Methods and Tools for Irrigation Scheduling

UC ANR Grapevine Short Course
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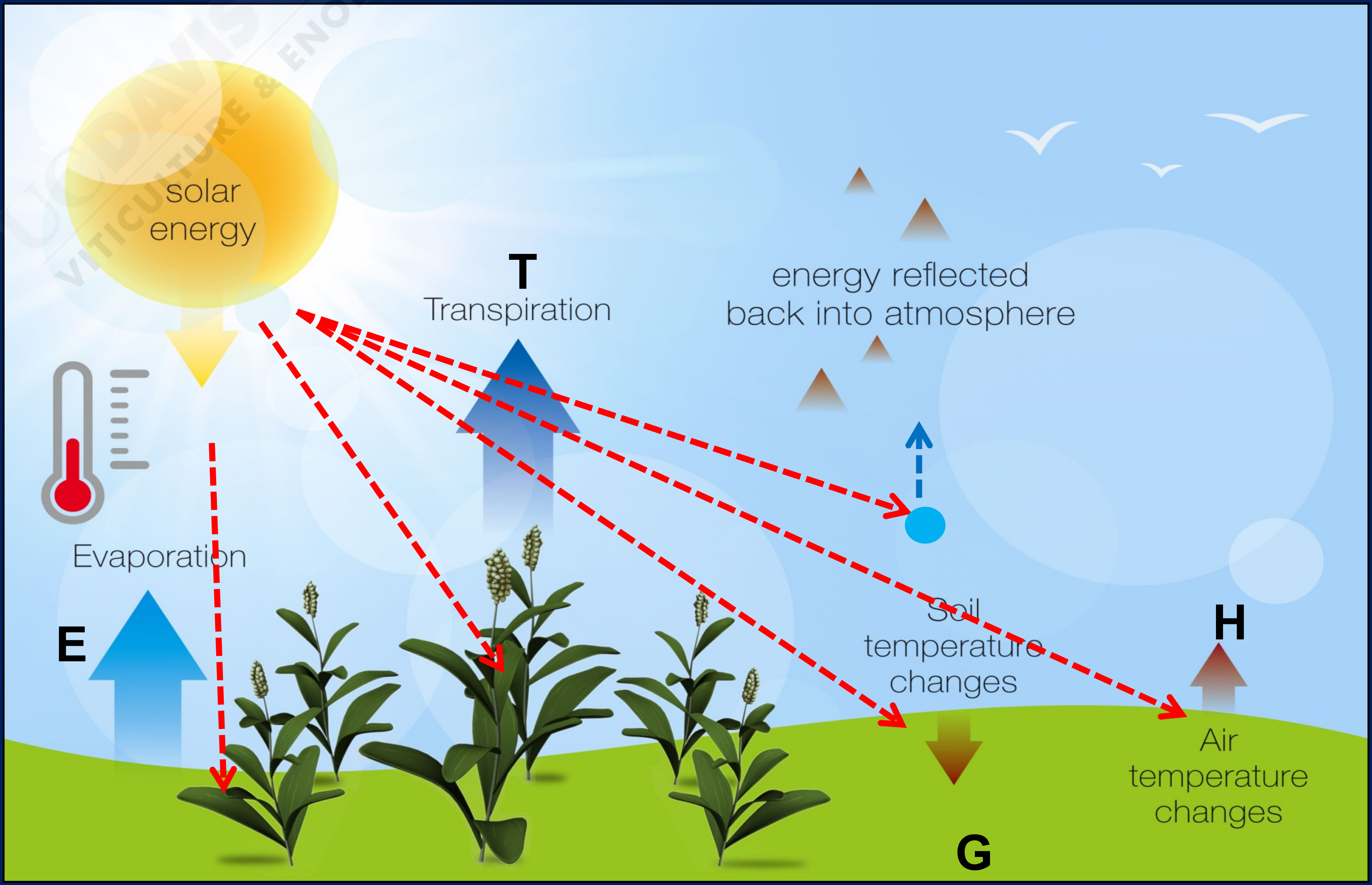
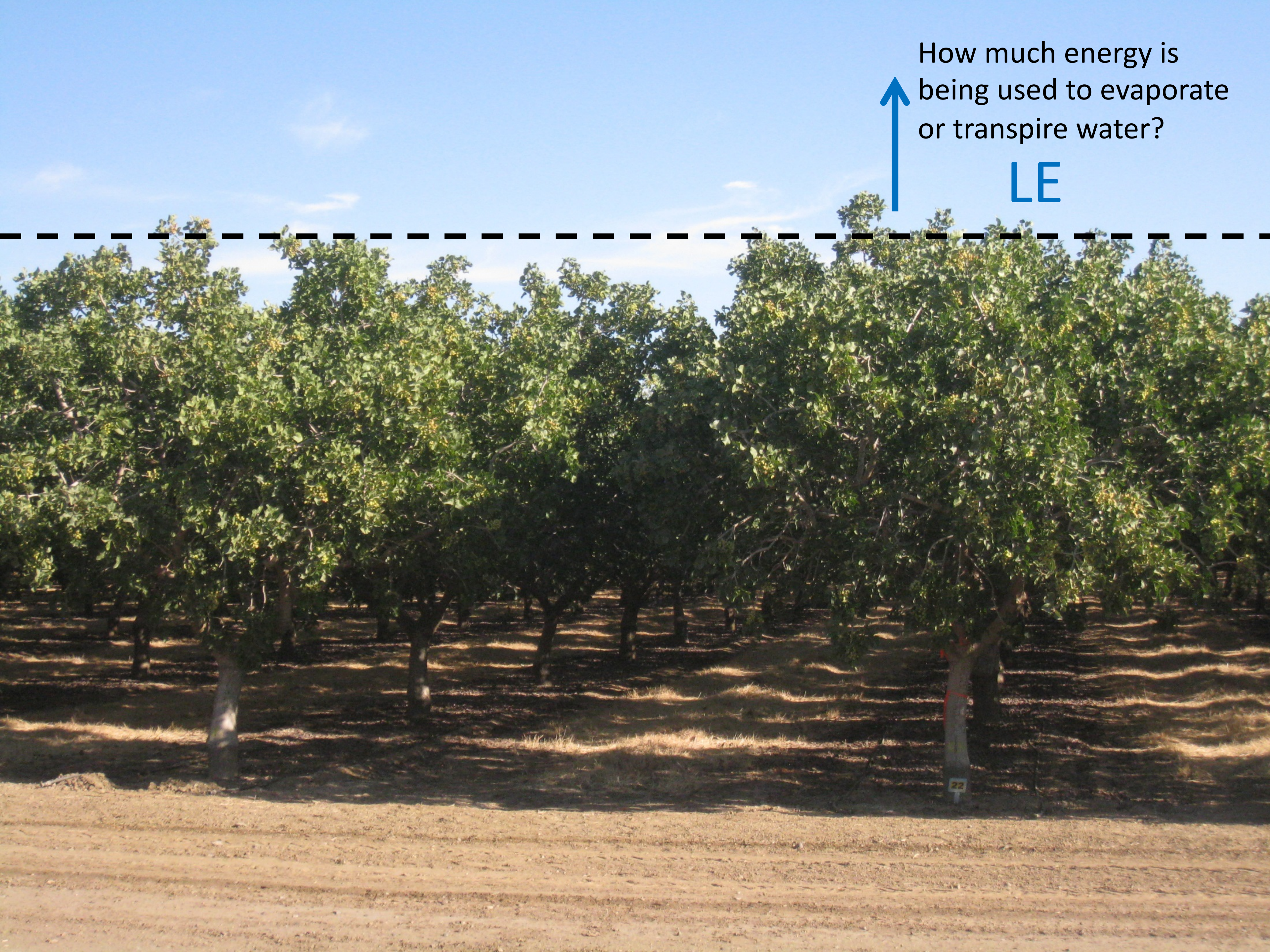
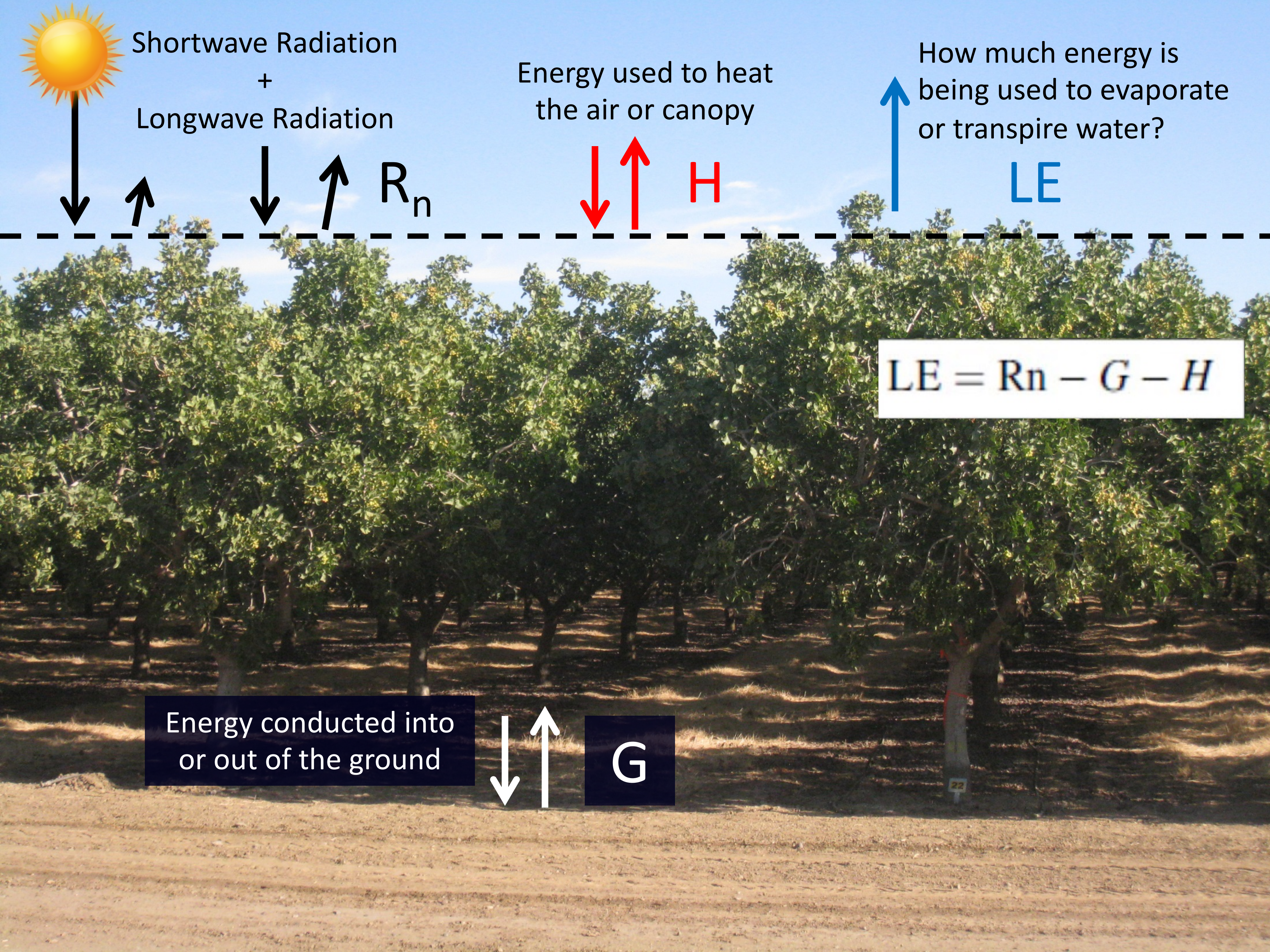
PRESENTATION OUTLINE

1) Review some Basics of Crop Water Use
2) Measuring Actual Evapotranspiration in Grapevine
3) Methods and Tools for Scheduling Irrigation
4) Discuss Advantages and Drawbacks of these Methods

WHAT DRIVES CROP WATER USE (Evapotranspiration)?




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



Shortwave Radiation
+
Longwave Radiation
R n
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

Residual of Energy Balance Method for Calculating Actual Crop Evapotranspiration

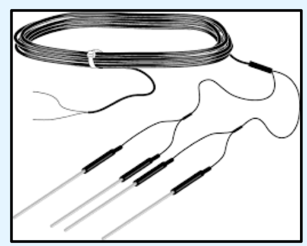
$$LE = \overbrace{R_n - G - H}^{\text{measured}}$$

Sensible Heat Flux

Eddy Covariance

Surface Renewal

Net Radiation



Ground Heat Flux


05/31/2013

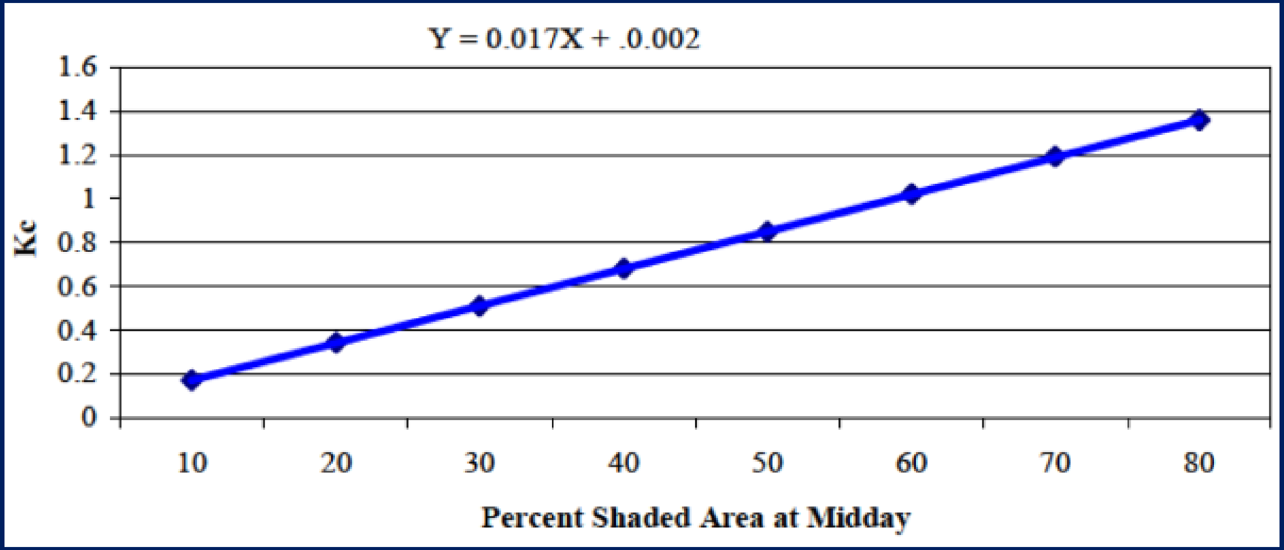

07/22/2014


08

WHAT DRIVES GRAPEVINE WATER USE (ET)?

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

VINE WATER USE (ET) INCREASE LINEARLY WITH THE % OF GROUND 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

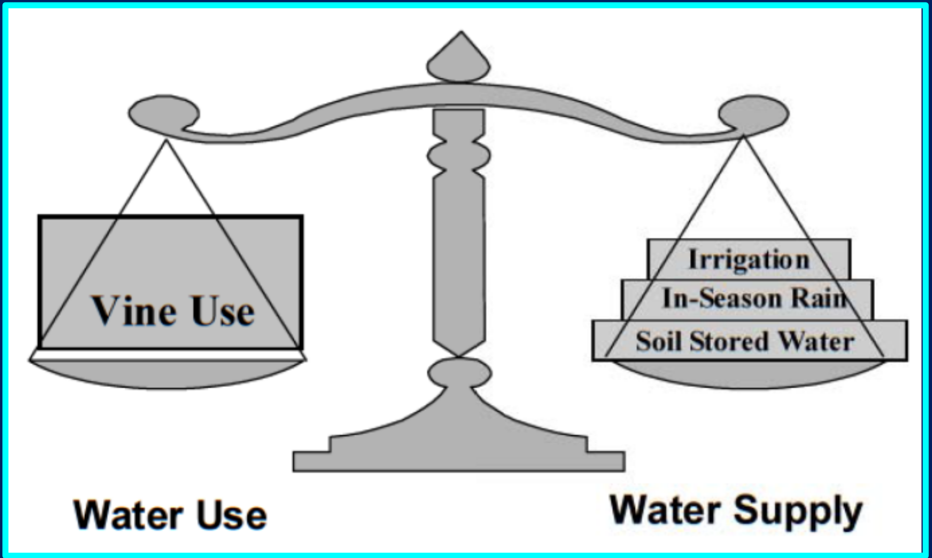
Shaded area: 31 sq-ft./77 sq-ft. = 40%

Kc = 1.7 x 0.40 = 0.68

WATER REQUIREMENTS OF GRAPEVINE

In California, mature grapevine needs anywhere from **18 to 28** inches of water per season to grow and produce at economic yield, depending on the training system, canopy size, row orientation, wind conditions

Grapevine can uptake and use water from various sources:



Moisture stored in the soil profile

In-season effective rainfall

Water applied and infiltrated from irrigation

Fog and Dew

IRRIGATION SCHEDULING

It provides answers to the following questions:

1) When to irrigate our crops? → Before plants face water deficit (or at specific deficit/stress levels beneficial for yield & quality)

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 to maintain a target stress level)

3) How to best apply the necessary amount of water? →

Uniformly or Site-specifically

Frequent-light or Infrequent-deep

Application rate and volume compatible with the soil infiltration and storage capacity, or energy rates

BENEFITS OF IRRIGATION SCHEDULING

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

2) Control vegetative growth

3) Reduce pruning costs, edging and shoots/leaves removal

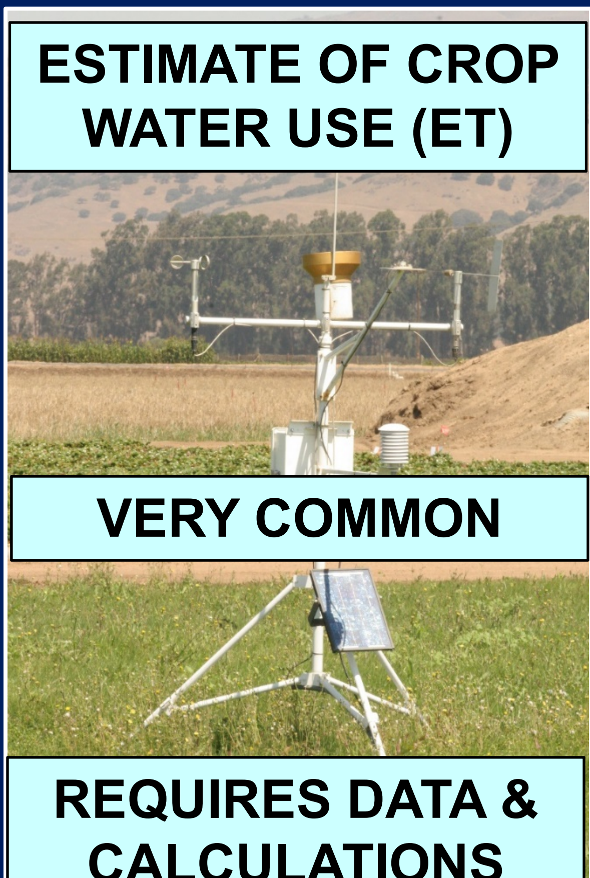
4) Improve fruit quality and value

5) Prevent/Mitigate frost/heat damages

6) Reduce losses of fertilizers and chemicals by deep percolation and off-site runoff

METHODS FOR IRRIGATION SCHEDULING

Weather-based



ESTIMATE OF CROP WATER USE (ET)

VERY COMMON

REQUIRES DATA & CALCULATIONS

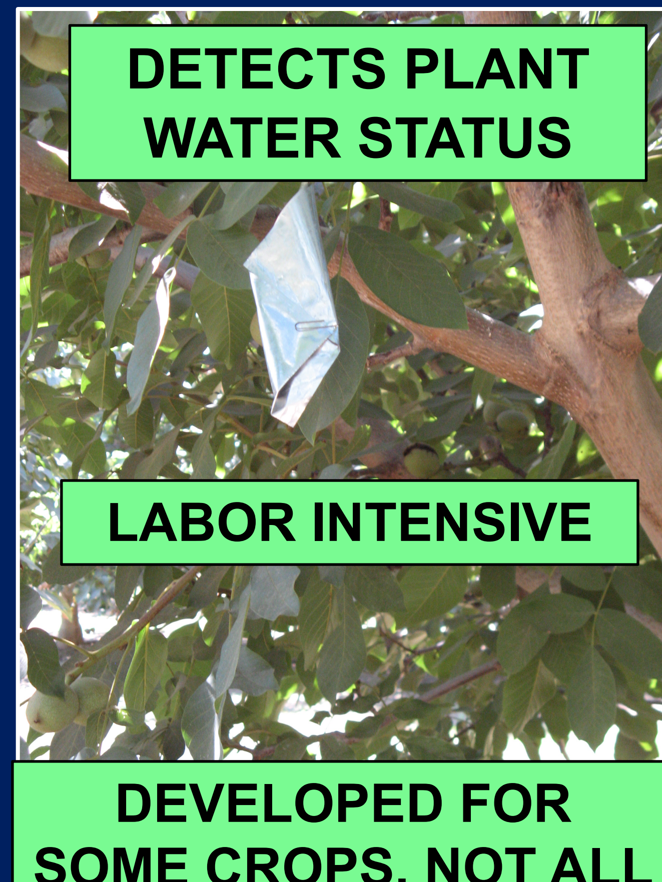
Soil-based

ASSESS SOIL WATER STATUS

EQUIPM. INTENSIVE

GOOD FOR PERIODIC CHECK

Plant-based



DETECTS PLANT WATER STATUS

LABOR INTENSIVE

DEVELOPED FOR SOME CROPS, NOT ALL

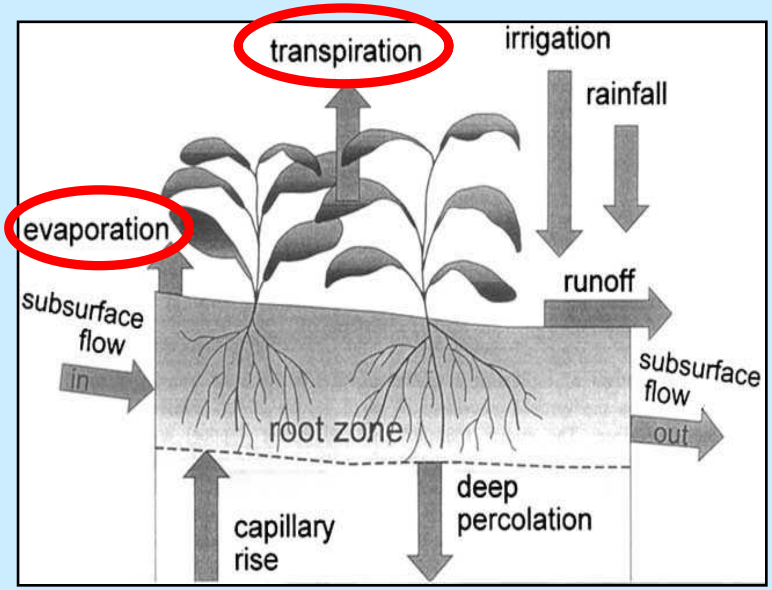
ALL IRRIGATION SCHEDULING METHODS REQUIRE SKILLED ON-FARM PERSONNEL & CAPACITY FOR TROUBLE-SHOOTING

WEATHER OR 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

$$ET_C = ET_O \times k_C$$



1) Use historical ET averages (ET_C, or ET_O and K_c values)
2) Use real-time ET_O and K_c values
3) Use ETo forecast and K_c values

Historical ET_C average estimates

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

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

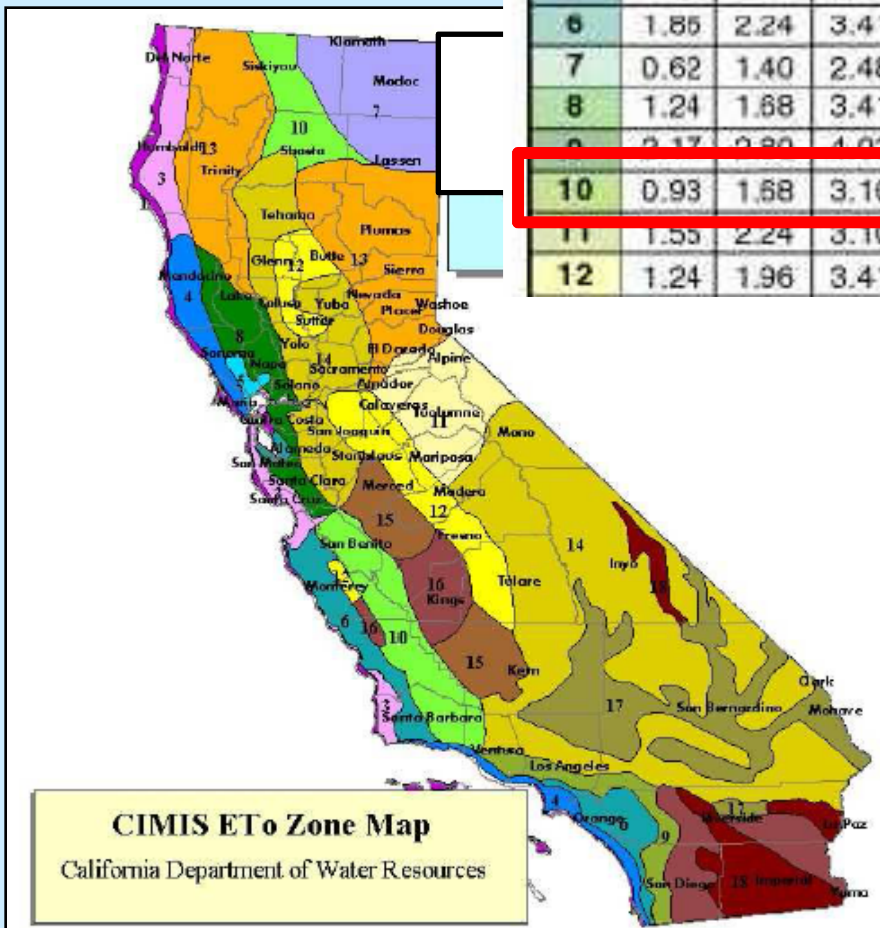
ETc Zone 10- drip & micro-spr - dry year	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC	YEAR
	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.
Precipitation	1,8	1,8	3,3	1,5	0,3	0,0	0,0	0,0	0,0	0,0	0,9	0,1	9,9
Grass Reference ETo	1,8	2,2	3,2	4,6	5,7	6,1	6,6	5,8	4,2	3,9	2,1	2,2	48,3
Apple, Pear, Cherry, 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

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

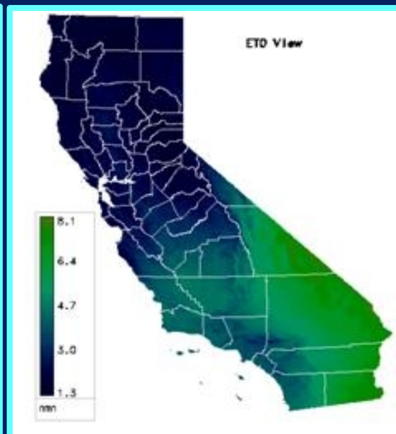


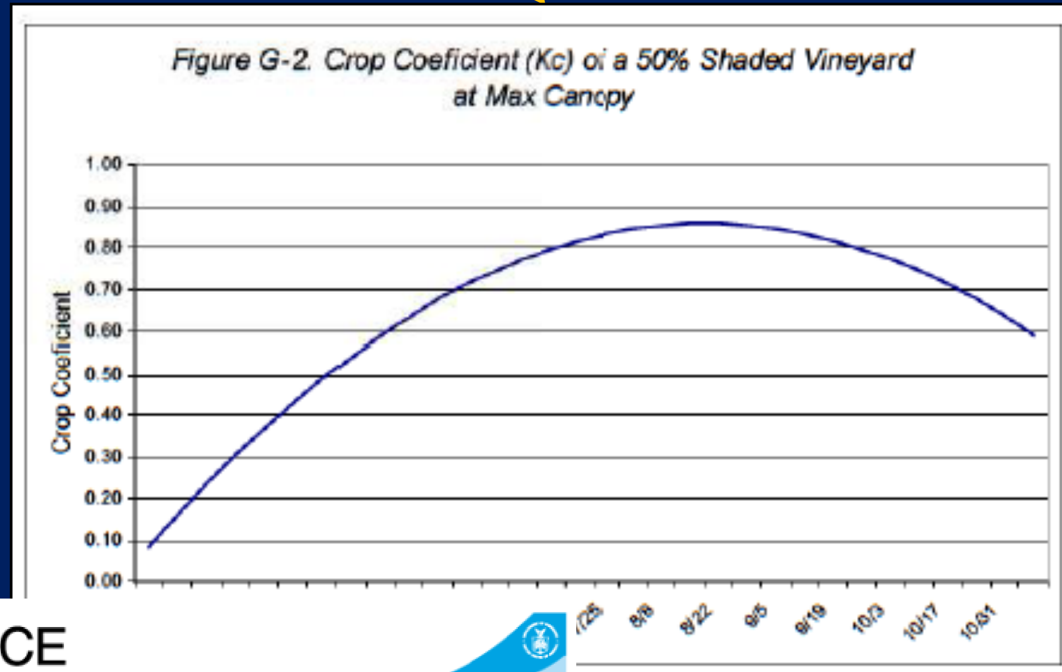
DATE	Almonds	Walnuts	Pistachios	Stone fruit	Prunes	Olives	Citrus	Apples	Pears	W. Grapes
Jan 1-15						0.80	0.65			
Jan 16-31						0.80	0.65			
Feb 1-15						0.80	0.65			
Feb 16-28						0.80	0.65			
Mar 1-15				0.55		0.80	0.65			
Mar 16-31	0.54	0.12		0.62		0.80	0.65			0.32
Apr 1-15	0.60	0.53	0.07	0.67	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	

ETc = ETo x Kc

CIMIS

CALIFORNIA DEPARTMENT OF WATER RESOURCES





NATIONAL WEATHER SERVICE

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

Custom Weather Forecast Table

			Wed Feb 13				Thu Feb 14			Fri Feb 15				Sat Feb 16				Sun Feb 17				Mon
Weather		Rain	Rain	Rain	Rain		Likely Rain Showers and TStorms	Likely Rain Showers	Likely Rain Showers	Rain Showers	Likely Rain Showers	Chance Rain Showers	Slight Chance Rain Showers	Chance Rain Showers		Likely Rain Showers			Chance Rain Showers			
Daily-Temp			High -998 Low --				High 64 Low 54			High 56 Low 48				High 56 Low 40				High 55 Low 38				H L
Chance of Precip	–	85%	90%	90%	95%	95%	70%	60%	70%	80%	70%	30%	15%	50%	70%	65%	55%	60%	50%	30%	10%	10
Precip		0.24"	0.14"	0.09"	0.34"	0.34"	0.02"	0.03"	0.16"	0.36"	0.14"	0.04"	0.02"	0.03"	0.06"	0.02"	0.02"	0.03"	0.01"	0.00"	0.00"	0.0
12-hr Snow Total		--	0"		0"		0"			0"	0"		0"		0"		0"		0"		0"	
FRET			-999"				0.07"			0.05"				0.06"				0.05"				

Can ET be used also to determine when to irrigate?

We can define an accounting system (check-book) with a threshold for no-stress called Maximum Allowable Depletion (MAD)

Like in a Bank Account, we withdraw money until a certain threshold is reached. At that level, we have to deposit some money to refill the account and avoid deficit **(RED)**

Estimate Maximum Allowable Depletion (ft.)

1. Rooting depth of the crop (ft.)
2. Water holding capacity of soil (in./ft.)
3. Maximum depletion of available soil moisture (40-60%)

Soil texture	Water-holding capacity: Range In./ft	Water-holding capacity: 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

Crop: Grapevine

Effective Root depth: 4.0 ft.

Soil: Sandy Loam

Water holding capacity: 1.5 in/ft

MAD: 60 %

Maximum Allowable Depl.: 3.6 ft.

Crop	Root Depth (ft)	MAD (%)
Alfalfa	8.0	55
Pasture	2.5	50
Turf	1.5	50
Small Grains	4.5	55
Beans	3.0	40
Corn	5.5	50
Potatoes	3.5	40
Sugar Beets	4.0	50
Cotton	5.0	55
Orchards	8.0	50-65
Grapes	6.0	65

DRAWBACKS OF ET-BASED SCHEDULING

Estimated ET may be quite different from the actual ET in the site-specific conditions of our vineyard/orchard

RISK OF OVER-IRRIGATION OR UNDER-IRRIGATION

Most of the available Kc information was developed for:

- ✓ Infrequent irrigation methods, such as surface or sprinkler irrigation
- ✓ Well-drained soils, level (flat) grounds
- ✓ Crop varieties, rootstocks, plant densities, and canopy management practices that were quite different from the current

MICRO-IRRIGATION IS A GAME-CHANGER
(SPOON-FEEDS WATER AND NUTRIENTS TO CROPS)

Looking only at ET may be limiting for Fruit and Nut Crops

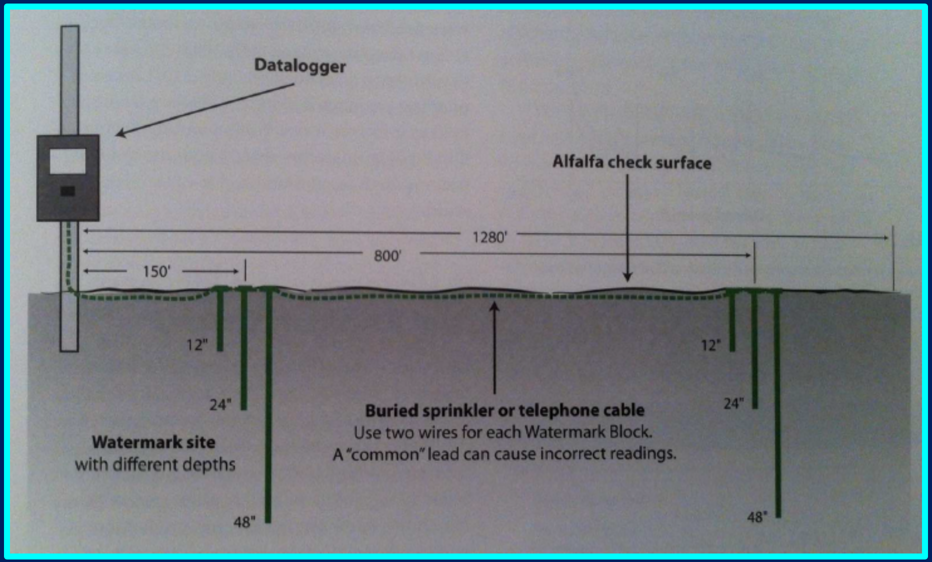
NEED TO LOOK AT THE PLANT WATER AND SOIL WATER STATUS

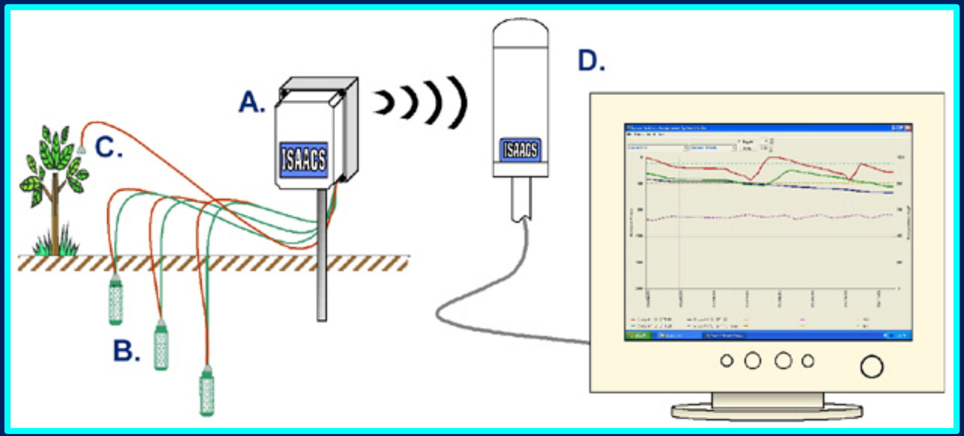

tule
Evapotranspiration Sensor

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 growth & production





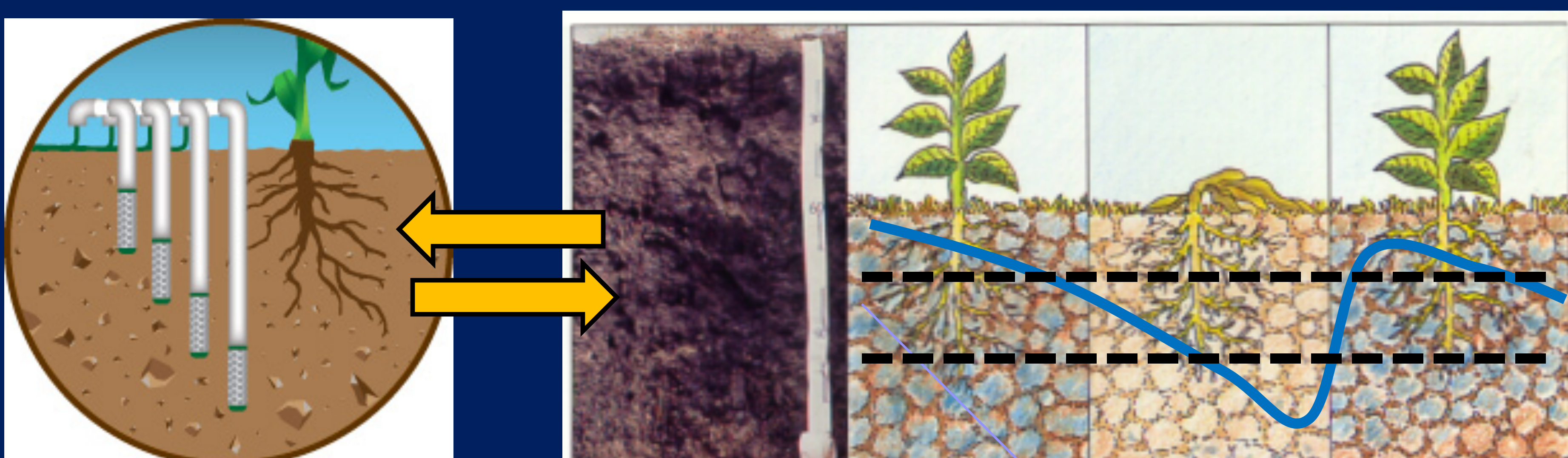
S.M.M. HELPS ANSWERING THE FOLLOWING QUESTIONS

✓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?



HOW IS SOIL MOISTURE MEASURED?

SOIL MOISTURE CONTENT (%, in/ft, mm/m)

How much water is available per unit of soil?

% weight = (weight of water/weight of dry soil) x 100

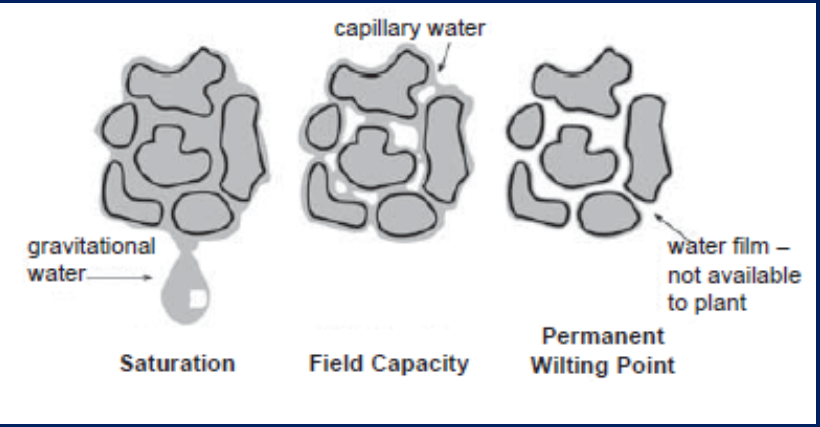
% volume = (volume of water/volume of soil) x 100

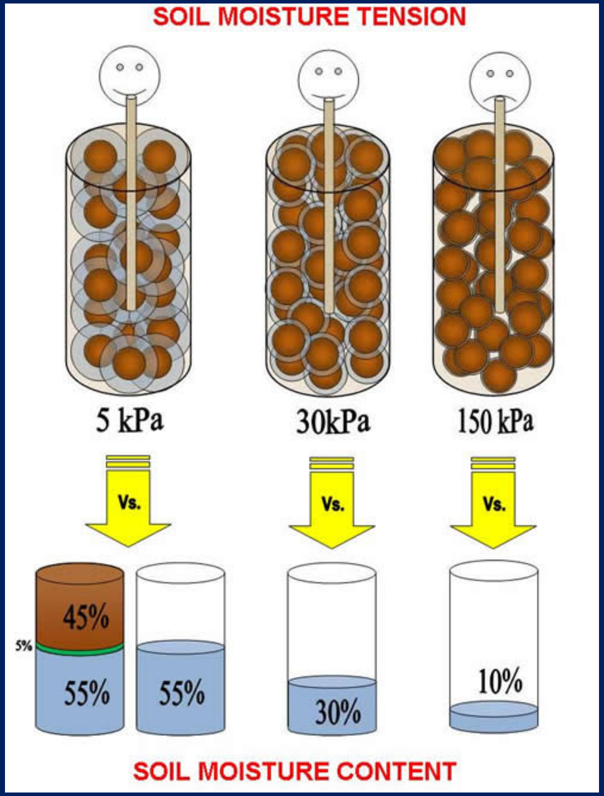
Depth = (inch of water/foot of soil) => MOST COMMON AND PRACTICAL

SOIL MOISTURE TENSION (centibars, kPa)

How strongly water is held by soil particles

The higher the tension, the drier the soil and the more difficult is for plant to extract water





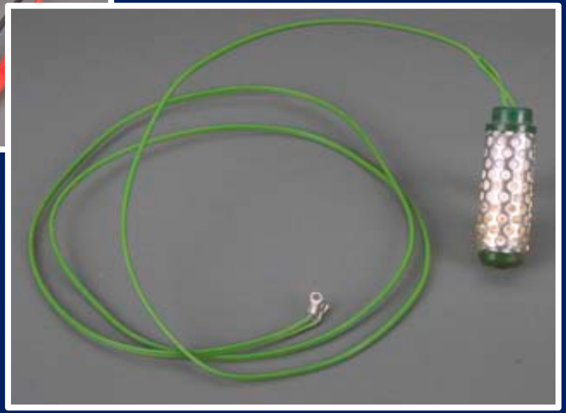
Some sensors measure soil water content and others measure soil water tension

In reality all sensors measure some properties/parameters that are related to soil moisture content or soil moisture tension through a specific calibration





SOIL WATER TENSION



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

GYPSUM BLOCKS (tension)

✓**Very cheap & Maintenance free**

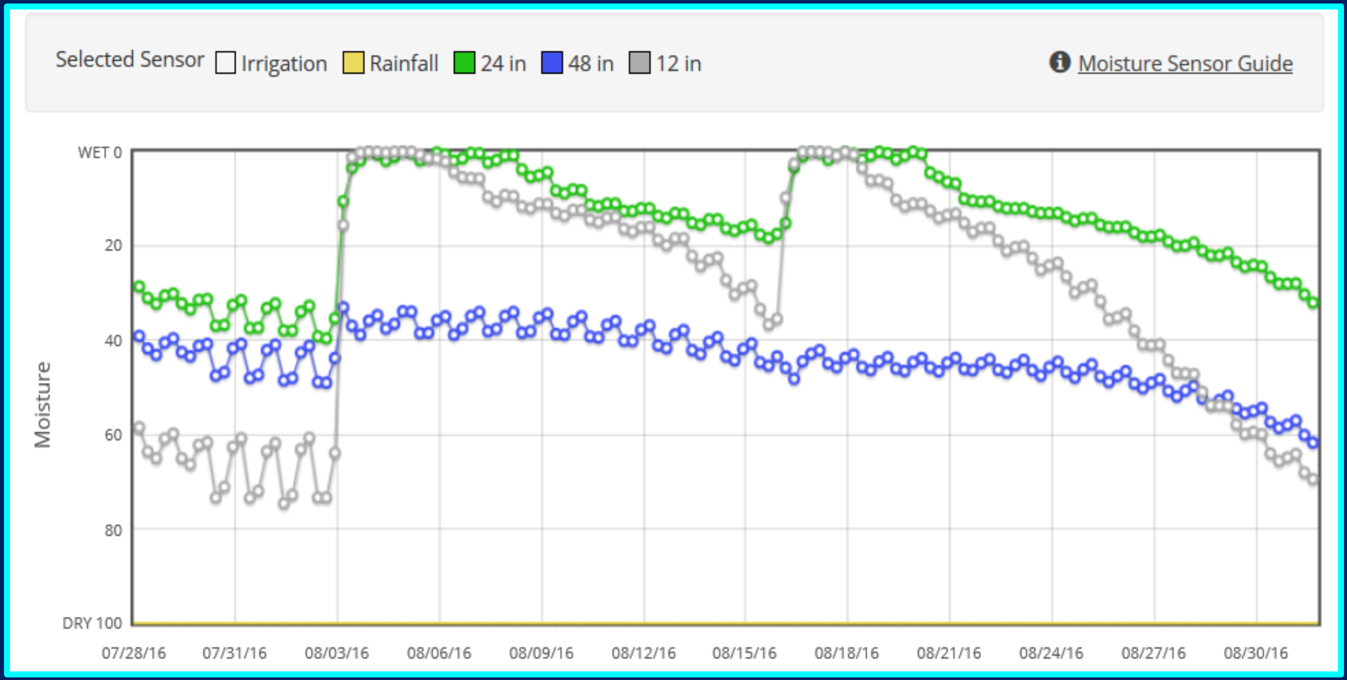
✓**Can last 1-5 years (soil moisture)**

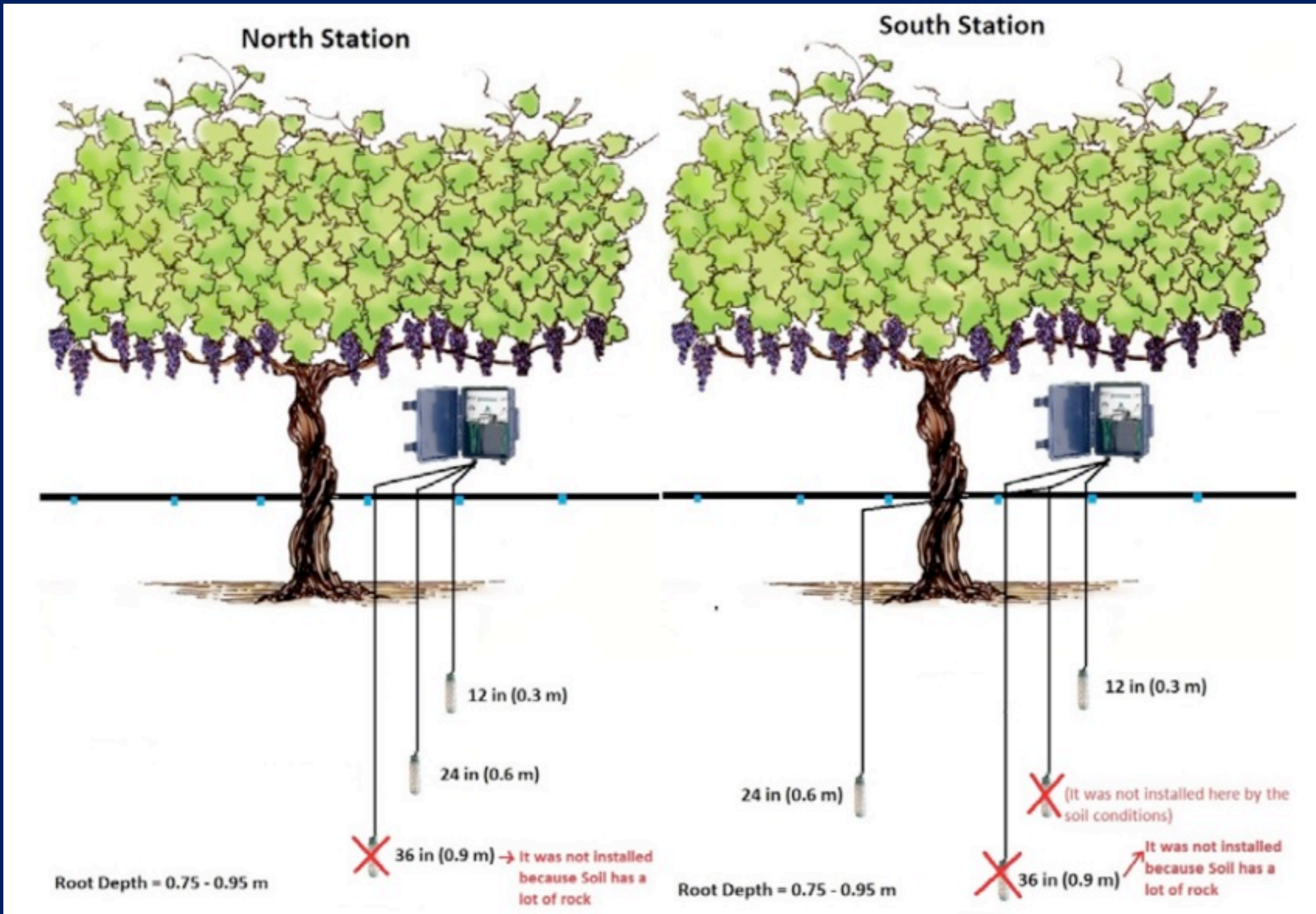
✓**Sensitive to soil temperature**

✓**Corrosion of electrodes**

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



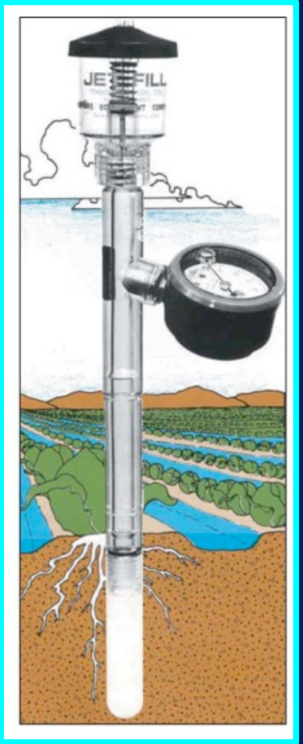

North Station
12 in (0.3 m)
24 in (0.6 m)
36 in (0.9 m) → It was not installed because Soil has a lot of rock
Root Depth = 0.75 - 0.95 m
South Station
12 in (0.3 m)
24 in (0.6 m)
(It was not installed here by the soil conditions)
36 in (0.9 m)
It was not installed because Soil has a lot of rock
Root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

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

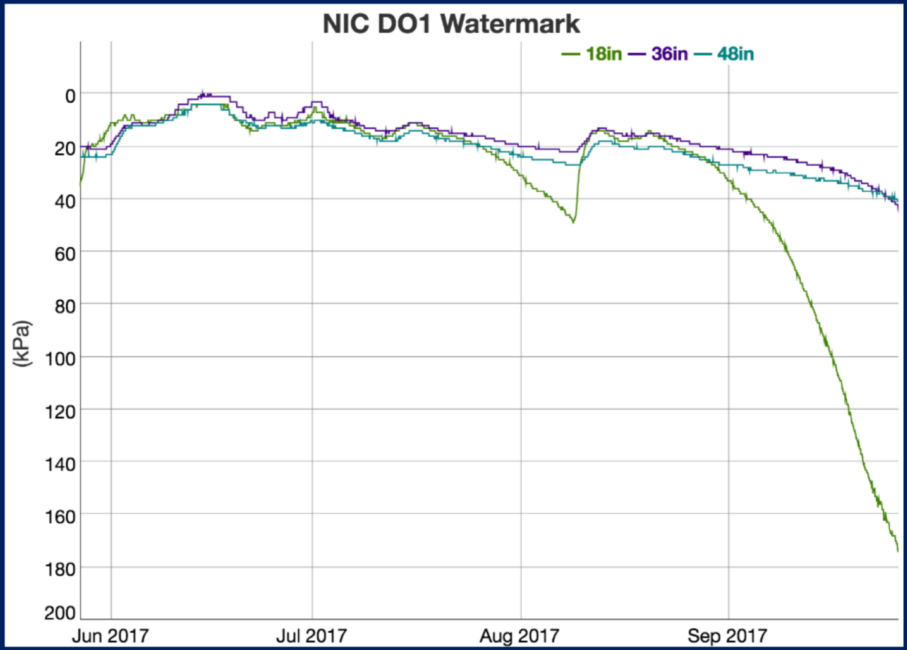
Soil Type	Soil Moisture Tension (centibars)
Sand or loamy sand	40-50
Sandy loam	50-70
Loam	60-90
Clay loam or clay	90-120

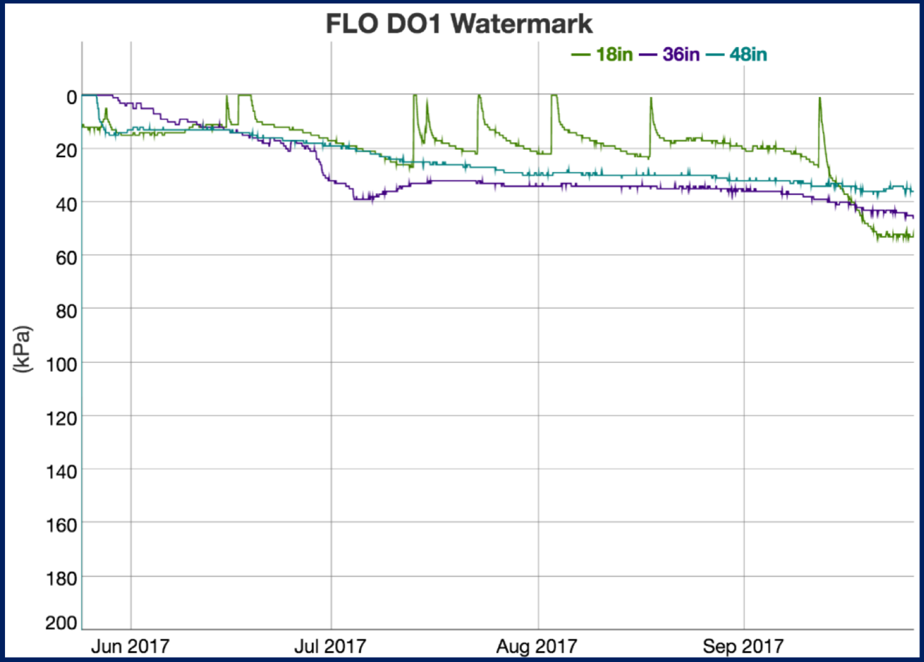
Soil moisture content at which irrigation should occur (@ 50% of PAW depleted)

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



DRAWBACKS OF SM-BASED SCHEDULING





Plants may face water stress even under well-watered soil conditions (salinity/sodicity, hypoxia, soil-water piling up due to perched water table or compaction layers)

WITH MICRO-IRRIGATION THERE MAY BE SOME PREFERENTIAL FLOW AND NON-HOMOGENEOUS SOIL MOISTURE

SM CAN BE USED AS FEEDBACK INFORMATION AFTER IRRIGATIONS

NEED TO LOOK AT THE PLANT WATER AND SOIL WATER STATUS

Methods to Monitor Plant Water Status (and Stress)

Leaf/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 midday 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.).

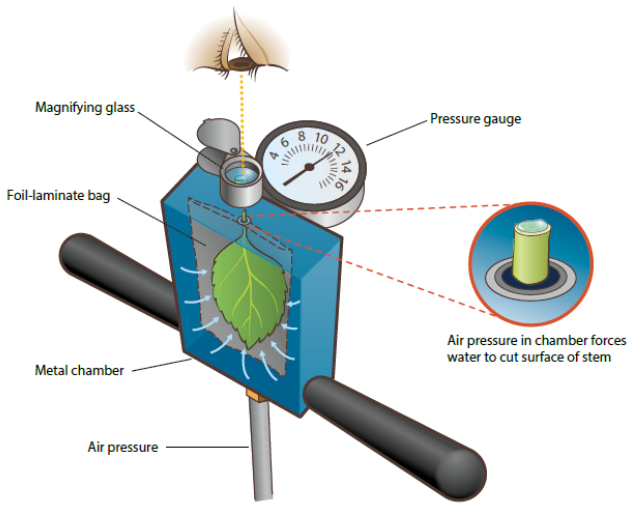
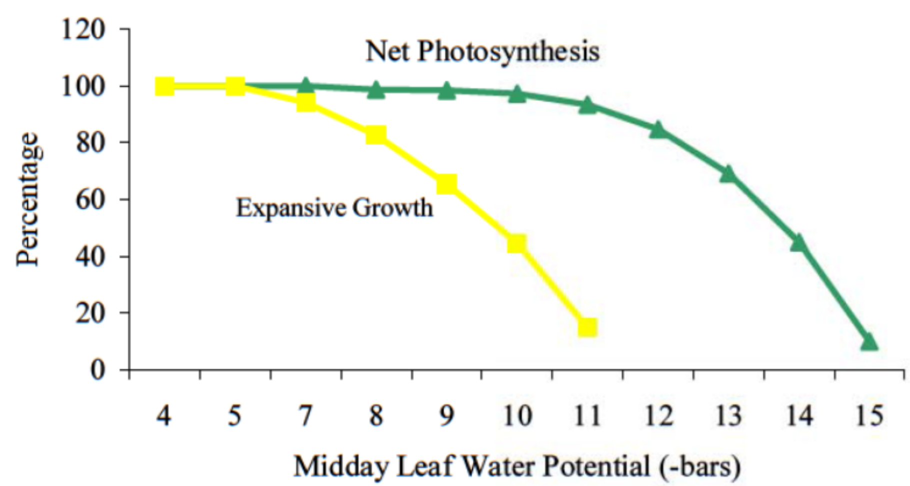


Figure 2. Schematic showing how water potential is measured in a severed leaf and stem (petiole) using a handheld pump-up pressure chamber. *Source:* Adapted from Plant Moisture Stress (PMS) Instrument Company.

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



Dendrometers and Other Plant Sensors

COMBINATIONS OF DIFFERENT APPROACHES

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

↓

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

↓

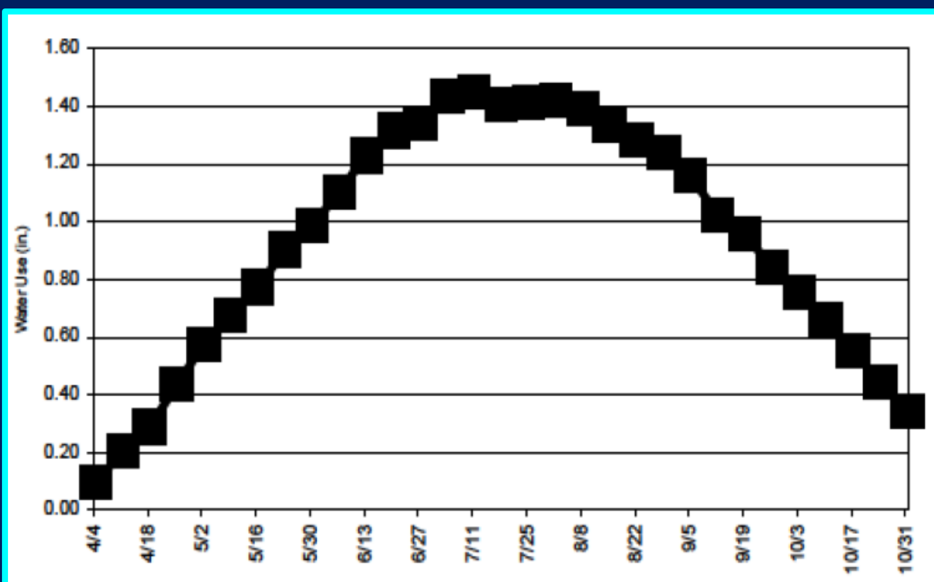
Soil-based
(Monitoring soil moisture) → **Check for Feedback**

First Step for Water-Efficient Irrigation of Vineyards

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

Full Irrigation

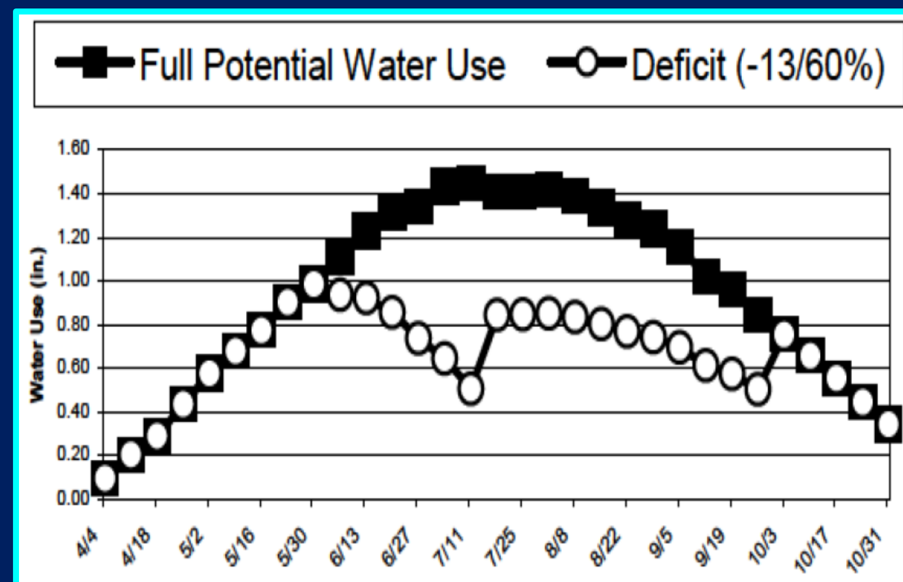
(full replenishment of water needs)



Partial (Deficit) Irrigation or RDI

(partial replenishment of water needs)

Timing & Levels of Water Deficits

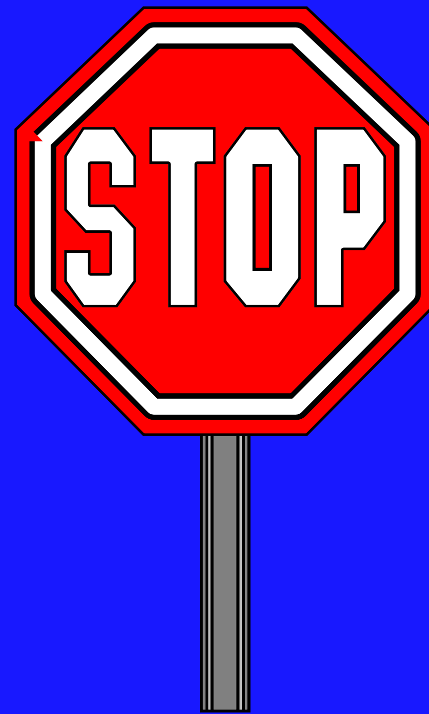


TAKE-HOME MESSAGES

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


STOP

WHAT IT TAKES TO BE RESOURCE-EFFICIENT?

Good System Design

✓Accurate & Skilled
✓Flexible Operation

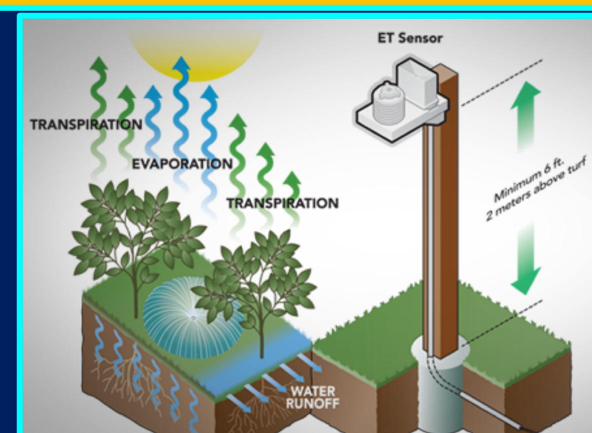
Proper Installation
Regular Maintenance
System Evaluation

Defined Irrigation Strategy

- Full Irrigation
- Deficit Irrigation (SDI, RDI)

Accurate Irrigation Scheduling & Control

Implementation of Schedule & Feedback



WEATHER-BASED SCHEDULING

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

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

Recommended installation of S. M. sensors