Irrigation Scheduling and Management in Walnuts

Plant, soil, and climate based methods

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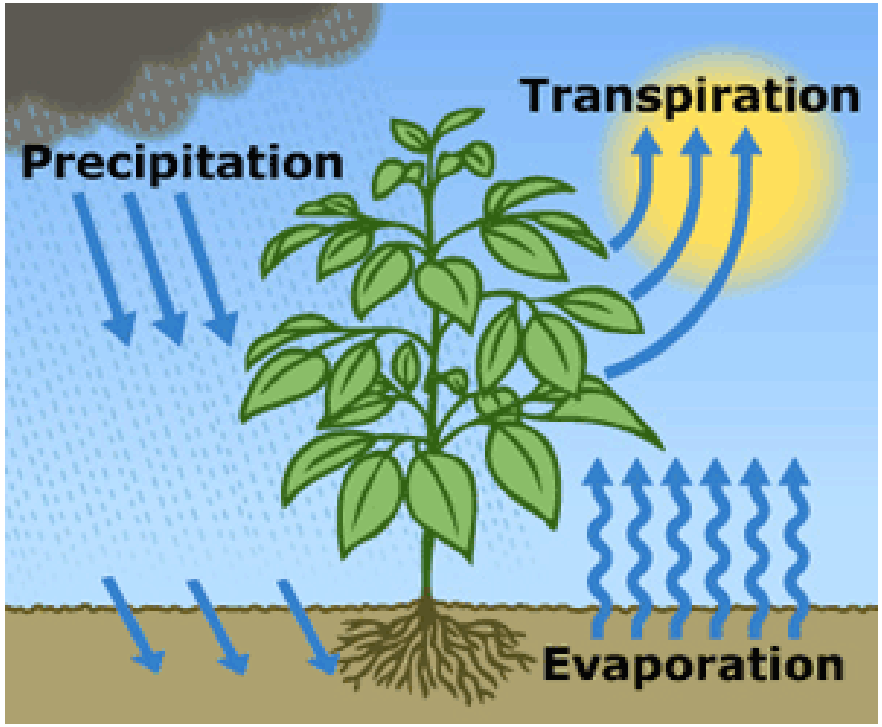
Effective Water Management Should:

- Support high yield potential
- Favor desirable nut quality
- Extend orchard life
- Assist pest management
- Use water and energy efficiently
- Contribute to efficient N management
- Include salinity management

Walnut Evapotranspiration-ET

The sum of evaporation and plant transpiration and the movement of water from land surfaces and plant canopies to the atmosphere.

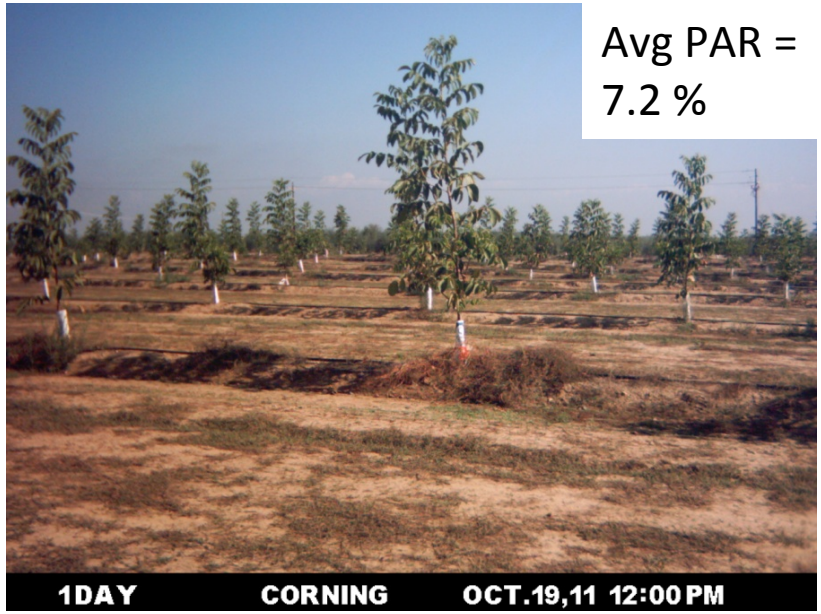


General Estimates of Walnut ET (inches)

	1st Leaf	2nd Leaf	3rd Leaf	4th Leaf	Mature Orchard
% Shading	1 to 9	9 to 23	23 to 35	35 to 55	70 to 80
Minimum Daily ET	0.01	0.03	0.05	0.07	0.08
Maximum Daily ET	0.13	0.18	0.31	0.31	0.28
Seasonal ET	<14.6	21.3	38.5	40.1	40.0
Seasonal ET (Ac-Ft)/Ac [1]	1.2	1.8	3.2	3.3	3.3

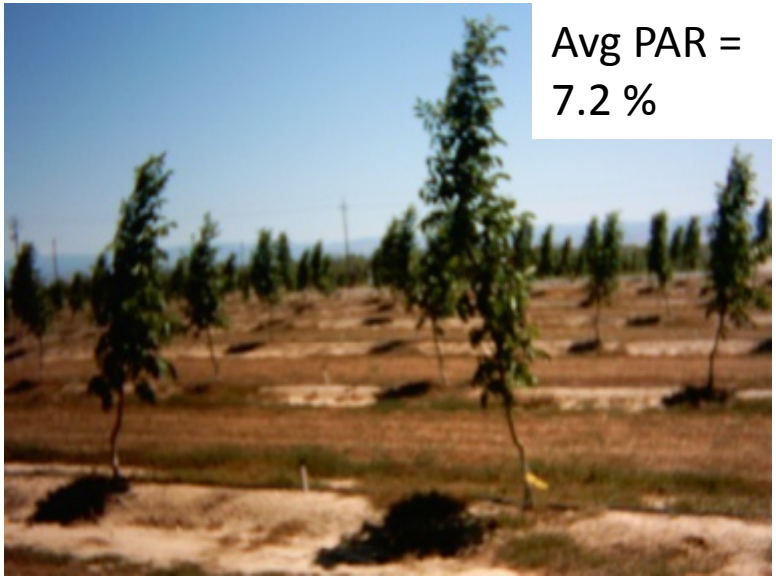
Approximately, 1212 m^3 per acre-foot (Ac-Ft) of water.

First Leaf – Chandler on Paradox, Bare Root Trees



Month	ET (inches)	ET (in./day)
April	0.4	0.01
May	1.5	0.05
June	2.3	0.08
July	3.9	0.13
August	3.4	0.11
September	2.1	0.07
October	1.0	0.03
Season Total	<14.6	

Second Leaf – Chandler on Paradox



Month	ET (inches)	ET (in./day)
April	0.9	0.03
May	2.4	0.08
June	3.5	0.12
July	5.6	0.18
August	4.6	0.15
September	2.9	0.10
October	1.4	0.05
Total	21.3	

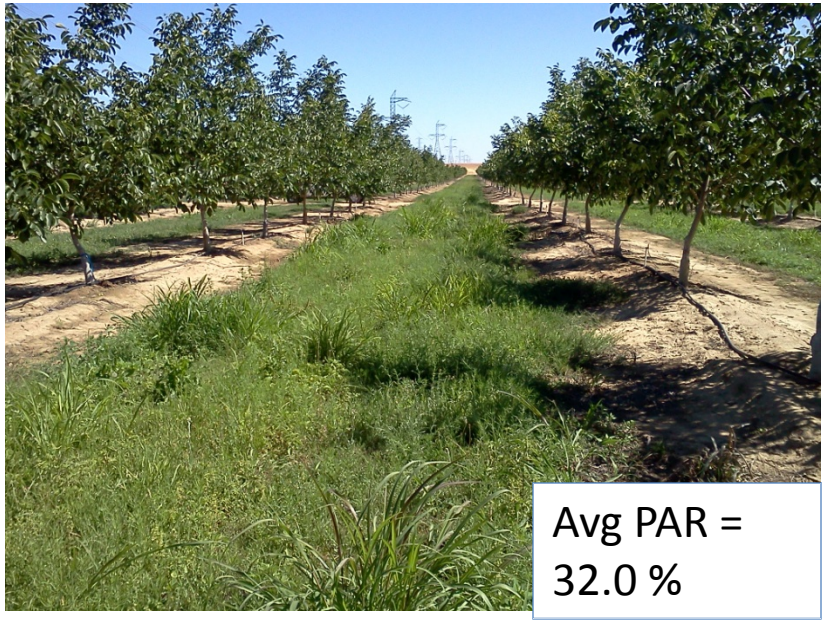
Third Leaf – Chandler on Paradox

Avg PAR = 19.5 %

Avg PAR = 32.0 %

Month	ET (inches)	ET (in./day)
April	1.6	0.05
May	4.9	0.16
June	6.6	0.22
July	9.7	0.31
August	7.6	0.25
September	5.2	0.17
October	2.9	0.09
Total	38.5	

Fourth Leaf – Chandler on Paradox

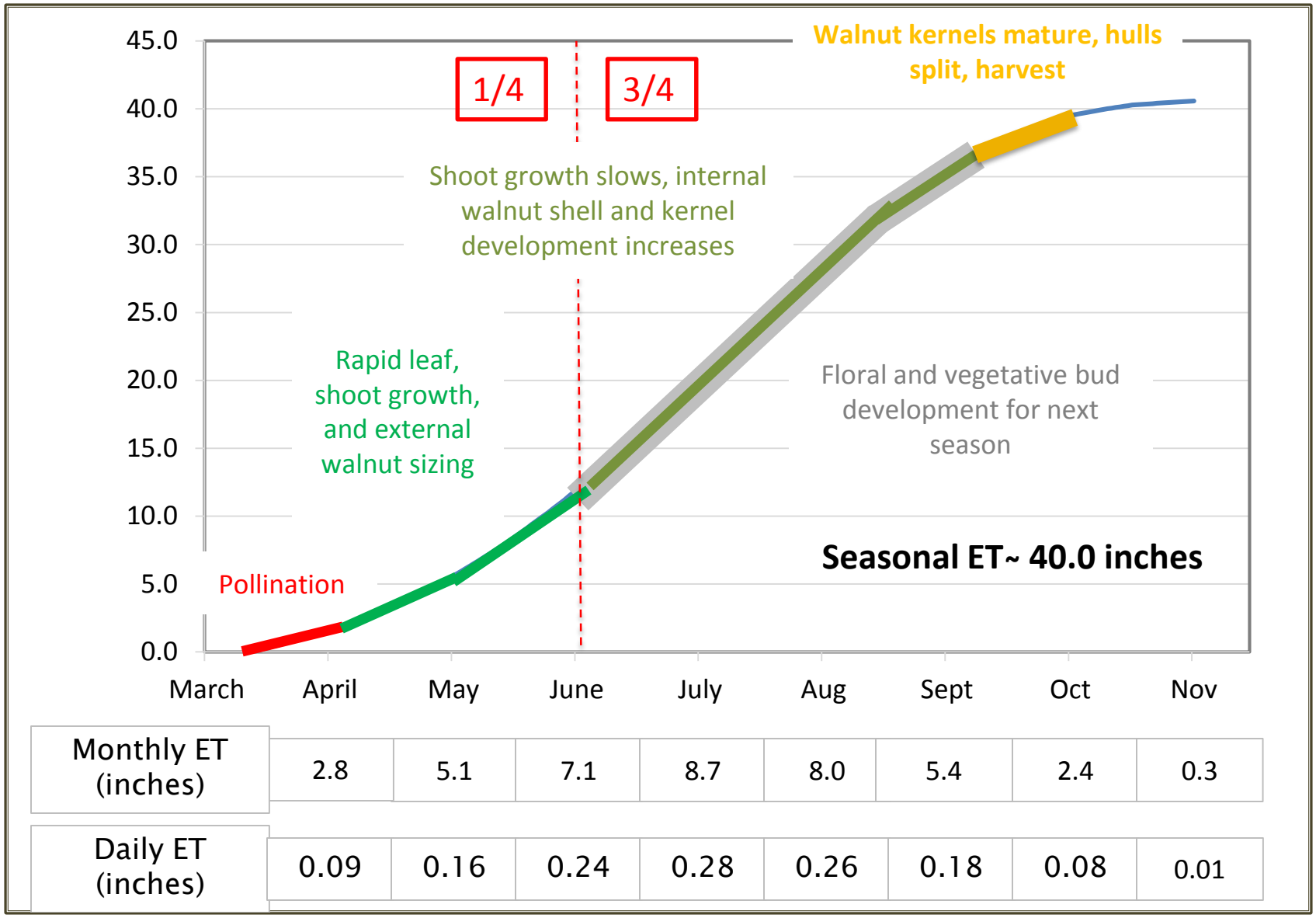


Avg PAR = 32.0 %

Avg PAR = 50.0 %

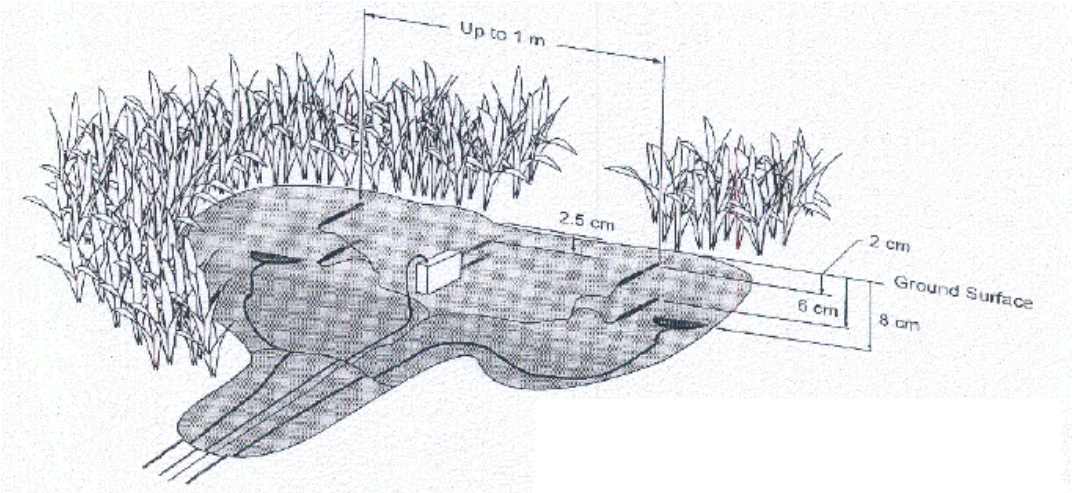
Month	ET (inches)	ET (in./day)
April	2.2	0.07
May	5.5	0.18
June	7.0	0.23
July	9.7	0.31
August	7.6	0.25
September	5.2	0.17
October	2.9	0.09
Total	40.1	

Seasonal ET (inches) – Mature Trees, 70 – 80 PAR

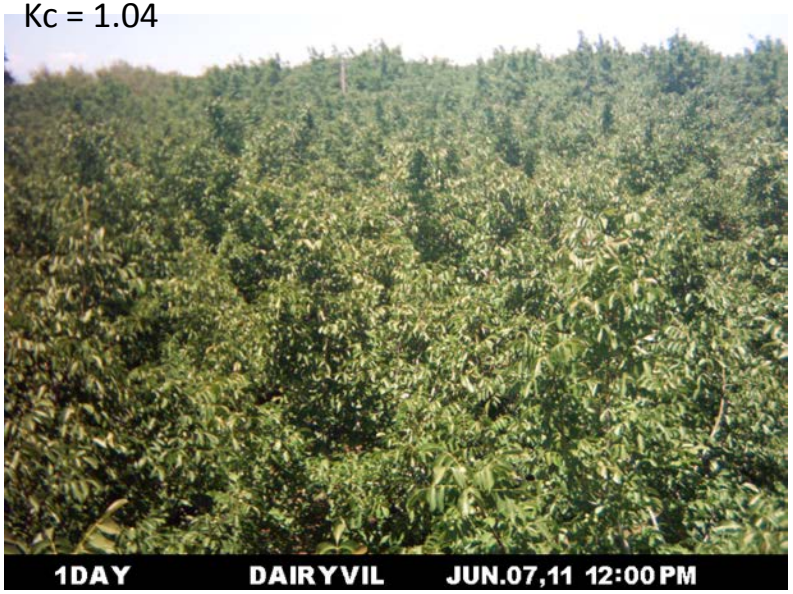


Monthly ET (inches)	2.8	5.1	7.1	8.7	8.0	5.4	2.4	0.3
Daily ET (inches)	0.09	0.16	0.24	0.28	0.26	0.18	0.08	0.01

Eddy Covariance – Atmospheric Measurement Technique Used in Recent Walnut ET and Crop Coefficients (Kc) Studies



Walnut ET is dynamic and can be modeled (ETo x Kc = ETc).



Comparison of Walnut Kc's -Chandler

Date	1998 Walnut Production Manual Average Walnut K_c	2011-16 Tehama County Average Walnut K_c[1]
March 16-31	0.12	NA
April 1-15	0.53	0.63
April 16-30	0.68	0.74
May 1-15	0.79	0.96
May 16-31	0.86	1.00
June 1-15	0.93	1.04
June 16-30	1.00	1.04
July 1-15	1.14	1.01
July 16-31	1.14	0.98
Aug 1-15	1.14	0.97
Aug 16-31	1.14	0.92
Sept 1-15	1.08	0.82
Sept 15-30	0.97	0.73
Oct 1-15	0.88	0.58
Oct 16-30	0.51	0.64
Nov 1-15	0.28	0.60

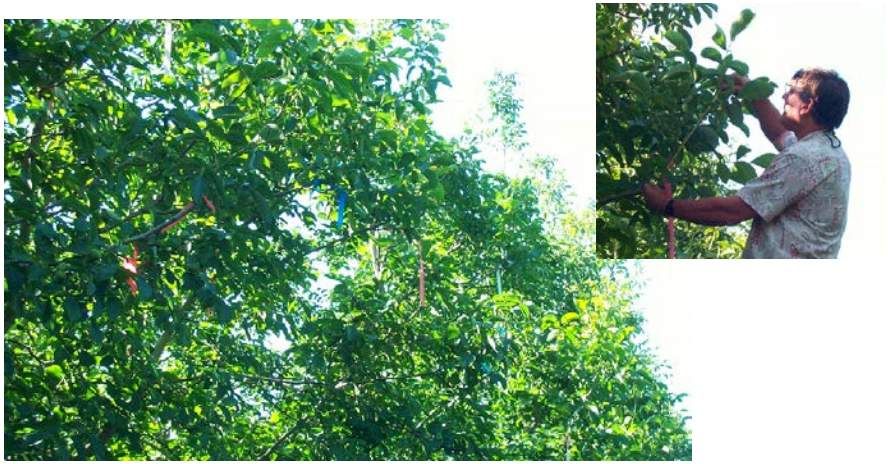
[1] Fulton, A.E, C.C. Little, R.L. Snyder, and B.D. Lampinen. Evaluation of Crop Coefficients and Evapotranspiration in English Walnut. July 16-19, 2017. ASABE 2017 Annual International meeting. Spokane, WA. DOI: 10.13031/aim.201. Paper Number 1701457.

Evaluation of Chandler Walnut Response to Summer Irrigation Management (June 15 and later)

Average Seasonal SWP (bars)	Seasonal Range in SWP (bars)	Average Applied Irrigation Water (inches / acre)
-4.0 to -5.5	-3.0 to -7.0	36 to 42
-6.2 to -7.0	-3.0 to -10	22 to 28
-7.5 to -8.6	-3.0 to -14	18 to 23

Effect of summer water stress on shoot growth

Average Seasonal SWP (bars)	Average Seasonal Shoot Growth (feet)
-3.6	3.5 a
-6.2	3.4 a
-7.5	2.4 b
	Average of 64 shoots per irrigation treatment



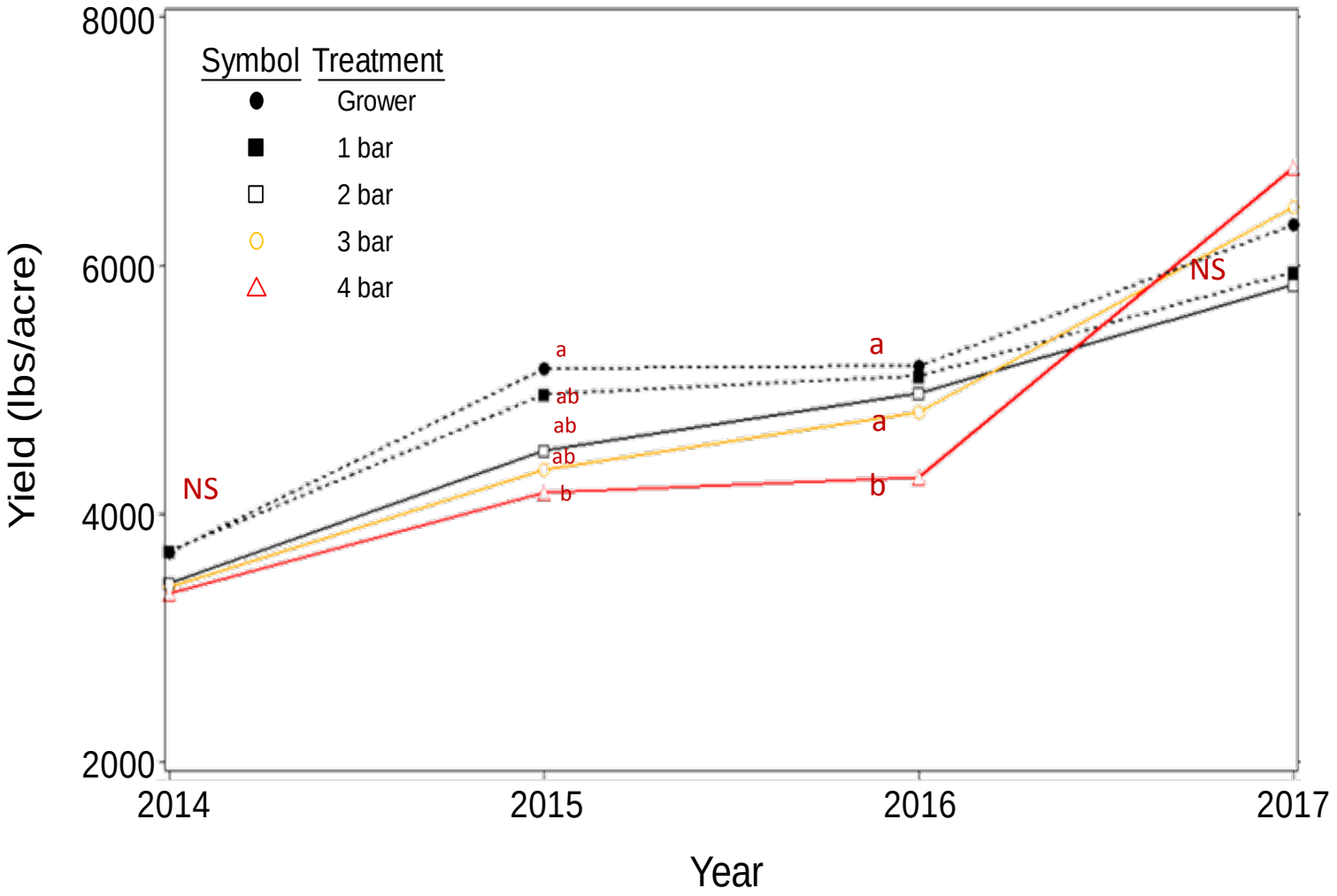
Effect of summer water stress on bud fruitfulness in walnut

Location	Three-year Average SWP (bars)	Change in buds that opened (%)	Change in floral buds (%)	Change in flowers per floral bud (%)	Change in Nut Load (%)
Tehama County CA	-3.6	0	0	0	0
	-6.2	-1	-18	-3	-24
	-7.5	-12	-12	-9	-31
San Joaquin CA	-5.5	0	0	0	0
	-7.0	-3	-15	-1	-16

Effect of summer water stress on Chandler/Paradox walnut yield

Location	Three-year Average SWP (bars)	2002 Yield (tons/ac)	2003 Yield (tons/ac)	2004 Yield (tons/ac)	2004 Yield Reduction (%)
Tehama County CA	-3.6	1.98 a	2.82 a	2.24 a	0
	-6.2	1.84 a	2.33 b	1.65 b	-26
	-7.5	1.74 a	2.07 b	1.31 b	-42
San Joaquin County CA	-5.5	3.55 a	4.43 a	3.77 a	0
	-7.0	3.26 a	3.94 a	2.98 b	-21
	-8.6	3.29 a	3.80 a	3.08 b	-18

Potential for delayed early season irrigation



Other Effects of Water Management on Walnut

- Nut quality – edible yield, nut size, kernel color
- Tree health and longevity
- Young tree growth and development

For a brief written summary of walnut responses to irrigation, Google:

UC ANR Publication 8503 – *Using the Pressure Chamber for Irrigation Management in Walnut, Almond, and Prune (Pages 15 and 16)*

FAQ's About Irrigation Management

- When should irrigation begin?
- How frequently should irrigation occur?
- How long should the irrigation system be run?
- When should irrigation be curtailed?
- How should young developing trees be irrigated?

Tools to answer re-occurring questions about when to irrigate and how much water to apply?

Method/Tool	Scientific Discipline
Water budget (Compare ET to applied water, in-season rain, and soil storage)	Biometeorology, engineering
Soil moisture depletion	Soil science, agronomy
Orchard water status (pressure chamber and midday stem water potential)	Horticulture, plant physiology

Note: Research and development of each of these irrigation scheduling methods dates back to 1960 or earlier. All three methods are linked together as a continuum - the "soil-plant- atmosphere (climate) continuum"

What is a water budget?

- A relatively inexpensive and simple water management tool
- *Informal or formal* accounting of the water used by the crop and supplied to it.
- Looking for a balance not a surplus or overdraft?
- A method of estimating soil moisture depletion or anticipating crop water stress
- Can be conducted at different time steps:
  - Daily, weekly, monthly, seasonally, or annually
  - **Need to use weekly or more frequent time step for irrigation management**

Example weekly water budget for mature Chandler walnuts

Date	Weekly ETc	Accum'd ETc	Effective In-season Rainfall	Effective Accum'd Rainfall	Accum'd Deficit	Irrigation Needed (hours per week)	
2012	(Inches per Week)					@ 0.04 in/hr	@ 0.07 in/hr
3/30-4/5	0.35	0.35	0.44	0.44	None	None	None
4/6-4/12	0.41	0.76	0.99	1.43	None	None	None
4/13-4/19	0.44	1.20	0.29	1.72	None	None	None
4/19-4/26	0.61	1.81	0.04	1.76	None	None	None
4/26-5/3	0.77	2.58	0.02	1.78	0.80	Not Yet	Not Yet
5/4-5/10	1.24	3.82	0.00	1.78	2.04	31	18
5/11-5/17	1.09	4.91	0.00	1.78	3.13	27	16
5/18-5/24	1.43	6.34	0.00	1.78	4.56	36	20
5/25-5/31	1.29	7.63	0.00	1.78		32	18
7/20-7/26	2.12	22.26	0.00	1.88		53	30
9/7-9/13	1.43	34.86	0.00	1.88		36	20
10/19-10/25	0.35	39.86	0.46	2.34		None	None

Another Example of a Weekly Water Budget

Walnut ET - 5/1/15 through 5/7/15 = 1.29"

Orchard #1 - R-5 sprinklers

1.29 ÷ 0.05 in/hour = 26 hours irrigation

Orchard #2 - R-10 sprinklers

1.29 ÷ 0.07 in/hour = 18 hours irrigation

Online Resources for Water Budgeting

- Weekly Sacramento Valley ET reports - http://www.sacvalleyorchards.com/et-reports/
- Wateright - http://www.wateright.net/WaterBalanceTutorial
- Mobile Irrigation Scheduler - http://weather.wsu.edu/is/
- CropManage –for tree crops
  - https://v3.cropmanage.ucanr.edu/Account/Login

Water budgeting requires:

- Knowing irrigation system water application rate
- An estimate of ET for walnut

It helps to:

- Understand the root zone and soil water storage
- Track in-season rainfall
- Know irrigation distribution uniformity

2015 UC ANR – DWR Collaborative Effort to Extend Real-Time ET Information

- Central Valley-wide Farm Advisor effort
  - Allan Fulton, Dani Lightle, Northern Sacramento Valley
  - Katherine Jarvis-Shean, Southern Sacramento Valley
  - Roger Duncan, Northern San Joaquin Valley
  - Mae Culumber, Central San Joaquin Valley
  - Blake Sanden, Southern San Joaquin Valley

Where to find Walnut ET Information?

WEEKLY ET REPORT
(Estimated Crop Evapotranspiration or ETc)
07/06/18 through 07/12/18

Crops (Leafout Date)	Tehama County - Gerber South			Butte County - Biggs			Butte County - Durham			Colusa County - Williams		
	Past Week of Water Use	Accum'd Seasonal Water Use	Next Week's Estimated ETc	Past Week of Water Use	Accum'd Seasonal Water Use	Next Week's Estimated ETc	Past Week of Water Use	Accum'd Seasonal Water Use	Next Week's Estimated ETc	Past Week of Water Use	Accum'd Seasonal Water Use	Next Week's Estimated ETc
Pasture [ETo]	1.90	29.61	1.89	1.73	27.83	1.79	1.62	25.87	1.69	1.66	27.05	1.82
Olives Table *	1.44	22.38	1.40	1.29	21.01	1.37	1.24	19.65	1.27	1.27	20.47	1.40
Olives High Density *	1.12	17.80	1.12	1.04	16.74	1.09	0.98	15.55	0.99	1.01	16.27	1.12
Citrus *	1.24	19.38	1.26	1.14	18.07	1.16	1.06	16.84	1.12	1.08	17.59	1.19
Almonds (2/16) *	2.10	27.40	2.10	1.92	25.61	2.00	1.80	23.90	1.90	1.84	24.64	2.03
Cling Peaches (3/1) *	1.98	20.31	2.04	1.80	18.82	1.94	1.69	17.65	1.80	1.73	17.89	1.97
Pistachios (4/16) *	2.28	21.60	2.24	2.05	19.76	2.14	1.94	18.44	2.04	1.97	18.53	2.17
Prunes (3/20) *	1.83	24.57	1.82	1.67	22.92	1.72	1.56	21.34	1.62	1.60	21.89	1.75
Walnuts (4/1) *	1.91	23.85	1.89	1.73	22.18	1.79	1.62	20.67	1.69	1.66	20.98	1.82
Urban Turf Grass	1.77	24.61	1.75	1.60	23.16	1.68	1.52	21.55	1.62	1.54	22.43	1.68
Past 7 days precipitation (inches)		(0.00)			(0.00)			(0.00)			(0.00)	
Accumulated precipitation (inches)		(6.44)			(5.68)			(7.33)			(3.79)	

Accumulations started on February 16, 2018 or on the approximate leafout date for a specific orchard crop as indicated in parentheses. Estimates are for orchard floor conditions managed with herbicide strip sprays and mowing. Weekly estimates of soil moisture can be as much as 25 percent higher in orchards with cover crops managed for maximum growth.

PAST WEEKLY APPLIED WATER IN INCHES, ADJUSTED FOR EFFICIENCY [1]

Crops	Tehama County - Gerber South			Butte County - Biggs			Butte County - Durham			Colusa County - Williams		
System Efficiency >>	70%	80%	90%	70%	80%	90%	70%	80%	90%	70%	80%	90%
Olives Table	2.1	1.8	1.6	1.8	1.6	1.4	1.8	1.6	1.4	1.8	1.6	1.4
Olives High Density	1.6	1.4	1.2	1.5	1.3	1.2	1.4	1.2	1.1	1.4	1.3	1.1
Citrus	1.8	1.6	1.4	1.6	1.4	1.3	1.5	1.3	1.2	1.5	1.4	1.2
Almonds (2/16)	3.0	2.6	2.3	2.7	2.4	2.1	2.6	2.3	2.0	2.6	2.3	2.0
Cling Peaches (3/1)	2.8	2.5	2.2	2.6	2.3	2.0	2.4	2.1	1.9	2.5	2.2	1.9
Pistachios (4/16)	3.3	2.9	2.5	2.9	2.6	2.3	2.8	2.4	2.2	2.8	2.5	2.2
Prunes (3/20)	2.6	2.3	2.0	2.4	2.1	1.9	2.2	2.0	1.7	2.3	2.0	1.8
Walnuts (4/1)	2.7	2.4	2.1	2.5	2.2	1.9	2.3	2.0	1.8	2.4	2.1	1.8

1 The amount of water required by a specific irrigation system to satisfy evapotranspiration. Typical ranges in irrigation system efficiency are: Drip, 80%-95%; Micro-sprinkler, 80%-90%; Sprinkler, 70%-85%; and Border-furrow, 50%-75%.

For further information concerning all counties receiving this report, contact the Tehama Co. Farm Advisor's office at (530) 527-3101 or the Glenn Co. Farm Advisor's office at (530) 865-1153. This same information and source is now available in the ET Reports section of the sacvalleyorchards.com website. Same information, just in a different format.

Water Budgeting – Talking Points

1. If incorporating science-based information into on-farm water management is new, water budgeting is a good place to begin.

2. How well do the ET estimates represent specific orchards?

3. Irrigation requirement is likely to be less than ET. **How much less?**

Potted Tree

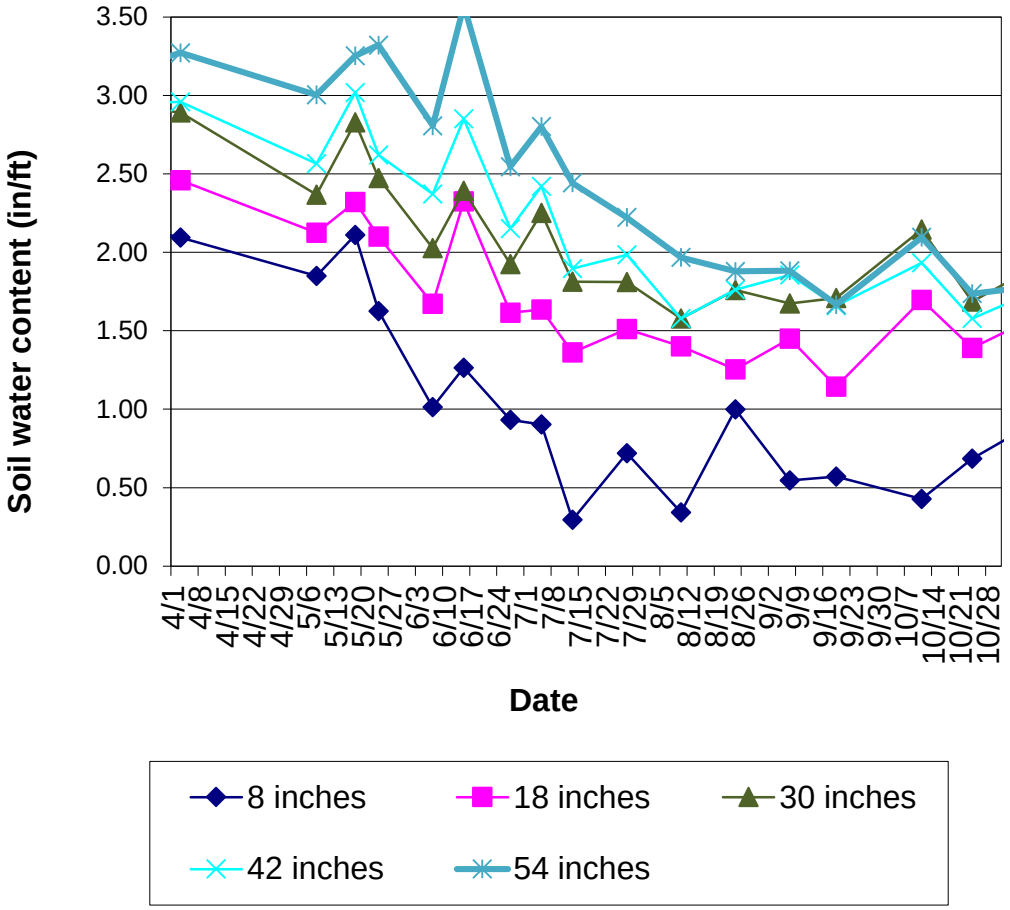
Grafted Tree

Un-pruned Tree

Headed Tree

Insights into the Walnut Root Zone of a 2nd Leaf Tree and Where it Get's Water?

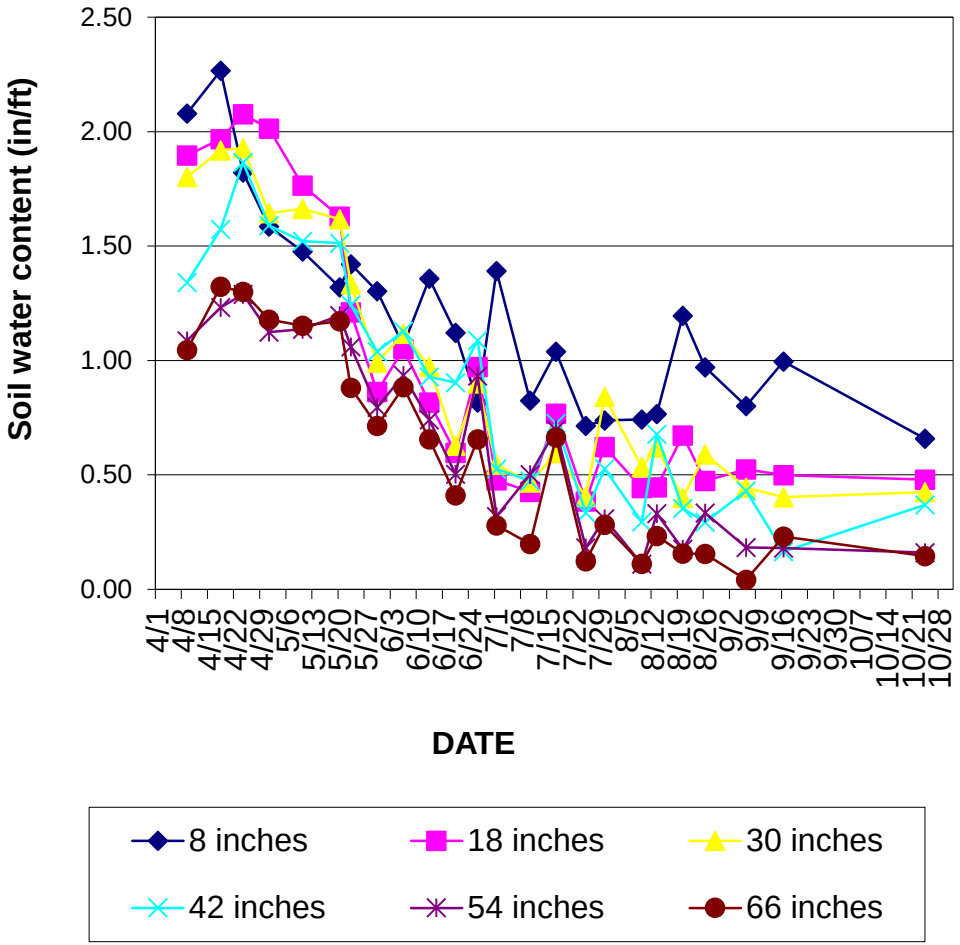
Arbuckle gravelly loam, ~1.8 in/ft available water



- Steady soil moisture content in April and May in 1st and 2nd feet.
- Instances of deep drainage May and June suggests duration of irrigation too long.
- Beginning in July, irrigation declined and tree was supplied water from storage in 2nd, 3rd, 4th, and 5th feet of soil.

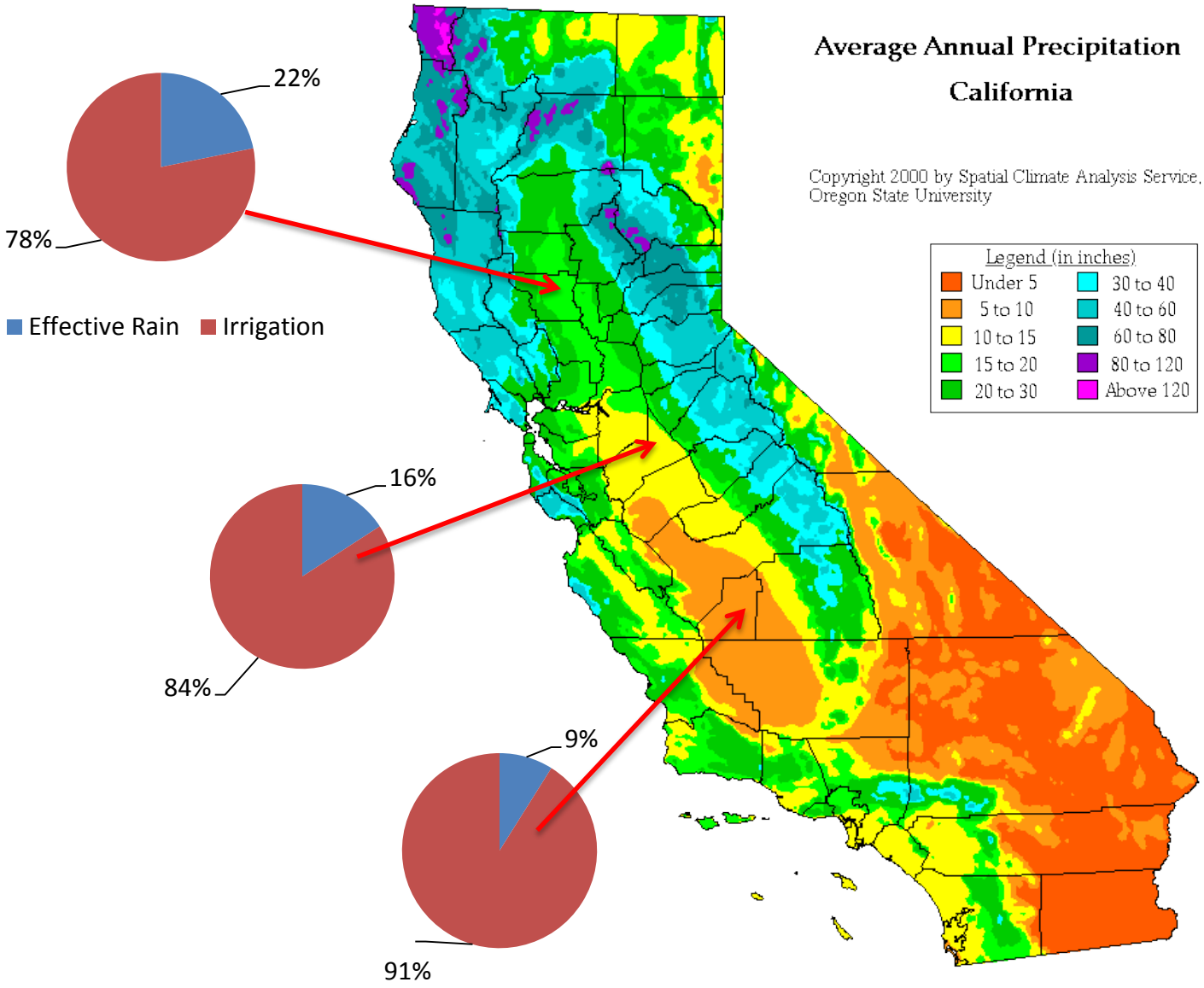
Insights into the Walnut Root Zone of a Mature Tree and Where it Get's Water?

Arbuckle gravelly loam, ~1.8 in/ft available water

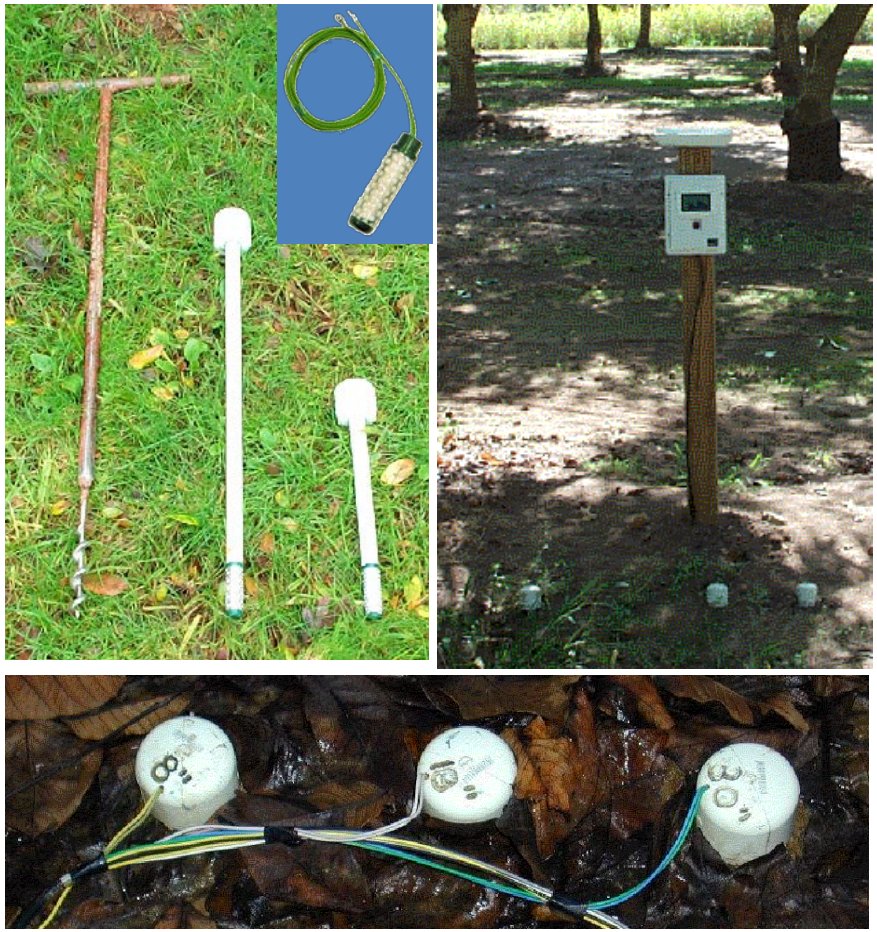


- Irrigation only infiltrated into top one or two feet of soil.
- Steady depletion of soil water from 1st through 6th feet during season.
- If monitored deeper, and if the soil profile has available water, trees may extract deeper.

Effective Storage of Rainfall Can Influence How Much Irrigation is Needed to Supply ET to Deep Rooted Walnuts



Example Sensors to Monitor Soil Moisture Depletion in the Root Zone



Monitoring Soil Moisture Depletion and Refill – Feel Method

(For Reference, Google: USDA, Estimating Soil Moisture)

Sandier → More Clay

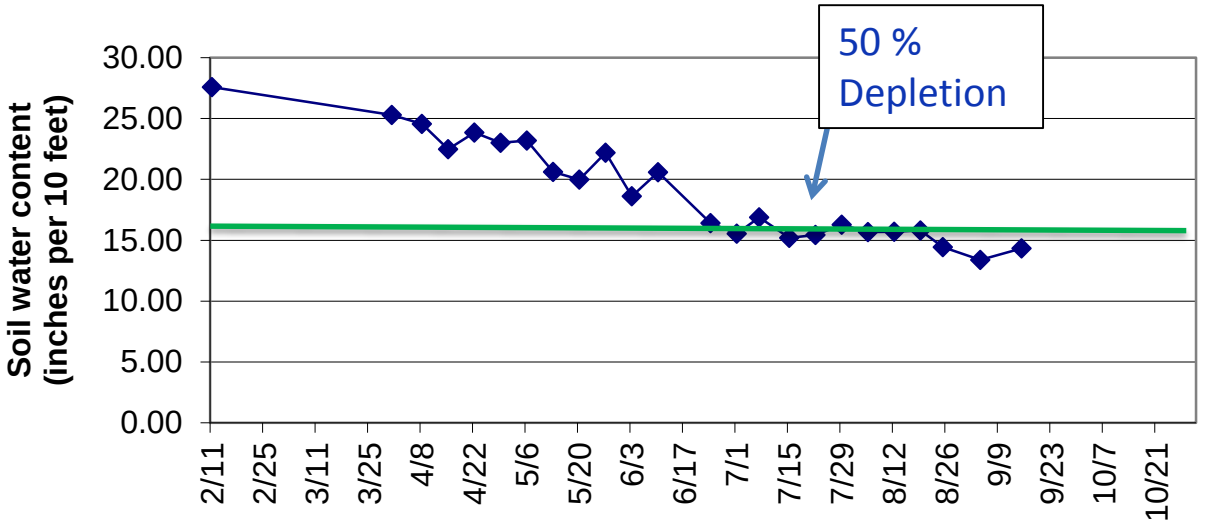
Wetter ↓ Drier






Soil moisture depletion method using volumetric moisture sensors

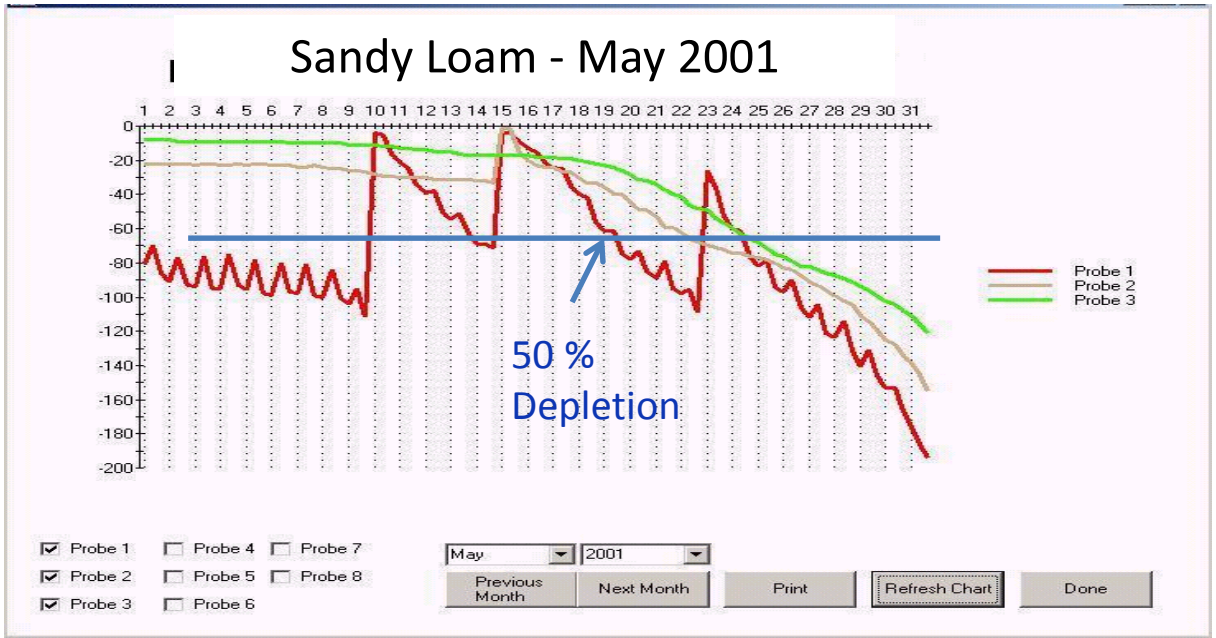
Soil Texture	Field capacity	Wilting Point	Available Water Capacity
	(Inches/ft of soil)		
Sandy loam	2.0	0.6	1.4
Fine sandy loam	2.6	0.8	1.8
Loam	3.2	1.2	2.0
Silt loam	3.5	1.4	2.1
Clay loam	3.8	1.8	2.0
Clay	4.0	2.6	1.4



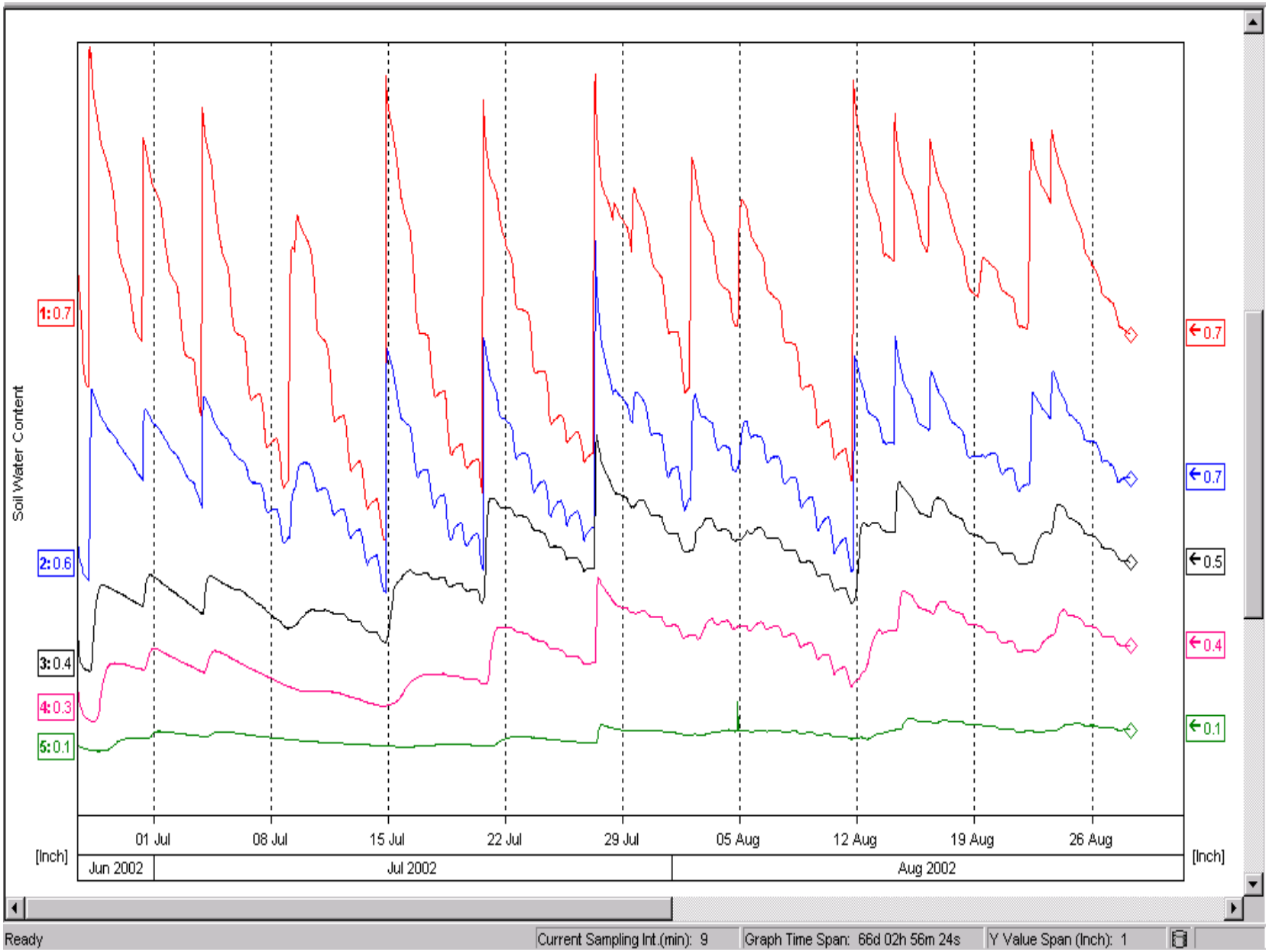
Soil moisture depletion method using moisture tension sensors.

Soil Tension	Sand/Loamy Sand	Sandy Loam	Loam/Silt Loam	Clay Loam/Clay
(centibars)	Depletion of the Plant Available Water (%)			
10	0	0	Not fully drained	Not fully drained
30	40	25	0	0
50	65	55	10	10
70	75	60	25	20
90	80	65	35	25
110	85	68	40	32
130	87	70	47	38
150	90	73	52	43
170	95	76	55	46
190	98	79	58	49

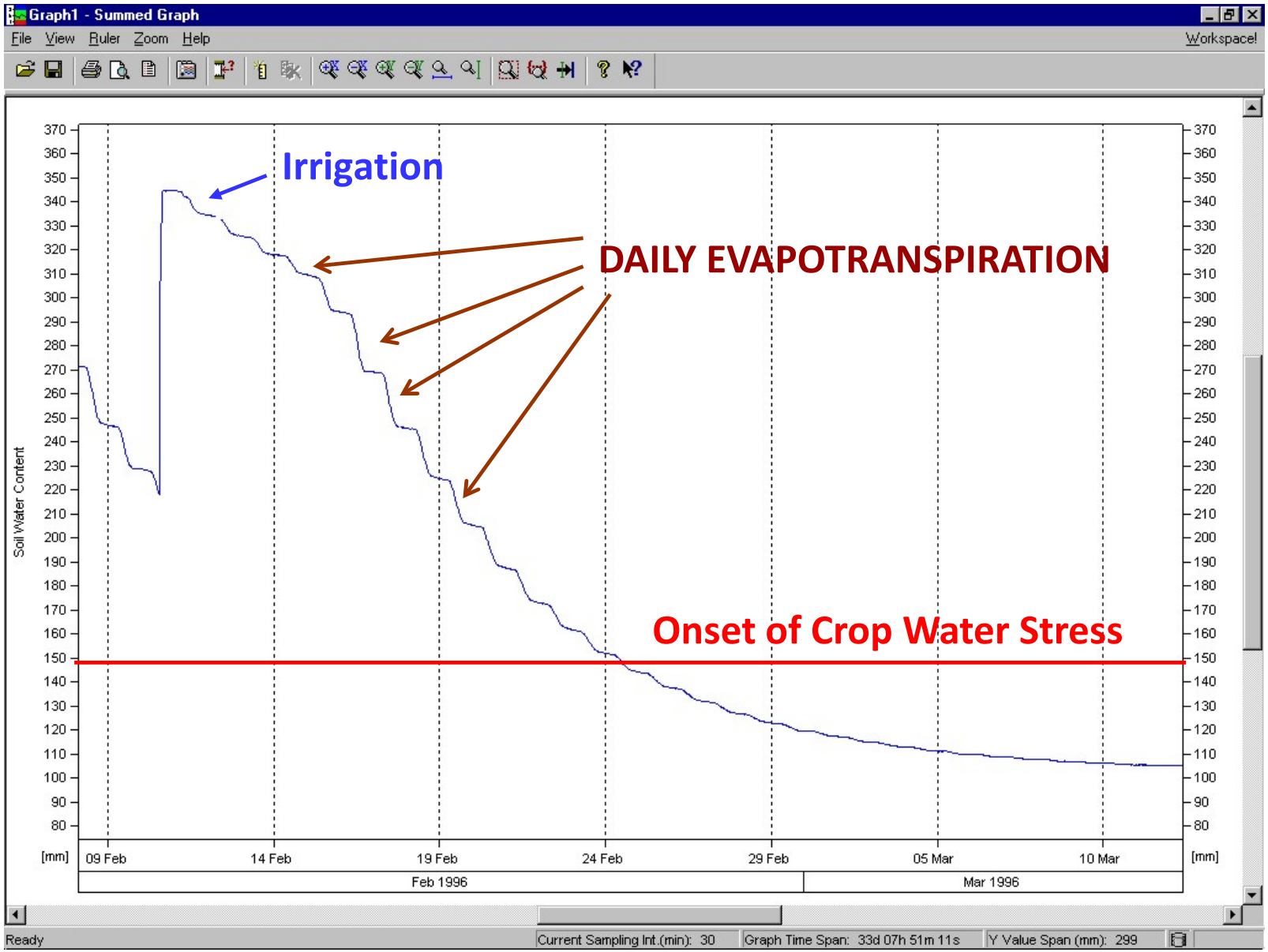
Table adapted from Scheduling Irrigations: When and How Much Water to Apply. Division of Agriculture and Natural Resources Publication 3396. University of California Irrigation Program. University of California, Davis. pp. 106.



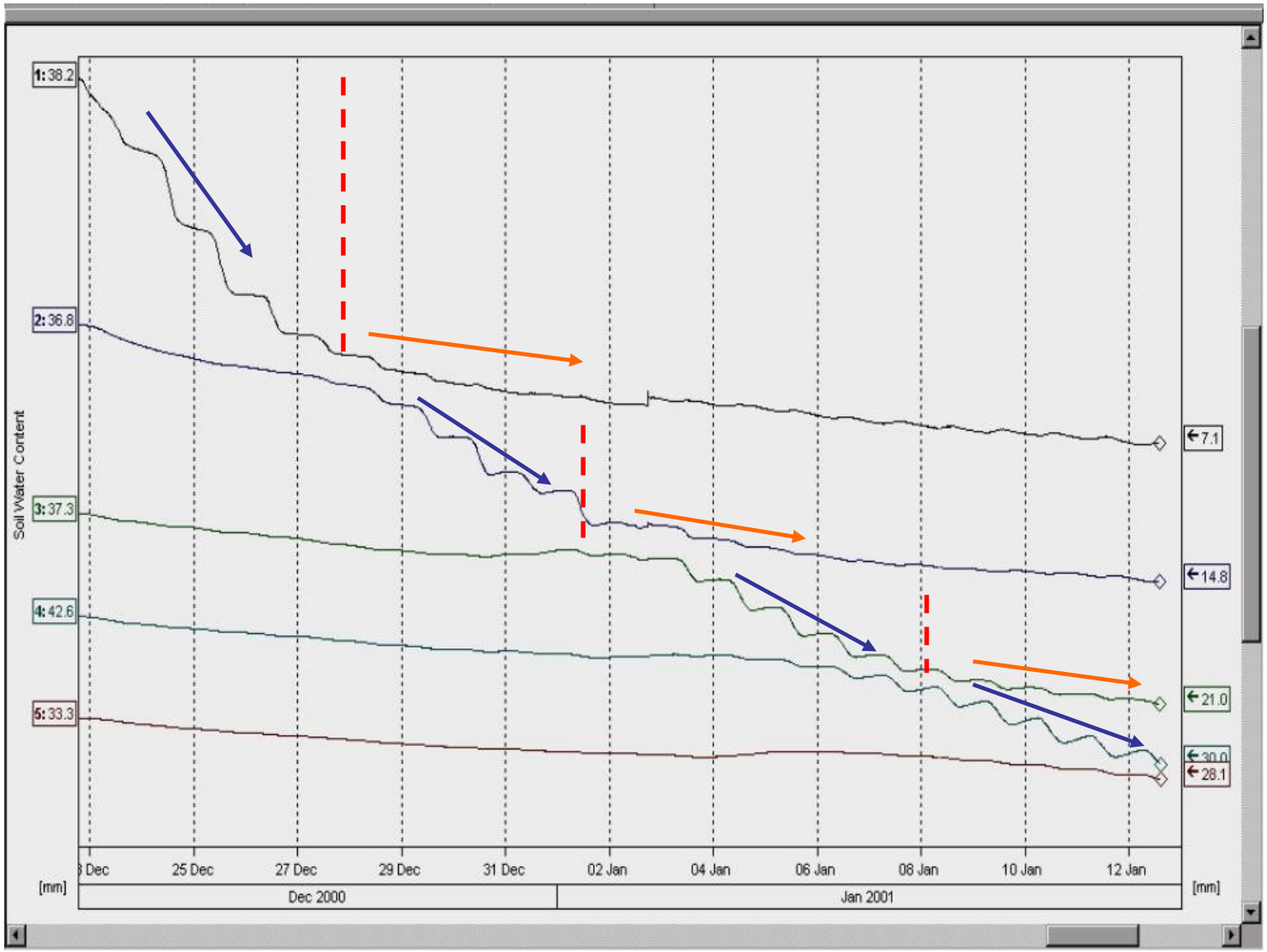
Applications of high frequency soil moisture sensors



Concept of detecting crop ET and water stress with high frequency soil moisture monitoring



Concept of Evaluating Soil Moisture Availability with depth



Soil Moisture Depletion – Talking Points

1. Soil moisture depletion method can lead to improved irrigation decisions on frequency and duration.

2. Soil moisture sensors coupled with radio telemetry
   - Excel at convenient, timely delivery of information
   - Deliver more detailed information than manual measurements
   - Useful for measuring effective rainfall during dormant season

3. Sometimes acquiring representative data can be a challenge
   - Soil and orchard variability
   - Depth of profile to monitor
   - Root distribution and density
   - Distribution of applied water
   - Small volumes of soil monitored
   - Gravelly soils and soils with shrinking and swelling characteristics

Monitor Orchard Stress (pressure chamber, midday SWP)

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Various Styles and Manufacturers of Pressure Chambers

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Agriculture and Natural Resources

Example orchard water status (pressure chamber) data from young, developing walnuts

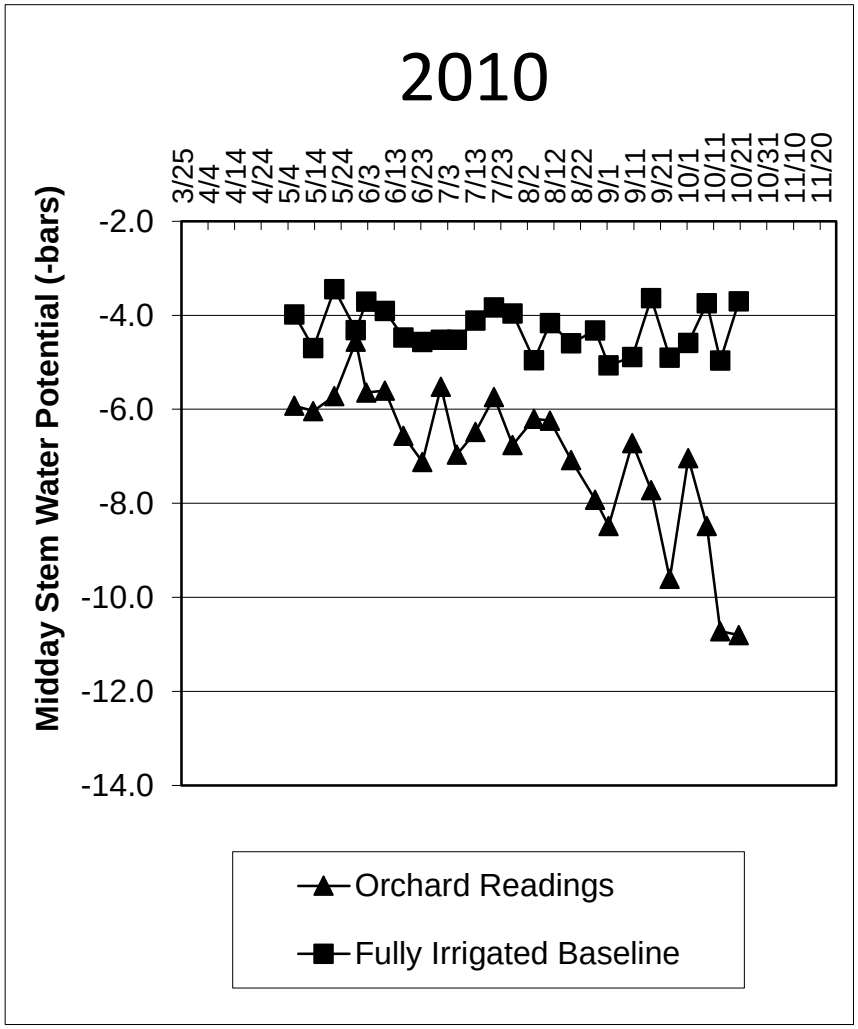

Table 1. Midday SWP interpretive guidelines.[1]

SWP range (bars)	General Stress Level	Baseline consideration for		Water stress symptoms in walnut
		Normal or Cool Weather	Above Normal and Hot Weather	
Higher than -2	None	Likely above baseline	Very likely above baseline	Not commonly observed, but if measured, they indicate overly wet soil conditions and risk to long term tree root health. Yellowing tree canopies, small leaves, and nuts may be visible.
-2 to -4	None	At or slightly below baseline	Likely to be above baseline	Fully irrigated. Commonly observed when orchards are irrigated according to estimates of real-time evapotranspiration (ET_c). If sustained, long term root and tree health may be a concern, especially on California Black rootstock.
-4 to -6	Minimal	As much as 2 bars below typical baseline	At or slightly above baseline	High rate of shoot growth visible, suggested level from leaf-out until mid-June when nut sizing is completed.
-6 to -8	Mild	May be 2 to 4 bars below baseline	Near or possibly above baseline	Shoot growth in non-bearing and bearing trees has been observed to decline. These levels do not appear to affect kernel development or quality.
-8 to -10	Moderate	May be 4 to 6 bars below baseline	May be within 2 bars of baseline	Shoot growth in non-bearing trees may stop, nut sizing may be reduced in bearing trees and bud development for next season may be negatively affected.
-10 to -12	High	May be 6 to 8 bars below baseline	Likely 2 to 4 bars below baseline	Temporary wilting of leaves and shrivel of hulls has been observed. New shoot growth may be sparse or absent and some defoliation may be evident. If sustained, nut size will likely be reduced with darker kernel color.
-12 to -14	Very High	May be 8 to 10 bars below baseline	Likely 6 to 8 bars below baseline	Results in moderate defoliation. Should be avoided.
-14 to -18	Severe	Likely 10 to 14 bars below baseline	May be 8 to 10 bars below baseline	Severe defoliation, trees are likely dying.
Below -18	Extreme	Substantially below baseline under all weather conditions		Not commonly measured in walnut. Trees are probably dead or dying.

[1] For more information refer to http://www.sacvalleyorchards.com/blog/.

Pressure Chamber, Midday SWP - talking points

1. Midday SWP uniquely integrates and quantifies how an orchard is responding to soil, water, and climatic conditions.

2. SWP can help confirm and adjust assumptions that are used with soil moisture depletion method or when using a water budget.

3. Must go into the orchard routinely.
   - Labor intensive
   - Limited acreage can be monitored in a day and with one instrument
   - Encourages routine observation of an orchard

4. Concern: “by the time SWP responds deep soil moisture is gone”.
   - May not be a concern. Can resolve this through trial and error.
   - **Use SWP in combination with water budget or soil moisture monitoring**

5. Orchard variability and achieving representative SWP monitoring can be a challenge, usually less than for soil moisture monitoring.

6. Comment: “Currently use the plant-based indicator to make irrigation decisions but foresee even greater management potential if there was a way to acquire high frequency crop water stress indicators”.

A Final FAQ About Irrigation Management

- What is a good tool or method to help make informed and effective water management decisions in walnuts?
- A combination of at least two of these methods recommended (soil, plant, ET)
- The answer depends on:
  1. How much irrigation is impacting short and long term production goals, in turn, **how much motivation** exists to invest in irrigation scheduling?
  2. Specific features of a farm operation and preferences that will affect the ability to adopt any of these tools.


Thank You!