University of California
Agriculture and Natural Resources

Resource-efficient Design and Management of Micro-irrigation for Vineyards

Rancho California Water District
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PRESENTATION OUTLINE

1) Review the Concepts of Irrigation Efficiency
2) Design Considerations for Micro-Irrigation Systems
3) Estimating Vineyards' Water and Energy Requirements

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4) Methods and Tools for Irrigation Scheduling
5) Selecting and Executing an Irrigation Strategy
6) Q & A

IRRIGATION EFFICIENCY @ FIELD SCALE

What fraction of the total water applied to field is beneficially used by the crop

$$I.E. = \frac{Water\ used\ by\ the\ crop\ for\ E.T. + Other\ Uses}{Total\ water\ applied\ onto\ the\ field}$$

Beneficial is the water used for crop production & health

- ✓Canopy Transpiration (T)
- ✓Chemical applications for pest & weeds control, fertilizers & nutrients
- ✓Frost Protection & Canopy Cooling
- ✓Leaching salts + soil amendments (gypsum, humic/fulvic acids and others)

$$Irr.Eff. = \frac{Water\ used\ by\ the\ crop\ for\ ET + Other\ Beneficial\ Uses}{Total\ water\ applied\ onto\ the\ field}$$

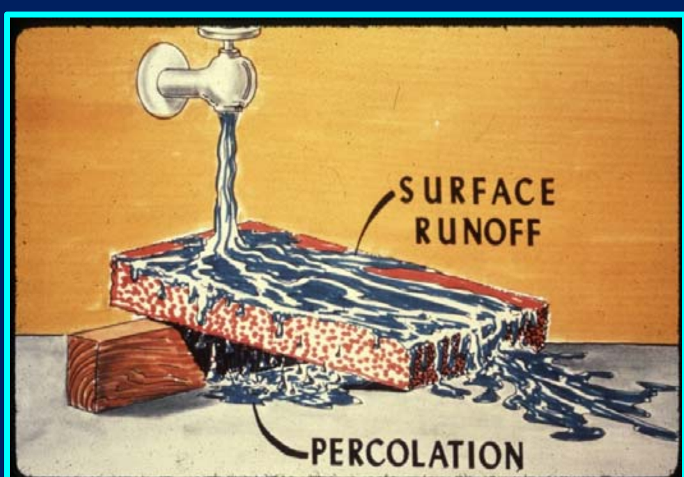
Water Applied to the field

- ✓Replenish Soil Moisture Depleted since the last irrigation event (ETc)
- ✓Soil Evaporation + Deep Percolation + Surface Runoff + Wind Drift
- ✓Leakages from pipes, canal, ditches + valves/gates stuck-open, wrong commands, operational losses, irrigation over-run, etc.
- ✓Water draining out of pipes and hoses after irrigation shut-off (pulsing on-off)
- ✓Pipe flushing + Screen cleaning & Filters back-flush
- ✓Pipe & hose chemical injection (keep the pipe system clean and functional)

Application Efficiency (A.E.) vs. Irrigation Efficiency (I.E.)

single irrigation event

$$A.E. = \frac{\text{Water stored in the soil root zone}}{\text{Total water applied onto the field}}$$



entire irrigation season

$$I.E. = \frac{\text{Water beneficially used by the crop}}{\text{Total water applied onto the field}}$$

Distribution Uniformity (D.U.) vs. Irrigation Efficiency (I.E.)

Distribution Uniformity:

is a number (%) describing how evenly water is distributed across the field/among plants

Irrigation Efficiency:

is the fraction of the applied water that is beneficially used by the crop

EXAMPLE

2 gallons per tree in July

The trees will use every drop of this applied water

D.U. = 100%; I.E. = ~100%

200 gallons per tree in July

Trees will use only a fraction of the applied water

D.U. = 100%; I.E. << 100%

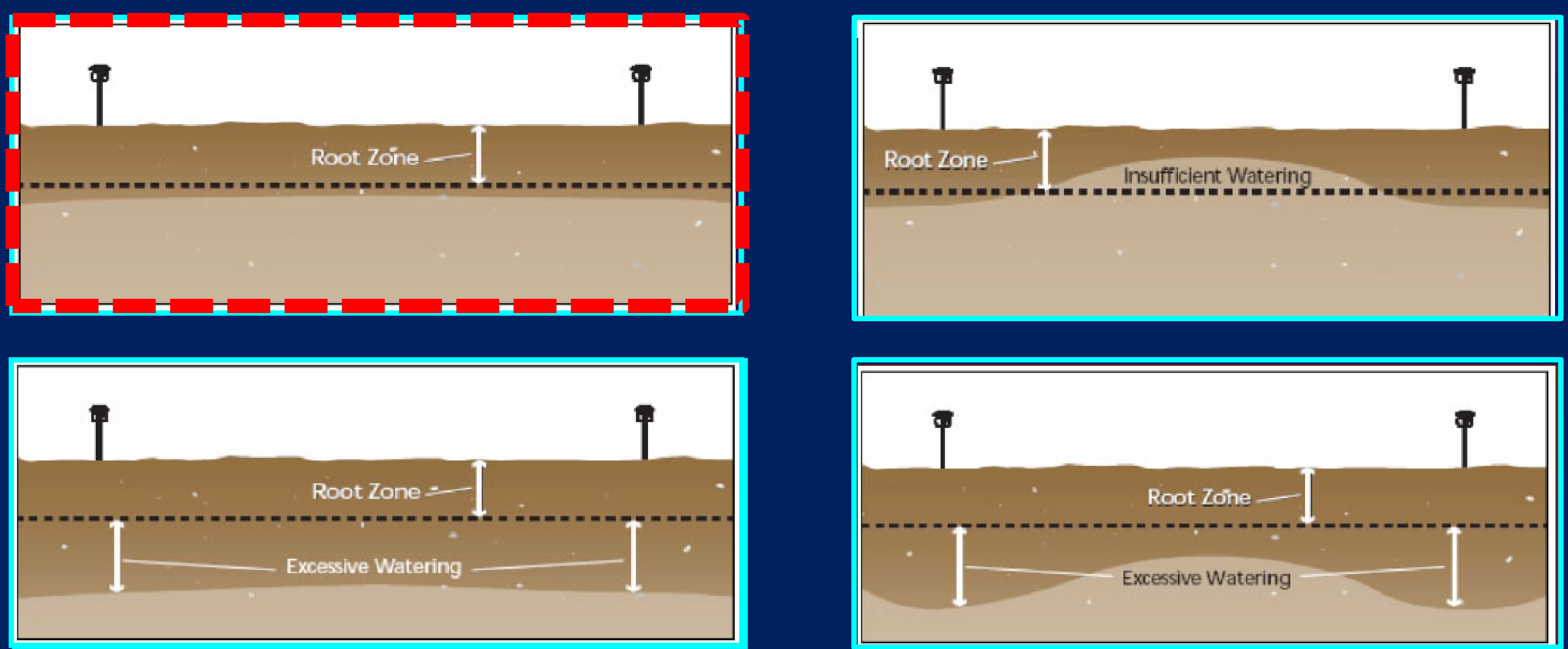
Irrigation Efficiency Components

Irrigation Application

- ✓Adequacy of application (depth or volume infiltrated & stored)
- ✓Application Uniformity (DU)

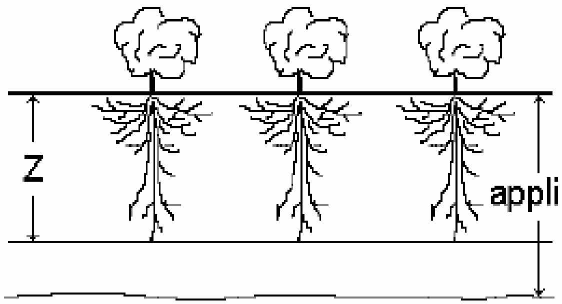
Irrigation Losses

- ✓Soil Evaporation
- ✓Deep percolation
- ✓Runoff
- ✓Wind drift (sprinkler)



Adequacy of application refers to the depth or volume of water that infiltrates in the root zone and is available for plant use (T)

ADEQUACY OF APPLICATION



Uniform, but average depth applied exceeds the soil water deficit (too much deep percolation)

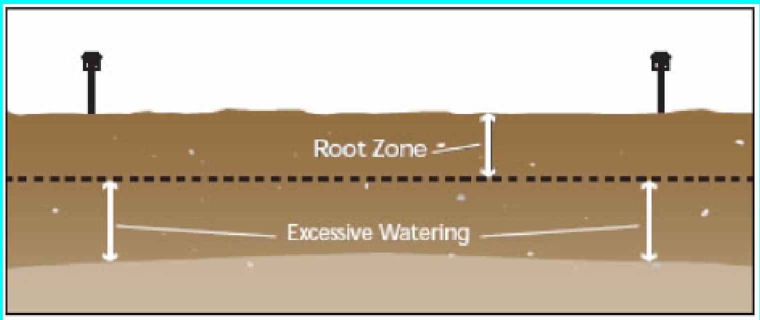


FIGURE 3: Depiction of irrigation resulting in good DU but poor irrigation efficiency

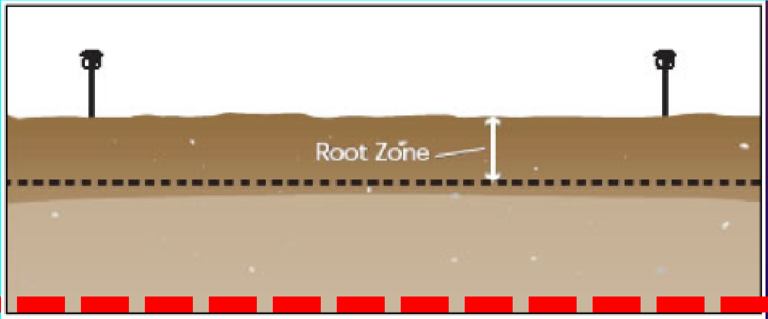
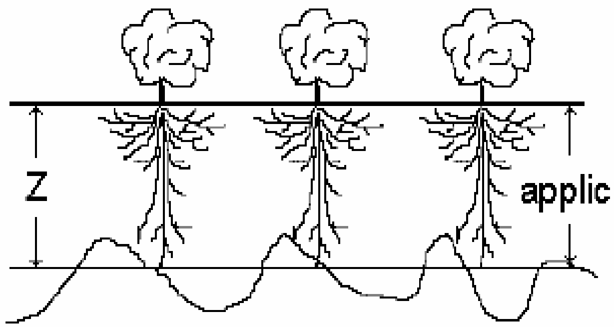


FIGURE 4: Depiction of irrigation sufficiently watering the entire field with good DU and irrigation efficiency

Whether an irrigation is adequate or not depends on the irrigation set-time & soil moisture status/depletion @ irrigation start

Whether water is distributed evenly among plants (D.U.) mainly depends on proper system design, operation & maintenance

UNIFORMITY OF APPLICATION



Average depth is correct, but application is highly nonuniform, with underirrigation and DP

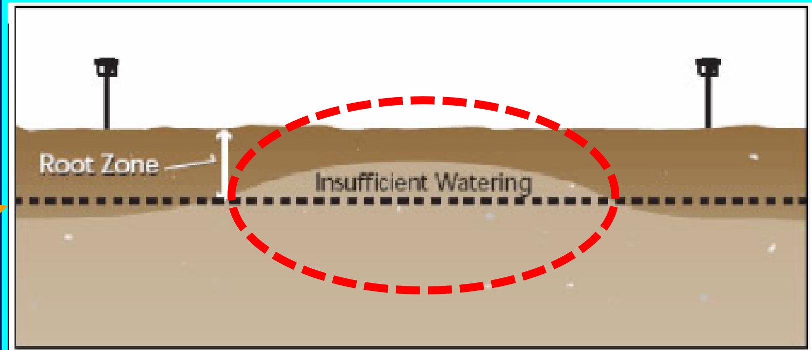


FIGURE 2: Depiction of irrigation resulting in poor DU and insufficient irrigation in parts of the field

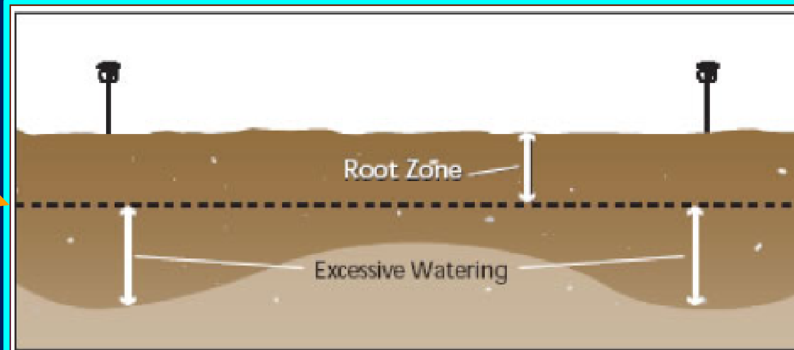
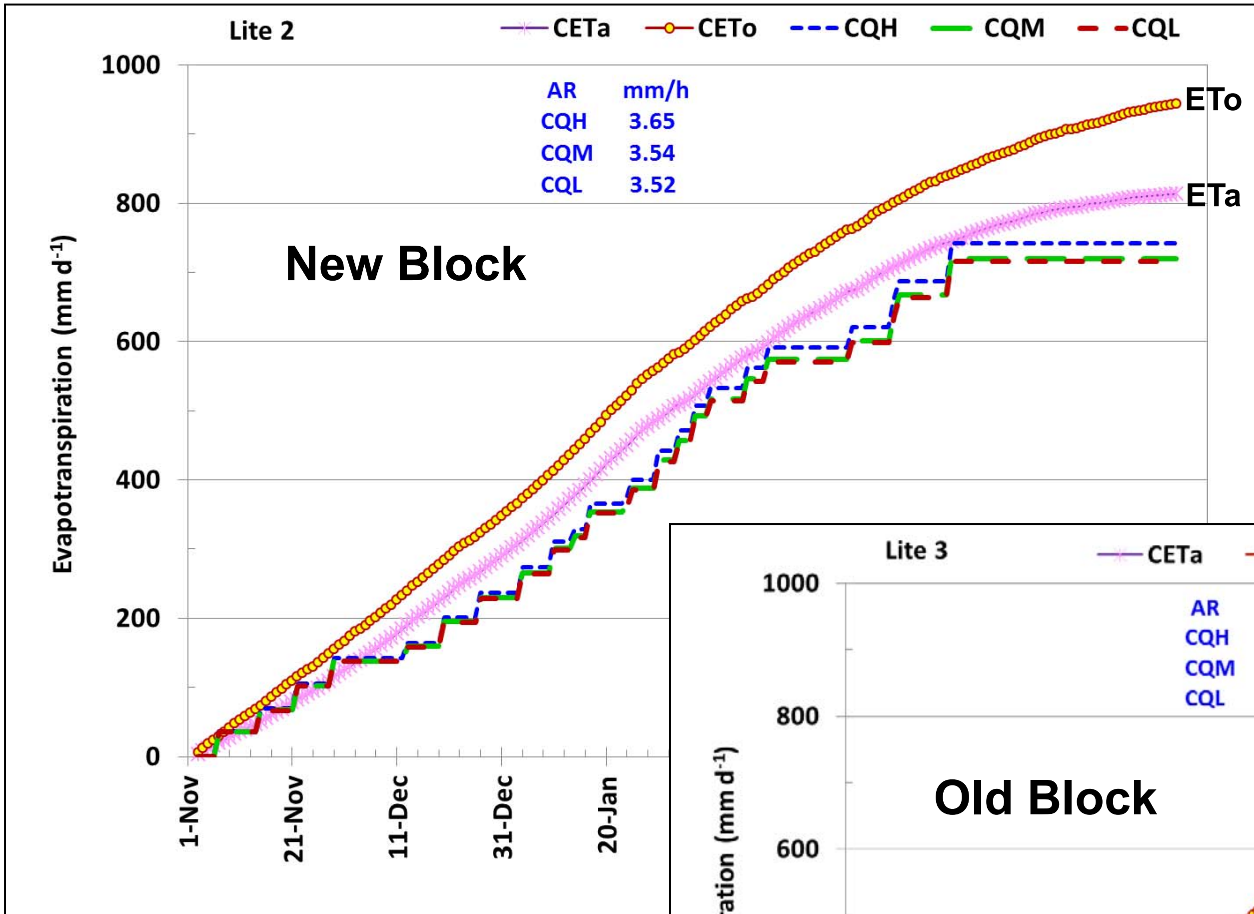
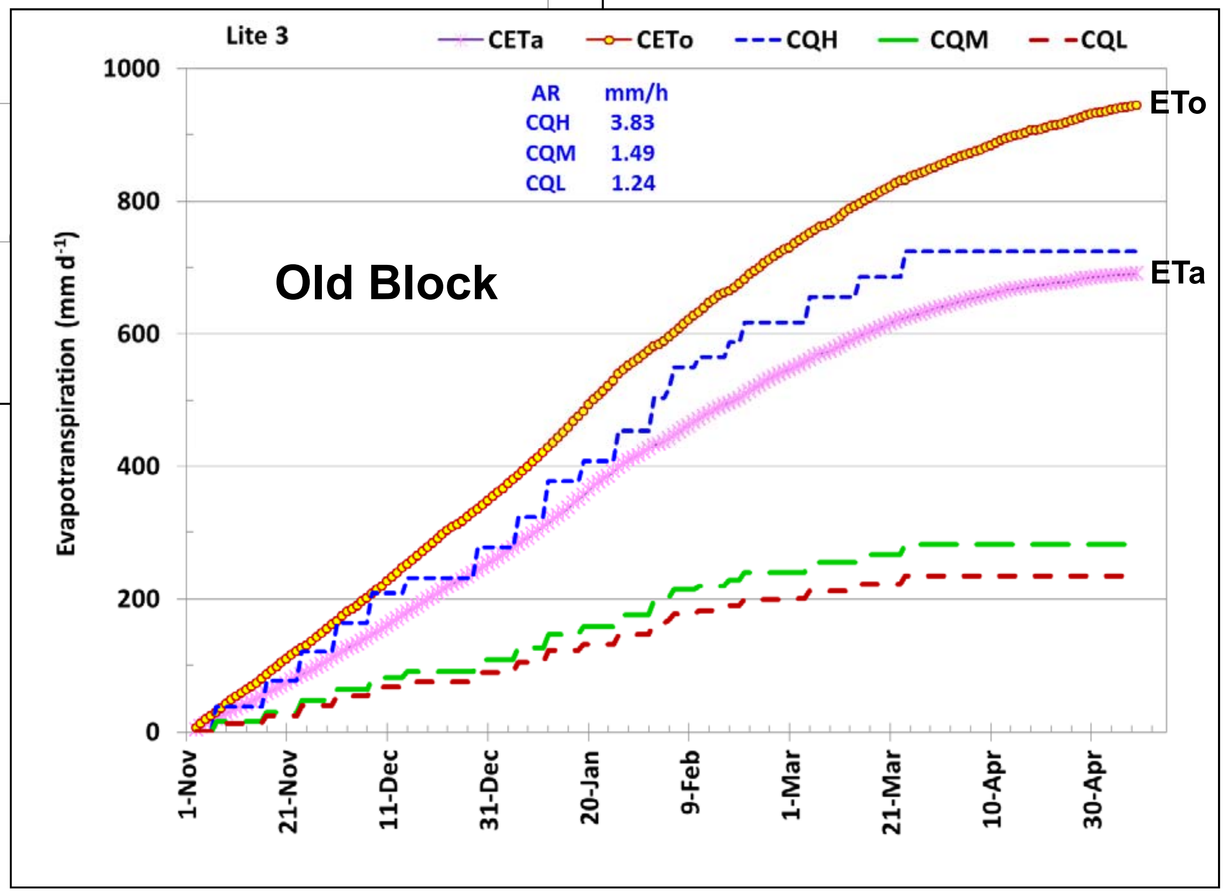


FIGURE 1: Depiction of irrigation resulting in poor DU and excessive watering

Some parts of the field must be over-irrigated so that the areas receiving less water can be adequately irrigated.

This over-irrigation can cause excessive deep percolation


Lite 2
CETa
CETo
CQH
CQM
CQL
AR mm/h
CQH 3.65
CQM 3.54
CQL 3.52
New Block
ETo
ETa
Evapotranspiration (mm d-1)
1000
800
600
400
200
0
1-Nov
21-Nov
11-Dec
31-Dec
20-Jan


Lite 3
CETa
CETo
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CQL
AR mm/h
CQH 3.83
CQM 1.49
CQL 1.24
Old Block
ETo
ETa
Evapotranspiration (mm d-1)
1000
800
600
400
200
0
1-Nov
21-Nov
11-Dec
31-Dec
20-Jan
9-Feb
1-Mar
21-Mar
10-Apr
30-Apr

Why should we care about being efficient irrigators?

✓**REDUCE WATER AND ENERGY BILLS FOR PRODUCING OUR CROPS** (sprinkler & micro-irrigation, groundwater pumping)

✓**GROW MORE ACREAGE WITH SAME WATER/ENERGY OR OBTAIN HIGHER YIELD**

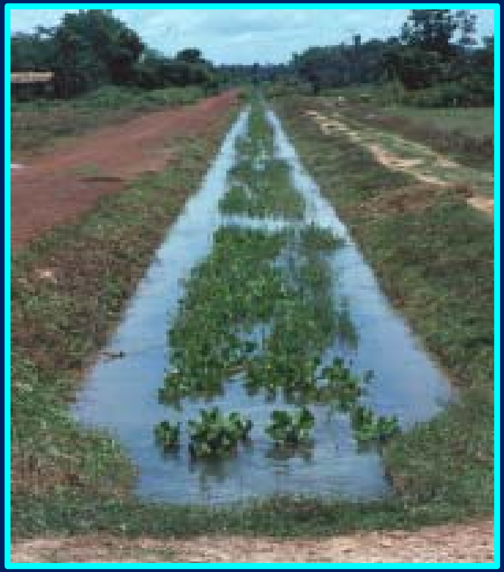
✓**HEALTHY CROP** => LESS WATER-RELATED PROBLEMS (water stress, hypoxia, asphyxia, phytophtora, weeds growth, etc.)

✓**BETTER CONTROL ON WATER & NUTRIENTS** AVAILABLE IN THE SOIL TO PLANTS

✓**COMPLIANCE WITH EXISTING ENVIRONMENTAL REGULATIONS** (ILRP, SGMA, AB 589, BILL32)

INEFFICIENT IRRIGATION OFTEN LEADS TO:

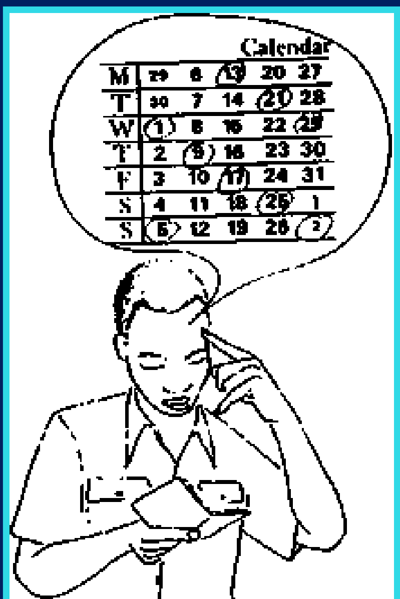
- ✓ **Higher costs** (labor, water, nutrients, pumping)
- ✓ **Crop yield lower than max potential** (or alternate bearing)
- ✓ **Uneven/slow plants development & production**
- ✓ **Leaching nutrients, fertilizers and pesticides**



WHAT IT TAKES TO BE EFFICIENT?

Good System Design

- ✓Accurate & Skilled
- ✓Flexible Operation



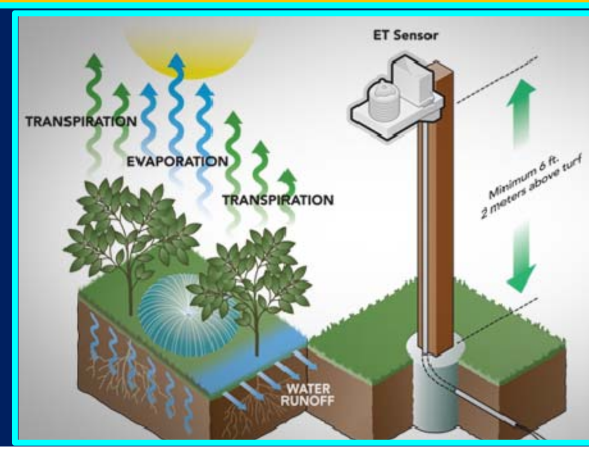
Proper Installation
Regular Maintenance
System Evaluation

Defined Irrigation Strategy

- Full Irrigation
- Deficit Irrigation (SDI, RDI)

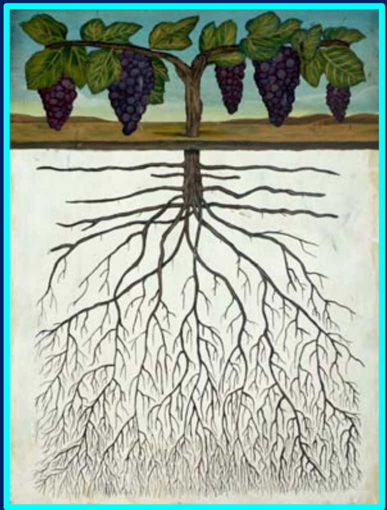
Accurate
Irrigation Scheduling
& Control

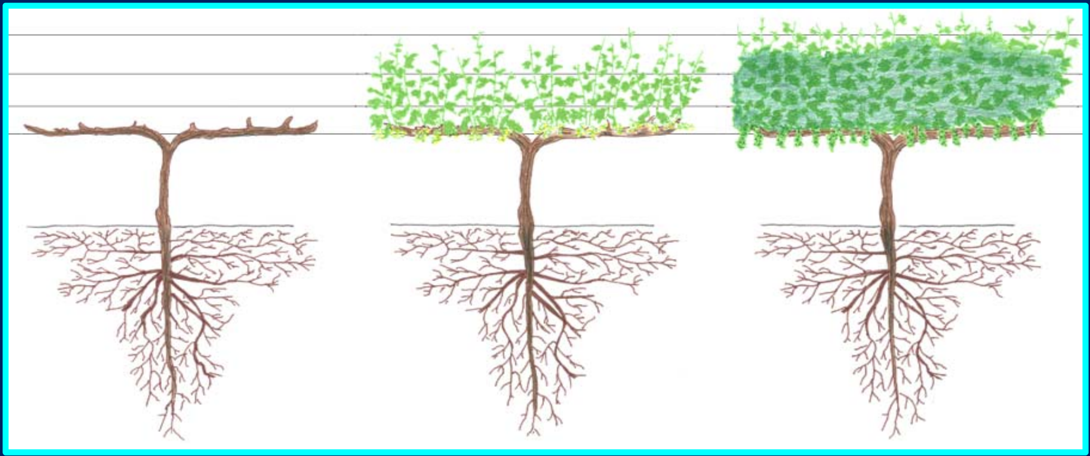
Implementation of
Schedule & Feedback



Root system of mature grapevine consists of a woody framework of older roots from which multi-branching roots develop in multiple directions that:

- ✓ Mine the soil deeply and horizontally
- ✓ Thrive in soils with good balance between water and air (un-saturated soils)
- ✓ Do not benefit from soil compaction, saturation and wetting-drying cycles



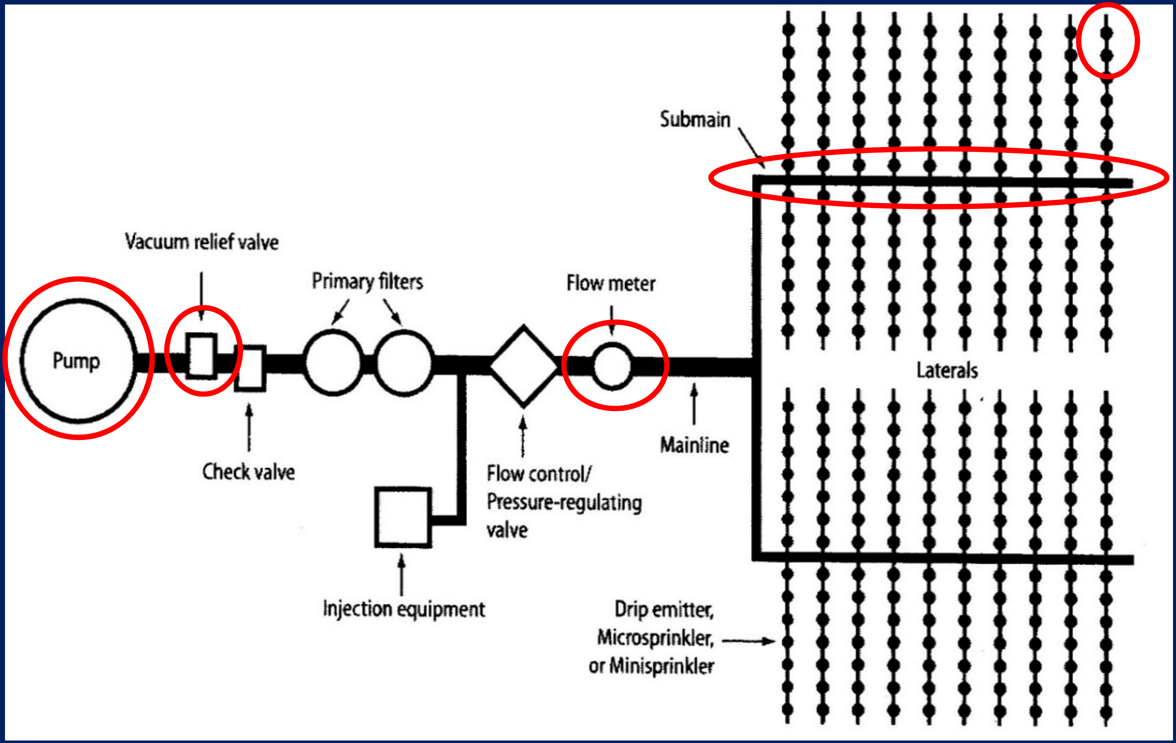


Low volume micro-irrigation is mostly used for wine grape, as it allows careful management of amounts and timing of irrigation/nutrient applications

Surface and sprinkler irrigation have been associated with increased incidence of fungal diseases to leaf, canopy and clusters.

DESIGN STAGE - Important aspects where to focus attention:

1) Conduct preliminary site testing/evaluations (soil, slopes, water supply, plant spacing & density, trellis system, canopy size, etc.)
2) Define the **water application rate** based on soil properties (**infiltration rate**; **water holding capacity**, slope, etc.) and crop water needs (ET)
3) Size the different system components from downstream to upstream
4) Ensure operational flexibility to the system



Flexibility of Operation => range of operating conditions (Q, P)

During its life the irrigation system may be operated with different conditions

- Water needs of immature vines are small, and increase with time
- Blocks at different elevations and distances from the water supply
- Blocks with different emitters (application rates), due to soil differences
- Composite systems (different flow rate and pressure => single and double line, drip and micro-sprinkler, alternating or solid, etc.)
- Groundwater level decreasing with time

APPLICATION RATE << SOIL INTAKE RATE (inch/hr)

System	Appl. Rate (in./hr)
Surface Irr.	0.40 – 0.45
Sprinkler	0.12
Micro-sprinkler	0.05
Drip	0.01 - 0.03

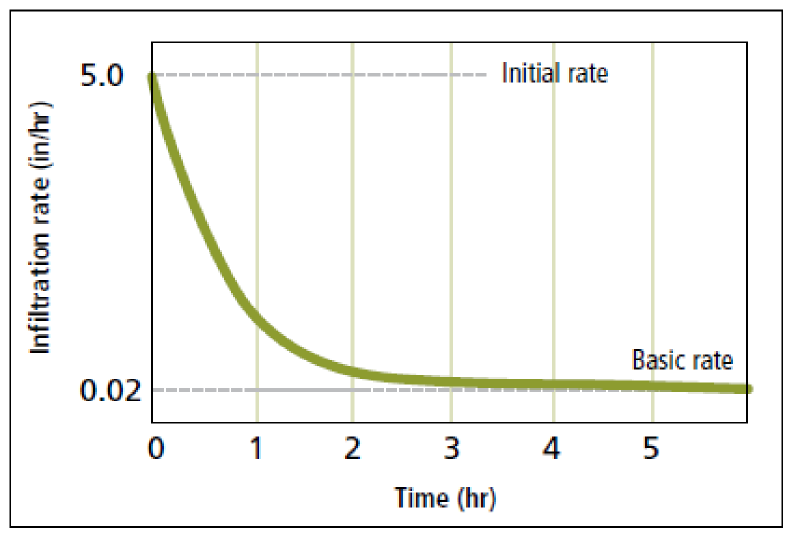


Table 1. Recommended maximum application rates for soils of various textures

Soil type	Maximum application rate (in/hr) at slope		
	0–5%	5–8%	8–12%
coarse sandy soil	1.5–2.0	1.0–1.5	0.75–1.0
light sandy soil	0.75–1.0	0.5–0.8	0.4–0.6
silt loam	0.3–0.5	0.25–0.4	0.15–0.3
clay loam, clay	0.15	0.10	0.08

Source: NRCS 1984.

Ranges of Water-Holding Capacities (W_A = FC - WP) for different soils

Soil texture	Water-holding capacity Range In./ft	Average In./ft
1. Very coarse texture—very coarse sands	0.38-0.75	0.50
2. Coarse texture—coarse sands, fine sands, and loamy sands	0.75-1.25	1.00
3. Moderately coarse texture—sandy loams	1.25-1.75	1.50
4. Medium texture—very fine sandy loams, loams, and silt loams	1.50-2.30	2.00
5. Moderately fine texture—clay loams, silty clay loams, and sandy clay loams	1.75-2.50	2.20
6. Fine texture—sandy clays, silty clays, and clays	1.60-2.50	2.30
7. Peats and mucks	2.00-3.00	2.50

NOTE: 1 mm/m = 0.012 in./ft.

Cost: $40-60 per acre

Max depth to apply per irrigation (D_{GMAX})

$$D_{GMAX} = \left[\left(\frac{MAD}{100} * \frac{P_W}{100} * W_a * Z_E \right) / Eff_{APPL.} \right]$$

D_{GMAX} (in.) = Max. Gross Depth of water to apply per irrigation

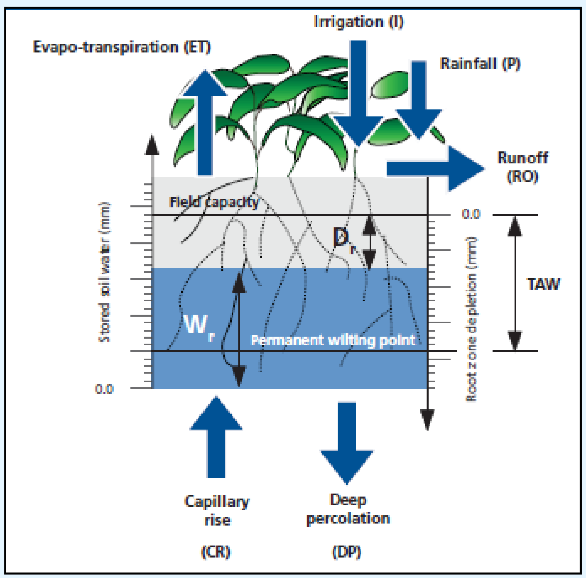
MAD = Management Allowable Depletion (depletion threshold for no stress)

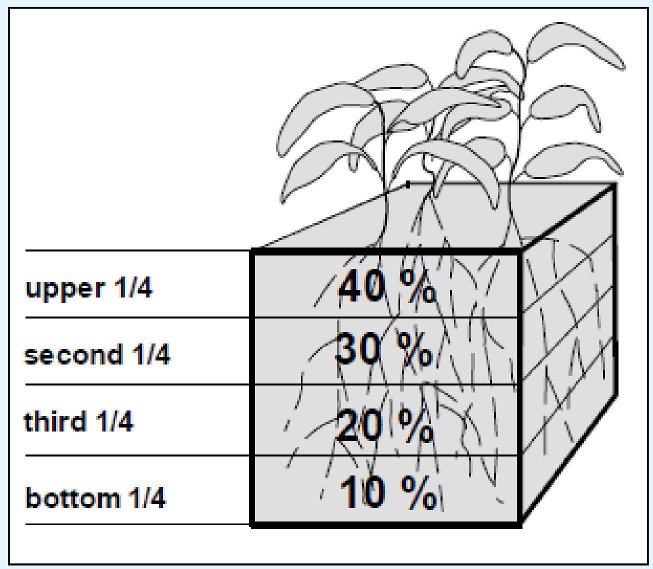
W_a (in./ft.) = Available Water-holding Capacity of the soil (FC-WP)

P_W (%) = Percent Wetted Area

Z_E (ft.) = Effective Root Depth (60-70% of actual root depth)

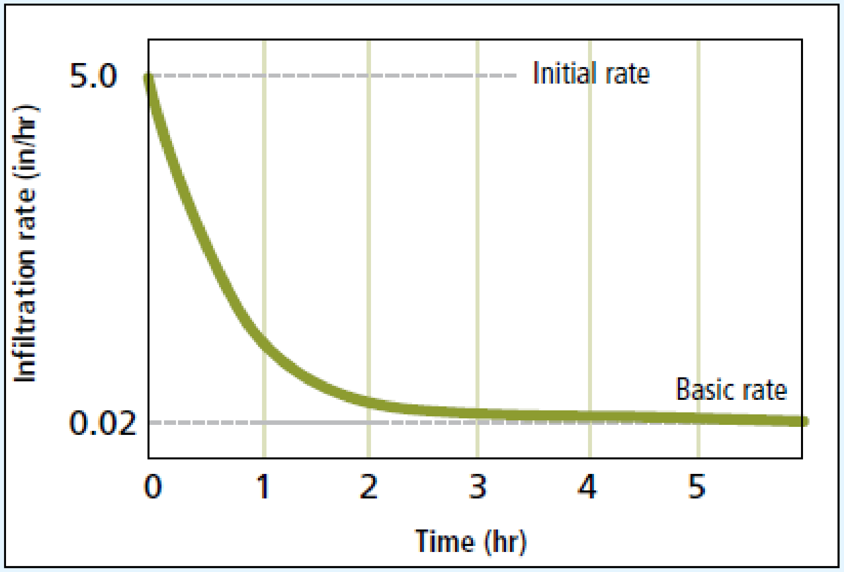
$Eff._{APPL.}$ = Application Efficiency of the selected irrigation method





Max Irrigation Set-Time, T_{IRR} (hr)

$$T_{IRR} = \frac{D_{G\ MAX}}{Appl.\ Rate} = \frac{D_{G\ MAX}}{< Soil\ \ Intake\ \ Rate}$$



D_{GMAX} (in.) = Max. Gross Water Depth of water to apply per irrigation

Appl. Rate < = Soil Intake Rate (in./hr)

System	Appl. Rate (in./hr)
Gravity	0.43
Drip	0.03
Micro-sprinkler	0.05
Sprinkler	0.12

Table 1. Recommended maximum application rates for soils of various textures

Soil type	Maximum application rate (in/hr) at slope		
	0–5%	5–8%	8–12%
coarse sandy soil	1.5–2.0	1.0–1.5	0.75–1.0
light sandy soil	0.75–1.0	0.5–0.8	0.4–0.6
silt loam	0.3–0.5	0.25–0.4	0.15–0.3
clay loam, clay	0.15	0.10	0.08

Source: NRCS 1984.

Note: Metric conversion: 1 in = 2.54 cm.

How to convert water depth (in.) to gallons per plant?

$$Water\ volume\ (gals/day) = Water\ Depth\ (in/day) * crop\ spacing\ (ft^2) * 0.623$$

Evapotranspiration (inches per day)

Crop Spacing (ft^2) = row spacing × plant spacing	0.05	0.1	0.15	0.2	0.25	0.3	0.35	0.4
100	3	6	9	12	16	19	22	25
200	6	12	19	25	31	37	44	50
400	12	25	37	50	62	75	87	100
600	19	37	56	75	93	112	131	150
800	25	50	75	100	125	150	174	199
1000	31	62	93	125	156	187	218	249
1200	37	75	112	150	187	224	262	299
1400	44	87	131	174	218	262	305	349
1600	50	100	150	199	249	299	349	399
1800	56	112	168	224	280	336	392	449
2000	62	125	187	249	311	374	436	498
2200	69	137	206	274	343	411	480	548
2400	75	150	224	299	374	449	523	598

From Larry Schwankl, Blaine Hanson, and Terry Prichard, *Low-Volume Irrigation*. University of California, Davis, 1993.

Calculation Example

<u>Mature vineyard</u>: Cabernet Sauvignon, 5 x 6 ft. spacing, VSP trellis

Irrigation system: Single dripline

Root depth, Z = ~ 5 ft

Effective rooting depth, Z_E = 70% x 5 ft = 3.5 ft

Wetted area, P_W = 25%

<u>Sandy loam soil</u>

F.C. = 3.25 in./ft

P.W.P. = 1.67 in./ft

T.A.W. = 3.25 – 1.67 = 1.60 in/ft

M.A.D. = 50 % of T.A.W. = 0.5 x 1.60 in/ft = 0.80 in/ft

<u>Max gross irrigation depth to apply</u>

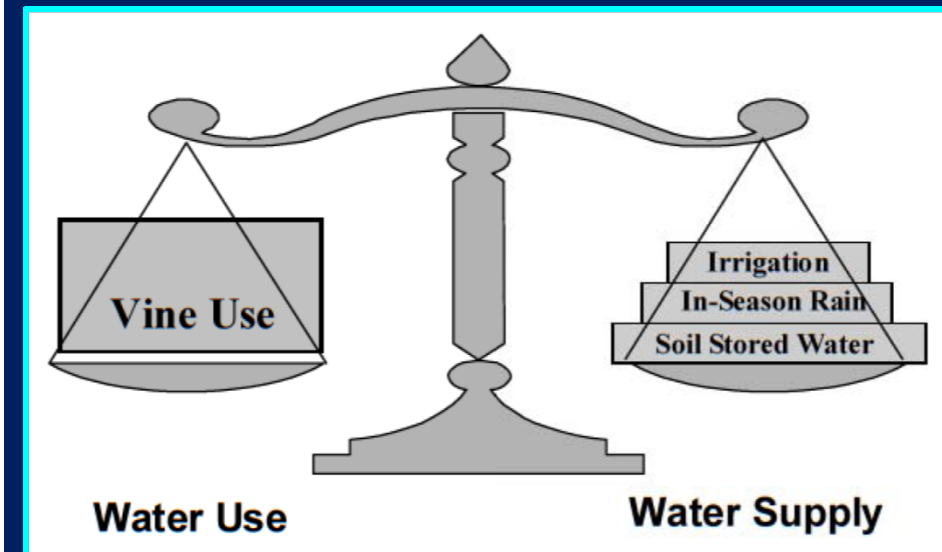
$\mathbf{D_G}$ = (MAD * TAW * Pw * Z_E)/Eff_A = (0.5 * 1.60 in/ft * 0.25 * 3.5 ft)/0.90 = **0.8 in.**

Vol (gal/plant) = D_G x Spacing x 0.623 = 0.8 in. x 5 ft x 6 ft x 0.623 **= 15 gal/plant**

WATER REQUIREMENTS OF WINE GRAPES

In California, mature wine grapes vineyards need anywhere from **20 to 28 inches** of water to grow and produce at maximum yield, depending on the training system and canopy size (light interception by the canopy)

Wine grapes can uptake and use water from various sources:



Moisture stored in the soil profile

Effective in-season rainfall

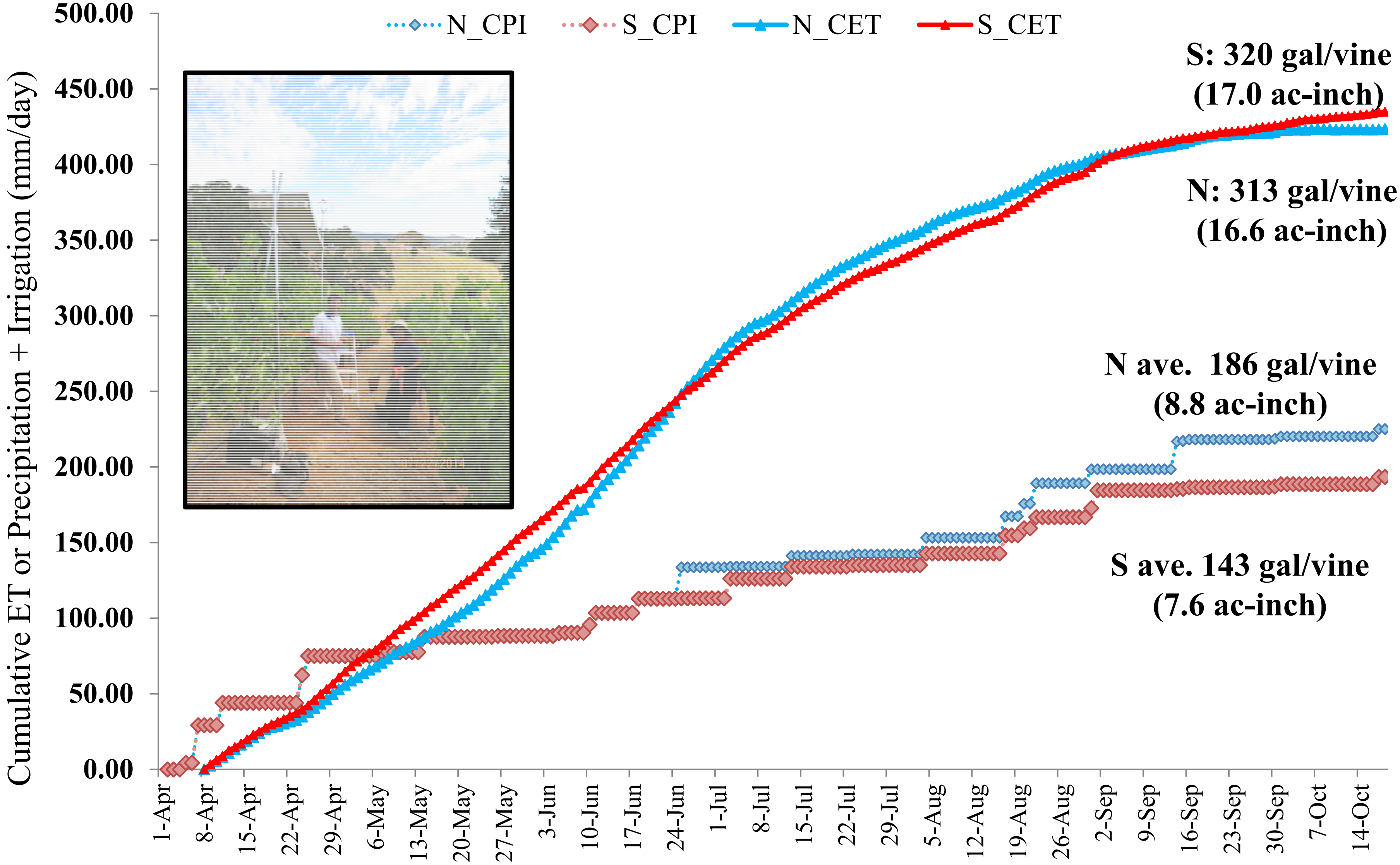
Water applied and infiltrated from irrigation

Fog and Dew

To calculate the irrigation water to apply, one must account for actual ET, residual soil moisture, rainfall, and the target level of water deficit

Cumulative ET (mm/day) and cumulative precipitation + irrigation (mm/day) on North and South facing slopes at Safari Vineyards (April 8-Oct 18, 2016)

(D. Zaccaria, L. Wunderlich, R. Snyder, K. Shackel)



AMOUNT OF IRRIGATION WATER TO APPLY

$A_{pp.}W_{ater} = (ET_a - R_{eff})/AE_{AVE}$

R_{eff} = [Rainfall – 0.25 in.) x 0.8

System	AE_{AVE}
Gravity (Surface Irr)	70-85%
Drip	85-90%
Micro-sprinkler	80-90%
Sprinkler	70-90%

AW = 18 in/0.85 = 21 in

Max ET_{Daily} = 0.2 in => Max $AW_{3\text{-}day}$ = 0.6 in/0.85 = 0.7 in (< 24 hr)

Micro-irrigation systems are typically designed to deliver the peak water amounts in 20/24 hrs

$$T_{IRR} = \frac{D_{G\ MAX}}{Appl.\ Rate} = \frac{D_{G\ MAX}}{< Soil\ \ Intake\ \ Rate}$$

If soil intake rate and water holding capacity allow, application rate can be increased to reduce irrigation set time and benefit from tiered energy rates or DR

System	Appl. Rate (in./hr)
Surface Irr.	0.40 – 0.45
Sprinkler	0.12
Micro-sprinkler	0.05
Drip	0.03

Typical Flow Rates and Pressures

Drip & Micro-sprinkler: 0.5-30 gph @ operating pressure of 20-35 psi

- Micro-irrigation emitters require only 7-10 psi;
- Cleaning and delivering the water to the emitters on flat grounds typically require additional 15-20 psi;
- Filters are the critical system components, requiring around 15-20 psi (20-25 psi if back-flushing);

ENERGY REQUIREMENTS TO IRRIGATE WINE GRAPES

It takes 1.37 whp-hr/ac-ft per foot of lift

(power the pump must provide to lift 1 ac-foot of water by 1 foot)

FUEL SOURCE	PUMP OUTPUT
ELECTRICITY	0.885 whp-hr/kWh
NATURAL GAS (925 BTU)	61.7 whp-hr/MCF
NATURAL GAS (1000 BTU)	66.7 whp-hr/MCF
DIESEL	12.50 whp-hr/gal
PROPANE	6.89 whp-hr/gal

Source of Energy	Energy Units to Lift Water
Electricity	1.55 kWh/ac-ft per foot of lift
Natural Gas (925 BTU)	0.22 MCF/ac-ft per foot of lift
Natural Gas (1000 BTU)	0.20 MCF/ac-ft per foot of lift
Diesel	0.10 Gal/ac-ft per foot of lift
Propane	0.20 Gal/ac-ft per foot of lift

Source: Nebraska Pumping Plant Performance Criteria (NPPPC)

Mature Vineyard with Micro-Sprinkler vs. Drip Irrigation

Vineyard (ET - R_{EFF})= 18 in. => 1.5 ft. of water per season

Area = 40 acres

Irrigation methods: Micro-Sprinkler (35 psi) vs. Drip Irrig. (25 psi) @ pump out.

Water Lift = 100 ft (from aquifer level to ground)

$TDH_{MICRO-SPR.}$: 100 ft + (35 psi x 2.31 ft/psi) = 180 ft.

TDH_{DI}: 100 ft + (25 psi x 2.31 ft/psi) = 158 ft.

Total ac-ft $_{MICRO-SPR.}$ = 1.5/0.80 = 1.9 ac-ft.

Total ac-ft $_{DI}$ = 1.5/0.90 = 1.7 ac-ft

Diesel => 0.10 gal/ac-ft per foot of lift

Ave. Price of Diesel for Ag.= $3.50 per gallon

System	$Eff._A$
Gravity (surface)	0.70
Drip & SDI	0.90
Micro-sprinkler	0.80
Sprinkler	0.75

Vol. Dies. Micro-Sprinkler: 40 ac x 1.9 ac-ft x 180 ft x 0.10 gal/ac-ft = 1,368 gal

Cost for Micro-Sprinkler irrigation: 1,368 gal x $3.50 per gallon = **$4,790**

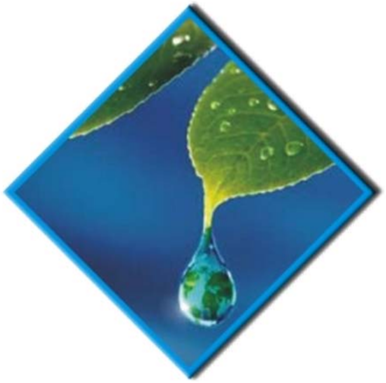
Vol. Dies. Drip Irrigation = 40 ac x 1.7 ac-ft x 158 ft x 0.10 gal/ac-ft = 1,075 gal

Cost for Drip Irrigation: 1,075 gal x $3.50 per gallon = **$3,760**

2ND PART - OBJECTIVES

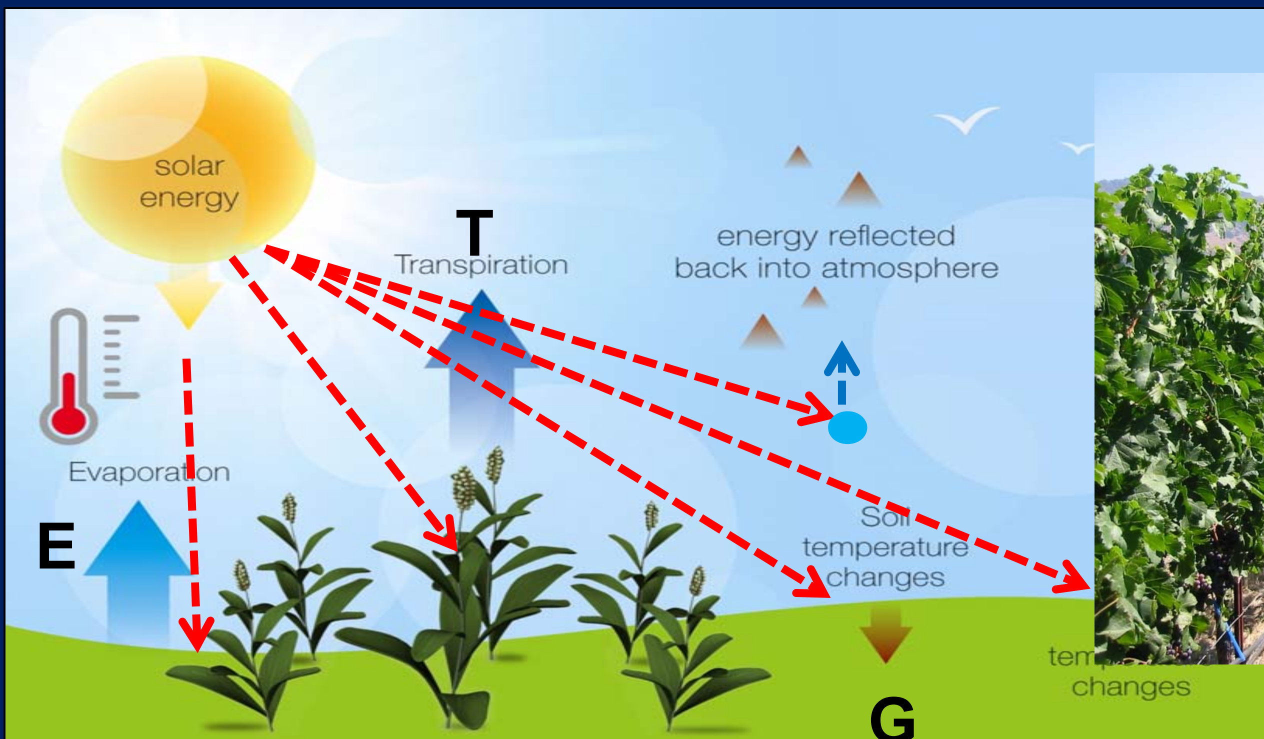
1) Review main methods for scheduling irrigations

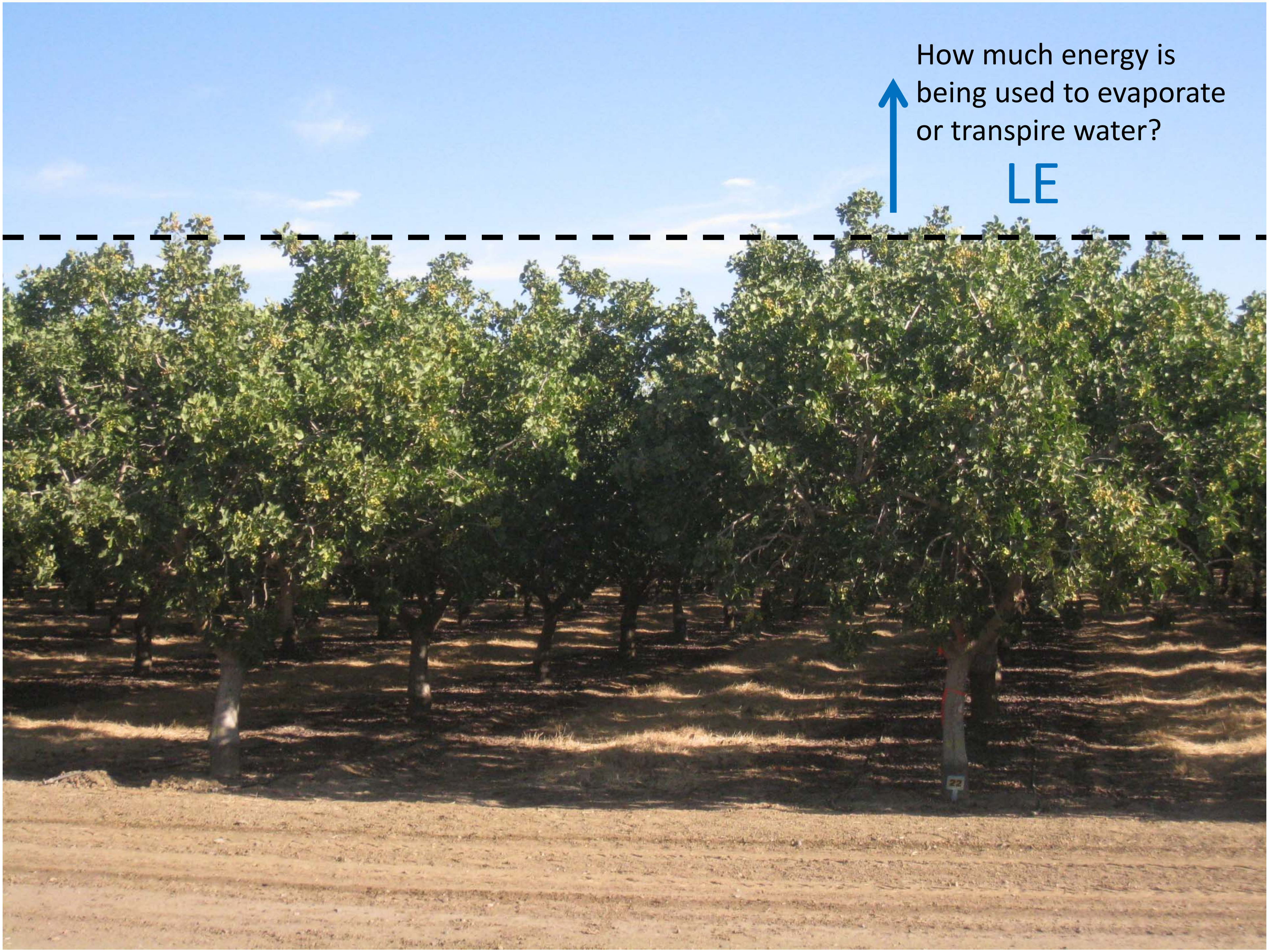
2) Discuss advantages and disadvantages of these approaches

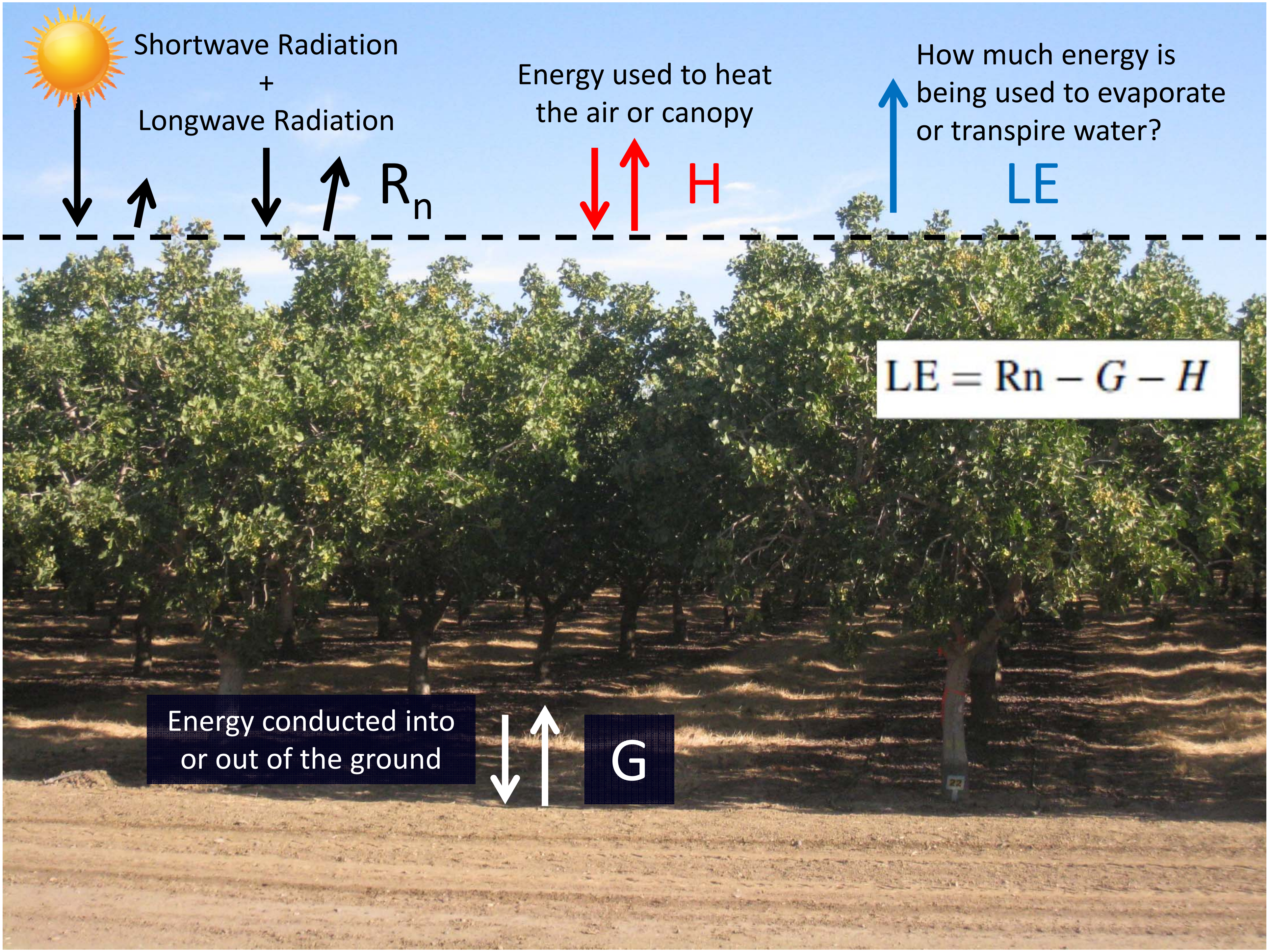


WHAT DRIVES WINEGRAPES WATER USE (ET)?

- ✓ **Water use is driven by the solar energy intercepted by canopy**
- ✓ **The canopy encounters this energy as direct radiation from the sun and indirect radiation sources (warm air, wind)**
- ✓ **The combined effect of these energy sources on the plants canopy determine vine water use when soil moisture is not limited.**




How much energy is being used to evaporate or transpire water?
LE



Shortwave Radiation
+
Longwave Radiation
Rn
Energy used to heat the air or canopy
H
How much energy is being used to evaporate or transpire water?
LE
LE = Rn − G − H
Energy conducted into or out of the ground
G




UCDAVIS



tule
Evapotranspiration
Sensor

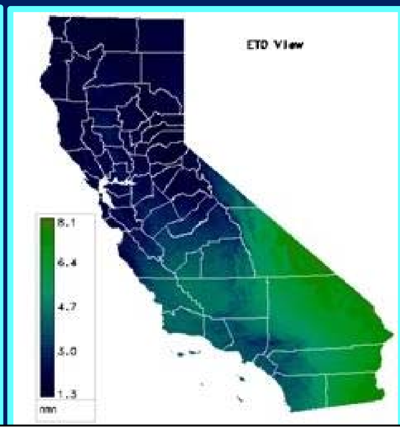

05/31/20

07/22/2014


08

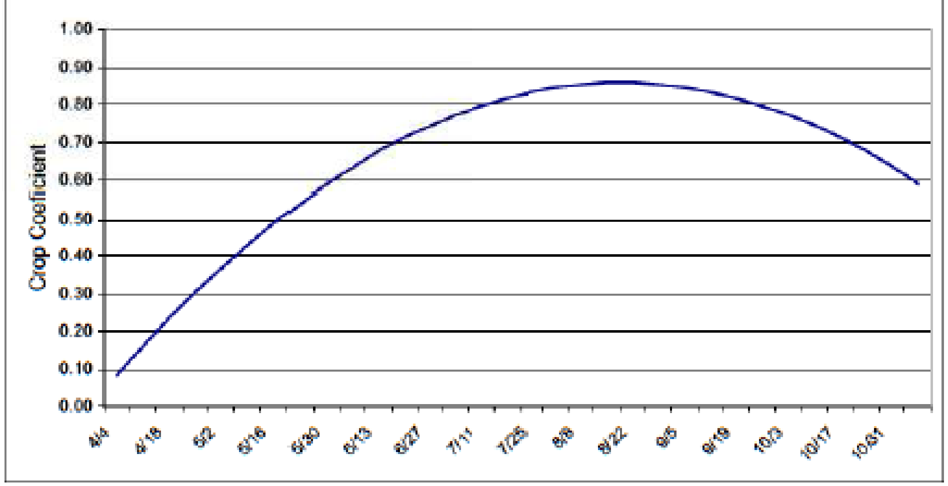

ETc = ETo x Kc

CIMIS
CALIFORNIA DEPARTMENT OF WATER RESOURCES

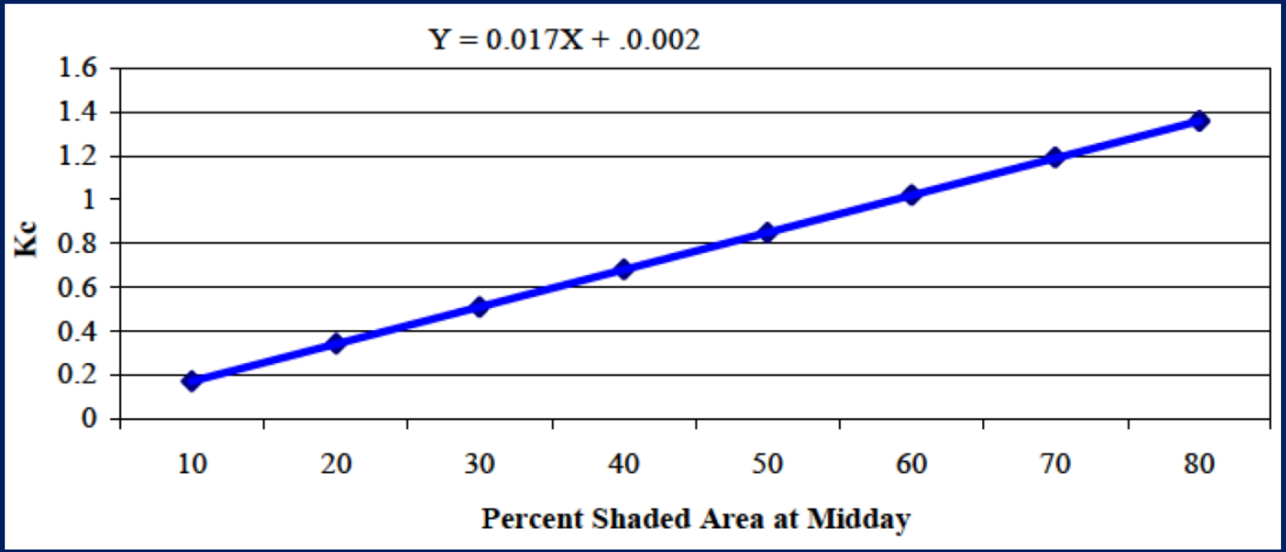


DATE	Almonds	Walnuts	Pistachios	Stone fruit	Prunes	Olives	Citrus	Apples	Pears	W. Grapes
Jan 1-15						0.80	0.65			
Jan 16-31						0.80	0.65			
Feb 1-15						0.80	0.65			
Feb 16-28						0.80	0.65			
Mar 1-15				0.55		0.80	0.65			
Mar 16-31	0.54	0.12		0.62		0.80	0.65			0.32
Apr 1-15	0.60	0.53	0.07	0.67	0.62	0.80	0.65			0.41
Apr 16-30	0.66	0.68	.43	0.73	0.84	0.80	0.65			0.50
May 1-15	0.73	0.79	0.68	0.78	0.96	0.80	0.65	0.59		0.59
May 16-31	0.79	0.86	0.93	0.85	0.96	0.80	0.65	0.67	0.55	0.69
June 1-15	0.84	0.93	1.09	0.87	0.96	0.80	0.65	0.76	0.55	0.78
June 16-30	0.86	1.00	1.17	0.87	0.96	0.80	0.65	0.84	0.78	0.82
July 1-15	0.93	1.14	1.19	0.87	0.96	0.80	0.65	0.92	0.80	0.82
July 16-31	0.94	1.14	1.19	0.87	0.96	0.80	0.65	1.00	0.85	0.82
Aug 1-15	0.94	1.14	1.19	0.87	0.95	0.80	0.65	1.00	0.87	0.82
Aug 14-31	0.94	1.14	1.12	0.87	0.92	0.80	0.65	1.00	0.87	0.77
Sept 1-15	0.94	1.08	0.99	0.87	0.84	0.80	0.65	1.00	0.87	0.66
	0.91	0.97	0.87	0.82	0.78	0.80	0.65	1.00	0.87	0.55
	0.85	0.88	0.67	0.75	0.69	0.80	0.65	1.00	0.87	0.44
	0.79	0.51	0.50	0.68	0.57	0.80	0.65	0.91	0.87	
	0.70	0.28	0.35			0.80	0.65	0.59	0.87	
						0.80	0.65		0.75	
						0.80	0.65		0.70	
						0.80	0.65		0.65	

Figure G-2. Crop Coeficient (Kc) of a 50% Shaded Vineyard at Max Canopy



VINE WATER USE (ET) INCREASE LINEARLY WITH THE % OF LAND SURFACE SHADED BY THE VINES' CANOPY (L. Williams, 2002)



Kc = 0.002 + 0.017 x % Shaded Area

simplified formula: Kc = 1.7 x % Shaded Area

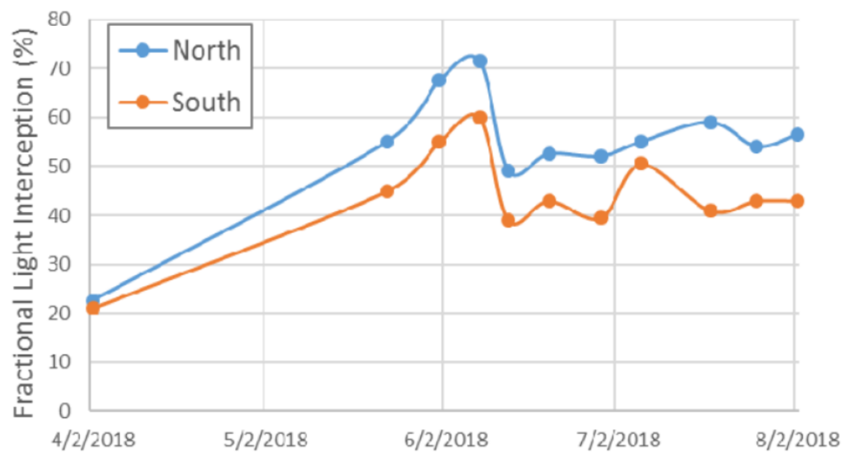
Calculation example

7-foot vine spacing x 11-foot row spacing = 77 sq-ft. x vine

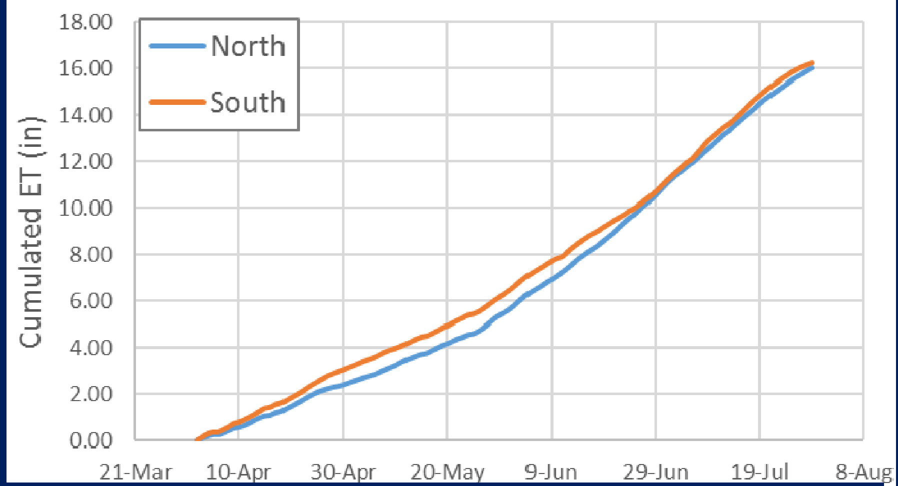
Shaded area: 31 sq-ft./77 sq-ft. = 40%

Kc = 1.7 x 0.40 = 0.68

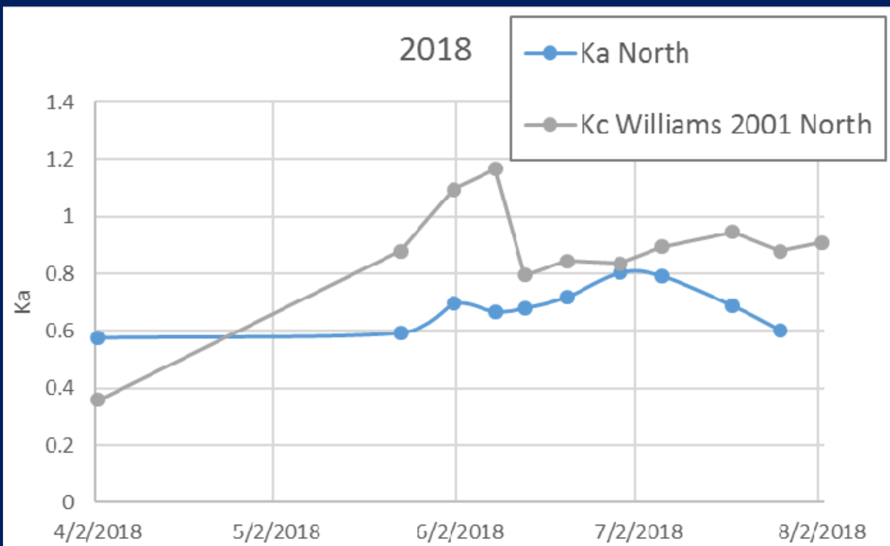
Light Intercepted by the Vine Canopy (Paso Panel) over the crop seasons 2018

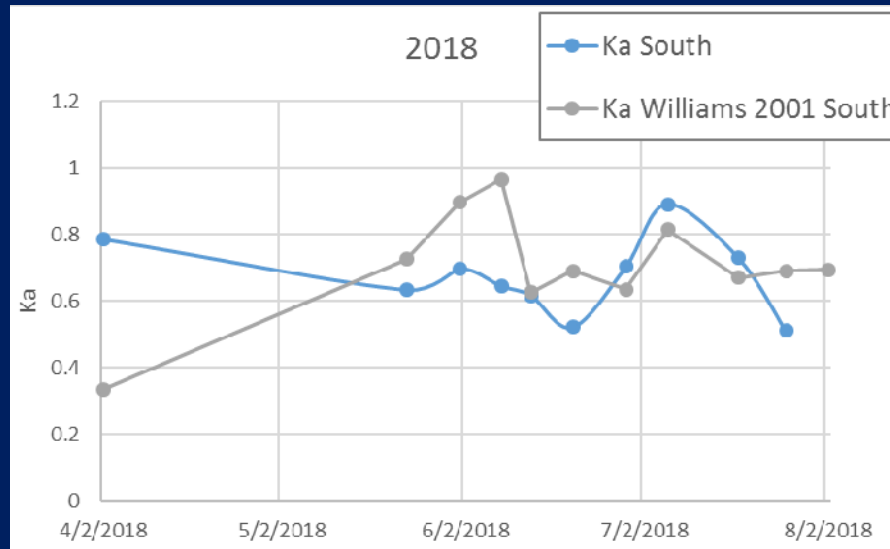


Cumulative Vineyard ET over the crop seasons 2018



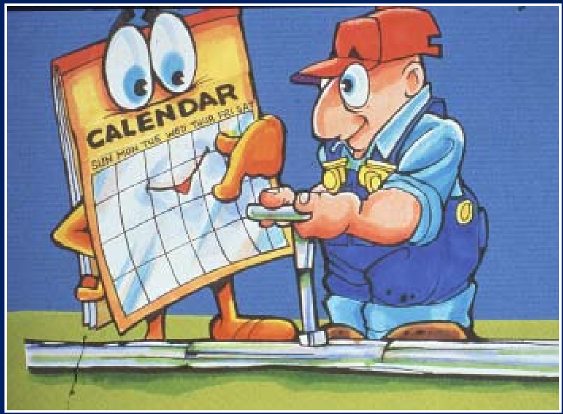
Results from our Safari Trial on N-facing vs. S-facing Slope





The model developed by Larry Williams to predict Kc in level vineyards does not seem to work accurately on hillside vineyards

IRRIGATION SCHEDULING



It provides answers to the following questions:

1) When to irrigate our crops? → Before plants face water deficit (or at specific deficit levels)

2) How much water to apply? → The amount of water used by the crop since the last irrigation or rainfall

(or a portion of ET max)

3) How to best apply the necessary amount of water? → Uniformly or Site-specifically

Application rate and volume compatible with the soil infiltration and storage capacity

BENEFITS OF IRRIGATION SCHEDULING

1) Increase on-farm profit (reduced water and energy costs, increased yields and/or quality of production, etc.)

2) Control of excess vegetative growth

3) Reduced cost of pruning, edging and shoots/leaves removal

4) Increased fruit quality

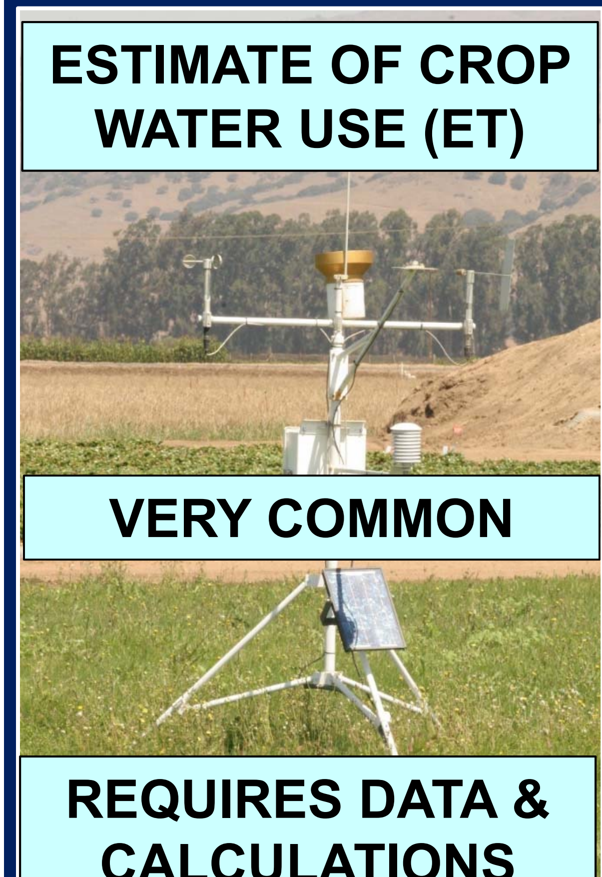
5) Prevent or Mitigate heat damage

6) Reduced fertilizers and chemical losses by deep percolation and off-site runoff

METHODS FOR IRRIGATION SCHEDULING

Weather-based

ESTIMATE OF CROP WATER USE (ET)



VERY COMMON

REQUIRES DATA & CALCULATIONS

Soil-based

ASSESS SOIL WATER STATUS

EQUIPM. INTENSIVE

GOOD FOR PERIODIC CHECK

Plant-based

DETECTS PLANT WATER STATUS

LABOR INTENSIVE

DEVELOPED FOR SOME CROPS, NOT ALL

ALL IRRIGATION SCHEDULING METHODS REQUIRE SKILLED ON-FARM PERSONNEL & CAPACITY FOR QUICK TROUBLE-SHOOTING

COMBINATIONS OF DIFFERENT APPROACHES

Plant-based
(Monitoring plant water status) → **Proper Irrigation Timing**

↓

Weather-based
(Estimating the crop water use) → **Adequate Irrigation Amount**

↓

Soil-based
(Monitoring soil moisture) → **Check for Feedback**

WEATHER-BASED SCHEDULING

It relies on measurements of solar radiation, relative humidity, air temperature and wind speed to estimate evapotranspiration (ETo)

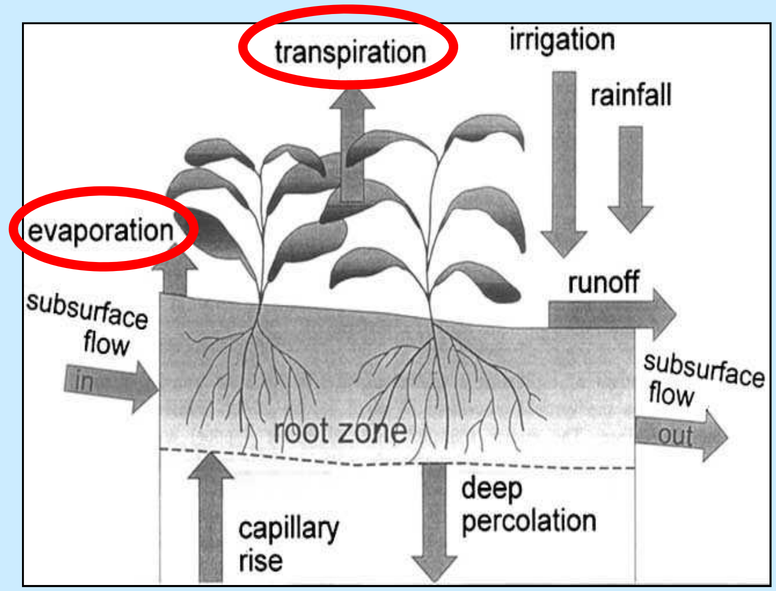
Reference Evapotranspiration (ETo) :
Solar Radiation + Relative Humidity + Air Temperature + Wind Speed

ET-BASED SCHEDULING

Basic criterion:
replenish the amount of water used by the crop (ET_C) since the last irrigation

Crop ET = Reference ET x Crop Coefficient

$$ET_C = ET_O \times k_C$$



✓Use historical ET averages (ET_C, or ET_O and K_c values)

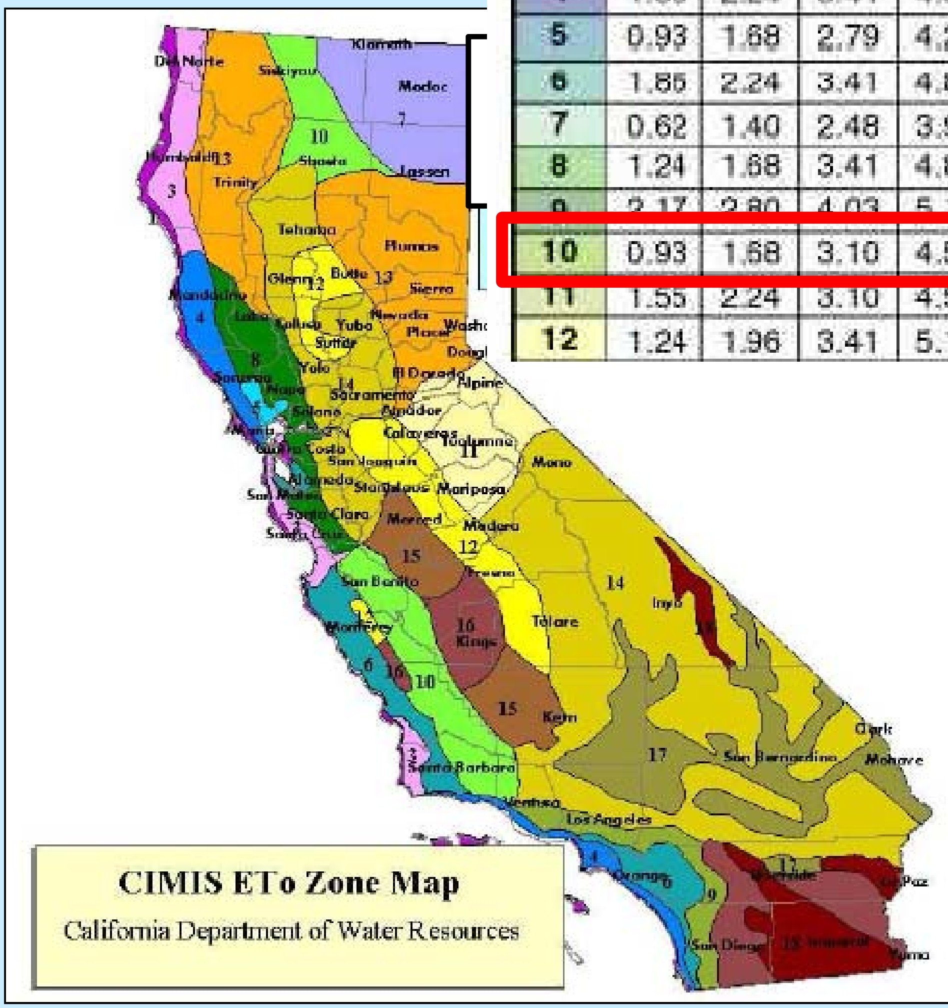
✓Use real-time ET_O and K_c values

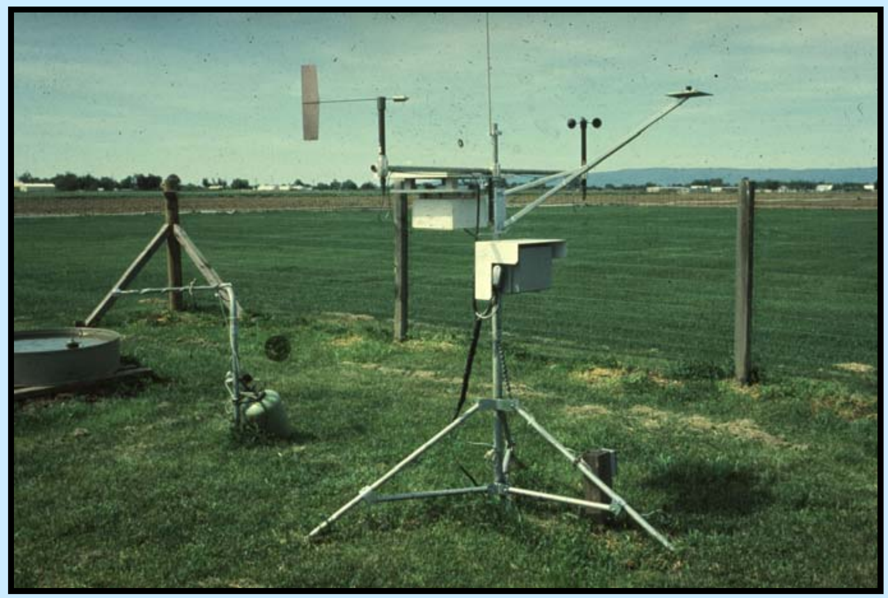
Historical ET_o average estimates: http://wwwcimis.water.ca.gov/cimis

CIMIS

Monthly Average Reference Evapotranspiration by ETo Zone (inches/month)

Zone	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1	0.93	1.40	2.48	3.30	4.03	4.50	4.65	4.03	3.30	2.48	1.20	0.62	33.0
2	1.24	1.68	3.10	3.90	4.65	5.10	4.96	4.65	3.90	2.79	1.80	1.24	39.0
3	1.86	2.24	3.72	4.80	5.27	5.70	5.58	5.27	4.20	3.41	2.40	1.86	46.3
4	1.86	2.24	3.41	4.50	5.27	5.70	5.89	5.58	4.50	3.41	2.40	1.86	46.6
5	0.93	1.68	2.79	4.20	5.58	6.30	6.51	5.89	4.50	3.10	1.50	0.93	43.9
6	1.86	2.24	3.41	4.80	5.58	6.30	6.51	6.20	4.80	3.72	2.40	1.86	49.7
7	0.62	1.40	2.48	3.90	5.27	6.30	7.44	6.51	4.80	2.79	1.20	0.62	43.4
8	1.24	1.68	3.41	4.80	6.20	6.90	7.44	6.51	5.10	3.41	1.80	0.93	49.4
9	2.17	2.80	4.03	5.10	5.89	6.60	7.44	6.82	5.70	4.03	2.70	1.86	55.1
10	0.93	1.68	3.10	4.50	5.89	7.20	8.06	7.13	5.10	3.10	1.50	0.93	49.1
11	1.55	2.24	3.10	4.50	5.89	7.20	8.06	7.44	5.70	3.72	2.10	1.55	53.0
12	1.24	1.96	3.41	5.10	6.82	7.80	8.06	7.13	5.40	3.72	1.80	0.93	53.3





Average bi-weekly k_C values (UC Cooperative Extension)

DATE	Almonds	Walnuts	Pistachios	Stone fruit	Prunes	Olives	Citrus	Apples	Pears	W. Grapes
Jan 1-15						0.80	0.65			
Jan 16-31						0.80	0.65			
Feb 1-15						0.80	0.65			
Feb 16-28						0.80	0.65			
Mar 1-15				0.55		0.80	0.65			
Mar 16-31	0.54	0.12		0.62		0.80	0.65			0.32
Apr 1-15	0.60	0.53	0.07	0.67	0.62	0.80	0.65			0.41
Apr 16-30	0.66	0.68	.43	0.73	0.84	0.80	0.65			0.50
May 1-15	0.73	0.79	0.68	0.78	0.96	0.80	0.65	0.59		0.59
May 16-31	0.79	0.86	0.93	0.85	0.96	0.80	0.65	0.67	0.55	0.69
June 1-15	0.84	0.93	1.09	0.87	0.96	0.80	0.65	0.76	0.55	0.78
June 16-30	0.86	1.00	1.17	0.87	0.96	0.80	0.65	0.84	0.78	0.82
July 1-15	0.93	1.14	1.19	0.87	0.96	0.80	0.65	0.92	0.80	0.82
July 16-31	0.94	1.14	1.19	0.87	0.96	0.80	0.65	1.00	0.85	0.82
Aug 1-15	0.94	1.14	1.19	0.87	0.95	0.80	0.65	1.00	0.87	0.82
Aug 14-31	0.94	1.14	1.12	0.87	0.92	0.80	0.65	1.00	0.87	0.77
Sept 1-15	0.94	1.08	0.99	0.87	0.84	0.80	0.65	1.00	0.87	0.66
Sept 16-30	0.91	0.97	0.87	0.82	0.78	0.80	0.65	1.00	0.87	0.55
Oct 1-15	0.85	0.88	0.67	0.75	0.69	0.80	0.65	1.00	0.87	0.44
Oct 16-31	0.79	0.51	0.50	0.68	0.57	0.80	0.65	0.91	0.87	
Nov 1-15	0.70	0.28	0.35			0.80	0.65	0.59	0.87	
Nov 16-30						0.80	0.65		0.75	
Dec 1-15						0.80	0.65		0.70	
Dec 16-31						0.80	0.65		0.65	

California Irrigation Management Information System
Department of Water Resources
Office of Water Use Efficiency
Rendered in ENGLISH units
July 15, 2013 - July 31, 2013
Printed on February 3, 2014

Real-time ET_O data

http://wwwcimis.water.ca.gov/cimis/data.jsp

Monterey Bay - San Benito - 126

Date	CIMIS ETo (in)	Precip (in)	Sol Rad (Ly/day)	Avg Vap (mBars)	Max Air Temp (°F)	Min Air Temp (°F)	Avg Air Temp (°F)	Max Rel Hum (%)	Min Rel Hum (%)	Avg Rel Hum (%)	Dew Pt (°F)	Avg wSpd (MPH)	Wnd Run (miles)	Avg Soil Temp (°F)
07/15/13	0.19	0.00	604	13.9	71.4	52.6	58.9	97	58	82	53.4	4.0	97.4	75.9
07/16/13	0.20	0.00	635	14.5	72.8	55.0	61.5	94	57	78	54.6	4.0	96.2	75.6
07/17/13	0.22	0.00	643	15.5	80.2	53.8	65.4	94	51	73	56.4	3.6	86.1	76.2
07/18/13	0.22	0.00	642	14.6	83.0	50.4	63.2	98	45	74	54.6	3.1 Y	75.4 Y	76.4
07/19/13	0.20	0.00	616	13.9	79.7	47.4	60.7	100	45	77	53.3	3.1 Y	76.0 Y	76.0
07/20/13	0.19	0.00	605	14.3	74.4	51.2	59.5	98	58	82	54.1	3.4	81.1	75.9
07/21/13	0.20	0.00	594	15.0	80.4	52.6	62.1	98	48	79	55.4	3.3	80.6	75.9
07/22/13	0.14	0.00	440	16.7	79.2	55.4	65.2	98	58	79	58.4	3.3	80.7	76.1
07/23/13	0.19	0.00	539	17.0	82.9	58.1	68.3	91	51	72	58.9	3.9	94.8	76.9
07/24/13	0.23	0.00	638	16.0	85.1	55.4	66.8	96	39	72	57.3	3.3	79.2	77.3
07/25/13	0.21	0.00	624	15.3	80.8	52.1	63.7	98	48	76	56.0	3.4	82.4	77.1
07/26/13	0.20	0.00	606	15.4	80.8	53.9	62.8	99	46	79	56.1	3.5	85.6	76.8
07/27/13	0.20	0.00	601	15.4	79.8	54.6	62.7	99	49	79	56.1	3.4	82.2	76.8
07/28/13	0.18	0.00	574	14.9	71.0	54.3	59.9	97	67	85	55.3	3.7	89.5	76.4
07/29/13	0.17	0.00	565	15.1	69.8	56.1	60.7	94	68	83	55.6	4.5	107.6	76.0
07/30/13	0.19	0.00	580	15.1	74.9	53.6	62.2	94	57	79	55.6	4.0	96.5	76.0
07/31/13	0.19	0.00	591	14.4	74.2	52.6	61.3	96	54	78	54.4	3.6	87.6	75.9
Tot/Avgs	3.32	0.00	594	15.1	77.7	53.5	62.6	97	53	78	55.6	3.6	87.0	76.3

Historical ET_C average estimates

http://www.itrc.org/projects/cacrop.htm

ZONE 10 ET_C - drip & micro-spray – TYPICAL YEAR

ETc Zone 10- drip & mic_spray - typical year	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC	YEAR
	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.
Precipitation	5,68	0,12	0,54	0,14	0,17	0,06	0,84	0,56	0,06	0,81	3,14	4,51	16,63
Grass Reference ETo	1,45	2,7	4,08	5,49	6,68	6,29	6,5	6,23	5,27	4,09	2	1,69	52,47
Apple, Pear, Cherry, Plum and Prune	1,65	0,47	0,91	2,44	5,9	5,98	6,41	6,15	4,81	2,78	1,17	1,66	40,34
Apples, Plums, Cherries etc w/covercrop	1,67	2,68	3,55	4,76	7,21	7,41	7,73	7,37	5,97	4,05	1,86	1,99	56,26
Peach, Nectarine and Apricots	1,65	0,47	0,91	2,19	5,39	5,76	6,12	5,9	4,57	2,67	1,17	1,66	38,46
Immature Peaches, Nectarines, etc	1,66	0,47	0,7	1,23	3,07	3,28	3,83	3,57	2,61	1,86	1,18	1,67	25,13
Almonds	1,65	0,47	1,13	2,97	5,87	5,63	6,18	5,88	4,55	2,61	1,17	1,66	39,78
Almonds w/covercrop	1,67	2,28	2,86	4,82	6,86	6,66	7	6,73	5,26	3,57	1,8	1,96	51,46
Immature Almonds	1,66	0,47	0,91	1,91	3,45	3,5	3,93	3,65	2,78	1,79	1,18	1,67	26,89
Walnuts	1,65	0,47	1,06	1,79	5,26	6,86	7,05	6,87	5,2	3,14	1,23	1,66	42,24
Pistachio	1,65	0,47	0,49	1,15	2,4	4,93	7	6,84	5,34	3,21	1,22	1,66	36,37
Pistachio w/ covercrop	1,67	2,28	2,58	3,66	4,69	6,08	7,23	7,05	5,88	4,21	1,81	1,96	49,09
Immature Pistachio	1,66	0,47	0,49	0,67	1,34	2,91	4,64	4,31	3,27	2,18	1,21	1,67	24,8
Misc. Deciduous	1,65	0,47	0,91	2,34	5,63	5,72	6,14	5,88	4,57	2,77	1,17	1,66	38,92
Small Vegetables	1,71	1,27	3,52	5,46	1,01	0,09	0,74	1,57	1,37	1,57	1,68	1,96	21,96
Tomatoes and Peppers	1,7	0,46	1,25	0,77	3,38	6,59	6,37	1,47	0,11	0,78	1,21	1,69	25,78
Potatoes, Sugar beets, Turnip etc..	1,7	0,86	2,06	5,54	7,13	6,69	6,26	0,64	0,11	0,78	1,21	1,69	34,66
Melons, Squash, and Cucumbers	1,7	0,46	0,49	0,19	0,94	0,76	3,55	4,57	1,56	0,78	1,21	1,69	17,89
Onions and Garlic	1,72	2,24	3,57	4,73	4,48	0,97	0,75	0,53	0,11	0,78	1,87	1,78	23,53
Strawberries	1,7	0,46	1,64	1,39	2,41	5,91	6,28	3,13	0,11	0,78	1,21	1,69	26,69
Citrus (no ground cover)	1,67	2,39	2,92	3,75	4,36	4,15	4,74	4,36	3,47	3,42	1,87	1,98	39,07
Immature Citrus	1,68	1,37	1,94	2,18	2,65	2,5	3,08	2,87	2,13	2,3	1,55	1,85	26,1
Avocado	1,65	0,47	0,91	2,34	5,63	5,72	6,14	5,88	4,57	2,77	1,17	1,66	38,92

Historical ET_C average estimates

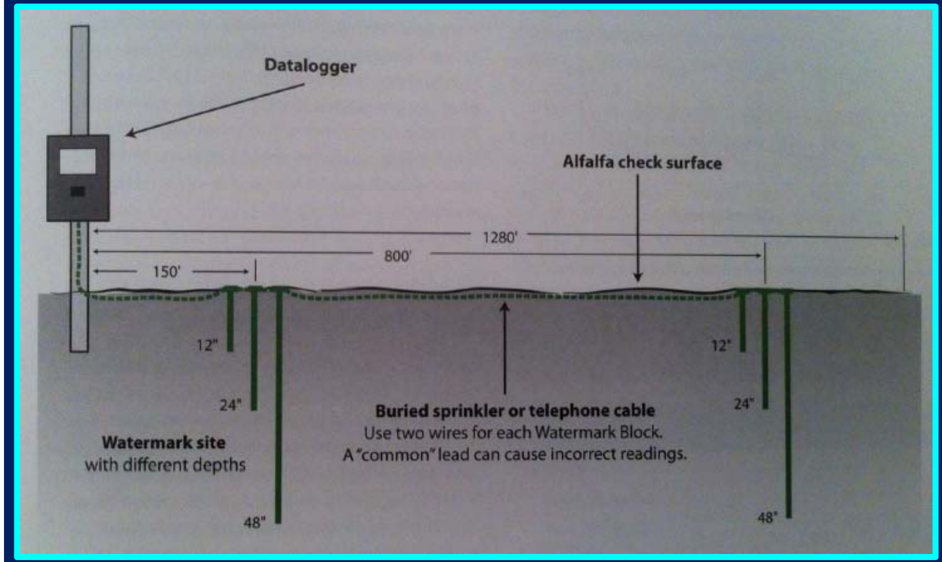
ZONE 10 ET_C - drip & micro-spray – DRY YEAR

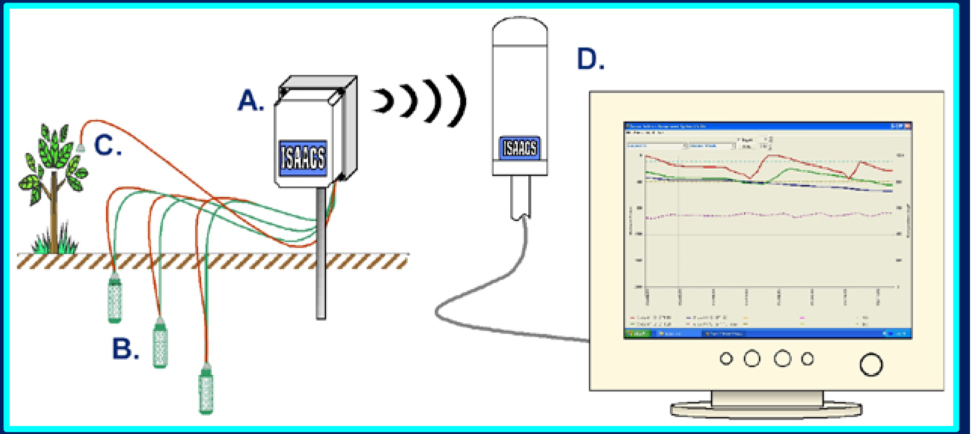
ETc Zone 10- drip & micro-spr - dry year	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC	YEAR
	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.
Precipitation	1,8	1,8	3,3	1,5	0,3	0,0	0,0	0,0	0,0	0,0	0,9	0,1	9,9
Grass Reference ETo	1,8	2,2	3,2	4,6	5,7	6,1	6,6	5,8	4,2	3,9	2,1	2,2	48,3
Apple, Pear, Cherry, Plum and Prune	0,8	1,7	2,2	3,2	5,1	5,8	6,2	5,5	3,7	2,1	0,8	0,2	37,3
Apples, Plums, Cherries etc w/covercrop	1,7	2,6	3,5	5,0	6,2	7,3	7,8	6,7	4,7	3,4	2,0	1,5	52,3
Peach, Nectarine and Apricots	0,8	1,7	2,2	3,1	4,7	5,4	5,9	5,2	3,5	2,0	0,8	0,2	35,4
Immature Peaches, Nectarines, etc	0,8	1,7	2,1	2,2	2,8	3,1	3,3	3,0	2,0	1,0	0,8	0,2	22,9
Almonds	0,8	1,7	2,4	3,7	5,1	5,5	5,9	5,2	3,5	1,9	0,8	0,2	36,6
Almonds w/covercrop	1,6	2,5	3,4	5,0	6,0	6,5	6,8	6,0	4,1	2,7	1,8	1,3	47,6
Immature Almonds	0,8	1,7	2,3	2,6	3,3	3,2	3,5	3,1	2,1	1,0	0,8	0,2	24,4
Walnuts	0,8	1,7	2,3	2,7	4,6	6,7	7,1	6,3	4,0	2,4	0,9	0,2	39,5
Pistachio	0,8	1,7	2,0	2,2	2,2	4,7	7,0	6,2	4,2	2,5	0,9	0,2	34,5
Pistachio w/ covercrop	1,6	2,5	3,3	4,1	4,2	5,8	7,4	6,5	4,5	3,4	1,8	1,3	46,3
Immature Pistachio	0,8	1,7	2,0	1,8	1,3	2,8	4,1	3,7	2,5	1,4	0,8	0,2	23,1
Misc. Deciduous	0,8	1,7	2,2	3,2	4,9	5,5	5,9	5,1	3,6	2,0	0,8	0,2	35,8
Small Vegetables	1,7	2,1	3,2	4,8	1,0	0,0	0,0	1,0	1,2	0,8	1,7	2,1	19,6
Tomatoes and Peppers	0,8	1,7	2,4	1,9	3,0	6,4	5,8	0,6	0,0	0,0	0,8	0,2	23,5
Potatoes, Sugar beets, Turnip etc..	1,5	1,9	2,7	5,0	6,0	6,5	5,9	0,1	0,0	0,0	0,8	0,2	30,7
Melons, Squash, and Cucumbers	0,8	1,7	2,1	1,4	1,1	0,7	3,3	4,0	1,3	0,0	0,8	0,2	17,3
Onions and Garlic	1,0	2,4	3,4	4,3	4,0	0,9	0,0	0,0	0,0	0,0	1,6	0,5	18,1
Strawberries	0,8	1,7	3,1	1,8	2,2	5,8	6,2	2,4	0,0	0,0	0,8	0,2	24,9
Flowers, Nursery and Christmas Tree	0,8	1,7	2,2	3,2	4,9	5,5	5,9	5,1	3,6	2,0	0,8	0,2	35,8
Citrus (no ground cover)	1,7	2,6	3,3	4,2	4,0	3,9	4,1	3,6	2,7	2,6	1,9	1,7	36,4
Immature Citrus	1,1	2,2	2,7	3,0	2,5	2,3	2,5	2,2	1,6	1,5	1,4	1,0	24,0
Avocado	0,8	1,7	2,2	3,2	4,9	5,5	5,9	5,1	3,6	2,0	0,8	0,2	35,8

SOIL MOISTURE MONITORING

Keeps track of what happens in the root zone with regard to:

1. How much water infiltrates during an irrigation
2. How much water is taken up by plants between irrigations
3. Maintaining good soil water conditions for plants production





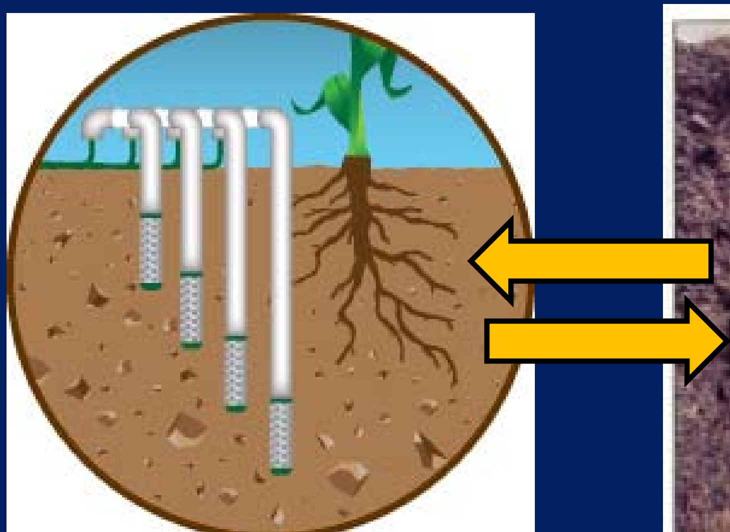
S.M.M. HELPS ANSWERING THE FOLLOWING QUESTIONS

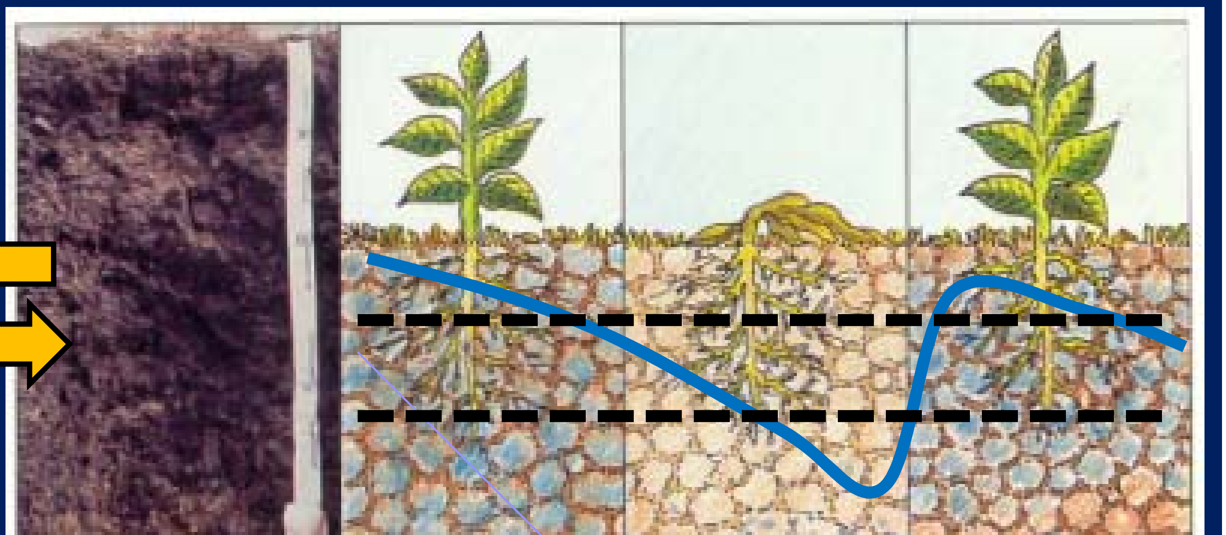
✓When to start irrigation (and when to stop it)?

✓Has enough water infiltrated the root zone during an irrigation?

✓Are we applying enough, insufficient, or excessive water?

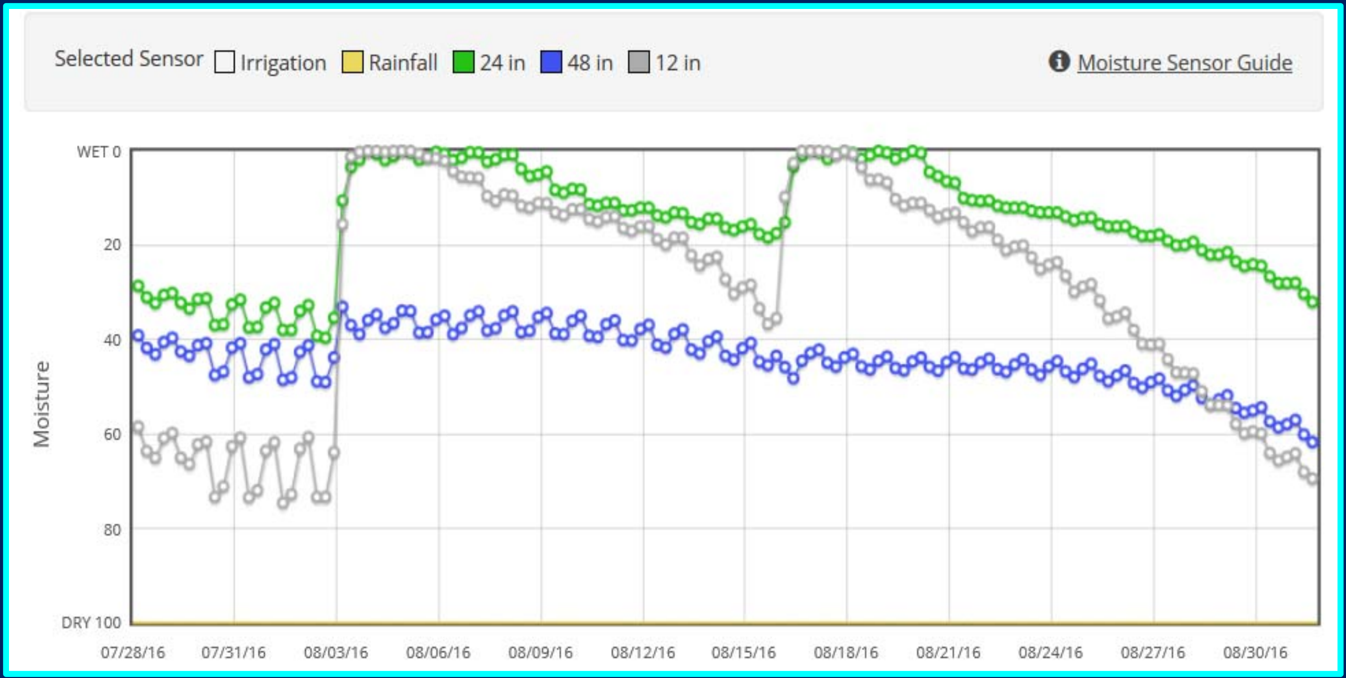
✓Is there any deep soil water reserve for crop water uptake during periods of no irrigation, or at bud-break or green-up?



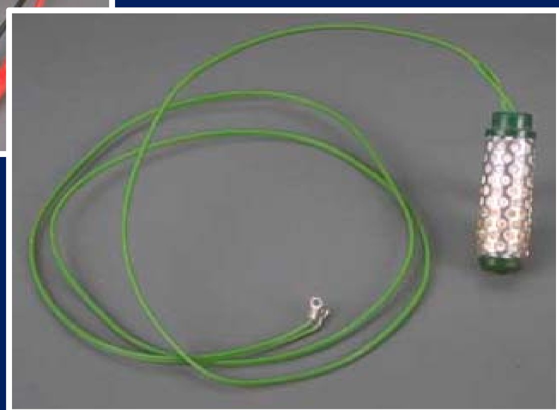


SOIL MOISTURE-BASED IRRIGATION SCHEDULING

1. Observe soil moisture frequently
2. Start irrigation at target level of soil moisture (allowable depletion, allowable matric potential or tension)
3. Stop irrigation when soil moisture reaches target levels
4. The next irrigation could also be predicted based on the measured soil moisture depletion rate



SOIL WATER TENSION

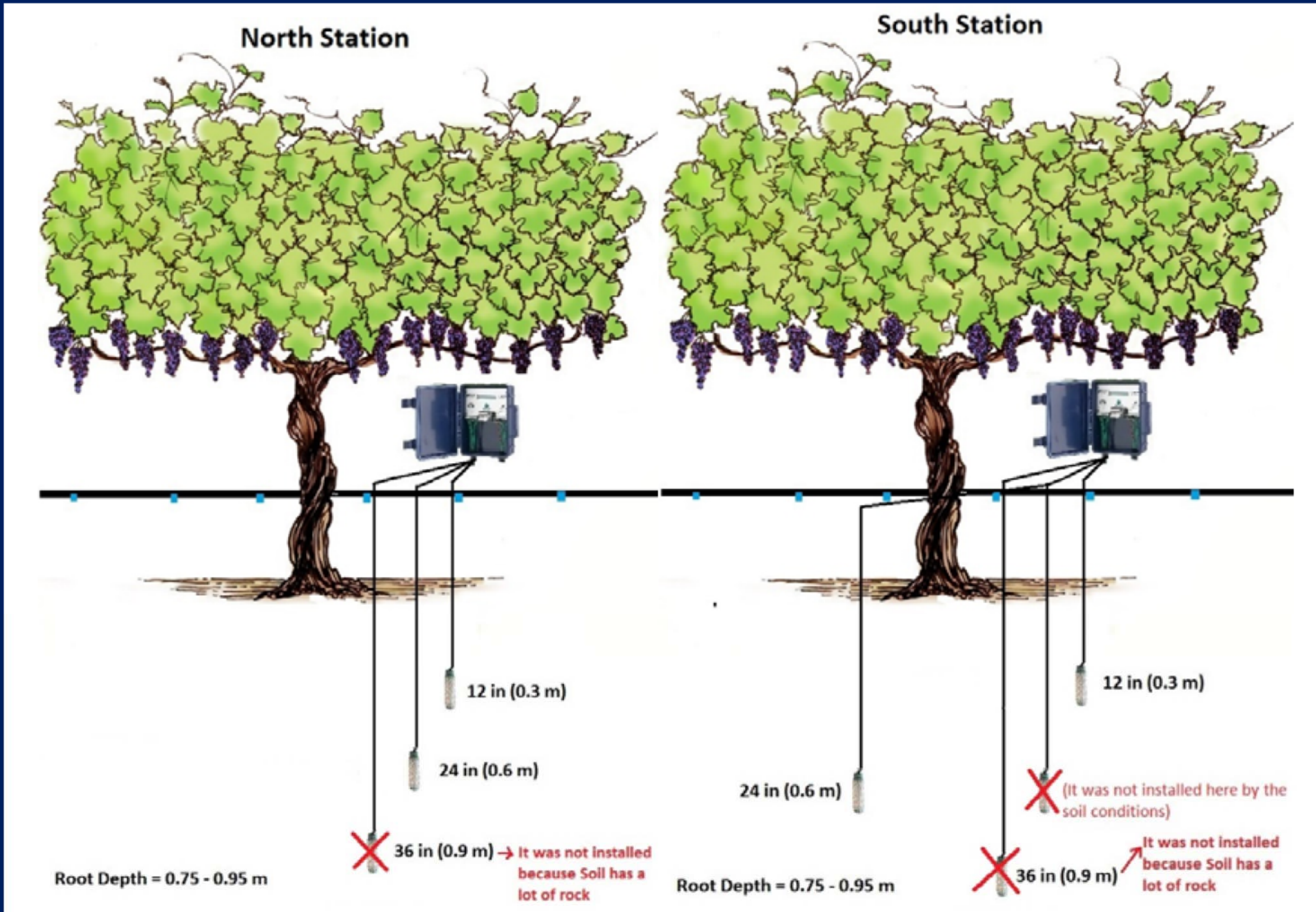


GYPSUM BLOCKS (tension)

- ✓**Very cheap & Maintenance free**
- ✓**Can last 1-3 years (soil moisture)**
- ✓**Sensitive to soil temperature**
- ✓**Corrosion of electrodes**

WATERMARK (tension)

- Read from 0 to 200 centibars
  - Low soil moisture tension indicates moist soil
  - High soil moisture tension indicates dry soil
- Saturated soil after irrigation or rainfall
  - Reading < 5-10
- Don’t need further calculations; easy to interpret
- Robust and reliable in field conditions
- Buffers against salinity
- Can be hooked up with data loggers and telemetry and monitor in continuous mode


North Station
12 in (0.3 m)
24 in (0.6 m)
36 in (0.9 m) → It was not installed because Soil has a lot of rock
Root Depth = 0.75 - 0.95 m
South Station
12 in (0.3 m)
24 in (0.6 m)
(It was not installed here by the soil conditions)
36 in (0.9 m)
It was not installed because Soil has a lot of rock
Root Depth = 0.75 - 0.95 m

Recommended values of soil moisture tension at which irrigation should occur (50% of PAW)

Soil Type	Soil Moisture Tension (centibars)
Sand or loamy sand	40-50
Sandy loam	50-70
Loam	60-90
Clay loam or clay	90-120

Soil moisture content at which irrigation should occur (@ 50% of PAW depleted)

Soil Texture	Soil Moisture Content (%)
Sand	7
Loamy Sand	12
Sandy Loam	15
Loam	20
Silt Loam	23
Silty Clay Loam	28
Clay Loam	27
Sandy Clay Loam	24
Sandy Clay	22
Silty Clay	30
Clay	31

Methods to Monitor Plant Water Status (and Stress)

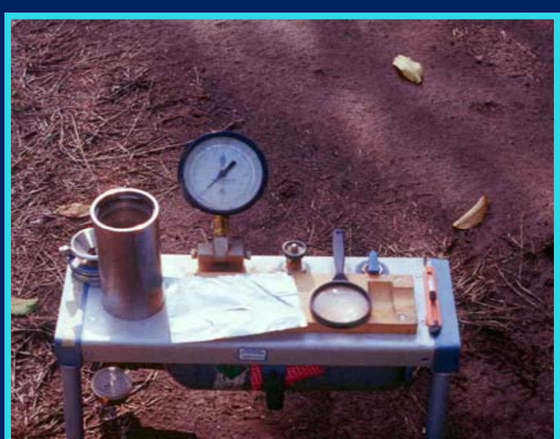
Stem Water Potential

Sap Flow

Canopy Temperature

Pressure Chamber to Measure Leaf/Stem Water Potential

- ✓ Pressure bombs consist of a chamber that can be brought to different pressures using nitrogen gas or air.
- ✓ The petiole of a leaf protrudes from the chamber so that one can see when water bubbles from the end.
- ✓ By slowly stepping up the pressure in the chamber one can determine the water potential in the leaf.
- ✓ The higher pressure, the more the leaf is water stressed.



Mid-day Stem Water Potential

- ✓ A popular measure of water potential in trees and vines.
- ✓ Leaf is covered with a bag to block out light during the mid day period when a tree is undergoing the most water stress.
- ✓ After 10-15 minutes the stomata of the leaf close and the water potential of the leaf equilibrates with the water potential of the tree.
- ✓ Values of stem water potential have been calibrated to shoot growth, and fruit quality in a few crops (almonds, grapes, etc.).

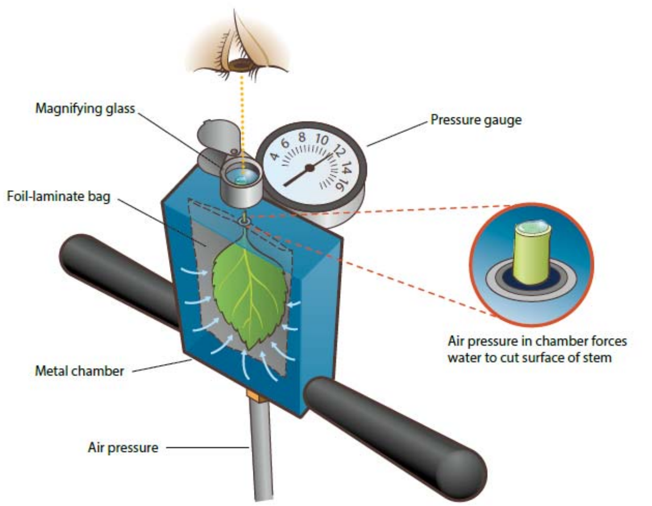
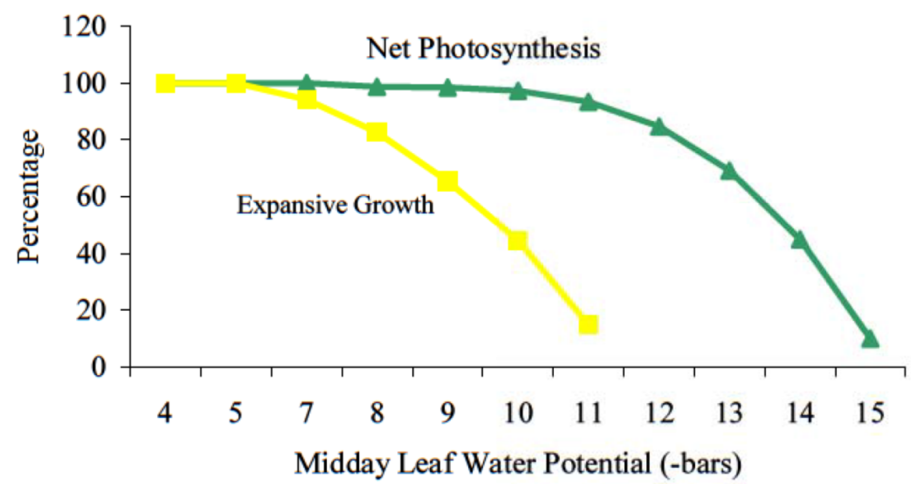


Figure 2. Schematic showing how water potential is measured in a severed leaf and stem (petiole) using a handheld pump-up pressure chamber. *Source:* Adapted from Plant Moisture Stress (PMS) Instrument Company.

Figure D-8. Relative rate vs. leaf water potential



Dendrometers and Other Devices

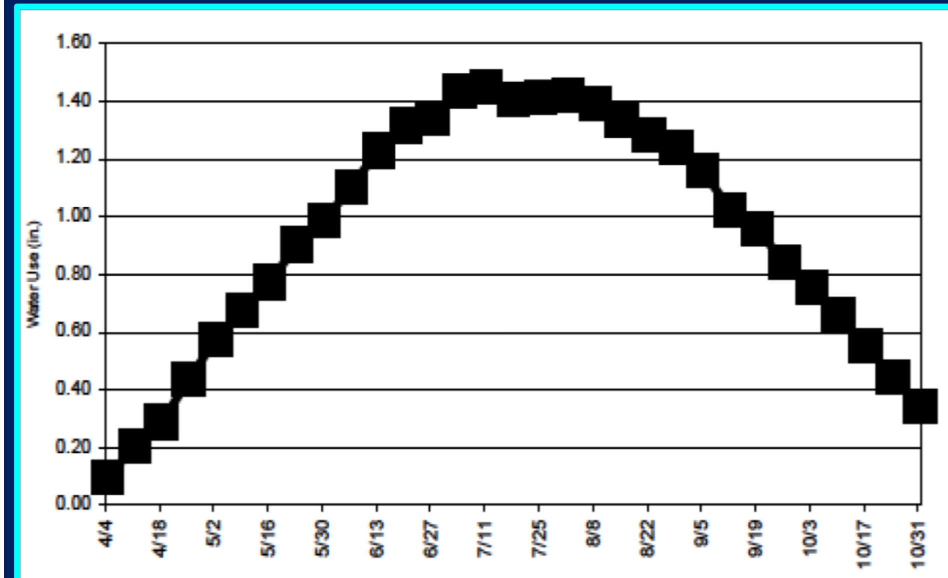
First Step for Water-Efficient Irrigation of Vineyards

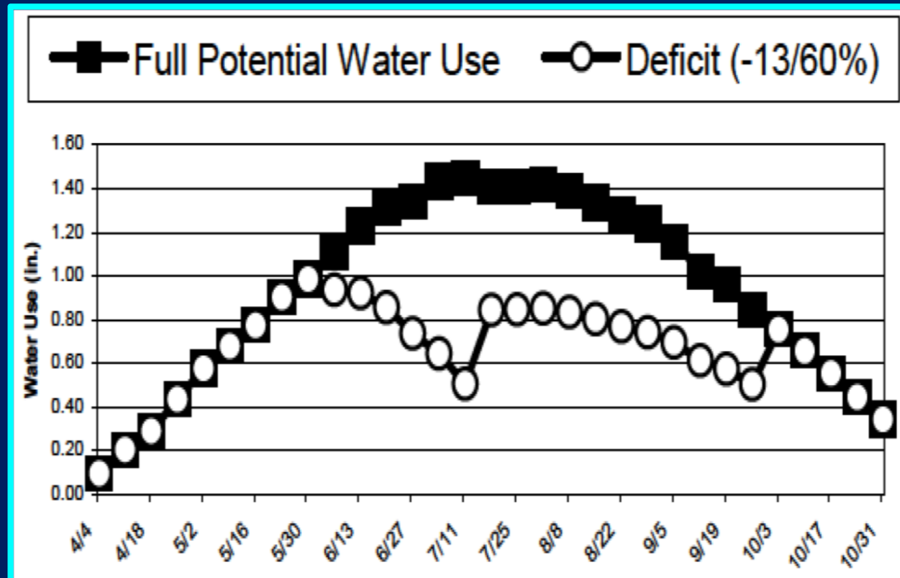
Define the Irrigation Strategy
(to Pursue Yield/Quality Targets)

Full Irrigation
(full replenishment of water needs)

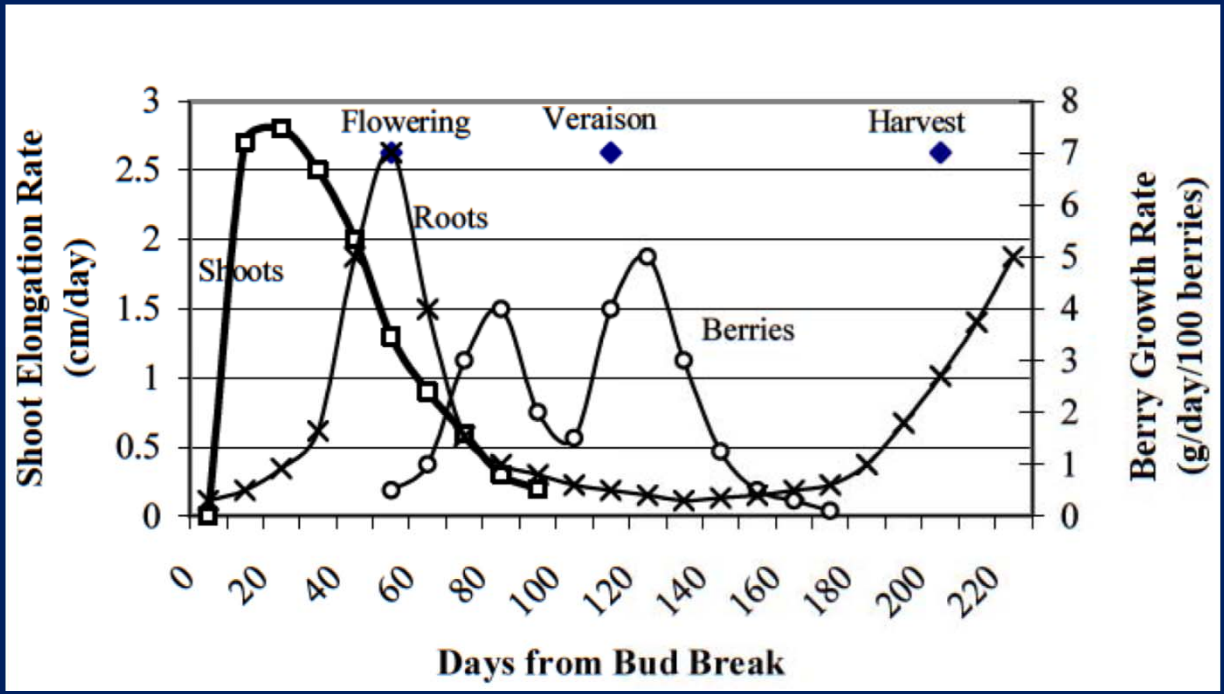
Partial (Deficit) Irrigation
(partial replenishment of water needs)

Timing & Levels of Water Deficits





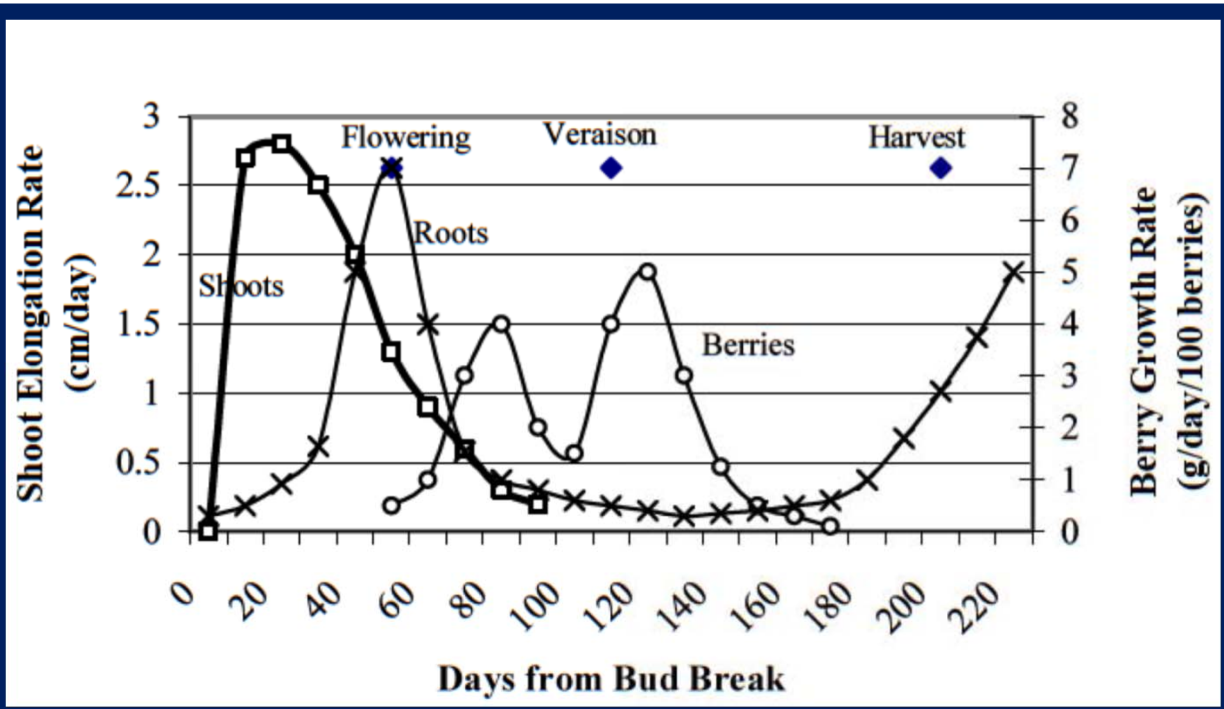
Water use is influenced by vine canopy growth
(from bud-break to full canopy expansion)



Growth of shoots and leaves begin after bud break, proceeds at fast rate and then declines before flowering, approaching zero around veraison.

Berry growth rate is fast after flowering, then declines and increases again peaking near veraison.

Root growth has two fast growth periods: 1) from bud break to flowering; 2) near and after harvest



Most soils in California climate can provide sufficient water for basic shoot growth, root growth and initial berry growth (cell division) until a month before veraison

From before veraison, mild water shortage (deficit) can limit the shoot and lateral growth, which can provide more light to the fruit, increasing pigments and phenolics (better grapes and wine color and flavor)

In full irrigation strategy, excessive water applications if the soil is not well draining, can cause water stress due to logging & asphyxia (with flower drop, stomata closing and reduced growth)

Irrigation Scheduling based on Deficit Threshold/RDI Level

Levels of winegrape water deficit 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

Values of Midday SWP (-bars) to expect for fully irrigated prune vines, under different T and RH

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

Irrigation Scheduling based on Deficit Threshold/RDI Level

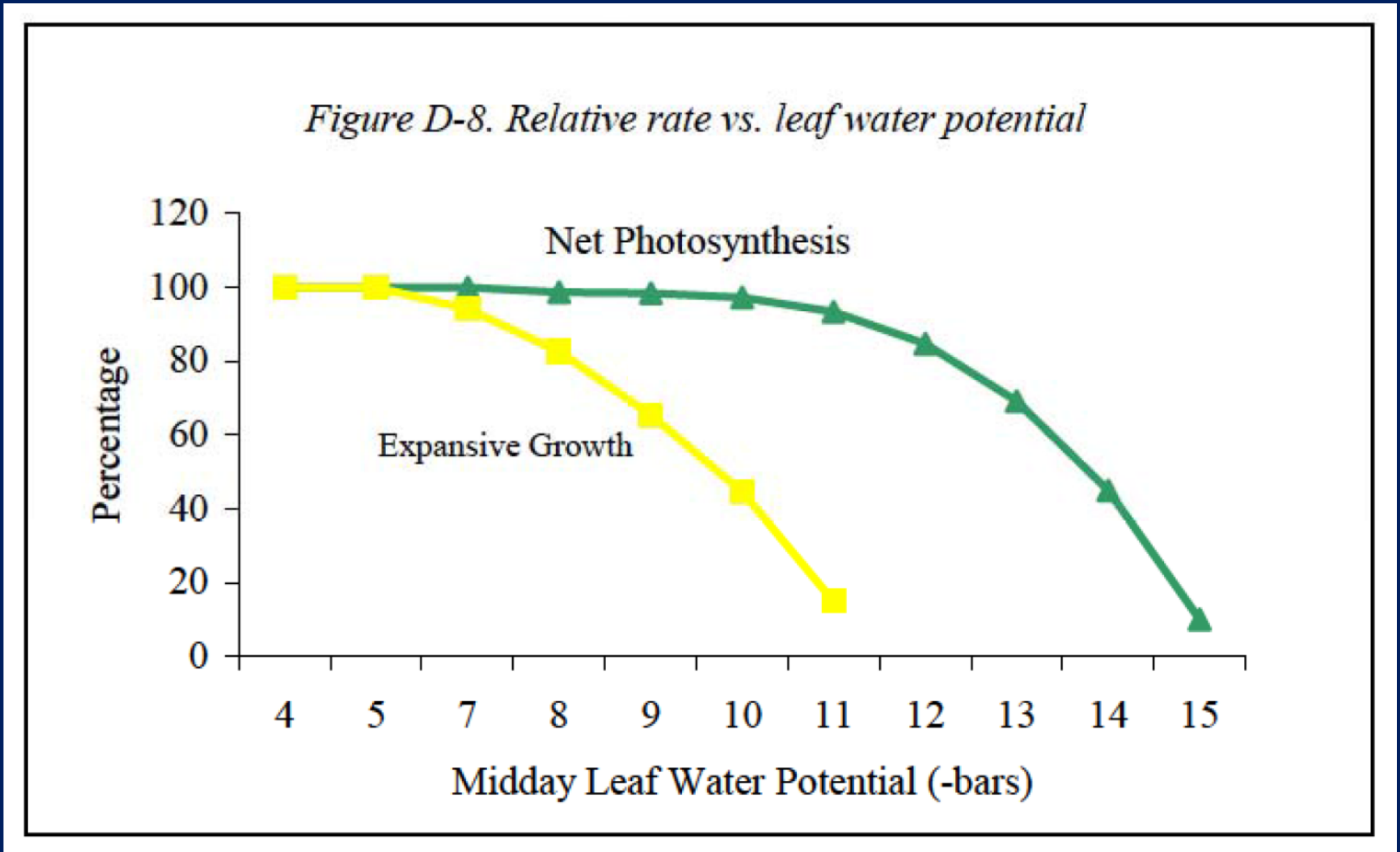
Tested Irrigation Treatments: timing of applications and volumes of water applied

Treatment Number	Leaf Water Potential Trigger at Which Irrigation Will Begin	Criteria for Subsequent Irrigation (RDI%)
1	no trigger <-10 bars	supply full water
2	-12 bars	supply 60% of daily full water use
3	-12 bars	supply35% of daily full water use
4	-14 bars	supply 60% of daily full water use
5	-14 bars	supply 35% of daily full water use
6	-12 bars	supply 35-60% (variable) of daily full water use

Experimentation in the Sacramento Valley and North Coast showed that -12 -13 bars for white varieties and -14 -15 bars for red varieties are reasonable water deficit thresholds to start irrigation

A RDI after the deficit threshold can be selected to reduce vegetative growth, ensure continued photosynthesis, adequate fruit cover to protect from heat and sunburn, and to prevent new vegetative growth.

Moderate pre-veraison to veraison water deficits usually produce higher quality fruits and wines



Moderate water deficits in the period pre-veraison to veraison can control expansive vegetative growth while still allowing photosynthesis at unaffected rates to produce carbohydrates

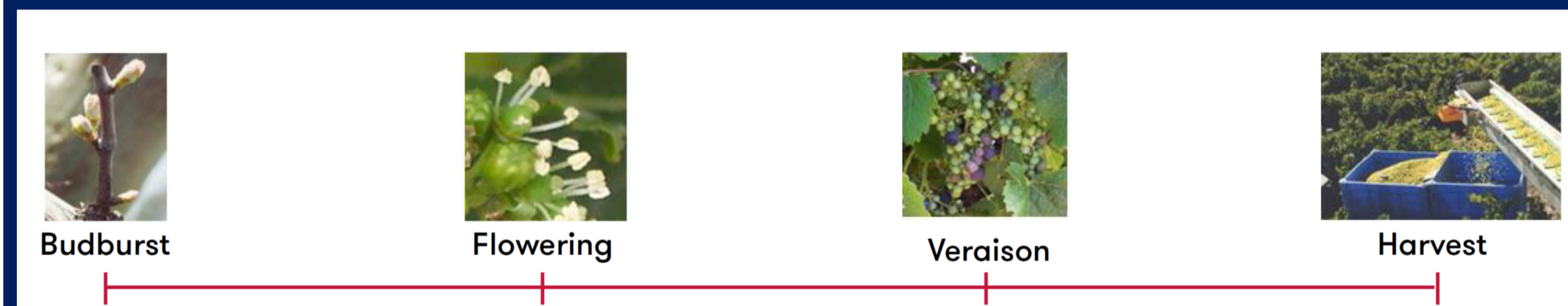
HEAT DAMAGE

Can happen as a result of heatwaves - 5 consecutive days with T_{max} > 95^o F, or 3 consecutive days with T_{max} > 105^o F

Heatwaves can be easily predicted by weather forecasters

How hot it will be and the duration of the heatwave are more difficult to predict

Irrigation systems are designed and managed on vineyards with a sense of what is "normal" or expected in a region



Flowers are highly susceptible to heat, wind and water stress. Exposure of the vine to extreme heat may result in poor fruitset (yield loss)

Berries are susceptible to heat damage as they soften. Dark grapes may get hotter than surrounding air. For wineries, heat may also increase the requirements for cooling (loss of yield and quality)

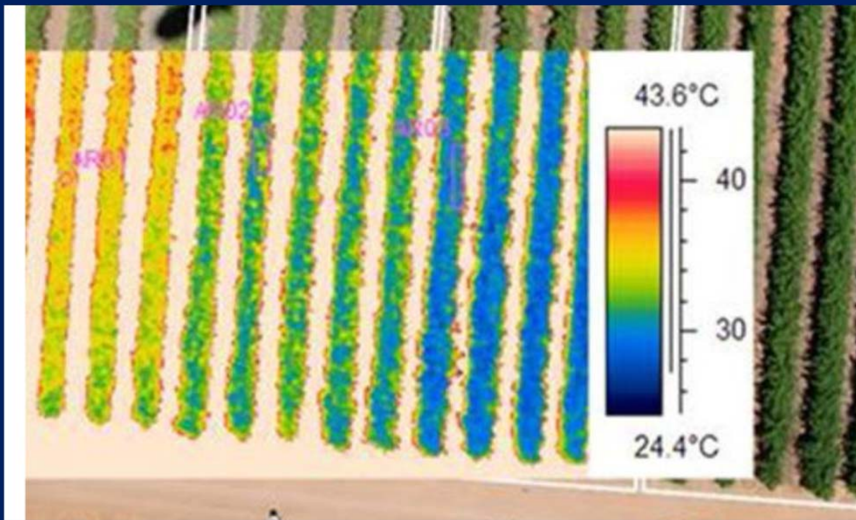
Maximize Transpirational Cooling

Water loss through stomata has cooling effect on the leaves and bunches.

Irrigation during heatwaves will foster transpiration, which contributes to vineyard cooling

Avoid water deficit during vegetative growth will ensure sufficient vegetation to protect bunches from heat

Another way of achieving cooling is with the use of sprinkler irrigation or mist



Moderate Deficit | **Mild Deficit** | **Full Irrigation**

Before	During	After
Irrigate*	Irrigate*	Irrigate*
Cease deficit irrigation		Monitor for pests and diseases
Reconsider any leaf removal or canopy manipulation strategy		

Irrigation before and during heatwaves reduces soil temperature, avoiding that grapes receive heat reflected/transmitted from the soil

TAKE-HOME MESSAGES

- **Define your irrigation strategy based on:**
  - ✓ Targets of yield and quality
  - ✓ Economics (water cost, energy cost, price rewards for yield or quality, or both)
  - ✓ Site-specific conditions (soil, water supply, slope, aspect, etc.)

- **Learn how to implement your strategy - it takes a few crop seasons to learn how to do it**
  - ✓ Select what parameter to monitor over the crop season (ET, Soil, Plant, or a combination of the three)
  - ✓ Schedule irrigation according to your strategy, but get feedback on schedule implementation

- **Do not rely only on your experience & Think beyond the current crop season**
  - ✓ Every year is different and there are things you are not experienced
  - ✓ What happens in this season will have some effects on the next couple of seasons

THANK YOU !!

QUESTIONS OR COMMENTS?