Pistachio Irrigation: Determining Water Needs and Managing Drought

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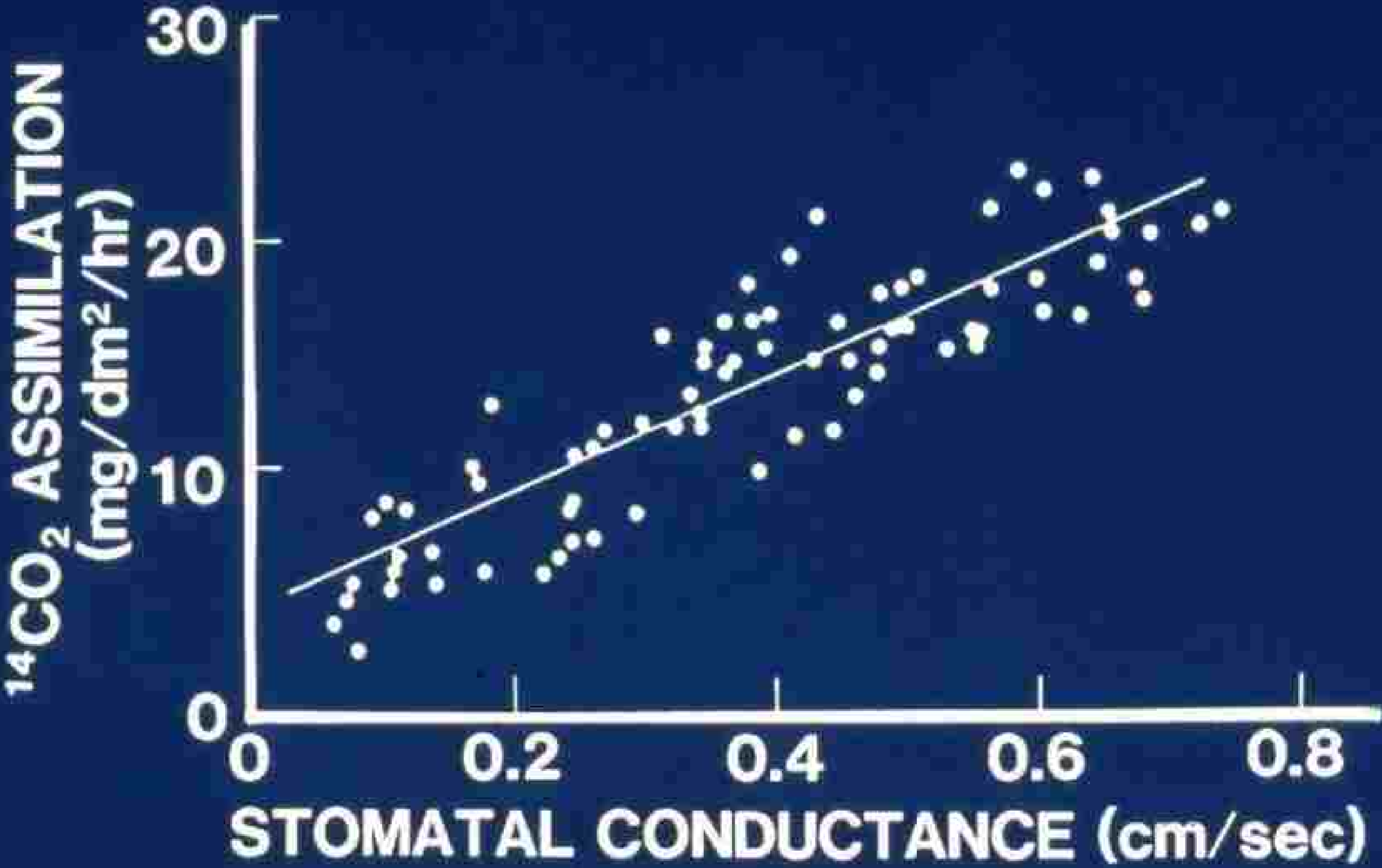
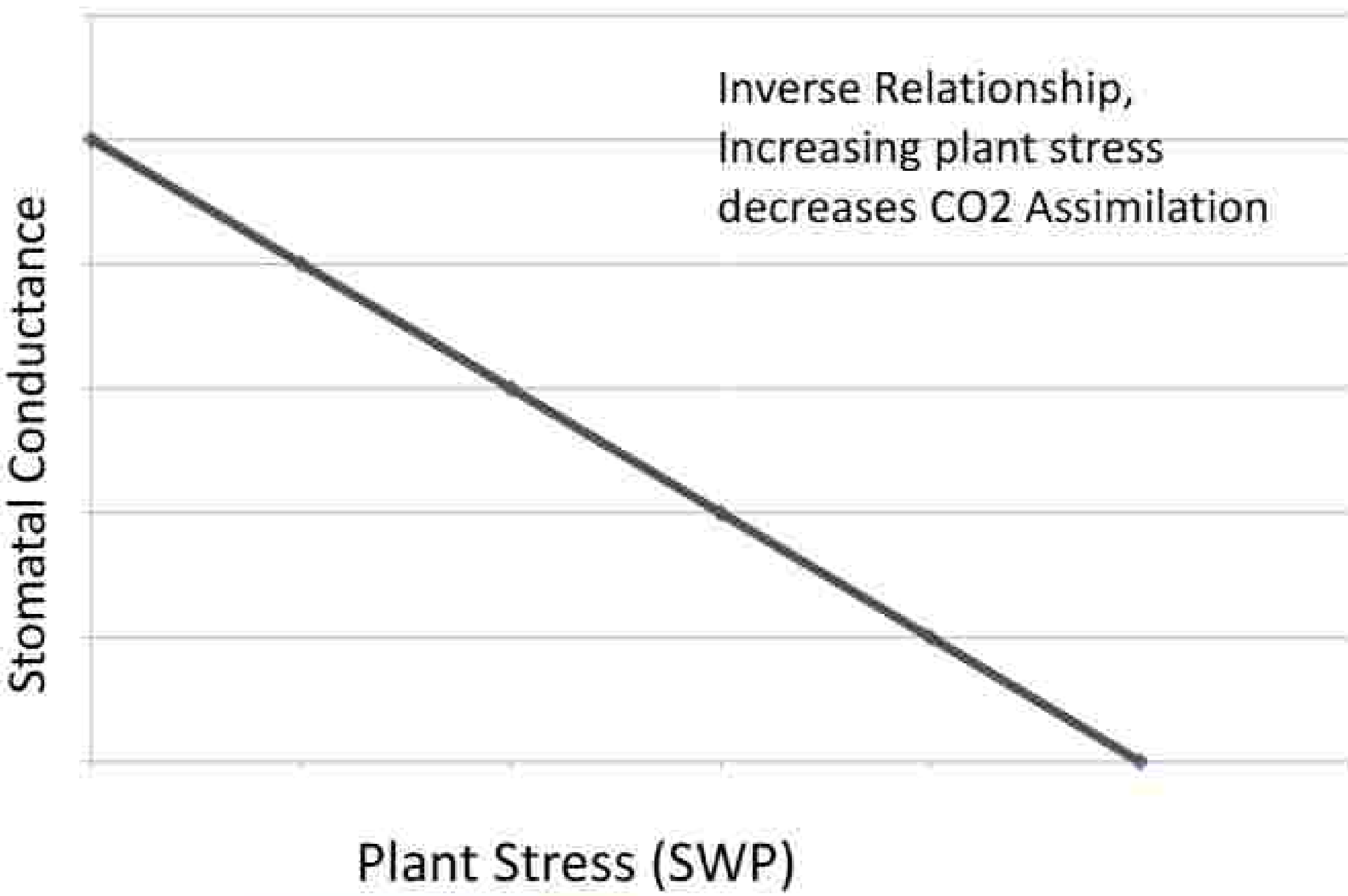
8th Advances in Pistachio Production

November 14-16, 2017



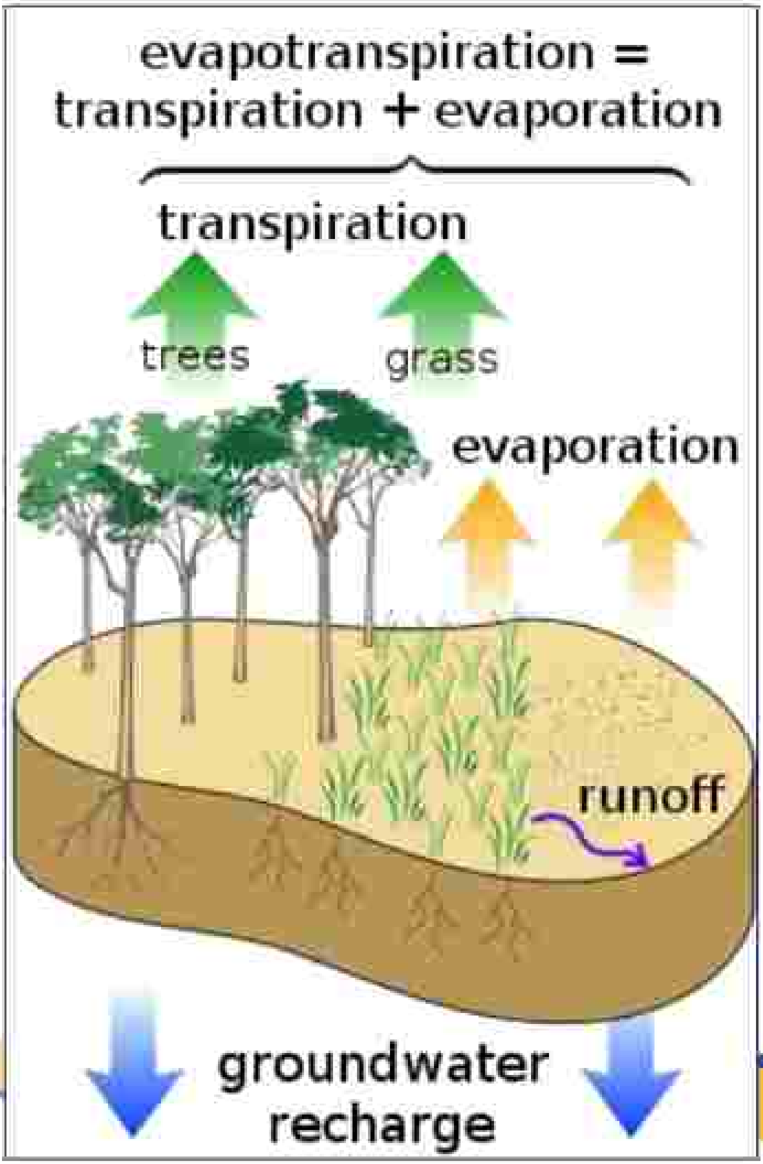
$^{14}CO_2$ ASSIMILATION (mg/dm^2/hr)
30
20
10
0
0
0.2
0.4
0.6
0.8
STOMATAL CONDUCTANCE (cm/sec)

Water Use In the Orchard: Importance



Water Use in the Orchard

- Transpiration – needed for plant growth
- Evaporation – Due to environmental conditions
- Runoff/ Deep percolation – Due to over-application



Irrigation scheduling

How much water does your crop need **this** irrigation?

- Evapotranspiration
  - (ET_0 = ET_C x K_C /irrigation efficiency)

How much water is being **applied** per irrigation?

- Measure
  - Flow meter
  - Irrigation efficiency testing
  - Coffee can test

How do we calculate water use?

Evapo-transpiration of the reference crop (non-stressed tall grass)

Known, Variable

$$ET_c = ET_o \times K_c$$

Evapo-transpiration of the Crop of Interest (pistachios)

Unknown

Crop Coefficient – ratio of water need of crop v/s water need of grass

Known, Fixed

Determining Evapotranspiration

30 Year AVG ETo

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	46.8
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
13	1.24	1.96	3.10	4.80	6.51	7.80	8.99	7.75	5.70	3.72	1.80	0.93	54.3
14	1.55	2.24	3.72	5.10	6.82	7.80	8.68	7.75	5.70	4.03	2.10	1.55	57.0
15	1.24	2.24	3.72	5.70	7.44	8.10	8.68	7.75	5.70	4.03	2.10	1.24	57.9
16	1.55	2.52	4.03	5.70	7.75	8.70	9.30	8.37	6.30	4.34	2.40	1.55	62.5
17	1.86	2.80	4.65	6.00	8.06	9.00	9.92	8.68	6.60	4.34	2.70	1.86	66.5
18	2.48	3.36	5.27	6.90	8.68	9.60	9.61	8.68	6.90	4.96	3.00	2.17	71.6

Variability between stations within single zones is as high as 0.02 inches per day for zone 1 and during winter months in zone 13. The average standard deviation of the ETo between estimation sites within a zone for all months is about 0.01 inches per day for all 200 sites.

Information System (CIMIS)

The whole Central Valley covers Zones 12 to 16: for an "normal year" ETo of 53.3 to 62.5 in/yr, with most area @ 53 to 58 inches.

How to determine Real Time ETo

How to determine Real Time ETo

www.cimis.water.ca.gov/UserControls/Reports/MonthlyReportViewer.aspx

California Irrigation Management Information System (CIMIS)

CIMIS Monthly Report

Rendered in ENGLISH Units.
November 2013 - October 2014
Printed on Sunday, November 02, 2014

Fresno State - San Joaquin Valley - Station 80

Month Year	Total ETo (in)	Total Precip (in)	Avg Sol Rad (Ly/day)	Avg Vap Pres (mBars)	Avg Max Air Temp (°F)	Avg Min Air Temp (°F)	Avg Air Temp (°F)	Avg Max Rel Hum (%)	Avg Min Rel Hum (%)	Avg Rel Hum (%)	Avg Dew Point (°F)	Avg Wind Speed (mph)	Avg Soil Temp (°F)
Nov 2013	2.17	0.26	248	8.7	69.2	40.6	53.4	88	28	63	40.7	2.8	57.8
Dec 2013	1.67	0.28	224	9.4	59.8	28.9 K	43.3	61	38	66	32.8	2.8	49.2
Tots/Avgs	3.84	0.7	236	7.8	64.5	35.1	48.3	81	33	65	36.7	2.7	53.5

Fresno State - San Joaquin Valley - Station 80

Month Year	Total ETo (in)	Total Precip (in)	Avg Sol Rad (Ly/day)	Avg Vap Pres (mBars)	Avg Max Air Temp (°F)	Avg Min Air Temp (°F)	Avg Air Temp (°F)	Avg Max Rel Hum (%)	Avg Min Rel Hum (%)	Avg Rel Hum (%)	Avg Dew Point (°F)	Avg Wind Speed (mph)	Avg Soil Temp (°F)
Jan 2014	1.52 K	0.03 L	234 L	7.2 L	64.4 L	33.5 L	47.2 L	81 L	37 L	65 L	37.8 L	2.5 L	48.5 L
Feb 2014	1.78 K	1.23 L	304 L	10.4 L	70.0 L	40.1 L	50.4 L	88 L	49 L	81 L	45.2 L	3.7 L	55.5 L
Mar 2014	4.35	0.73	446 K	8.8	72.2 K	45.4	58.7	90	35	59	44.0	4.4 K	58.3
Apr 2014	5.86	0.81	580 K	10.4	77.0	46.8	63.3	87	30	53	45.0	5.0 K	61.8
May 2014	8.34	0.22	693 K	9.8 K	84.4	55.0 K	70.8	72	21	38 K	43.8 K	5.7 K	68.7
Jun 2014	8.88	0.00 K	740 K	11.2 K	91.3 K	59.1	78.7 K	70 K	19 K	38 K	47.2 K	5.3 K	72.6 K
Jul 2014	8.65	0.02	659 K	14.4	97.0	67.2 K	82.8	68	21	39	54.2	4.9 K	77.2
Aug 2014	7.83 K	0.00	592 K	14.1	94.4	64.5 K	79.8	74	22	41	53.8	4.5 K	78.3
Sep 2014	6.45	0.97 K	511	13.8	90.9	60.7	75.7 K	78	26	48 K	53.1 K	4.1 K	75.4
Oct 2014	4.13 K	0.42 K	392 K	11.5 K	83.0	51.5	66.4 K	85 K	23 K	52	48.1	3.4 K	66.4 K
Tots/Avgs	57.83	3.8	515	11.3	82.8	52.4	66.1	80	28	52	47.2	4.4	63.5

Flag Legend	
M - All Daily Values Missing	K - One or More Daily Values Flagged

Determining the crop coefficient (Kc)

Month	Goldhamer, et al (1992)	Zaccaria, et al (Being researched)
April	0.25	0.25
May	0.71	0.75
June	1.13	0.85
July	1.19	0.90
Aug.	1.15	0.85
Sept.	0.95	0.75
Oct.	0.60	0.40

Two ways to schedule irrigation

Apply water to meet an estimated demand

1. Can use historical ET_o, or "normal year" values for your area
2. Results in deficit irrigation if crop more vigorous, conditions warmer than expected
3. Over-application water lost to deep percolation for less vigorous / saline conditions

Apply irrigation to replace water used that week

1. Can use real time CIMIS ET_o and K_c values and calculate crop water use
2. Estimate water use from soil moisture loss using sensors or hand probing
3. Monitoring location, crop K_c and ET_o must be represent real average of orchard

Two ways to schedule irrigation

Irrigation based on Historical ETo

30 YR AVG ET_o	K_c	30 YR AVG ET_c
1.24	0	0
1.96	0	0
3.41	0	0
5.1	0.25	1.28
6.82	0.71	4.84
7.8	1.13	8.81
8.06	1.19	9.59
7.13	1.15	8.20
5.4	0.95	5.13
3.72	0.6	2.23
1.8	0	0
0.93	0	0
		40.08

Irrigation based on Real-Time ETo

	ET_o	K_c	2013/2014 RT ET_c
Jan	1.52	0	0
Feb	1.78	0	0
Mar	4.35	0	0
April	5.96	0.25	1.49
May	8.34	0.71	5.92
June	9.03	1.13	10.20
July	8.65	1.19	10.29
Aug	7.8	1.15	8.97
Sept	5.97	0.95	5.67
Oct	4.13	0.6	2.31
Nov	X	0	0
Dec	X	0	0
			44.85

Two ways to schedule irrigation

Irrigation based on Historical ETo

Irrigation based on Real-Time ETo

30 YR AVG ET_o	K_c	30 YR AVG ET_c		ET_o	K_c	2013/2014 RT ET_c
1.24	0	0	Jan	1.52	0	0
1.96	0	0	Feb	1.78	0	0
3.41	0	0	Mar	4.35	0	0
5.1	0.25	1.28	April	5.96	0.25	1.49
6.82	0.71	4.84	May	8.34	0.71	5.92
7.8	1.13	8.81	June	9.03	1.13	10.20
8.06	1.19	9.59	July	8.65	1.19	10.29
7.13	1.15	8.20	Aug	7.8	1.15	8.97
5.4	0.95	5.13	Sept	5.97	0.95	5.67
3.72	0.6	2.23	Oct	4.13	0.6	2.31
1.8	0	0	Nov	X	0	0
0.93	0	0	Dec	X	0	0
		40.08				44.85

~10% Difference in extreme year due to early season

Pistachio Kc , ET for the San Joaquin Valley (Goldhamer, 1992)

Growth Stage	Approx Phenology	Period	Crop Coef. (Kc)	ETo	ETc
Stage 1	Bloom	Apr 1-15	0.07	2.36	0.17
	Leafout	Apr 16-30	0.43	2.36	1.10
	Shell Expansion	May 1-15	0.68	3.19	2.17
Stage 2	**Shell Hardening**	**May 16-31**	**0.93**	**3.40**	**3.16**
		June 1-15	**1.09**	**3.84**	**4.19**
		June 16-30	**1.17**	**3.84**	**4.49**
Stage 3	**Nut Fill**	**July 1-15**	**1.19**	**4.13**	**4.92**
		July 16-31	**1.19**	**4.41**	**5.25**
	Nut Fill/Shell Split	**Aug 1-15**	**1.19**	**3.54**	**4.21**
	Shell Split	**Aug 16-31**	**1.12**	**3.78**	**4.23**
	Hull Slip	**Sept 1-15**	**0.99**	**2.66**	**2.63**
Harvest	**Harvest**	**Sept 16-30**	**0.87**	**2.66**	**2.31**
Post-Harvest	**Postharvest**	**Oct 1-15**	**0.67**	**1.71**	**1.15**
		Oct 16-31	0.50	1.83	0.91
		Nov 1-15	0.35	0.80	0.28

~36-40 applied inches for San Joaquin Valley

Historical ET_c For Pistachio - Goldhamer

		Zone 12[4]		Zone 14[5]		Zone 15[6]		Zone 16[7]	
Month	K_c	ET_o[1]	ET_c[2]	ET_o[1]	ET_c[2]	ET_o[1]	ET_c[2]	ET_o[1]	ET_c[2]
January	0	1.24	0	1.55	0	1.24	0	1.55	0
February	0	1.96	0	2.24	0	2.24	0	2.52	0
March	0	3.41	0	3.72	0	3.72	0	4.03	0
April	0.25	5.1	1.28	5.1	1.28	5.7	1.42	5.7	1.42
May	0.71	6.82	4.84	6.82	4.84	7.44	5.28	7.75	5.50
June	1.13	7.8	8.81	7.8	8.81	8.1	9.15	8.7	9.83
July	1.19	8.06	9.59	8.68	10.33	8.68	10.33	9.3	11.07
August	1.15	7.13	8.20	7.75	8.91	7.75	8.91	8.37	9.62
September	0.95	5.4	5.13	5.7	5.42	5.7	5.42	6.3	5.99
October	0.6	3.72	2.23	4.03	2.42	4.03	2.42	4.34	2.60
November	0	1.8	0	2.1	0	2.1	0	2.4	0
December	0	0.93	0	1.55	0	1.24	0	1.55	0
Total (in)			40.1		42		42.9		46

[1] Evapotranspiration of the reference crop (ET_o)is sourced from the 30 year CIMIS average for the respective zone (http://www.cimis.water.ca.gov/App_Themes/images/etozonemap.jpg)

[2] Evapotranspiration rates for almonds were calculated by multiplying ET_o by the crop coefficient (K_c).

[4] Zone 12 represent ET_o rates from Chico, Fresno, Madera, Merced, Modesto, and Visalia.

[5] Zone 14 represent ETo rates from Newman, Red Bluff, and Woodland.

[6] Zone 15 represent ETo rates from Bakersfield and Los Banos.

[7] Zone 16 represent ETo rates from Coalinga and Hanford.

Calculating Orchard Water Use
(Example for May, inches)

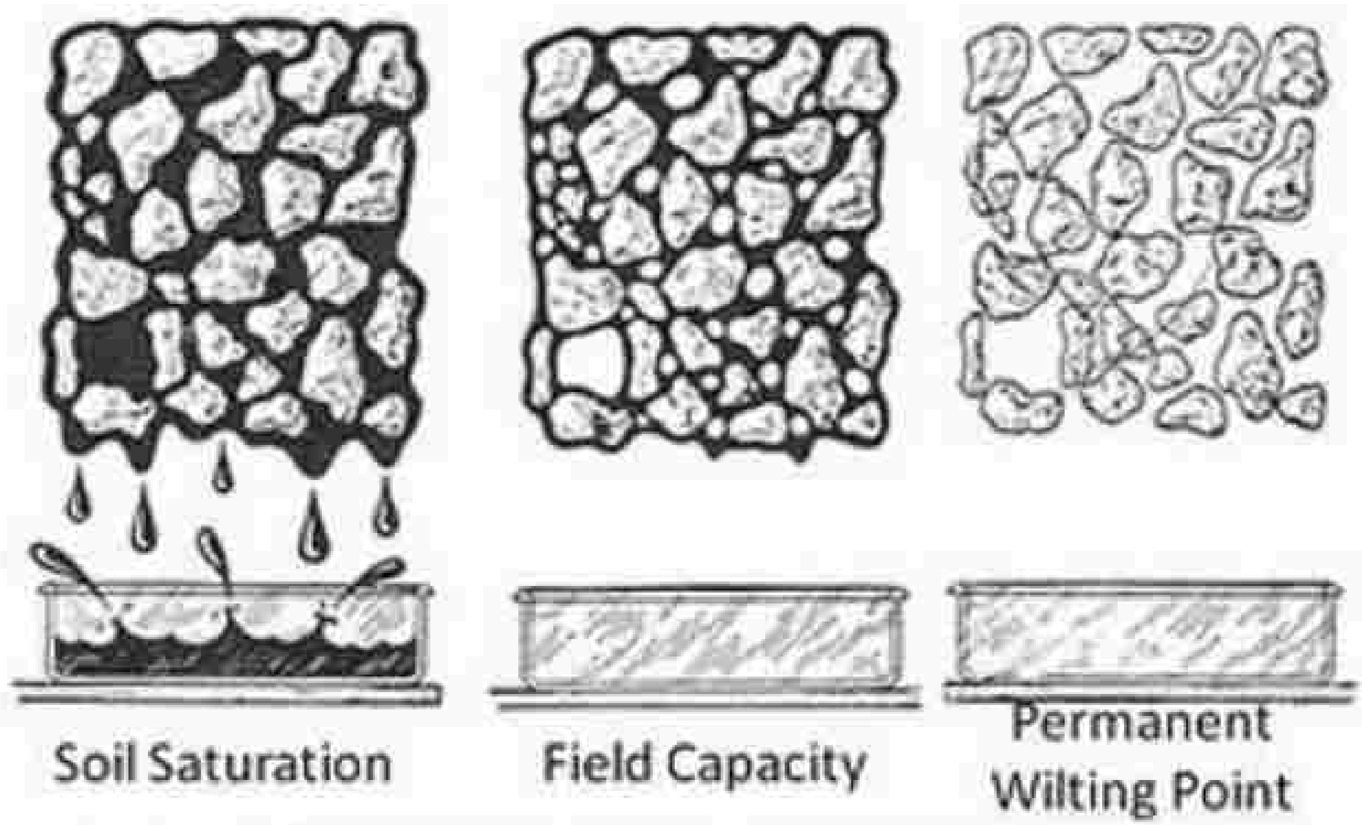
Week	ETo for the week (Grass water use) provided by CIMIS	Pistachio Kc	ETc for the week (water lost from the orchard)	Cumulative total of water use by the Pistachio Orchard
May 1st- 7th	1.65	0.68	1.12	1.12
8th - 14th	1.20	0.68	0.86	1.98
15th- 21st	1.39	0.93	1.29	3.27
22nd-28th	1.19	0.93	1.11	4.38
29th- 31st	0.72	0.93	0.67	5.05

How do we calculate a water application?

- We now know ETc, but how much do we need to apply to each tree?
  - Water use (Gals/day) = crop spacing (ft^2) x ET (In/day) x 0.623

- <u>Example:</u> ET is 0.25 in/day, spacing is 22' x 18'
  - Tree Crop spacing 22'x18' = 396 ft^2
  - Water use per tree = 396 x 0.25 x 0.623 = 61.68 gallons/day

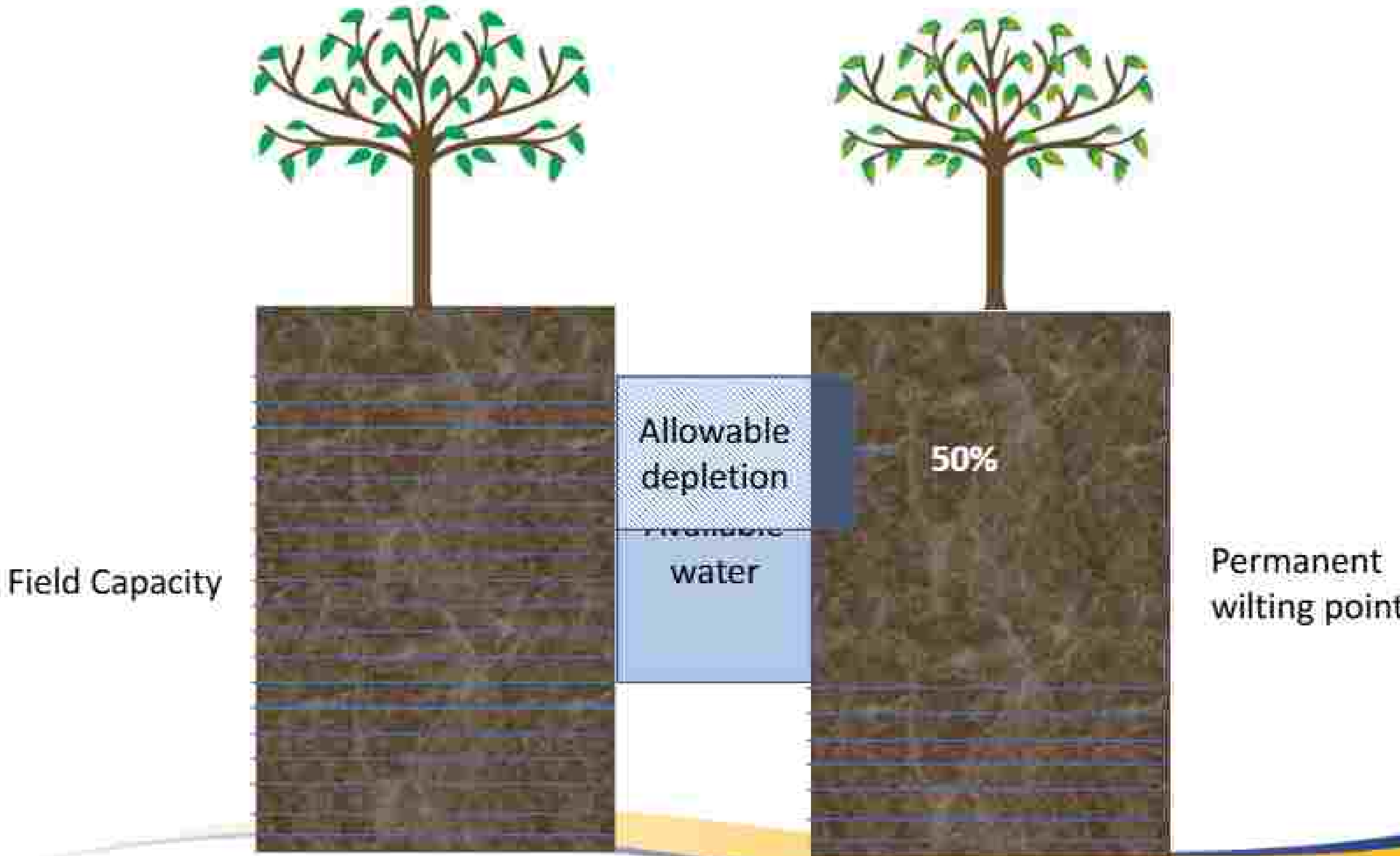
Taking into account soil textures



Soil water holding capacity

- **Field capacity** =water remaining in the soil after free water from rain or irrigation has drained out (3-4 days)
- **Permanent wilting point=** amount of water still left in the soil that the plant can not absorb
- **Available water=** Field capacity-permanent wilting point= usable water for plant

Soil water holding capacity



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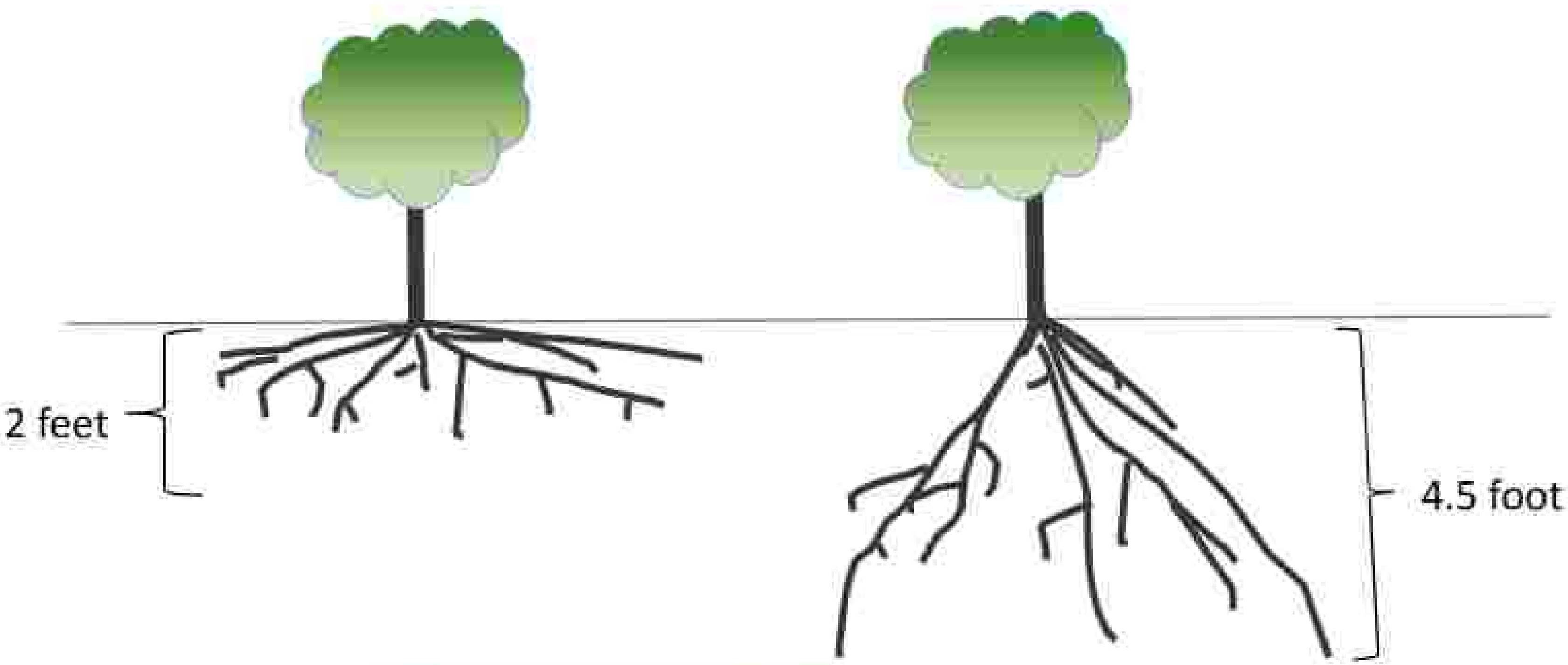
Root Zone

- Rooting zone must be taken in to consideration



Available water

Type of Soil	Range in/ft	Average in/ft
Very Course to course textured sand	0.5 to1.00	0.75
Moderately course sandy loams	1.00 to 1.50	1.25
Medium textured- fine sandy loam to silty clay loam	1.25 to 1.75	1.50
Fine and very fine- silty clay to clay	1.50 to 2.50	2.00
Peats and mucks	2.00 to 3.00	2.50

Estimate the available water and multiply by rooting depth

Example: yolo silty clay loam at field capacity= 1.50 in/ft x 5 ft rooting depth= 7. 5 in available water to tree

Allowable depletion= 3.75 in

Water Holding Capacity

Soil Surface	Soil Texture	Depth in Feet	Available Water Holding Capacity (From Table 3)	Available water in each soil layer (in)
1"-12"	Sand	1	0.6	0.6
13"-24"	Loamy Sand	1	0.8	0.8
25-42"	Sandy Loam	1.5	1.0	1.5
			Total:	2.9

Allowable Depletion: 1.45"

Needs to be determined once in orchards life.

Need to account for the extent of subbing under drip emitters…

Irrigation System Considerations: Volume of Wetted Soil

Irrigation Type	% of wetted area	% of AWHC	Notes
Single line drip	20-30%	20-30%	Larger area in heavier soil, w/more emitters
Double line drip	20-50%	20-50%	Larger area in heavier soil, w/more emitters
Microsprinkler	30-60%	30-60%	Determine area by calculating area as a percentage of orchard floor

Easy to over-irrigate/lose water to deep percolation if not taken into account the % of wetted area

Irrigation System Considerations: System Inefficiency

- Take into irrigation system inefficiency

System	Ea (%)
Basin/Flood	65 - 80
Furrow	65-75
Solid Set Sprinkler	75-85
Micro-sprinkler	85-90
Drip	90-95

Slightly more water will be needed to ensure that the trees receive adequate water

Irrigation System Considerations: System Maintenance

Most systems start declining in performance after the first few years

Lack of annual maintenance

A 70% DU takes 22% more water to adequately irrigate than 90% DU

Reduced Field variability, "hotspots"

Guidelines for DU Testing:

http://micromaintain.ucanr.edu

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How do we calculate water use?

We also need to factor in efficiency.

$$ET_c = \frac{ET_o \times k_c}{Ea}$$

If total more than WHC, than irrigate more frequently to match water applied with WHC

Bringing It All Together: The Weather

Account for "effective" rainfall

Assume only 50% is effective

Merced - San Joaquin Valley - Station 148

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 (%)
04/08/2012	0.18	0.00	539	8.6	79.7	34.8	58.1	93	24	52
04/09/2012	0.16	0.00	486	9.0	76.9	37.2	58.3	91	30	54
04/10/2012	0.15	0.00	446	9.7	69.9	41.3	56.3	87	41	63
04/11/2012	0.04	0.76	197	11.3	57.5	45.6	51.0	93	80	89
04/12/2012	0.08	0.16 R	375	10.9	59.8	50.4	54.6	91	65	75
04/13/2012	0.06	0.97	247	9.8	58.9	43.9	49.1	93	62	83
04/14/2012	0.08	0.00	317	9.9	60.0	43.6	50.4	91	59	79
Tots/Avgs	0.75	1.89	372	9.9	66.1	42.4	54.0	91	52	71

Bringing It All Together: The Site

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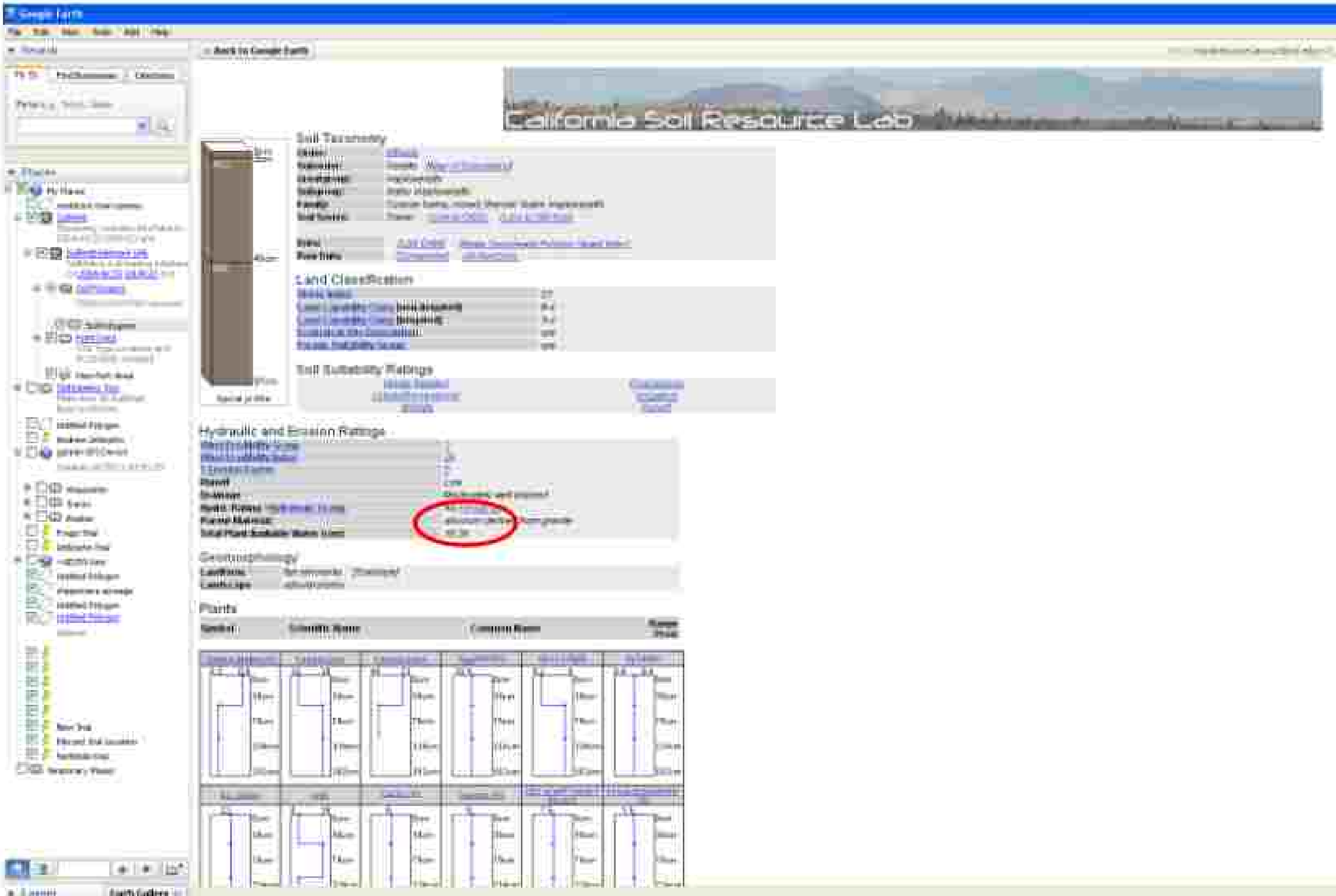


Bringing It All Together: The Site

Soil Profile Depth	Soil Type	WHC (Inches/Foot)	Available Water
0" – 18"	Fine Sandy Loam	2.0	1.5 * 2.33" = 3.5"
18" – 36"	Sandy Loam	2.0	1.5' * 2.0" = 3.0"
			TOTAL: 6.5"

6.50" of AWHC * 50% Depletion Percentage = 3.25" of Usable, Refillable Water

Bringing It All Together: Scenario 1

- Mature 22' x 18,' Kerman on UCB 1
- Microsprinkler, 14' pattern @ 10 GPH (~38% of orchard area)
- Tested, highly uniform irrigation distribution with efficiency rated at 93%
- Nut Fill – First week of July

Bringing It All Together: Scenario 1

- ETc:
  - (1.87 inches*1.19)/0.93 = 2.39 inches
- AWHC:
  - 3.25 inches * 38% (orchard floor) = 1.24 inches
    - Will need to irrigate twice to avoid percolation losses
- Water Use per week:
  - (396)(0.623)(2.39)=589 gallons/week
- Pump Time:
  - 589 gallons/week*Hour/10 gallon = 59 Hours/Week
    - Two sets of 30 hours

Bringing It All Together: Scenario 2

- Mature 22' x 18,' Kerman on Platinum
- Double Line Drip, 0.5 gallons/emitter, Emitter every 36 inches, 12 emitters/tree, 6 GPH/tree
  - Pattern – 3' diameter every emitter = ~22%
- Tested, highly uniform irrigation distribution with efficiency rated at 95%

Bringing It All Together: Scenario 2

- ETc:
  - (1.87 inches*1.19)/0.95 = 2.34 inches
- AWHC:
  - 3.25 inches * 0.22 = 0.715" (Need 3 irrigations)
- Water Use per week:
  - (396)(0.623)(2.34)=577 gallons/week
- Pump Time:
  - 577 gallons/week*Hour/(12 emitters*0.5 GPH) = 96 Hours/Week
  - 3 applications of 32 hours (or four applications of 24 hours)

System has issues in maintaining the ability to apply water to meet maximum demand

Weekly "Checkbook" Irrigation Scheduling Using Excel

(http://cekern.ucdavis.edu/Irrigation_Management, click SSJV IRRIGATION CHECKBOOK SCHEDULER)

Field (no.)________

PISTACHIO 44.3 INCHES "NORMAL YEAR" ET

VIGOR FACTOR	SOIL TYPE:	FIELD CAPACITY (in/ft):	REFILL POINT (in/ft):	ROOTING DEPTH (ft):	ROW SPACING:	IRRIG. SYSTEM:	NORMAL RUN TIME (hrs):	WETTED VOLUME (%):	Total Avail @ 100% (in):	AREA/ TREE (sq ft):	DESIGN FLOW (gph/ tree):	WET AREA APPLIC (in):	NUMBER of SETS:	TOTAL AREA APPLIC (in):
100%	Milham/ Panoche sandy clay loam	2.6	0.9	6	18' X 22'	4, 1 gph drips	24	35%	10.2	396	6	1.67	1	0.58

Week Ending:	4/7	4/14	4/21	4/28	5/5	5/12	5/19	5/26	6/2	6/9	6/16	6/23	6/30	TOTAL ET
"Normal Yr" ET:	0.08	0.26	0.42	0.74	0.95	1.16	1.39	1.61	1.85	2.00	2.18	2.25	2.25	17.16
Block ET (in/week):	0.08	0.26	0.42	0.74	0.95	1.16	1.39	1.61	1.85	2.00	2.18	2.25	2.25	
Run Time to Refill for Week (hrs):	3.4	10.8	17.4	30.6	39.3	47.9	57.0	66.1	75.9	82.4	89.7	92.8	92.8	TOTAL Irrig (in)
Actual Run (hrs):			24	24	24	24	48	72	72	72	96	96	96	15.75
Cumulative Deficit or Surplus (hrs):	-3.4	-14.3	3.7	-2.9	-22.6	-46.5	-67.8	-45.5	-40.6	-51.1	-52.5	-49.2	-55.5	
Estimated Soil Moisture Depletion or Excess (in):	-0.24	-0.99	0.26	-0.20	-1.57	-3.23	-4.71	-3.16	-2.82	-3.55	-3.64	-3.42	-3.85	Soil Moisture Depletion (in)
Estimated Soil Moisture (% available):	98%	90%	103%	98%	85%	68%	54%	69%	72%	65%	64%	66%	62%	-3.85
Actual Soil Moisture (% available):		98%		95%		60%	65%	75%		60%		60%		

What About Young Trees?

% of ET for Developing Pistachios

Age of Orchard	Drip	Fan Jet
Year 1	0.10	0.40
Year 2	0.20	0.45
Year 3	0.30	0.52
Year 4	0.40	0.59
Year 5	0.52	0.65
Year 6	0.65	0.70
Year 7	0.78	0.78
Year 8	0.90	0.90
Year 9 (>65% cover)	1.00	1.00

NORMAL YEAR WATER USE (ET) FOR PISTACHIOS IN THE SOUTHERN SAN JOAQUIN VALLEY

(Most recent published CIMIS "normal year" ETo for the SSJV. Table by Sanden, 2002)

Week Ending	Normal Year Grass ETo	[1]Crop Coef-ficients Kc	Drip Year 1	Drip Year 2	Drip Year 3	[2]Drip Year 4 & FJ Year 1	Drip Year 5 & FJ Year 3	Drip Year 6 & FJ Year 5	Year 7	Year 8	Mature Year 9 (>65% cover)
	Adjustment Facto		**0.10**	**0.20**	**0.30**	**0.40**	**0.52**	**0.65**	**0.78**	**0.90**	**1.00**
1/15	0.54										
2/1	0.70										
2/15	0.98										
3/1	1.26										
3/15	1.64										
4/1	2.08	0.05	0.01	0.02	0.03	0.04	0.05	0.07	0.08	0.09	0.10
4/15	2.55	0.07	0.02	0.04	0.05	0.07	0.09	0.12	0.14	0.16	0.18
5/1	3.15	0.43	0.14	0.27	0.41	0.54	0.70	0.88	1.06	1.22	1.35
5/15	3.50	0.68	0.24	0.48	0.71	0.95	1.24	1.55	1.86	2.14	2.38
6/1	3.79	0.93	0.35	0.70	1.06	1.41	1.83	2.29	2.75	3.17	3.52
6/15	4.00	1.09	0.44	0.87	1.31	1.74	2.27	2.83	3.40	3.92	4.36
7/1	4.25	1.17	0.50	0.99	1.49	1.99	2.59	3.23	3.88	4.48	4.97
7/15	4.35	1.19	0.52	1.04	1.55	2.07	2.69	3.36	4.04	4.66	5.18
8/1	4.33	1.19	0.52	1.03	1.55	2.06	2.68	3.35	4.02	4.64	5.15
8/15	4.11	1.19	0.49	0.98	1.47	1.96	2.54	3.18	3.81	4.40	4.89
9/1	3.64	1.12	0.41	0.82	1.22	1.63	2.12	2.65	3.18	3.67	4.08
9/15	3.10	0.99	0.31	0.61	0.92	1.23	1.60	1.99	2.39	2.76	3.07
10/1	2.70	0.87	0.23	0.47	0.70	0.94	1.22	1.53	1.83	2.11	2.35
10/15	2.20	0.67	0.15	0.29	0.44	0.59	0.77	0.96	1.15	1.33	1.47
11/1	1.73	0.50	0.09	0.17	0.26	0.35	0.45	0.56	0.68	0.78	0.87
11/15	1.20	0.35	0.04	0.08	0.13	0.17	0.22	0.27	0.33	0.38	0.42
12/1	0.88										
12/15	0.70										
12/31	0.52										
Total	**57.90**		**4.43**	**8.87**	**13.30**	**17.74**	**23.06**	**28.83**	**34.59**	**39.91**	**44.35**

[1] No weeds, bare middles. Goldhamer crop coefficients.

[2] FJ stands for Fanjet or any microsprinkler spraying a 10 to 15 foot diameter. Higher evaporative losses from this system create a first year water demand equal to a 4th leaf orchard on drip.

Part 2: Recommended Technology and Its Use for Irrigation Decision-Making

Irrigation scheduling

When should you start irrigation and how much to apply and how effective is it?

- Soil moisture monitoring
- Plant based monitoring

Soil Monitoring

- Water holding capacity of soil
  - Available water
  - Root zone

Soil Monitoring

- Ways to monitor soil
  - Soil moisture (water content)
    - Hand feel
    - Neutron probe
    - Capacitance probe
  - Soil tension (centibars)
    - Resistance blocks
    - Tensiometer

Soil Monitoring

Direct soil moisture by feel

Dry medium-textured soil

Wet medium-textured soil

Soil Monitoring

Direct soil moisture by feel

- Needs a well practiced hand
- Good way to learn your soil types and their water holding ability
- Testing your other methods
- Simplest tools required
  - Shovel
  - Soil augur

- **Con:** takes a long time and often do not go to deepest rooting depths

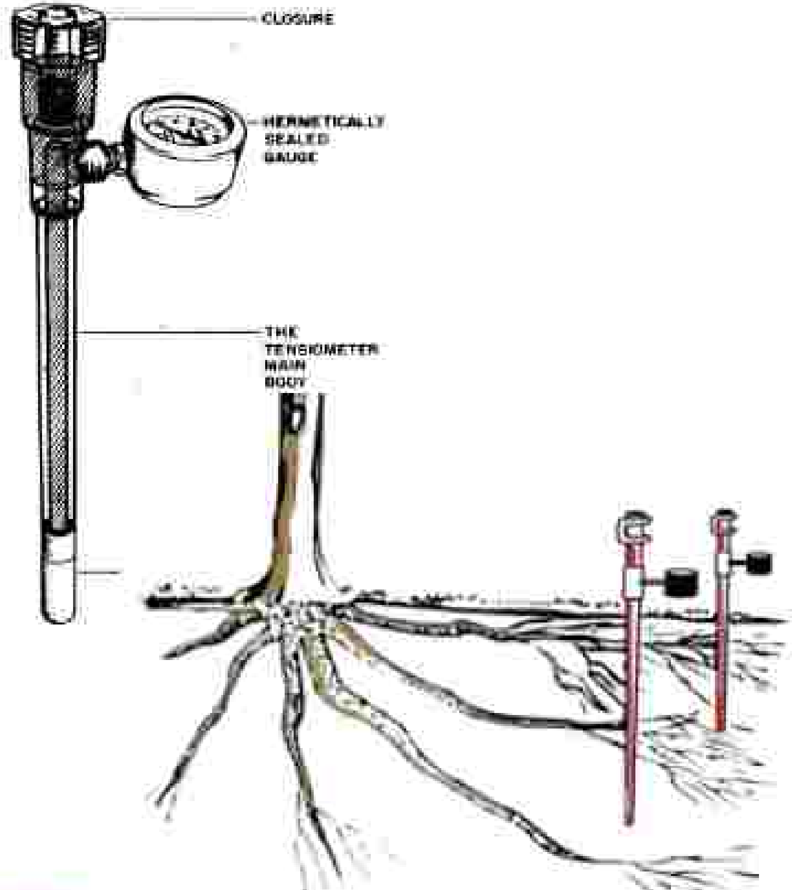
Soil Monitoring

Soil tension

- Definition: measures the surface tension that the water is held to the soil
- The tension increases as soils dry, plants spend more energy
- Measurement unit centibars (cb)
- Types
  - Tensiometer
  - Resistance blocks

Soil Monitoring

- **Tensiometer**



Soil Monitoring

- **Tensiometer**
  - **Pros:**
    - **no power needed**
    - **Not affected by salinity**
    - **Easy to install**
    - **Not expensive**
  - **Cons:**
    - **Requires maintenance**
    - **Not good for dry soil- can lose soil contact**
    - **Manually read and keep records**

Soil Monitoring

- Modified electrical resistance
  - Similar to the gypsum blocks but now are a composite

Soil Monitoring

- **Reading Soil Tension**

Use the following readings as a general guideline:

0-10 Centibars = Saturated soil

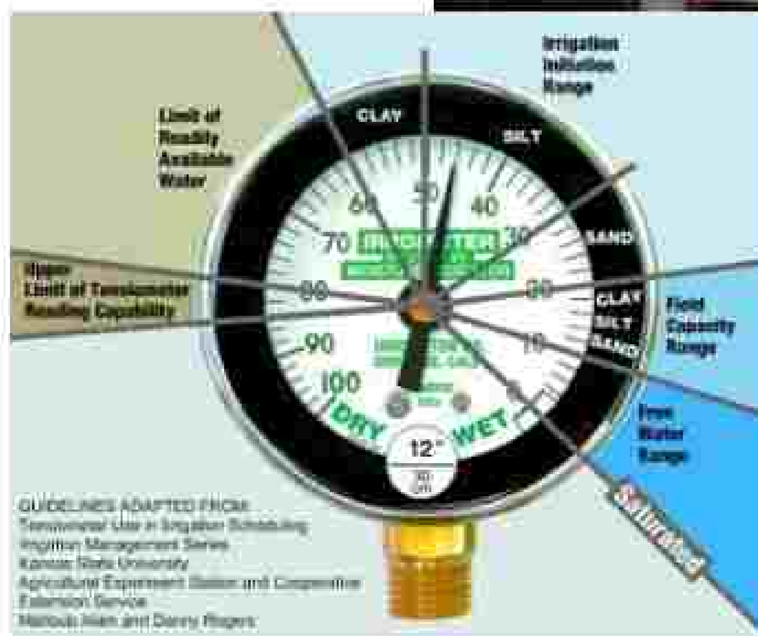
10-30 Centibars = Soil is adequately wet (except coarse sands, which are beginning to lose water)

<u>**30-60 Centibars** = Usual range for irrigation (most soils)</u>

60-100 Centibars = Usual range for irrigation in heavy clay

100-200 Centibars = Soil is becoming dangerously dry for maximum production. Proceed with caution!

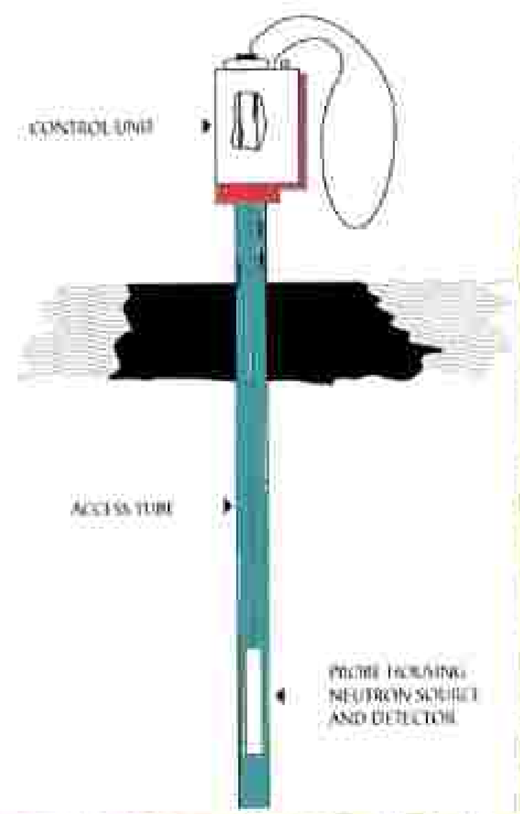
http://www.irrometer.com



Soil Monitoring

- **Modified electrical resistance**
  - Pros-
    - No maintenance
    - Least cost
    - Can have many sensors going different depths and areas
    - Possible to use data loggers or remotely
    - Easy hand held meter option
    - Easy to install
  - Cons-
    - Can have problems contacting soil in course textures
    - Can be affected by salinity
    - Need to periodically replace them (3-4 years)

Soil moisture monitoring with the neutron probe



A device using low levels of radiation, the neutron probe, was developed in the 1960's for checking soil moisture. Used mostly by researchers and irrigation consultants, it is often the standard check for the accuracy of other instruments. Largest sample "volume" to estimate moisture.

Sample Neutron Probe Data

Soil Depth inches	Field Capacity (in/ft)	Wilting Point (in/ft)	June 1 (in/ft)	June 1 (%) Depleted	June 8 (in/ft)	June 8 (%) Depleted
8	3.4	1.7	2.5	53	1.9	88
18	3.6	1.8	2.8	44	2.2	77
30	3.2	1.6	3.0	13	2.8	24
42	3.2	1.6	3.2	0	3.1	6
54	3.2	1.6	3.2	0	3.2	0
Total (in/5 ft)	16.6	8.3	14.7	------	13.0	-----
% Depleted Rootzone	0	100	22	------	43	-----

Soil Monitoring

Neutron probe

- Pros:
  - Adapts to many soil types
  - Reads actual water content
  - Only need to install access tubes
  - Reads multiple depths in one tube
- Cons:
  - Need radiation license to use
  - Needs to be calibrated to soil type
  - Reading includes water that is not free for plant use
  - Not possible to automate
  - Dependent on consultant

Dielectric Soil Moisture Sensors

Two Dielectric Methods

- Capacitance probes - frequency domain reflectometry (FDR)
- Time domain reflectometry (TDR)
- Many sensors available
  - EnviroSmart
  - Irrimax
  - Aquacheck
  - C-probe
  - Trase
  - Trime
  - ThetaProbe

General Dielectric Concept

- Measure dielectric constant or ability of a material to establish an electrical field
  - Air dielectric constant of 1
  - Dry soil dielectric constant of 3 to 5
  - Water dielectric constant of about 80
  - Change in dielectric constant for soil indicates change in soil moisture
  - More moisture increases the dielectric constant or the ability of the soil to concentrate the electrical field

Soil Monitoring

Dielectric sensors

- Pros:
  - Increased accuracy with calibration to soil type
  - Reads actual water content
  - Able to automate readings
- Cons:
  - Complicated electronics
  - Requires power
  - Some may be effected by salts or heavy soils
  - Errors can occur with loss of soil contact with sensor

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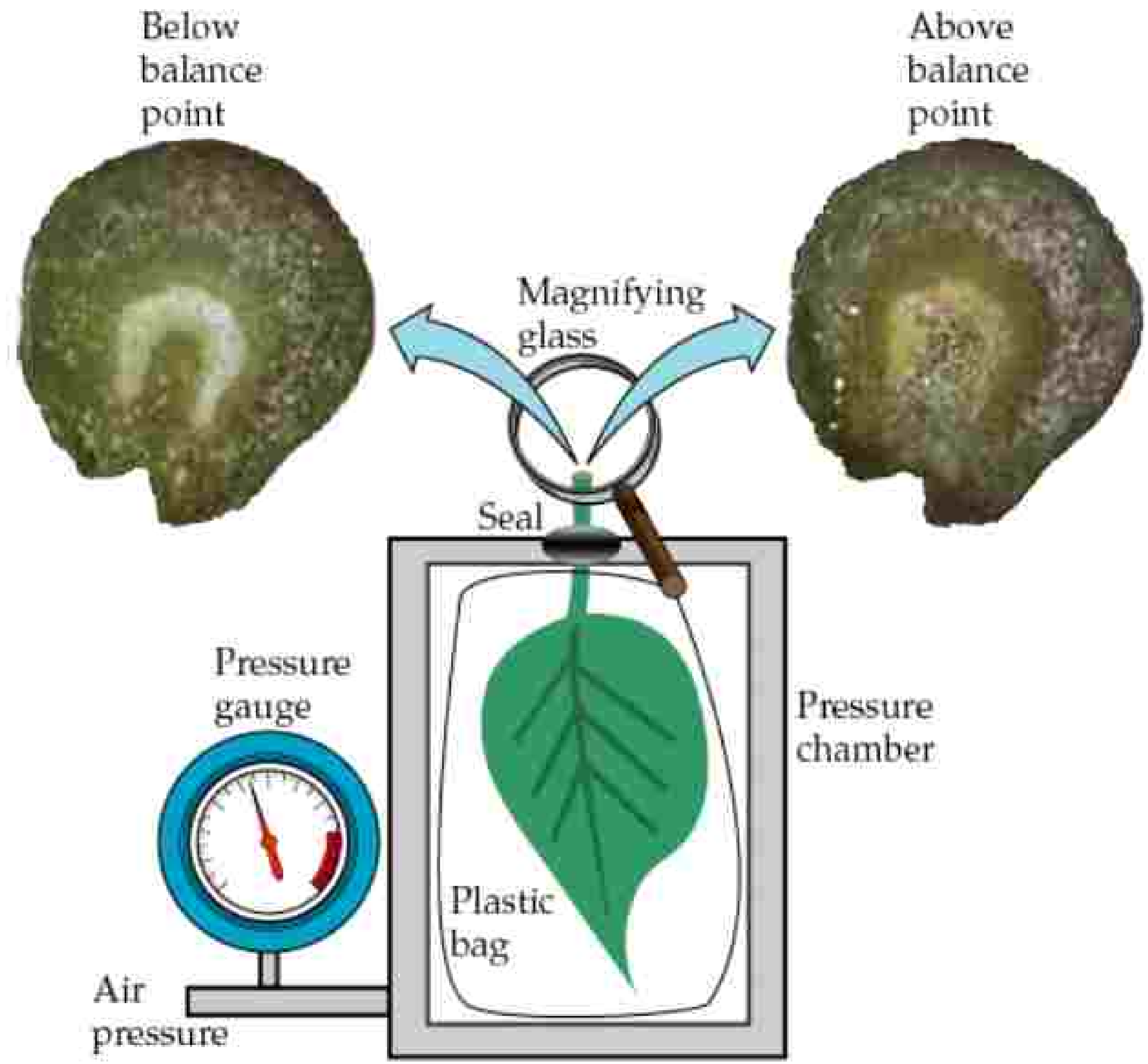
Plant Based monitoring

- Pressure chamber

Midday Stem Water Potential (MSWP) or (SWP)- measures resistance in bars



Below balance point
Above balance point
Magnifying glass
Seal
Pressure gauge
Pressure chamber
Plastic bag
Air pressure

Stem Water Potential Readings

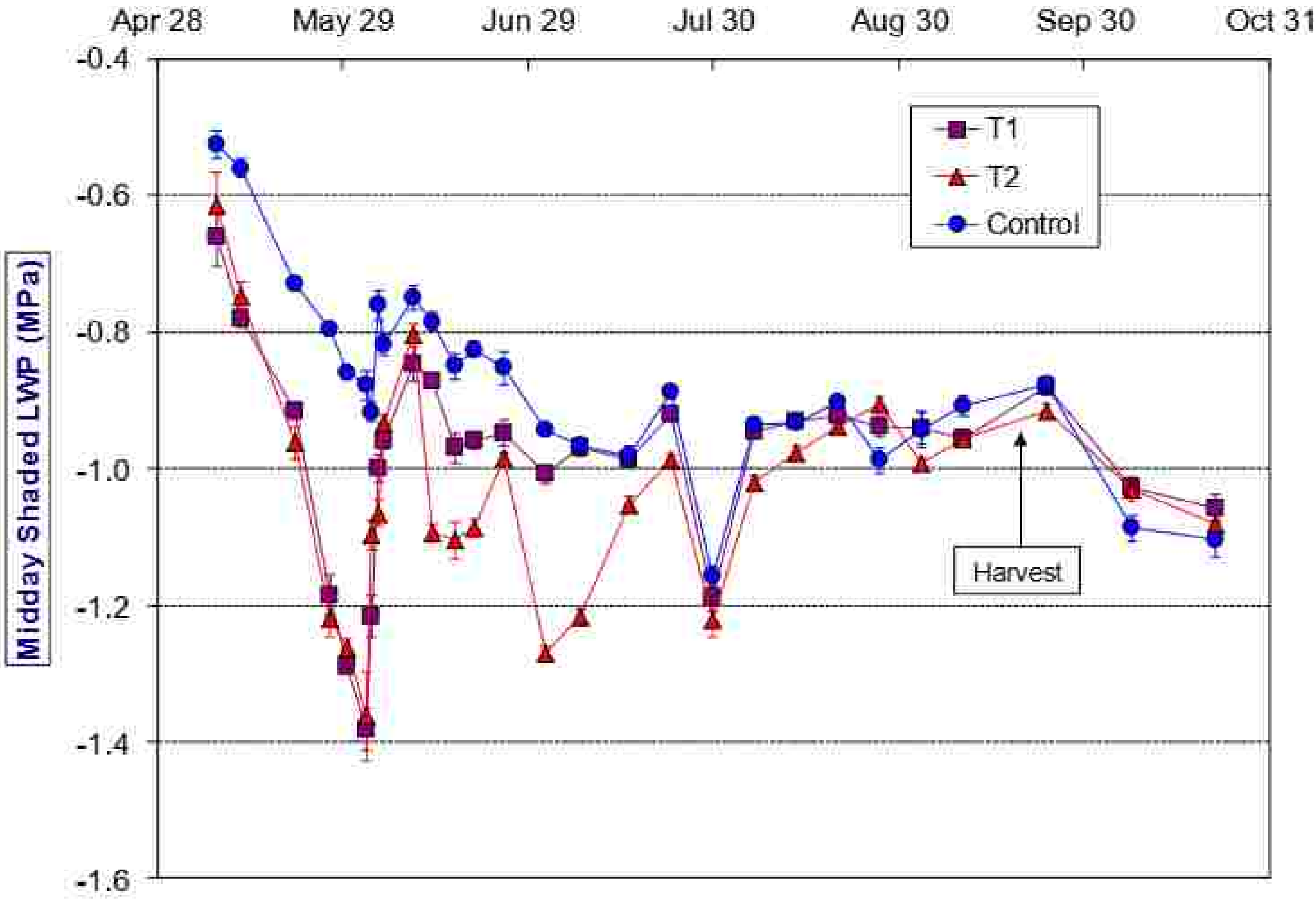
- Take reading between 12-3 pm
- Cover terminal leaflet on a shaded leaf in lower canopy w/a wet cloth
- Only remove one leaf at a time
- Record time and temp for baseline reading

Plant Based Monitoring

Irrigation decisions

- Baseline is about 1/10th of temperature
  - (80 degrees, baseline is -8 bars)
- Mature trees- allow SWP to drop 2-4 bars below baseline before irrigating
- Do not irrigate in spring until SWP is below baseline (3-4 bars)
- Young trees should be kept near baseline to promote growth
- -14 bars is considered moderately stressed, -18 bars is considered severely stressed

Plant Based Monitoring



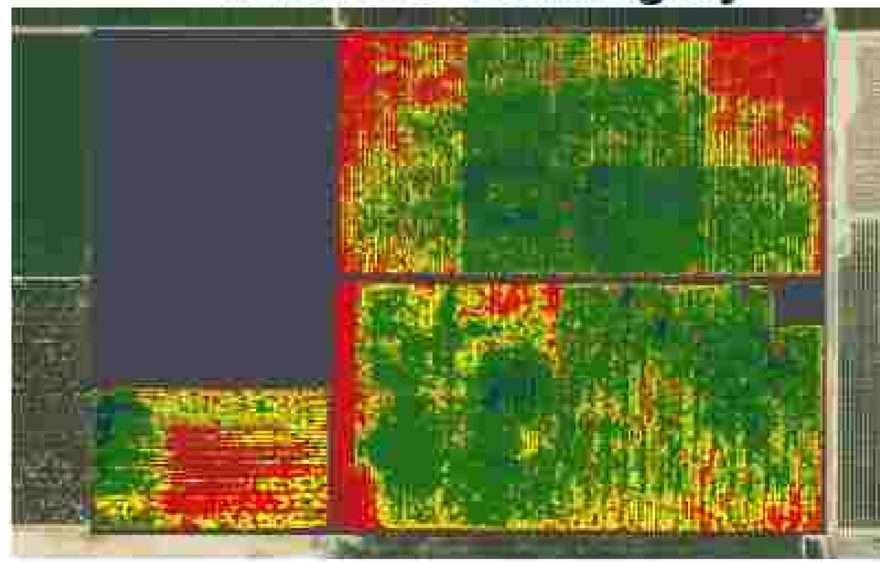
Plant Based Monitoring: Pressure Chamber

- Pros:
  - Soil type/salinity does not affect "stress" reading
  - Integrates moisture status of whole rootzone
  - Can monitor in any area of the orchard
  - No installation
- Cons:
  - Time consuming
  - Need trained personnel
  - Does not measure soil moisture depletion

Plant Based Monitoring: Aerial Imaging

What the eye sees – 180 acre almond orchard

Inefficiencies identified by water stress imagery



Courtesy of CERES Imaging

Stem water potential
(negative bars)

Red	20-24	Green	12-16
Yellow	16-20	Blue	8-12

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Plant Based Monitoring: Aerial Imaging

Pros

- Resolution can be quite high
  - 1 cm or less
- Potential to utilize for a variety of functions
  - Data collection
  - Leak checks
  - More
- Fast and easy to deploy, near real-time
- Fly in varying locations

Cons

- Imaging: NDVI has yet to be shown effective for perennial nut crops
  - Thermal has been shown to be effective, requires adjustment
- Data Processing issues
- Will require someone trained to use equipment or annual licensing of data

Putting the tools to work

1. Track ET
2. Monitor soil moisture
3. Collect pressure chamber readings
4. Irrigate
5. Check results

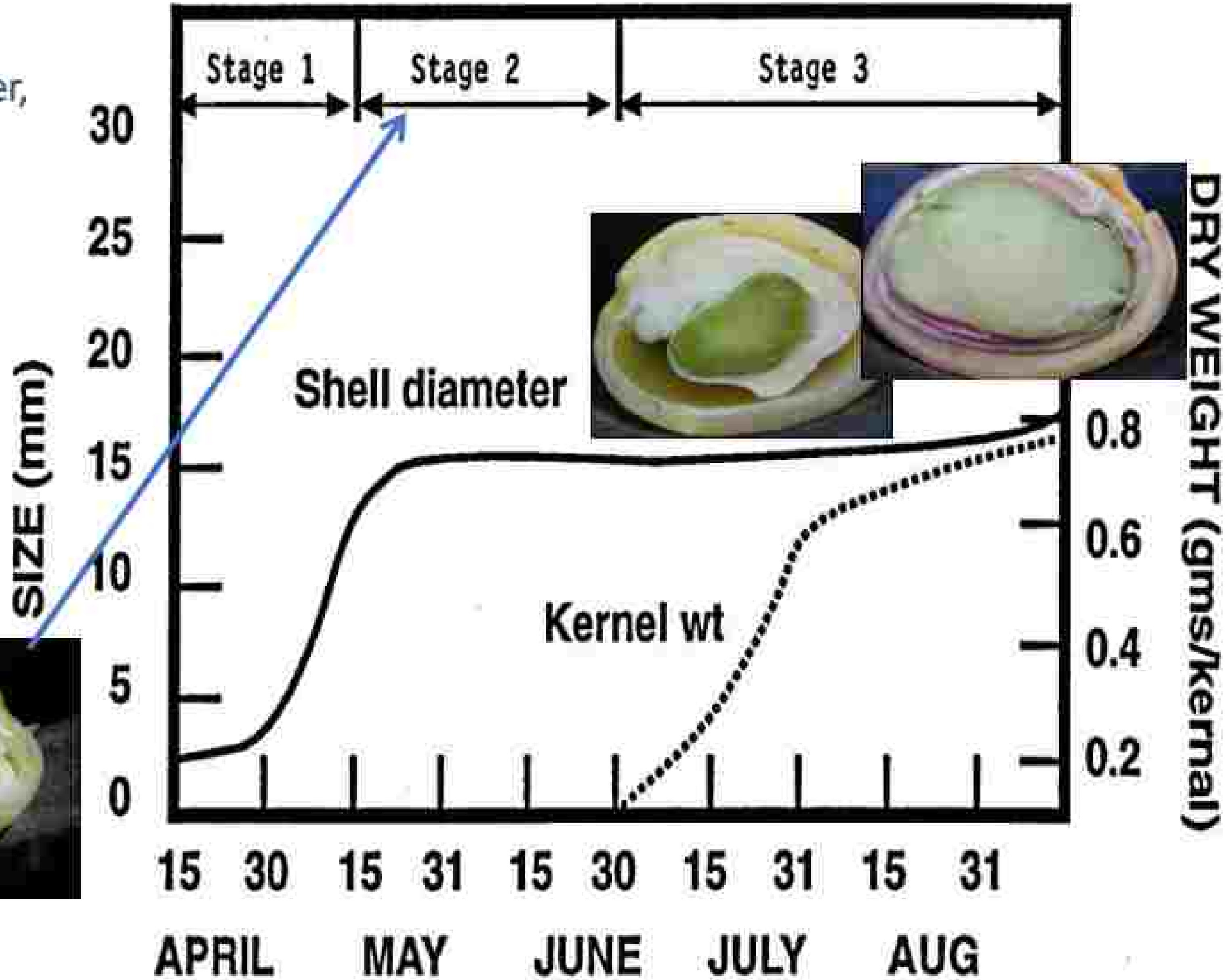
Part 3: Managing Drought within Pistachios – Regulated Deficit Irrigation

Regulated Deficit Irrigation (RDI)

Planned water deficits at specific crop developmental stages that control vegetative growth without negatively affecting production.

Timing of Pistachio Nut Development

(Dave Goldhamer, Pistachio Production Manual 2008)



Regulated Deficit Irrigation Impacts on Yield (Dave Goldhamer, Kettleman City 1988-92)

Irrigation Treatment	Split Nut Weight (g/nut)	Blanks (% nut load)	Split Nuts (%)	Total Nut Load (No./tree)	Removal by Harvester (% splits)	Dry Split Yield (lb/ac)	Water Use Efficiency (lb splits/inch irrigation)
0% Stage 1	1.24 b*	21.5 ab	87.8 d	12252	85.5 bc	2828 d	91.7 bc
0% Stage 2	1.29 bc	22.0 ab	73.6 b	10881	91.4 bc	2239 bc	91.7 bc
0% Stage 3	1.18 a	27.6 c	43.6 a	11187	72.6 a	1014 a	64.8 a
0% Postharvest	1.30 bc	22.8 abc	78.8 bc	11411	88.8 bc	2451 bcd	77.6 ab
50% Stage 2; 25% PH	1.30 bc	21.2 ab	81.7 cd	10874	89.5 bc	2744 cd	106.1 c
Control	1.32 c	22.5 ab	79.5 bc	11457	88.8 bc	2714 cd	81.5 ab

* Values followed by the same letter are not statistically different at p=0.05.

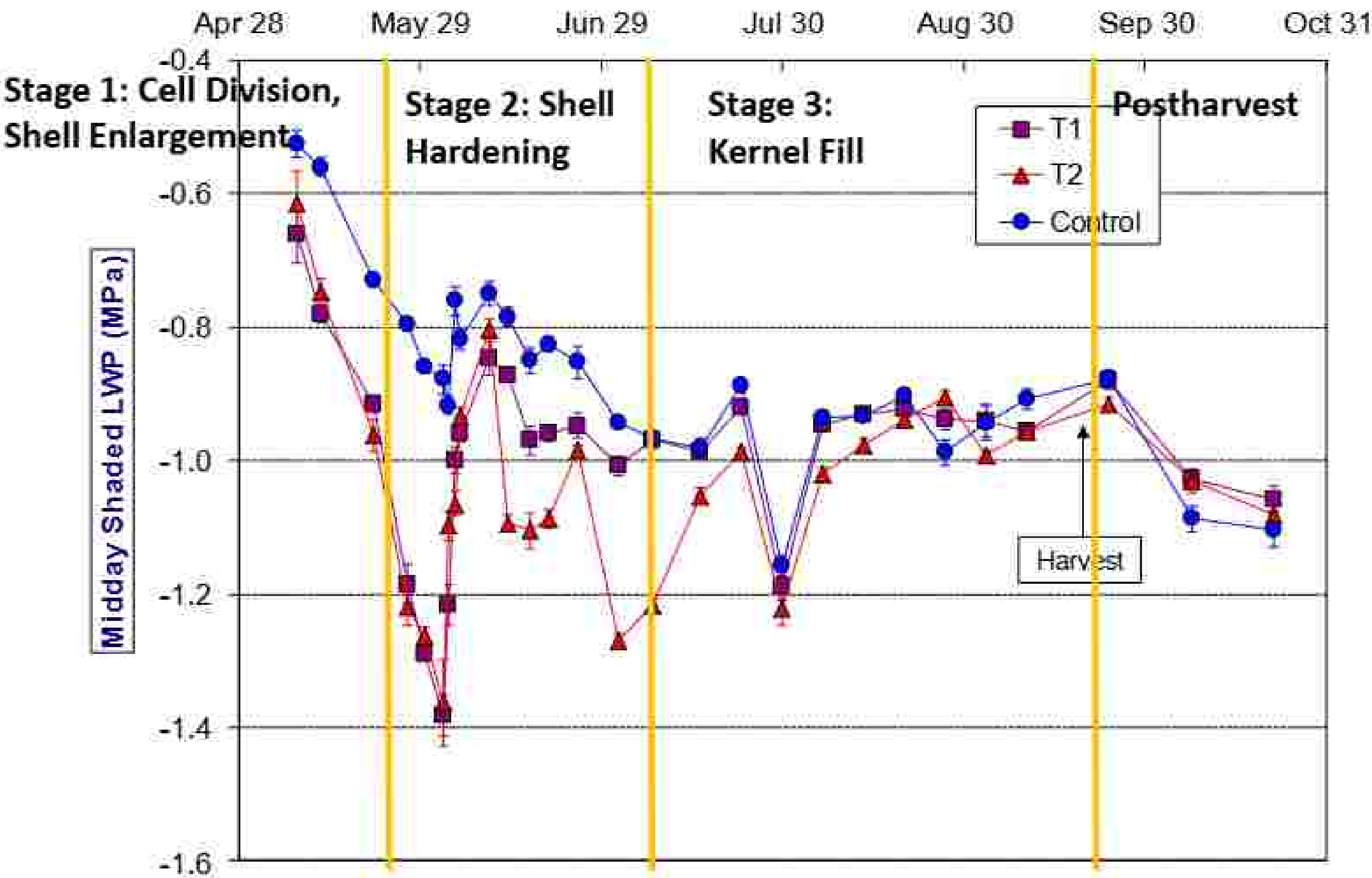
Can we use RDI to actually increase split %? (Dave Goldhamer)

T1: Stage 1 stress, target 14 to 16 bars before starting irrigation, followed by full irrigation for the season.

T2: Same as T1 but followed by 50% of potential ETc during Stage 2.

Control Fully irrigated for season.

Pistachio stem water potential over 2003 season (Dave Goldhamer)



Results of 2003-4 RDI study on split%

(Dave Goldhamer)

Rootstock	Irrigation Treatment	In-Season Irrigation (inches)	Dry Split Wt (g/nut)	Tree Fruit Load (No. nuts)	Blanks (No.)	Closed Shell (% by No.)	Removal by Harvester (% splits)	Dry Split Yield (lb/ac)	**Water Use Efficiency (lb splits/inch irrigation)
Atlantica	T1: -14 to -016 bar SWP	40.6	1.14 a*	12000	14.6	15.3 a	99.2	2630	64.8 ab
	T2: T1 + 50% stage 2 ET	34.2	1.13 a	12170	14.5	15.3 a	99.1	2690	78.7 a
	Control	47.0	1.23 b	11200	14	28.7 b	98.4	2160	46.0 b
				NSD	NSD		NSD	NSD	
PG1	T1: -14 to -016 bar SWP	40.6	1.17 a	17360	15.2	17.9 a	98.2	3380	83.3 ab
	T2: T1 + 50% stage 2 ET	34.2	1.19 a	16160	15.9	16.3 a	98.2	3430	100.3 a
	Control	47.0	1.25 b	16130	13.1	34.8 b	98.4	2860	60.9 b
				NSD	NSD		NSD	NSD	

* Numbers not followed by same letter are statistically different.

** Excludes water applied for barley cover crop.

Results of 2003-4 RDI study on split%

(Dave Goldhamer)

Rootstock	Irrigation Treatment	In-Season Irrigation (inches)	Dry Split Wt (g/nut)	Tree Fruit Load (No. nuts)	Blanks (No.)	Closed Shell (% by No.)	Removal by Harvester (% splits)	Dry Split Yield (lb/ac)	**Water Use Efficiency (lb splits/inch irrigation)
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	Control	47.0	1.25 b	16130	13.1	34.8 b	98.4	2860	60.9 b
				NSD	NSD		NSD	NSD	

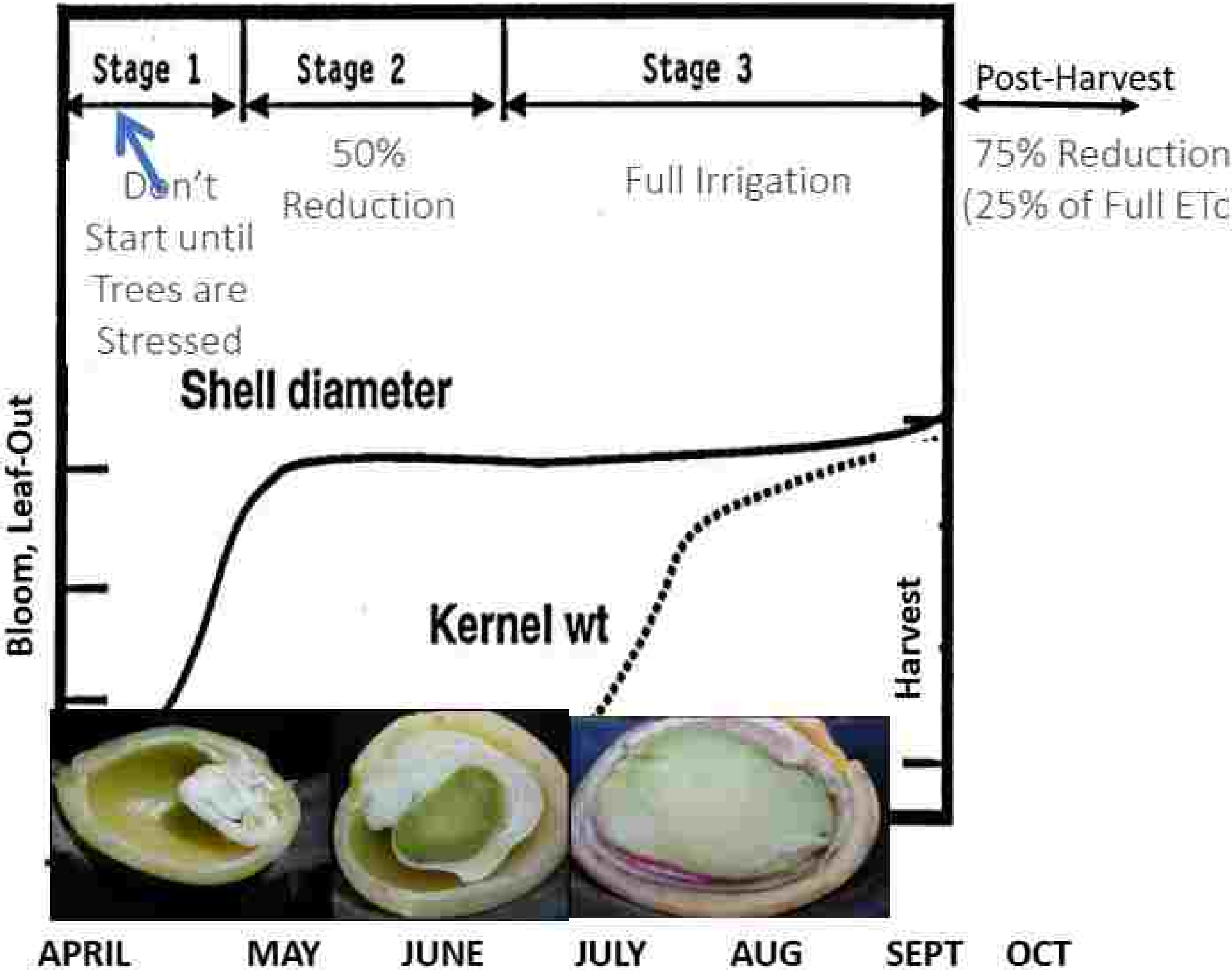
Irrigation treatments affected nut weight, but improved split %, all with no affect on yield

Stage 2 RDI irrigation schedule

(D. Goldhamer, 2008)

Growth Stage	Phenology	Period		Reference ETo (inches)	Kc	Normal ETc (inches)	RDI Level (%)	RDI ETc (inches)
Stage 1	Bloom	Apr	1-15	2.36	0.07	0.17	100	0.17
	Leafout	Apr	16-30	2.36	0.43	1.01	100	1.01
	Shell Expansion	May	1-15	3.19	0.68	2.17	100	2.17
Stage 2	Shell Hardening	May	16-31	3.4	0.93	3.16	50	1.58
	Shell Hardening	Jun	1-15	3.84	1.09	4.19	50	2.09
	Shell Hardening	Jun	16-30	3.84	1.17	4.49	50	2.25
Stage 3	Nut Filling	Jul	1-15	4.13	1.19	4.92	100	4.92
	Nut Filling	Jul	16-31	4.41	1.19	5.25	100	5.25
	Nuf Fill/Shell Split	Aug	1-15	3.54	1.19	4.21	100	4.21
	Shell Splitting	Aug	16-31	3.78	1.12	4.23	100	4.23
	Hull Slip	Sept	1-15	2.66	0.99	2.63	100	2.63
	Harvest	Sept	16-30	2.66	0.87	2.31	25	0.58
Post-harvest	Postharvest	Oct	1-15	1.71	0.67	1.15	25	0.29
	Postharvest	Oct	16-31	1.83	0.5	0.91	25	0.23
	Postharvest	Nov	1-15	0.8	0.35	0.28	25	0.07
					Totals	41.1		31.7

Timing of Pistachio Nut Development



Pistachio Irrigation Conclusions

- Pistachio trees are extremely drought tolerant.
- % splits and individual nut weight are the most sensitive to stress.
- Depending on soil type, salinity, irrigation system and management mature pistachios can use 30 to 50 inches of water over the season.
- Real time soil moisture/plant stress monitoring over the season is essential to maximize yield/efficiency and minimize disease.
- During mid May thru early July and postharvest pistachios are most tolerant of stress: potentially allowing for full yield with only 80-85% of full season ET.
- Successful RDI programs require full winter recharge of soil profile and understanding of soil water holding capacity and salinity.