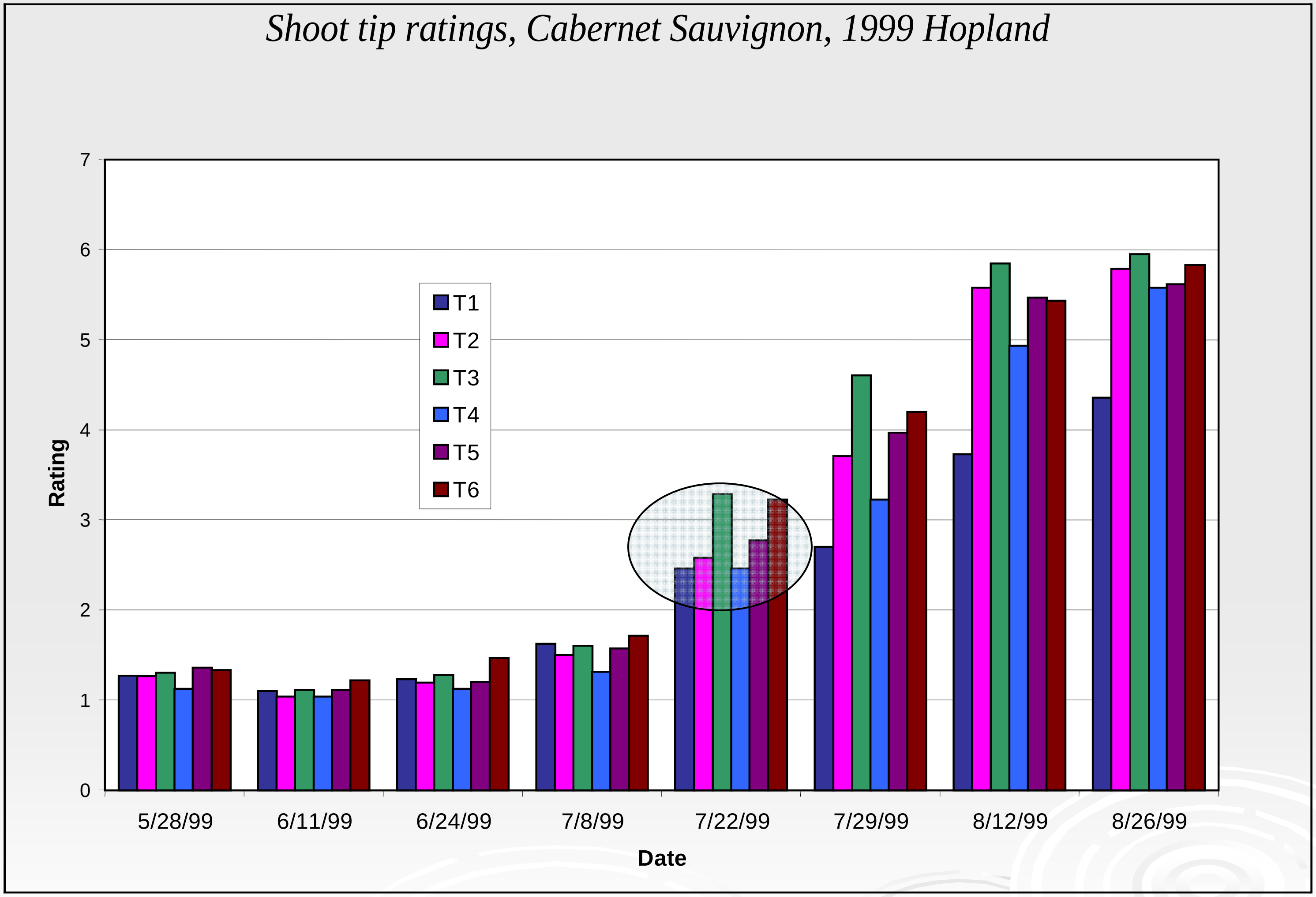
5 Tendrils gone

6 Tip dead

When to begin Irrigation

Figure F-2.. Shoot growth rates, Cabernet Sauvignon, 1999 Hopland




Shoot tip ratings, Cabernet Sauvignon, 1999 Hopland
Rating
Date
0
1
2
3
4
5
6
7
5/28/99
6/11/99
6/24/99
7/8/99
7/22/99
7/29/99
8/12/99
8/26/99
T1
T2
T3
T4
T5
T6

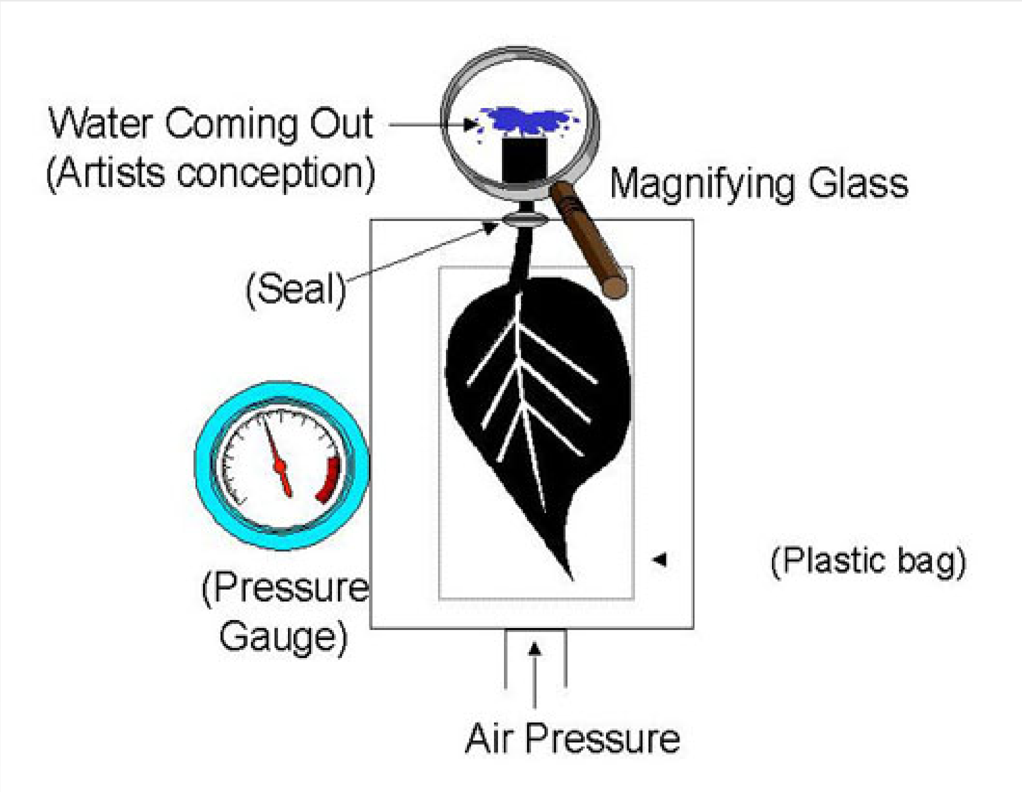
When to Begin irrigation

- Soil water depletion level
- Specific soil water content

Year	Water content	LWP
98	3.4	-12
99	3.8	-12
2000	2.4	-12

Syrah 2007 at -14 bars

Parts of a pressure chamber.



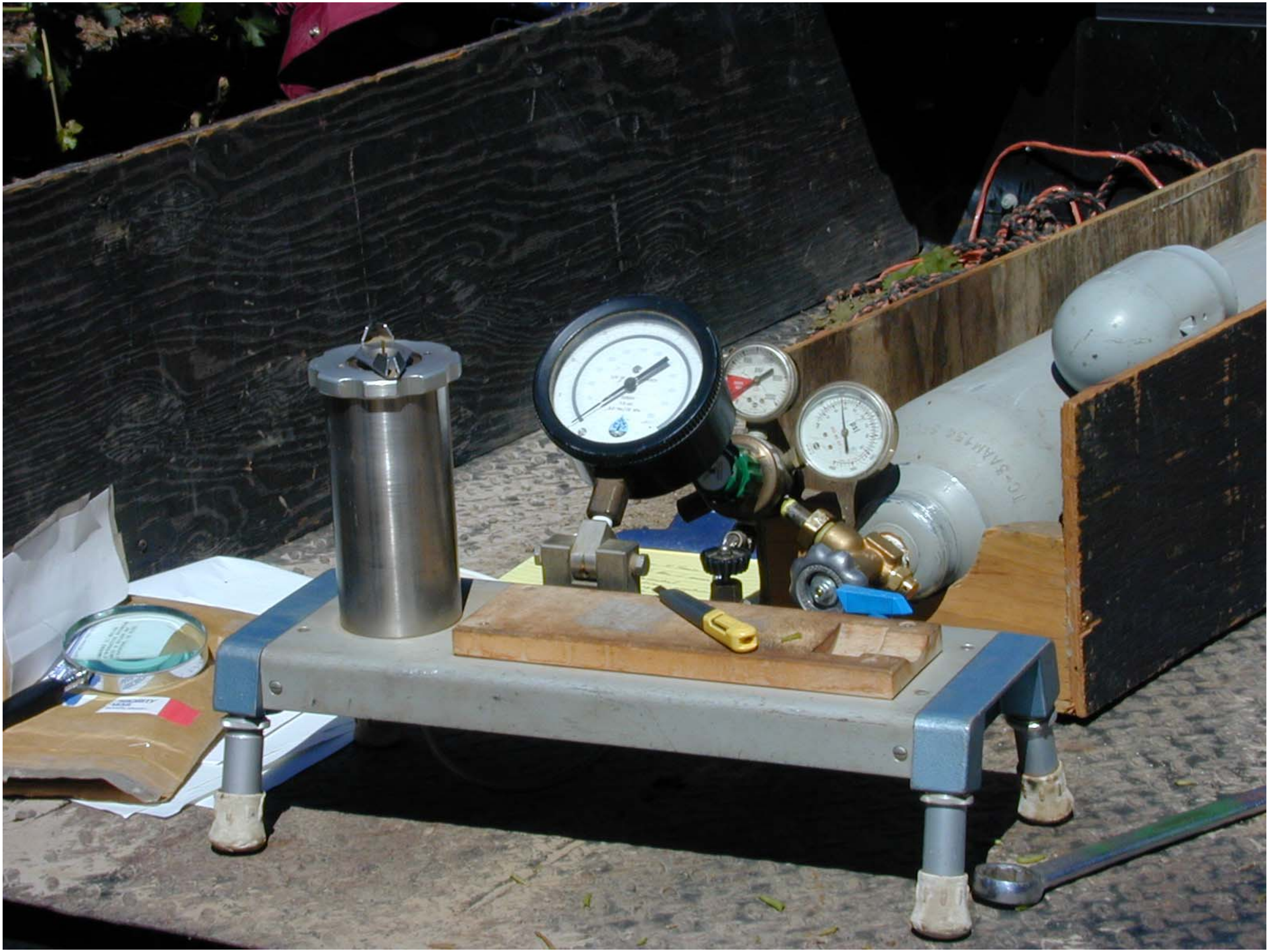
Leaf Collection

Cutting the Petiole

Place leaf in bag in chamber

Petiole in gland

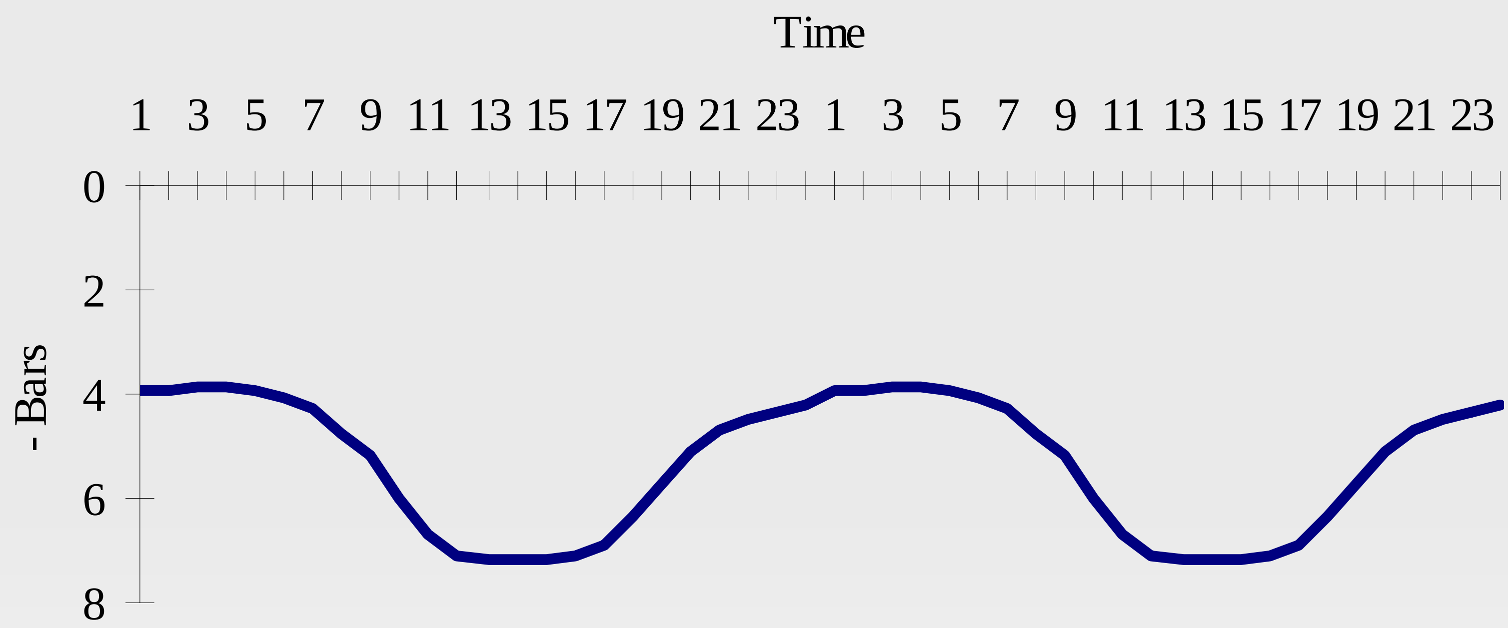

pms
INSTRUMENT CO.
CORVALLIS, OREGON, USA

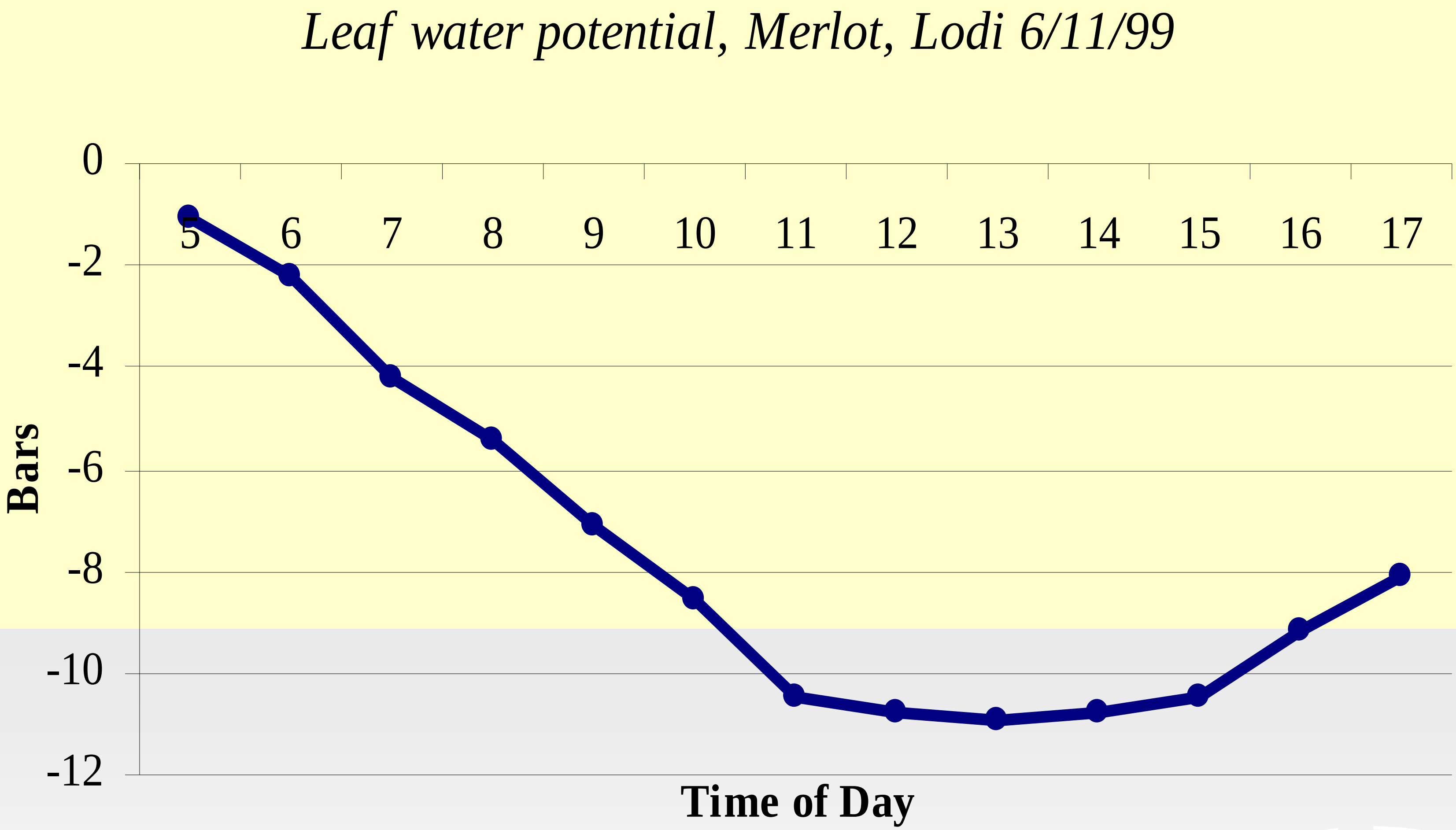



pms
INSTRUMENT CO.
Corvallis, Oregon USA
www.pmsinstrument.com


8
10
12
14
16
18
20
50
100
150
200
250
300
psi
BAR
BAR

Diurnal Leaf Water Potential





Weather condition at sampling

Soil dryness

When and how to sample

- Pre Dawn leaf water potential
- Mid-day leaf water potential
- Mid-day stem water potential

All are linearly correlated

Table F-1. Values of midday stem water potential (in Bars) to expect for fully irrigated prune, under different conditions of air temperature and relative humidity.
(from Ken. Shackel)

Temperature (°F)	Air Relative Humidity (RH, %)						
	10	20	30	40	50	60	70
70	**-6.8**	-6.5	-6.2	-5.9	-5.6	-5.3	-5.0
75	-7.3	-7.0	-6.6	-6.2	-5.9	-5.5	-5.2
80	-7.9	-7.5	-7.0	-6.6	-6.2	-5.8	-5.4
85	-8.5	-8.1	-7.6	-7.1	-6.6	-6.1	-5.6
90	-9.3	-8.7	-8.2	-7.6	-7.0	-6.4	-5.8
95	-10.2	-9.5	-8.8	-8.2	-7.5	-6.8	-6.1
100	-11.2	-10.4	-9.6	-8.8	-8.0	-7.2	-6.5
105	-12.3	-11.4	-10.5	-9.6	-8.7	-7.8	-6.8
110	-13.6	-12.6	-11.5	-10.4	-9.4	-8.3	-7.3
115	-15.1	-13.9	-12.6	-11.4	-10.2	-9.0	-7.8

Pressure Chamber MDLWP

- Vine selection
  - Select six vines with out nutritional, disease or any other obvious out of norm conditions
  - If considerable differences in soil conditions exist split the block into two for sampling
  - Tag the vine so you can return to them on the next sample date

Pressure Chamber MDLWP

- Sample number of 2 per vine
  - If more than 1 bar difference between leaves sample a third.
- Leaf selection
  - Young fully expanded leaf which has had full sun. Shaded leaves will not give the same as sun exposed leaves

Pressure Chamber MDLWP

- Sample Collection
  - Cover the leaf with a plastic bag while still attached to the vine
  - Excise the leaf at the petiole (leave long enough to stick out of the chamber)
  - Place leaf into chamber as quickly as possible

Pressure Chamber MDLWP

- Measurement
  - With leaf in chamber, increase pressure at no more than 0.3 bars per second until water appears on the surface of the cut petiole
  - Note the pressure

Pressure Chamber MDLWP

- Problems
  - Breaks in the leaf veins can cause low readings
  - Tightening the petiole seal too tight exuding non xylem water
  - Waiting too long to make the reading

Stress Threshold + RDI

- Begin irrigation at a specific leaf water potential “Stress Threshold”
- After threshold, irrigate at fraction of full water use

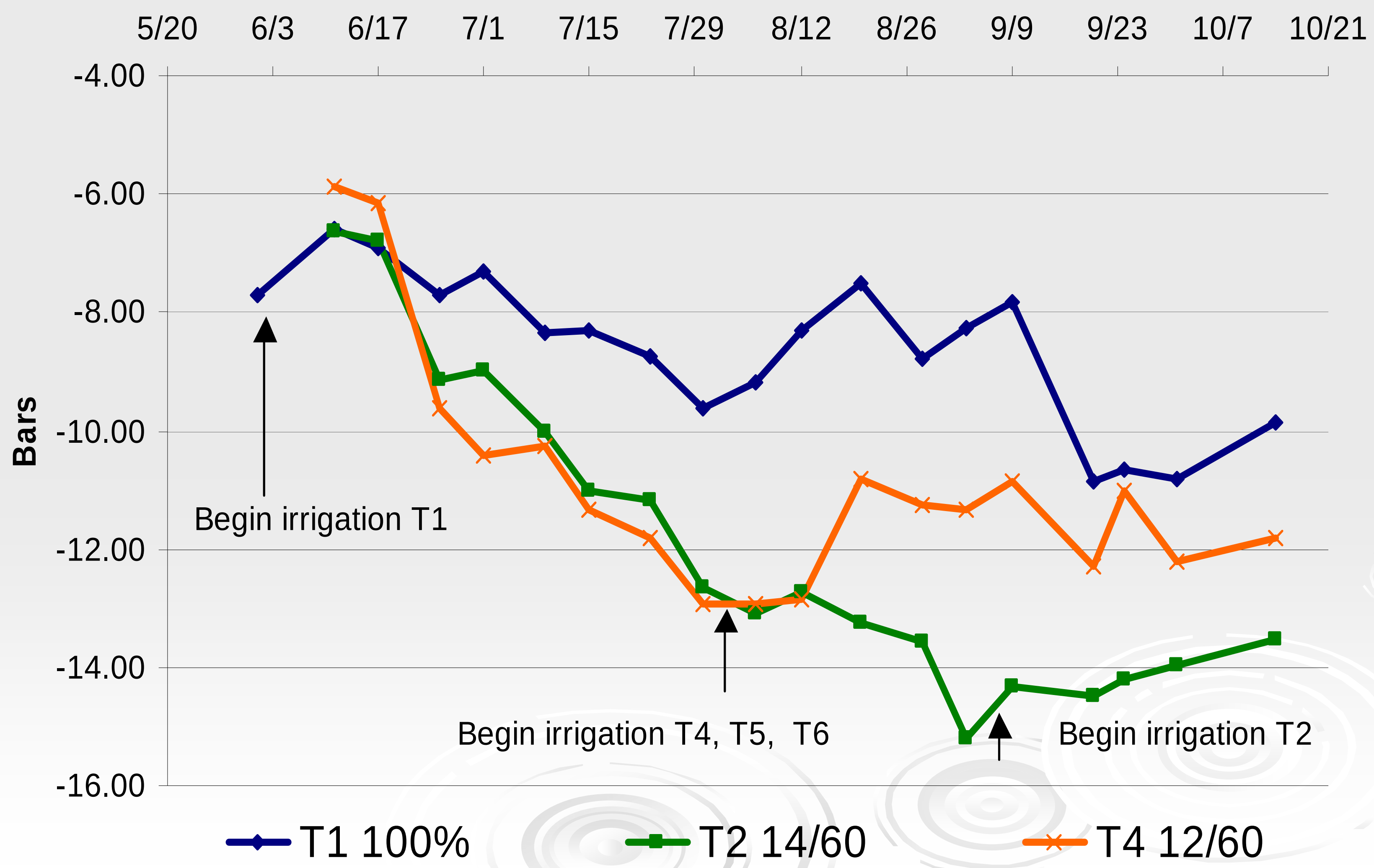
When to begin Irrigation

Stress Threshold Method

leaf water potential threshold

-12 to -14 bars

Mid-day Leaf Water Potential Hopland Cabernet 2000



How Much Water

Stress Threshold Method +RDI

After threshold a fraction of full vine water use

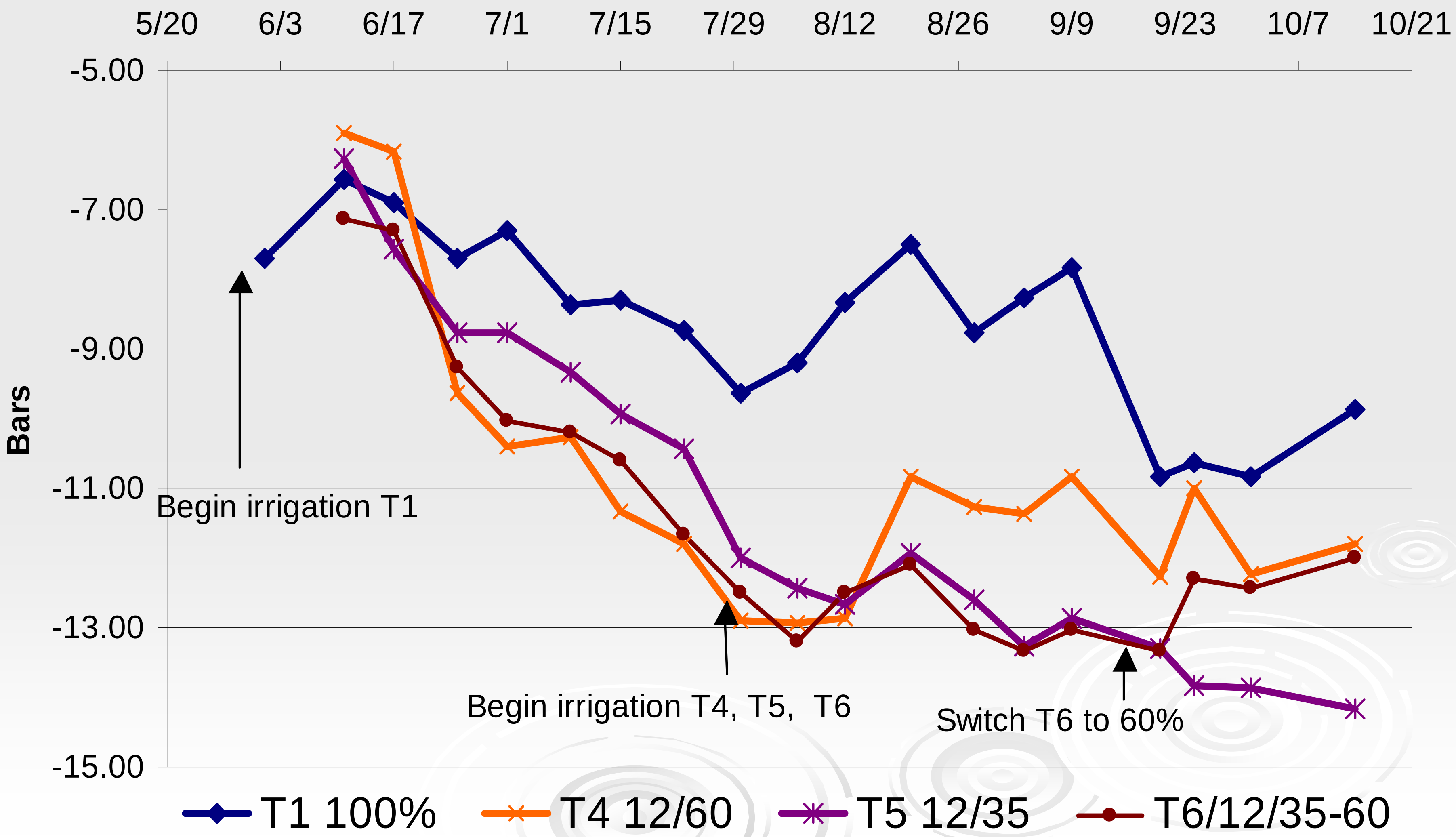
Full vine water use x RDI %

Rdi % --- 35 - 60%

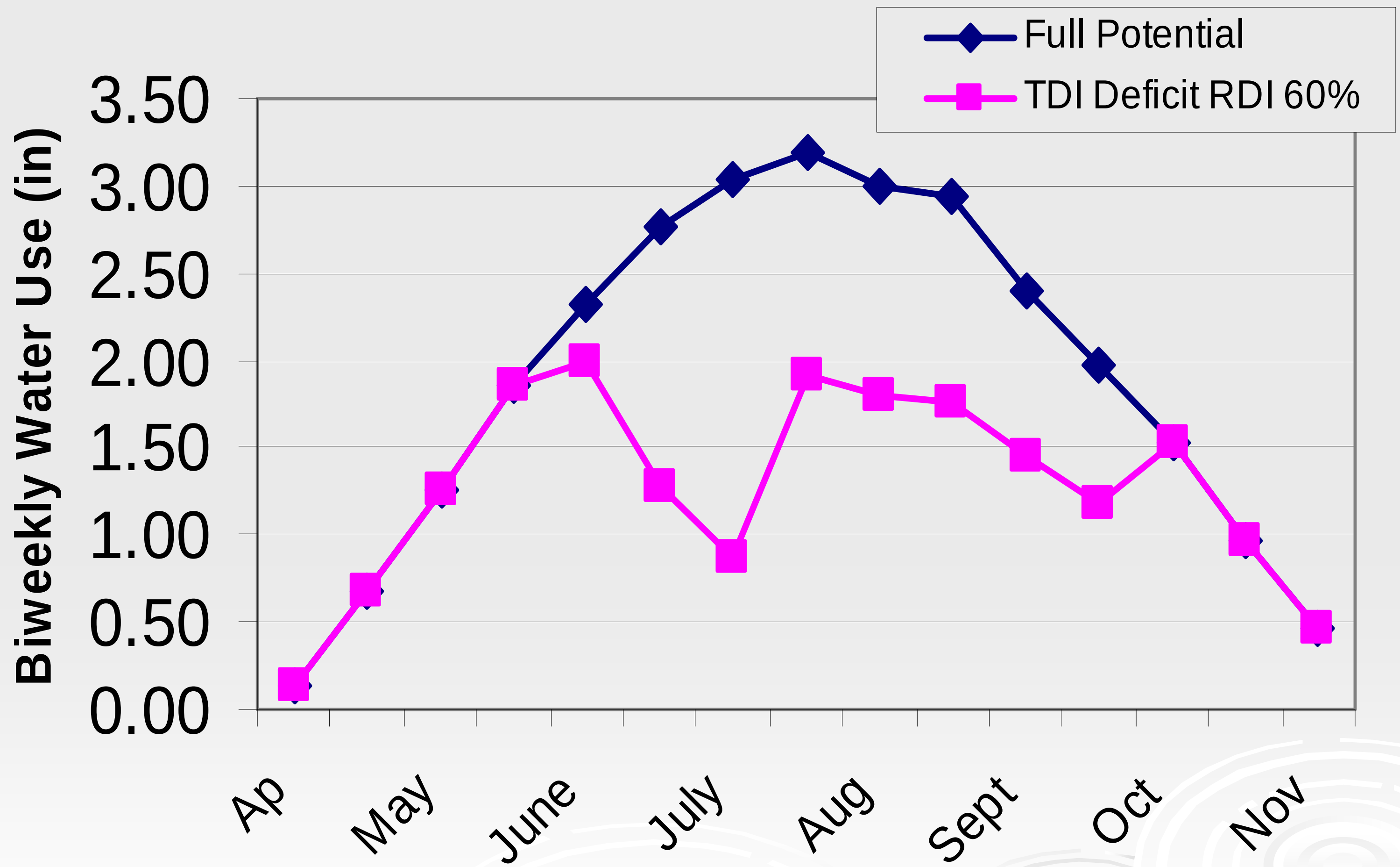
Post Threshold RDI %

- Prevent new vegetative growth
- Provide fruit cover
- Continue photosynthesis

Mid-day Leaf Water Potential
2000 Cabernet, Hopland



Water Use of Full Potential & Stress Threshold / RDI 60%



Monitor Effects of Strategy

Leaf Water Potential

Vegetative Growth

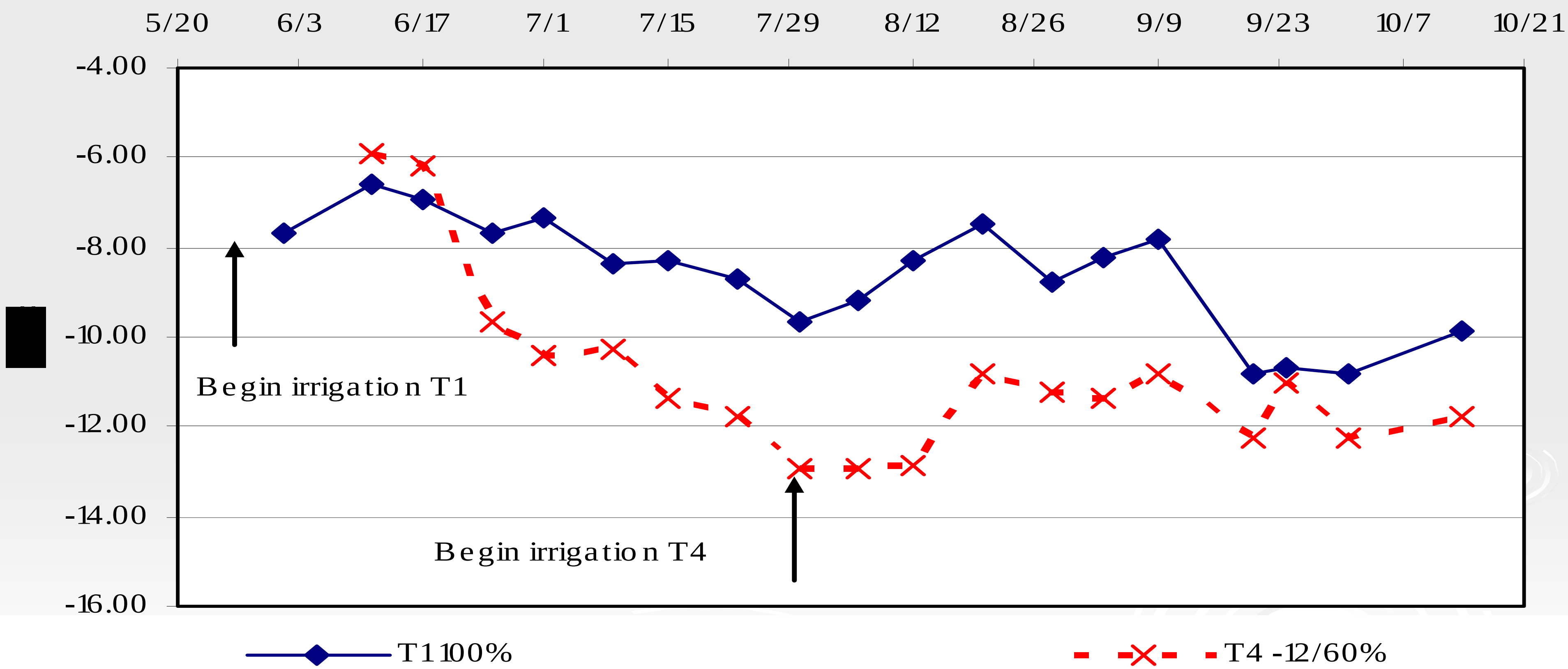
Yield

Quality

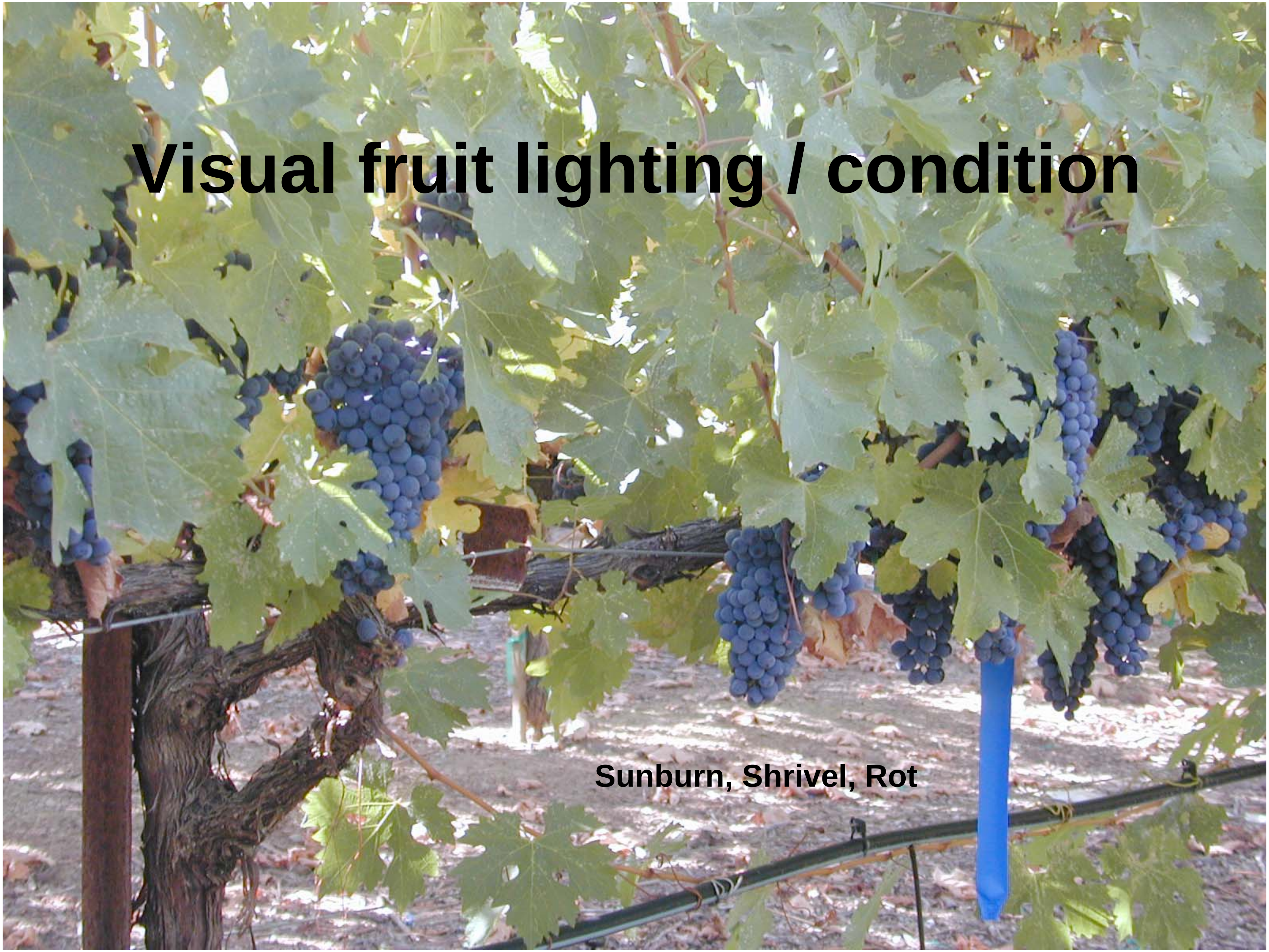
Winemaker Comments

Post Threshold Water Potential

Figure J-1. Leaf Water Potentials
Hopland Cabernet Sauvignon 2000



Visual fruit lighting / condition



Sunburn, Shrivel, Rot


T3
HARVEST


Severe Deficit
Loss of Leaf Cover

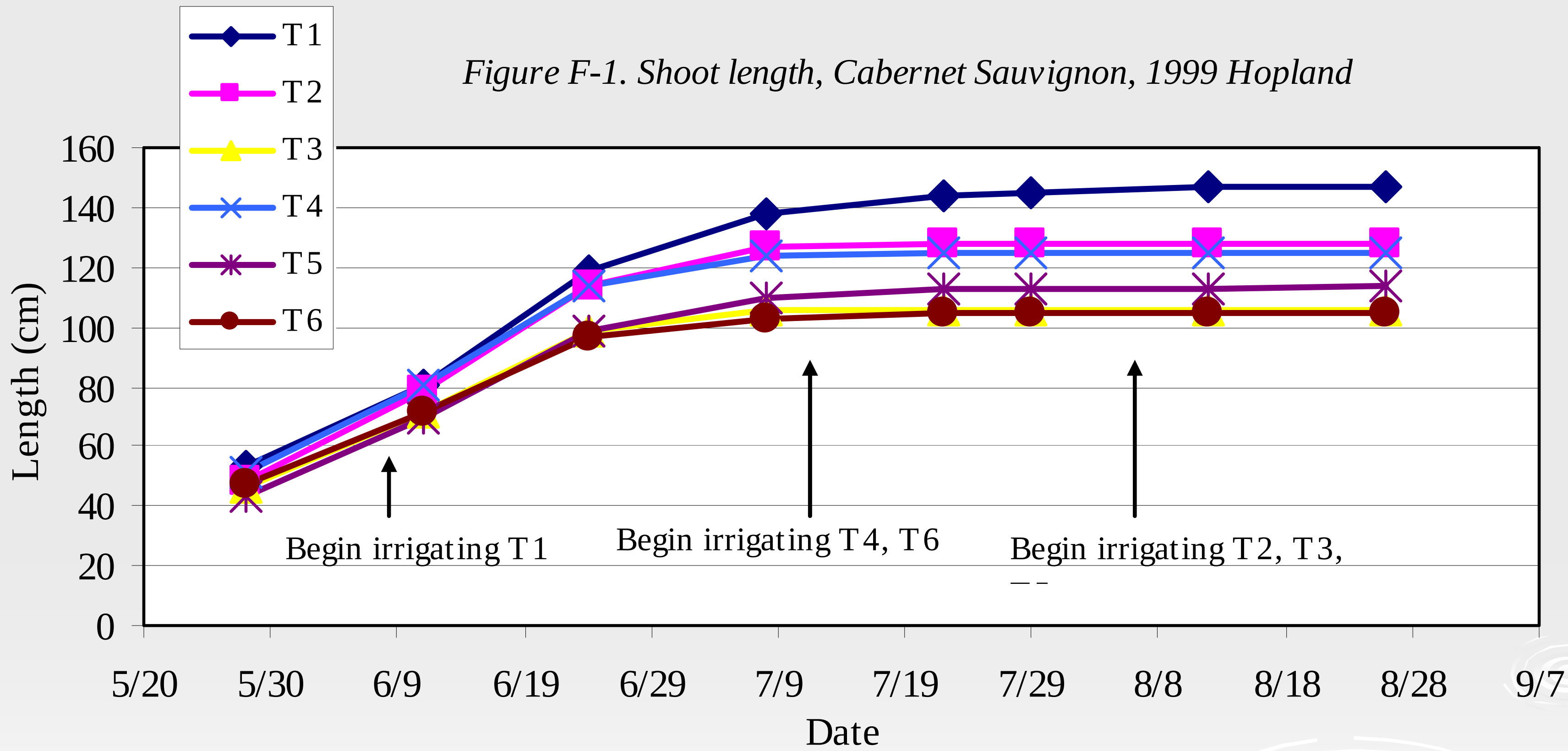
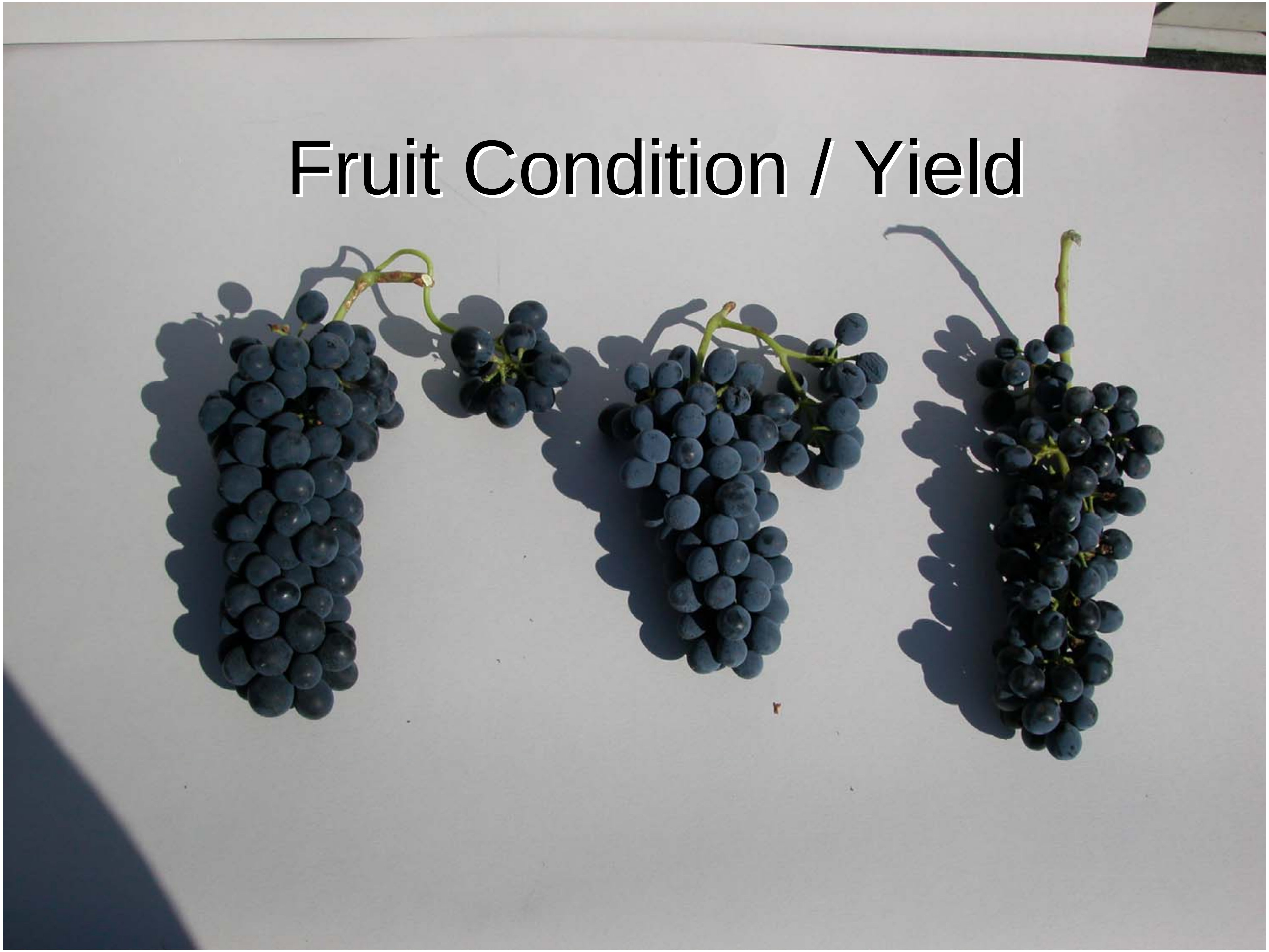


Figure F-1. Shoot length, Cabernet Sauvignon, 1999 Hopland
T1
T2
T3
T4
T5
T6
Length (cm)
160
140
120
100
80
60
40
20
0
Begin irrigating T1
Begin irrigating T4, T6
Begin irrigating T2, T3,
5/20
5/30
6/9
6/19
6/29
7/9
7/19
7/29
8/8
8/18
8/28
9/7
Date

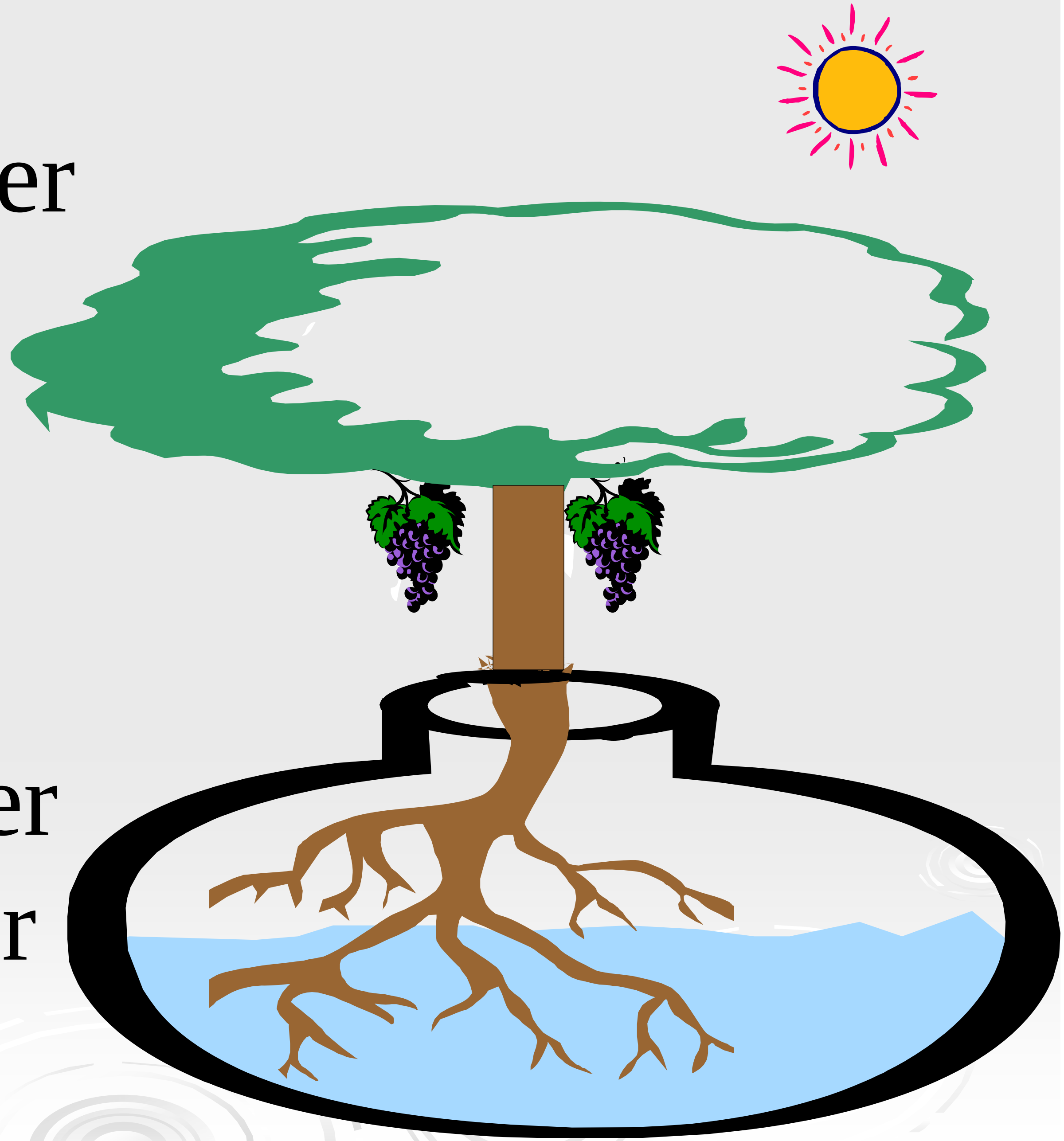
Fruit Condition / Yield



Vine Water Use

vs.

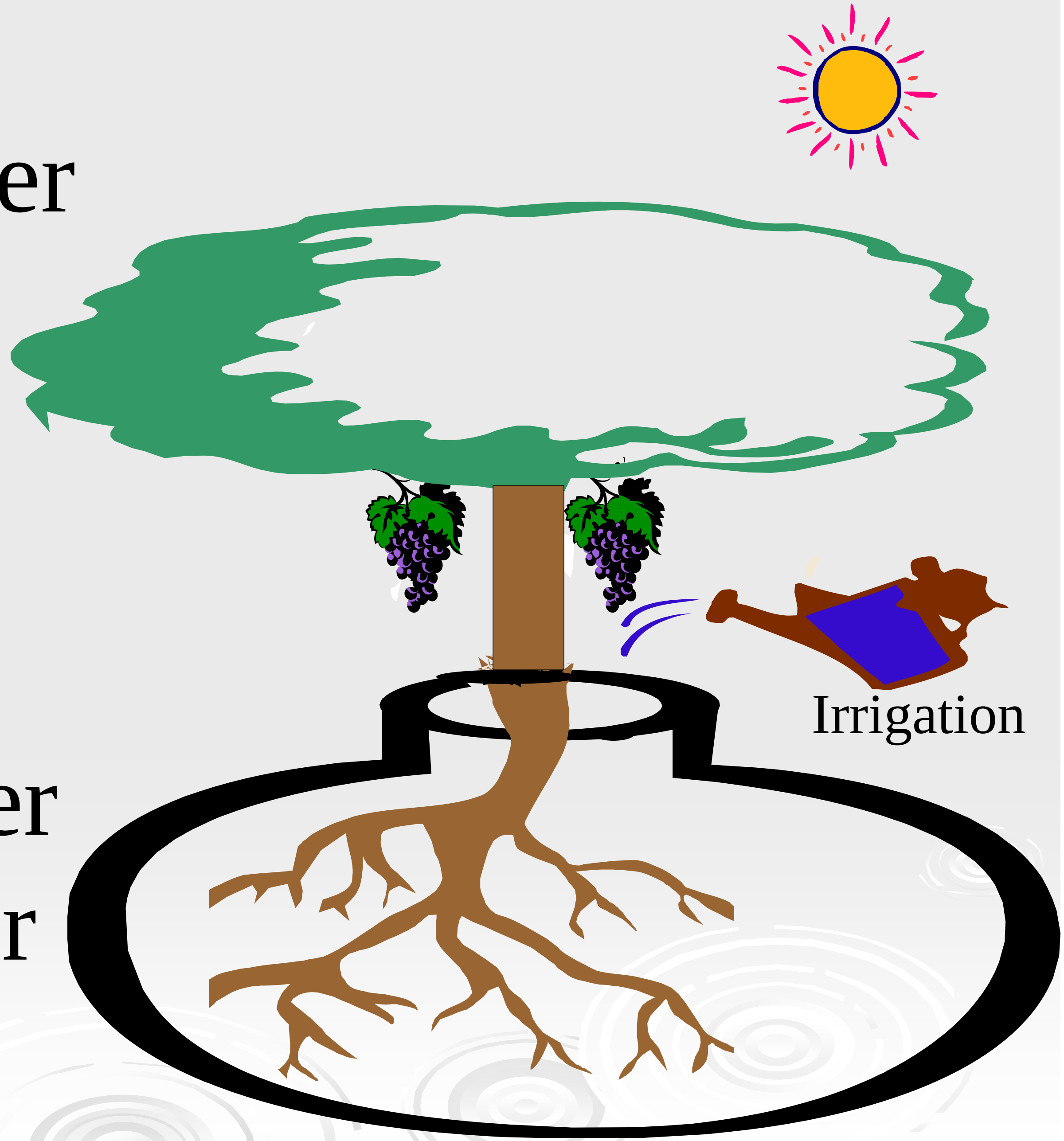
Soil Water Reservoir



Vine Water Use

vs.

Soil Water Reservoir



Vineyard Development

Soil/Climate Resources

- Selection
  - Rootstock
  - Clone
  - Spacing
  - Trellis type

Considerations Using ST+RDI

- Young Vines
- Extreme Climate Periods
- Use of Cover Crops
- Rootstocks
- Low Vigor Vineyards
- Extreme Climate areas
- Leaf Removal
- Water Savings
- Water Use Efficiency

Young Vines

Low Vigor Vineyards

Trun on Campbell
lab
Old Hutchinson Dr
Kleiber Hall Dr
Hutchison Dr
Hutchinson off ramp
La Rue Rd
Dairy Rd
Bioletti Way
Turn on Blacksmith
Blacksmith Rd
Turn on Brooks
Bainer Hall Dr
Garrod Dr
Arboretum
Levee Rd
Gate
Vineyard
WGI
Old Davis Rd
From I 80 Take Woodland 113
2589 ft
© 2009 Tele Atlas
Image © 2009 DigitalGlobe
Image © 2009 City of Davis
US Census Bureau
©2009 Google
Imagery Dates: 2005 - Aug 10, 2006
lat 38.529809° lon -121.767920° elev 59 ft
Eye alt 9031 ft