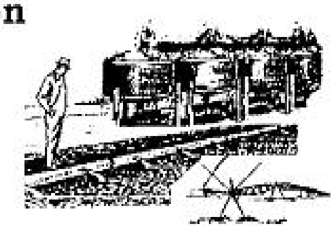
University of California Cooperative Extension

KERN SOIL AND WATER



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IRRIGATION 101: WHEN, HOW MUCH & HOW OFTEN TO IRRIGATE

Blake Sanden, Irrigation & Agronomy Kern County

2010 UCCE NorthSJV Almond Day, Modesto 1/28/10 World Ag Expo, Tulare 2/10/10

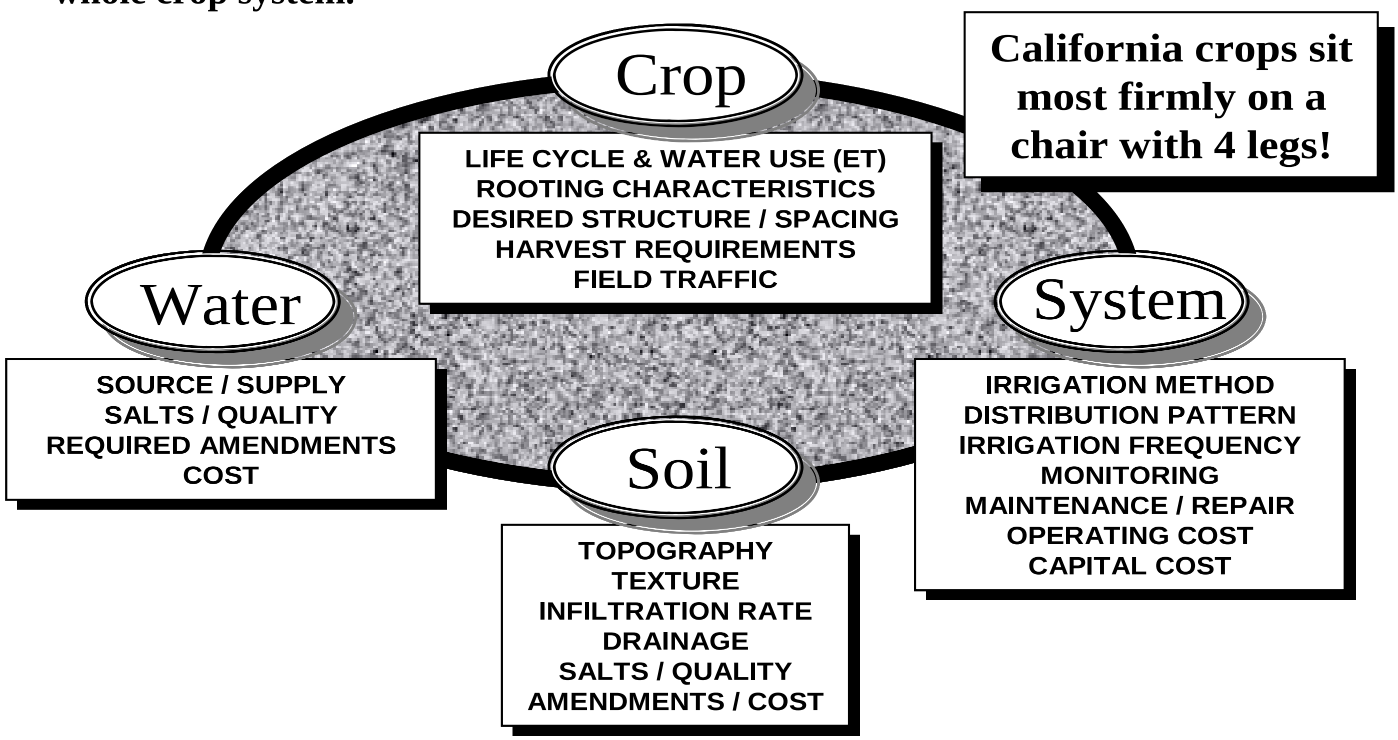
ESSENTIAL ELEMENTS for EFFICIENT IRRIGATION

1. **SOIL/WATER: Optimizing all factors / knowledge that affect irrigation uniformity, scheduling and water use efficiency.**
2. **CROP: Adjust crop rotation choices to fit water supply / quality.**
3. **TECHNOLOGY: Adopt techniques to track changes in soil/plant water status.**

ESSENTIALS TO OPTIMIZE PRODUCTION & PROFIT

- **AVAILABLE WATER**
- **ROOTZONE AERATION**
- **SUFFICIENT ROOTED VOLUME FOR ANCHORING AND NUTRIENTS**
- **AVAILABLE NUTRIENTS – N, P, K, Zinc, Boron, Iron, proper salt balance**
- **AVOID SATURATION & HIGH HUMDITY TO DECREASE DISEASE**
- **CROP STRUCTURE for MAX PHOTOSYNTHESIS & FRUIT DEVELOPMENT**
- **EQUIPMENT FOR TIMELY OPERATIONS**

The irrigation system is the "ESSENTIAL" integrating factor for the whole crop system.



Determining Plant Available Water by the "Feel Method"

Blake Sanden – University of California Cooperative Extension, Kern County

The ability to estimate the soil moisture in the crop rootzone that will be available to the crop is the key to understanding efficient irrigation and producing top yields. Knowing the texture of your soil tells you the maximum amount of water the soil will store between irrigations. Checking the soil moisture of your field every 3 to 4 days will tell you how quickly the crop is using stored water and when you need to irrigate again. Applying irrigation water too early causes water logging, possible disease, loss of fertilizer and decreased yield. Waiting too long between irrigations causes the crop to stress, reducing plant growth, photosynthesis and usually yield.

ESTIMATING AVAILABLE WATER HOLDING CAPACITY (AWHC): The maximum water a soil can hold in the field is called **field capacity (FC).** Following an irrigation it may take 1 to 3 days for excess water to drain out of the large pores, wormholes etc. The remaining water is held against gravity in the smaller pores of the soil. Obviously, a soil with a finer texture (more silt and clay) has a greater number of small pores and can store a greater amount of water in the rootzone. This is now **Field Capacity.** When soil moisture becomes so depleted that a plant wilts and does not recover, this is called the **Permanent Wilting Point (PWP)**. There is still a little water left in the soil, but it is held so tightly that it is unavailable to the plant. The amount of water available between **FC and PWP** is the **Available Water Holding Capacity (AWHC).** AWHC is expressed as a percent of the total soil volume:

$$\textbf{AWHC} = \textbf{\%Volume} = \frac{\textbf{inches depth of water}}{\textbf{12 inch depth of soil}}$$

Thinking of % volumetric water content in terms of **inches of available water per foot depth of rootzone** is the most convenient way to match crop water demand with how much water the soil can store. This is because crop water use (evapotranspiration, ET) is estimated as a depth of water over some period (daily, weekly, monthly, the whole season).

SIMPLIFIED SOIL TEXTURE CATEGORIES: For normal field irrigation scheduling it is usually sufficient for the production farmer to identify his soil by 4 basic types: Coarse, Sandy, Medium and Fine. Table 1 lists the characteristics associated with these types.

Table 1. Simplified soil texture categories, associated USDA soil textures, approximate available water holding capacity (AWHC) and length of soil "ribbon".

Category	**Textures**	**AWHC (in/12 inch soil)**	**"Ribbon" Length (inches)**
Coarse	S / LS	0.6 – 1.2	None. Ball only.
Sandy	LS / SL / L	1.2 – 1.8	0.4 - 1
Medium	L / SCL	1.4 – 2.2	1 - 2
Fine	SiL / SiCL / CL / SiC	1.7 – 2.4	> 2

So the basic rule of thumb (using the length of the soil ribbon you make with your thumb and forefinger) is: **if the wet soil at least makes a ball, but no ribbon your AWHC is about 0.7 to 1 inch/foot depth of soil. Then for all soils that make a ribbon:**

$$\textbf{AWHC(in/ft soil)} \sim \textbf{length of ribbon}$$

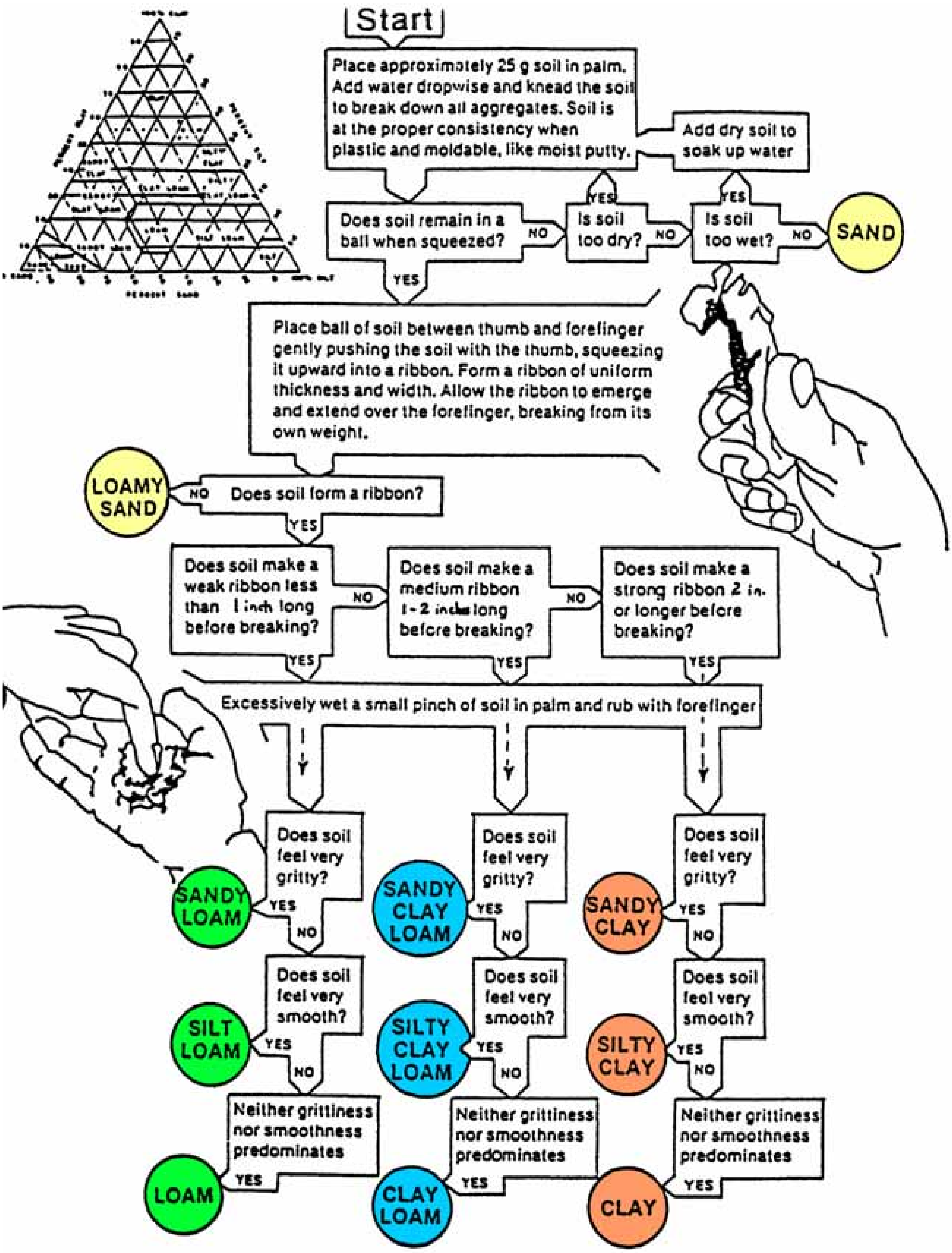
What this means is a field with sandy loam, (SL) has an AWHC of 1.2 to 1.6 in/ft. If this field is planted to blackeye beans or cotton rooted to a depth of 6 feet the soil can store a 7 to 9.5 inch depth of available water in the rootzone. A fine soil, like a silty clay loam (SiCL), can store 11 to 12 inches of water to 6 feet. For practical field irrigation scheduling you only want to use 50% to 60% of this total storage to avoid crop stress – about 4 inches for the SL and 6 inches for the SiCL. If the summer crop water use runs about 0.31 in/day then the sandy field needs water about every 12 to 15 days and the finer textured field needs water every 18 to 22 days. Soils with infiltration problems require more frequent irrigation. Table 2 shows the total AWHC for soils making different lengths of "ribbon" for coarse to fine soils for different rooting depths.

Table 2. Total available water holding capacity (AWHC) for different rootzone depths and length of soil ribbon.

Soil "Ribbon"	AWHC (inches) for Rootzone Depth		
Length (in)	**1.5 ft**	**3.0 ft**	**5.0 ft**
Ball Only	0.9	1.8	3.0
0.5	0.8	1.5	2.5
1.0	1.5	3.0	5.0
1.5	2.3	4.5	7.5
2.0	3.0	6.0	10.0
2.5	3.8	7.5	12.5

DETERMINING ACTUAL AVAILABLE WATER CONTENT IN THE FIELD USING THE "FEEL" METHOD AND A SOIL PROBE: Table 3 following is the most important table in this publication. The previous discussion was about the maximum amount of water a soil can hold (field capacity as shown for the clay loam soil at the right, making a 2.5 inch ribbon). But the production farmer has to manage fields not only with different soil textures but with crops at different stages of development, often different levels of salinity and with different potentials for maximum yield. So it is critical that the farmer can estimate how much water is still left in the soil and how quickly the crop is using this water so he can irrigate at just the right time. Irrigating too late stresses the crop. Irrigating too early leaches fertilizer, causes water logging and possible disease.

To accurately use this "feel" technique in the field takes some practice, equipment and willingness to do some digging. The top 1 foot of soil for any field crop will always dry out first. If plant roots are well developed then the 1 to 2 foot and later the 2 to 3 foot depths will supply more of the water used by the crop. In a well drained soil, most fully developed field crop roots can retrieve water to a 6 foot depth. It is essential to have some type of soil probe or auger that allows you to pull up a soil sample from the deeper rootzone – at least to a depth of 3 feet once a week and preferably to a depth of 4 to 6 feet at two to four week intervals.



From: ***A Flow Diagram for Teaching Texture-by-Feel Analysis*****, by Steve J. Thien, Journal of Agronomic Education; Vol. 8, 1979, pp 54-55.**

Table 3. Guide for Estimating Actual Available Field Soil Moisture by the "Feel" Method.

SOIL TEXTURE CLASSIFICATION								
Coarse (loamy sand)		**Sandy (sandy loam)**		**Medium (loam)**		**Fine (clay loam, silty clay loam)**		
Available Water (AW) in the Soil by Appearance (inches/foot soil)								
0.6-1.2 in/ft *AW@FC		**1.2-1.8 in/ft AW@FC**		**1.4-2.2 in/ft AW@FC**		**1.7-2.4 in/ft AW@FC**		
	AW		**AW**		**AW**		**AW**	Moisture Deficiency
Leaves wet outline On hand when	**1.0**	Appears very dark leaves wet outline	**1.6**	Appears very dark leaves wet outline	**1.9**	Appears very dark, leaves slight moisture	**2.2**	0
squeezed. Appears moist,	**0.7**	on hand, makes a short ribbon (0.5-0.75 inch)		on hand , will ribbon about 1 – 2 inches.	**1.7**	on hand when squeezed, will ribbon > 2 inches.		0.2
Makes a weak ball. Appears slightly		Quite dark color makes a hard ball.	**1.2**	Dark color, forms a plastic pall, slicks when rubbed.	**1.4**	Dark color will feel slick And ribbons easily	**1.8**	0.5
moist, sticks together slightly.	**0.4**	Fairly dark color, makes a good ball	**1.0**	Quite dark, forms a hard ball	**1.2**	Quite dark, will make		0.7
Dry, loose, flows thru fingers. (wilting point)	**0**	Slightly dark color makes a weak ball	**0.7**	Fairly dark, forms a	**1.0**	thick ribbon may slick when rubbed.	**1.4**	1.0
		Lightly colored by moisture, will not	**0.4**	a good ball		Fairly dark, makes a good ball.	**1.1**	1.2
		ball. Very slight color	**0**	Slightly dark, forms weak ball	**0.6**	Will ball, small clods will flatten out rather	**0.7**	1.4
		due to moisture. (wilting point)		Lightly Colored, small clods crumble	**0.2**	Slightly dark, clods	**0.4**	1.7
				Fairly easily. Slight color due to		Crumble. Some darkness due to		1.9
				moisture, small colds hard (wilting point).	**0**	unavailable moisture, clods are hard, cracked	**0**	2.2
						(wilting point)		

* **AW@FC:** Available Water @ Field Capacity = the available water a soil can store against gravity after irrigation and drainage.

Adapted from: Merriam, J.L. 1960. Field method of approximating soil moisture for irrigation. Am. Soc. Agri. Engr. Vol. 3. No.1.

There are many different styles of probes available. In general, an open-faced “push probe” is the quickest to use when the soil is moist, but you are limited to a depth of 3 feet and it doesn’t work in rocky soils. Using an auger or screw probe with extension handles every 2 to 3 weeks will allow you to sample to a depth greater than 4 feet. This will tell you if you are losing your deep moisture too quickly (usually because of limiting infiltration that does not refill the rootzone every irrigation) or if the field is too wet.

Before probing, scrape the loose dirt back from the edge of the bed so it doesn’t fall down the hole. Then insert the probe near the edge of the wetted area in the furrow and pull out a sample for every 1 foot depth. Use Table 3 to estimate the available water for each depth. **The following guidelines provide a very quick, rough estimate of the % available moisture:**

1. Ribbons easily: 90 – 100%
2. Plastic ball: 70 – 80%
3. Hard ball: 50 – 60%
4. Crumbly ball: < 50% Crop will begin to stress!

Table 4 shows the different irrigation intervals for flood almonds over the season appropriate for a given soil texture and average daily ET by month. This table shows that for most SL to CL soils ***that DO NOT have an infiltration problem*** a traditional 10 to 14 day irrigation interval during June and July is just about right for replacing 50% of the available soil moisture reserve to avoid stress. This is about 3 to 4 inches of water per irrigation. For sealing or saline soils the irrigation must be more frequent.

Table 4. Flood irrigation interval (days of moisture reserve) for almonds in the southern San Joaquin Valley@ 50% depletion by month and soil texture.

Mature Almonds		Assume managed rooting depth of 4 feet				
		Apr	**May**	**Jun**	**Jul**	**Aug**
Soil Texture	**Avg Daily ET**	**0.15**	**0.23**	**0.28**	**0.30**	**0.26**
Available Soil Moisture to 4 feet @ 50% depletion	**(in)**	**Days of Moisture Reserve for Average Daily ET by Month**				
Sand	**1.4**	9	6	5	5	5
Loamy Sand	**2.2**	15	10	8	7	8
Sandy Loam	**2.8**	19	12	10	9	11
Loam	**3.6**	24	16	13	12	14
Silt Loam	**3.6**	24	16	13	12	14
Sandy Clay Loam	**2.6**	17	11	9	9	10
Sandy Clay	**3.2**	21	14	11	11	12
Clay Loam	**3.4**	23	15	12	11	13
Silty Clay Loam	**3.8**	25	17	14	13	15
Silty Clay	**4.8**	32	21	17	16	18
Clay	**4.4**	29	19	16	15	17

After Ratliff LF, Ritchie JT, Cassel DK. 1983. Field-measured limits of soil water availability as related to laboratory-measured properties. Soil Sci Soc Am. 47:770-5.

Impact of field irrigation distribution uniformity (DU) on applied water and yield (alfalfa example):

DU is defined as the average infiltration depth of water for the "low quarter" (tail end or low pressure 25%) of the field, and is expressed as a percentage:

$$\textbf{DU (\%)} = 100 * \frac{\textbf{“low quarter” infiltration}}{\textbf{Average field infiltration}}$$

Figure 4 illustrates how this plays out in your crop rootzone for a field DU of about 80% with some deficit irrigation on the end. To insure that no more than about 12% of the field gets less than full ET, you divide the expected ET of the crop by the field application DU. So if the alfalfa has a 50 inch requirement for ET and the field has an **80% DU** then the **applied water required = 50/0.8 = 62.5 inches.** That's an extra foot of water! If the **DU is 90%** (which is achievable with quarter mile runs, the right on-flow rate, a tail water return system and proper scheduling) then **applied water = 50/0.9 = 55.5 inches.** So you can save 7 inches of water by improving the uniformity and still adequately water the field.

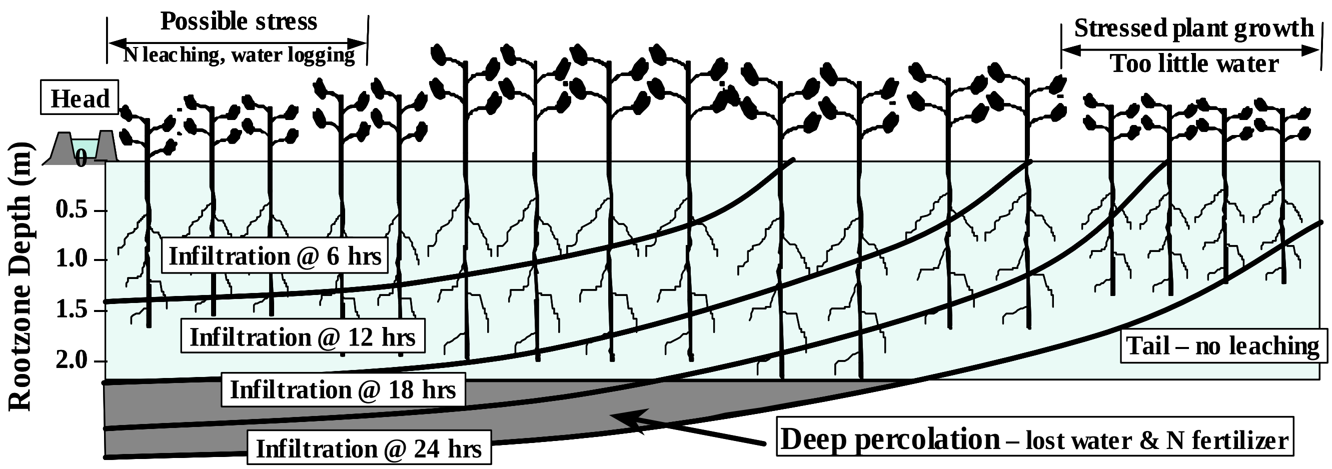


Fig. 4. Cross-section of crop rootzone during a 24 hour furrow irrigation.

Continuing with alfalfa for the moment, 12 ton yields in the SJV usually come from small plots at ag research stations where irrigations were very short and nearly 100% uniform. Actual field DU may range from a low of 65% for a coarse sandy border flood system with no tail water return to 95% for sub-surface drip or new pivots and linear move sprinklers in low wind conditions. In Kern County from 1988 to 2003, the average DU for border systems was 80% (Brian Hockett, unpublished data), ranging from 37 to 100%. (A 100% DU is theoretically possible on a cracking, sealing clay soil.) A total of 27 out of 80 borders evaluated had 90 to 100% DU. The average DU for 40 linear move sprinkler systems tested was only 77%.

So how does this play out in a production field. Figure 5 is a hypothetical alfalfa field that can yield 8.5 ton for the areas in the field where the irrigation schedule is just right. But this field does not drain well and where there is too much water you lose stand and yield to scald and phytophthora (the blocked end of the border and some of the head end in this case). Obviously, where the infiltration is too little (about 900 to 1150 feet from the head) the tonnage also decreases. Table 5 gives 3 scenarios using the production function in Figure 5 for a 70, 80 or 90% DU where the applied water for the season is 42, 48, 54 or 60 inches. Remember that a 55 inch water application is about right for a 50 inch ET requirement and a field with 90% DU.

Field Qtr	Qtr Irrig by Avg Depth (in)				Qtr Yield by Avg Depth (t/ac)			
70% DU	**42**	**48**	**54**	**60**	**42**	**48**	**54**	**60**
Wettest	55	62	70	78	8.5	7.6	6.0	5.0
Wet	46	53	59	66	8.2	8.6	8.1	6.7
Drier	38	43	49	54	6.6	7.8	8.5	8.5
Dry	29	34	38	42	3.6	5.3	6.6	7.6
	Field Average Yield (t/ac):				**6.7**	**7.3**	**7.3**	**7.0**
80% DU	**42**	**48**	**54**	**60**	**42**	**48**	**54**	**60**
Wettest	50	58	65	72	8.5	8.3	7.0	5.9
Wet	45	51	58	64	8.1	8.6	8.3	7.2
Drier	39	45	50	56	7.0	8.1	8.5	8.4
Dry	34	38	43	48	5.3	6.8	7.8	8.4
	Field Average Yield (t/ac):				**7.2**	**7.9**	**7.9**	**7.5**
90% DU	**42**	**48**	**54**	**60**	**42**	**48**	**54**	**60**
Wettest	46	53	59	66	8.2	8.6	8.1	6.7
Wet	43	50	56	62	7.8	8.5	8.4	7.6
Drier	41	46	52	58	7.3	8.3	8.6	8.2
Dry	38	43	49	54	6.6	7.8	8.5	8.5
	Field Average Yield (t/ac):				**7.5**	**8.3**	**8.4**	**7.8**

Table 5. Average seasonal applied water on the wettest to driest areas of an alfalfa field and the resulting yield for those areas for for various irrigation amounts and DU.

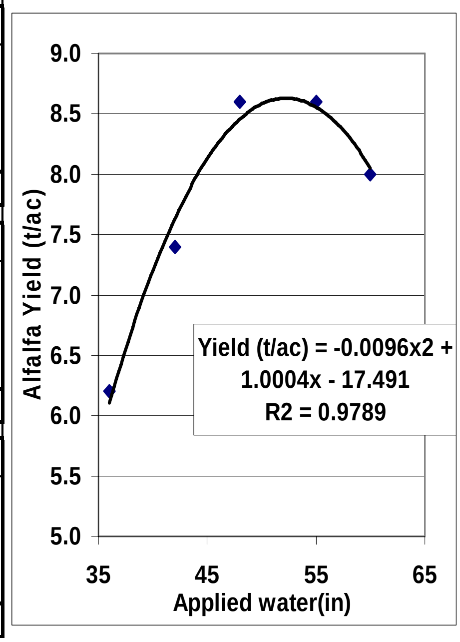


Fig. 5. Alfalfa production function for field sensitive to waterlogging.

Table 6. Recommended soil moisture tension levels as a trigger for irrigation of tree and field crops.

Applied Irrigation Depth: 0.75 to 1.5"			
	Moisture Reading (cb)		
Soil Type	**12"**	**24"**	**48"**
Sand/loamy sand	70	40	20
Sandy loam	50	30	20
Loam	45	25	20
Clay/Silt Loam	40	25	20
Applied Irrigation Depth: 2 to 4"			
	Moisture Reading (cb)		
Soil Type	**12"**	**24"**	**48"**
Sand/loamy sand	80	50	30
Sandy loam	70	40	25
Loam	65	40	20
Clay/Silt Loam	65	30	20
Applied Irrigation Depth: 4 to 6"			
	Moisture Reading (cb)		
Soil Type	**12"**	**24"**	**48"**
Sand/loamy sand	90	70	60
Sandy loam	90	60	40
Loam	80	50	30
Clay/Silt Loam	70	45	25

Note: Moisture readings in these tables are only a guide. Actual readings for irrigation scheduling will vary for each field. Adjust by watching the 48" depth reading. Too little irrigation will cause this reading to keep increasing over the season. Too much irrigation will push this reading down to 0 to 15 centibars.

If we apply 54 inches of water and we have a DU of 70% then the driest area of the field only gets 38 inches for the season and the wettest gets 70 inches. Looking at the right side of the table (Qtr Yield by Avg Depth) under the 54 inch column you can see that only ¼ of the field gets the right amount of water and hits the 8.5 t/ac. Half of the field yields less than 6.5 t/ac. So the average field yield is 7.3 t/ac. Improve the DU to 90% with tail water return and higher on-flows to reduce infiltration and water-logging you bump the whole field up to 8.4 t/ac with the same 54 inches of water! **Bottom line: improving irrigation DU pays.**

Checking soil moisture for scheduling irrigations: A number of growers have begun using Watermark® electrical resistance sensors in recent years to check the wetting and drying of the soil and improve their irrigation scheduling. This can be very useful in the spring and late summer when you may only need one irrigation between cuttings instead of two. In cooler Intermountain areas and for growers with severe water cutbacks, having some kind of soil moisture sensor can give you the confidence to cut back to one irrigation per cutting all season and still have sufficient moisture for decent tonnage. Table 6 provides approximate soil moisture tension guidelines for scheduling irrigations for coarse to fine soils for various depths of infiltrated water (micro to flood). The numbers in this table are for optimum irrigation efficiency and reasonable tree ET.

Estimating Soil Moisture Reserve & Microirrigation Set Times for Orchards

Soil Texture	Field Capacity (in/ft)	Wilting Point (in/ft)	Available Soil Moisture (in/ft)	Avg Drip Subbing Diameter from 1 to 4' Depth (ft)	*Moisture Reserve (gals)
Sand	1.2	0.5	0.7	2	4
Loamy Sand	1.9	0.8	1.1	3	16
Sandy Loam	2.5	1.1	1.4	4	35
Loam	3.2	1.4	1.8	5	70
Silt Loam	3.6	1.8	1.8	6	102
Sandy Clay Loam	3.5	2.2	1.3	7	100
Sandy Clay	3.4	1.8	1.6	7	123
Clay Loam	3.8	2.2	1.7	8	170
Silty Clay Loam	4.3	2.4	1.9	9	241
Silty Clay	4.8	2.4	2.4	9	305
Clay	4.8	2.6	2.2	10	345

*This is the maximum gallons of water stored to a 4' depth beneath a single drip emitter. In fine textured soils, the wetted volume of one emitter merges with another on the same hose and final gallons of moisture reserve per emitter will be less than the number shown in the table. Plant stress will usually be seen when about 50% of this reserve has been used.

Ref: Ratliff LF, Ritchie JT, Cassel DK. 1983. Field-measured limits of soil water availability as related to laboratory-measured properties. Soil Sci Soc Am. 47:770-5.

MOISTURE RESERVE FULL PEAK ALMOND ET – SOUTHERN SAN JOAQUIN VALLEY

Refill Times for Different Soil Textures and Micro Systems

[1]Irrigation Time to Refill & Moisture Reserve of 4 Foot Wetted Rootzone @ 50% to 100% Available

ALMONDS 0.30 inch/day ET

Soil Texture	Available Soil Moisture (in/ft)	Avg Drip Subbing Diameter from 1 to 4' Depth (ft)	**Dble-Line Drip 1-gph**, 10 per tree (irrig hrs)	Moisture Reserve @ 0.30"/day (days)	**10 gph Fanjet**, 1 per tree (irrig hrs)	Moisture Reserve @ 0.30"/day (days)	**14 gph Fanjet**, 1 per tree (irrig hrs)	Moisture Reserve @ 0.30"/day (days)
Sand	0.7	2	2.2	0.3	11.6	1.4	12.5	2.1
Loamy Sand	1.1	3	7.8	0.9	19.6	2.4	20.9	3.6
Sandy Loam	1.4	4	17.5	2.1	26.9	3.3	28.3	4.8
Loam	1.8	5	28.7	3.5	37.1	4.5	38.6	6.6
Silt Loam	1.8	6	35.9	4.4	39.7	4.8	40.8	7.0
Sandy Clay Loam	1.3	6	25.9	3.2	28.6	3.5	29.5	5.0
Sandy Clay	1.6	7	38.3	4.7	37.6	4.6	38.3	6.5
Clay Loam	1.7	8	47.5	5.8	42.6	5.2	42.9	7.3
Silty Clay Loam	1.9	9	60.6	7.4	50.6	6.2	50.5	8.6
Silty Clay	2.4	9	76.6	9.3	64.0	7.8	63.8	10.9
Clay	2.2	10	79.0	9.6	62.3	7.6	61.5	10.5

[1]Based on a tree spacing of 20 x 22'. Drip hoses 6' apart. 10 gph fanjet wets 12' diameter. 14 gph fanjet @ 15' diameter.

Note: Peak water use @ 0.30"/day and 20 x 22' spacing = 82 gallons/day/tree. 0.20"/day = 55 gallons/day/tree.

Table takes into account merging water patterns below soil surface for drip irrigation.

RESERVE @ 17% DEFICIT PEAK ALMOND ET – SOUTHERN SAN JOAQUIN VALLEY

Refill Times for Different Soil Textures and Micro Systems

[1]Irrigation Time to Refill & Moisture Reserve of 4 Foot Wetted Rootzone @ 50% to 100% Available

ALMOND RDI 0.25 inch/day ET

Soil Texture	Available Soil Moisture (in/ft)	Avg Drip Subbing Diameter from 1 to 4' Depth (ft)	Dble-Line Drip 1-gph, 10 per tree (irrig hrs)	Moisture Reserve @ 0.25"/day (days)	10 gph Fanjet, 1 per tree (irrig hrs)	Moisture Reserve @ 0.25"/day (days)	14 gph Fanjet, 1 per tree (irrig hrs)	Moisture Reserve @ 0.25"/day (days)
Sand	0.7	2	2.2	0.3	11.6	1.7	12.5	2.6
Loamy Sand	1.1	3	7.8	1.1	19.6	2.9	20.9	4.3
Sandy Loam	1.4	4	17.5	2.6	26.9	3.9	28.3	5.8
Loam	1.8	5	28.7	4.2	37.1	5.4	38.6	7.9
Silt Loam	1.8	6	35.9	5.2	39.7	5.8	40.8	8.3
Sandy Clay Loam	1.3	6	25.9	3.8	28.6	4.2	29.5	6.0
Sandy Clay	1.6	7	38.3	5.6	37.6	5.5	38.3	7.8
Clay Loam	1.7	8	47.5	6.9	42.6	6.2	42.9	8.8
Silty Clay Loam	1.9	9	60.6	8.8	50.6	7.4	50.5	10.3
Silty Clay	2.4	9	76.6	11.2	64.0	9.3	63.8	13.0
Clay	2.2	10	79.0	11.5	62.3	9.1	61.5	12.6

[1]Based on a tree spacing of 20 x 22'. Drip hoses 6' apart. 10 gph fanjet wets 12' diameter. 14 gph fanjet @ 15' diameter.

Note: Peak water use @ 0.25"/day and 20 x 22' spacing = 68.6 gallons/day/tree. 0.20"/day = 55 gallons/day/tree.

Table takes into account merging water patterns below soil surface for drip irrigation.

FULL PEAK CITRUS (33% deficit almond) ET – SOUTHERN SAN JOAQUIN VALLEY

Refill Times for Different Soil Textures and Micro Systems

[1]Irrigation Time to Refill & Moisture Reserve of 4 Foot Wetted Rootzone @ 50% to 100% Available

CITRUS (almond RDI) 0.20 inch/day ET

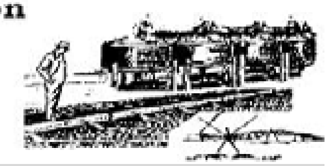
Soil Texture	Available Soil Moisture (in/ft)	Avg Drip Subbing Diameter from 1 to 4' Depth (ft)	Dble-Line Drip 1-gph, 10 per tree (irrig hrs)	Moisture Reserve @ 0.20"/day (days)	10 gph Fanjet, 1 per tree (irrig hrs)	Moisture Reserve @ 0.20"/day (days)	14 gph Fanjet, 1 per tree (irrig hrs)	Moisture Reserve @ 0.20"/day (days)
Sand	0.7	2	2.2	0.4	11.6	2.1	12.5	3.2
Loamy Sand	1.1	3	7.8	1.4	19.6	3.6	20.9	5.3
Sandy Loam	1.4	4	17.5	3.2	26.9	4.9	28.3	7.2
Loam	1.8	5	28.7	5.2	37.1	6.7	38.6	9.8
Silt Loam	1.8	6	35.9	6.5	39.7	7.2	40.8	10.4
Sandy Clay Loam	1.3	6	25.9	4.7	28.6	5.2	29.5	7.5
Sandy Clay	1.6	7	38.3	7.0	37.6	6.8	38.3	9.7
Clay Loam	1.7	8	47.5	8.6	42.6	7.7	42.9	10.9
Silty Clay Loam	1.9	9	60.6	11.0	50.6	9.2	50.5	12.9
Silty Clay	2.4	9	76.6	13.9	64.0	11.6	63.8	16.2
Clay	2.2	10	79.0	14.4	62.3	11.3	61.5	15.7

[1]Based on a tree spacing of 20 x 22'. Drip hoses 6' apart. 10 gph fanjet wets 12' diameter. 14 gph fanjet @ 15' diameter.

Note: Peak water use @ 0.20"/day and 20 x 22' spacing = 55 gallons/day/tree.

Table takes into account merging water patterns below soil surface for drip irrigation.

University of California Cooperative Extension
KERN SOIL AND WATER



Kern County 1031 S. Mt. Vernon Ave, Bakersfield CA 93307 Telephone: (661) 868-6218

Making Sense of Soil Moisture Checking and Sensors to Manage Limited Water

The best key to unlock efficient irrigation practice is to know exactly how much water your crop uses and replace it in a timely fashion that matches your irrigation system capacity and avoids crop stress and water logging. We have good "normal year" estimates of citrus water use (evapotranspiration, ET) for the San Joaquin Valley, but as any grower knows very few blocks are "normal". The Frost Nucellar on the Cajon loamy sand and fanjets in Edison doesn't behave the same as the Fukumotos planted to double-line drip on an Exeter clay loam.

So what's the trick for hitting optimum water management for a particular block? You have to keep account of your soil moisture reservoir in the crop rootzone. Tracking soil moisture tells you whether you're putting on too much or too little water to meet crop needs. It's also the key to increasing fruit set and quality in many crops such as canning tomatoes, improving flavor in most wine grape varieties and possibly help control puff and crease in citrus.

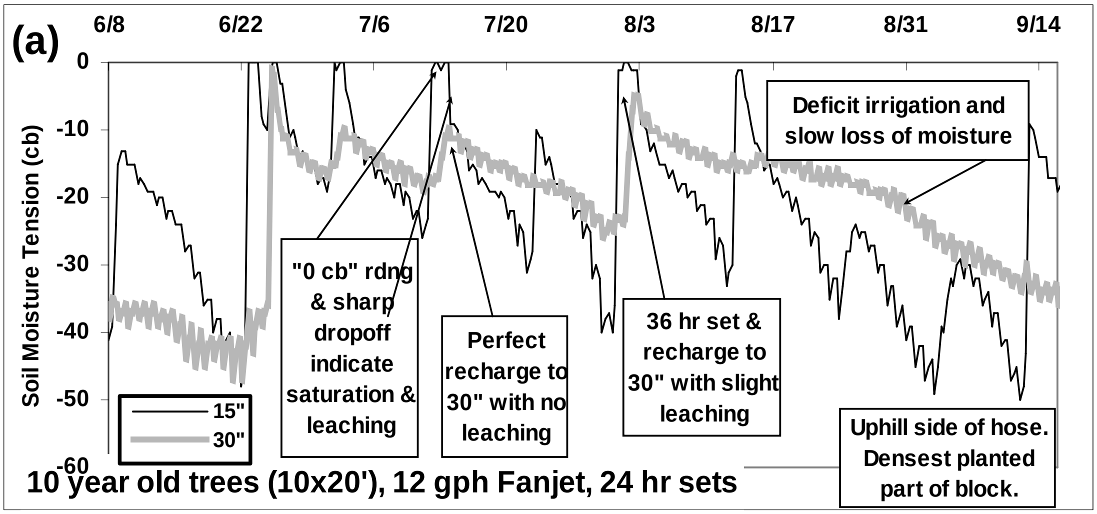
But any farmer and most ag consultants will tell you that checking soil moisture is not for the faint of heart because it requires auguring holes, pounding a soil probe, and/or installing moisture monitoring instruments to depths of 2 to 6 feet depending on the crop. Checking instruments or hand probing needs to be done on at least a weekly basis to be useful.

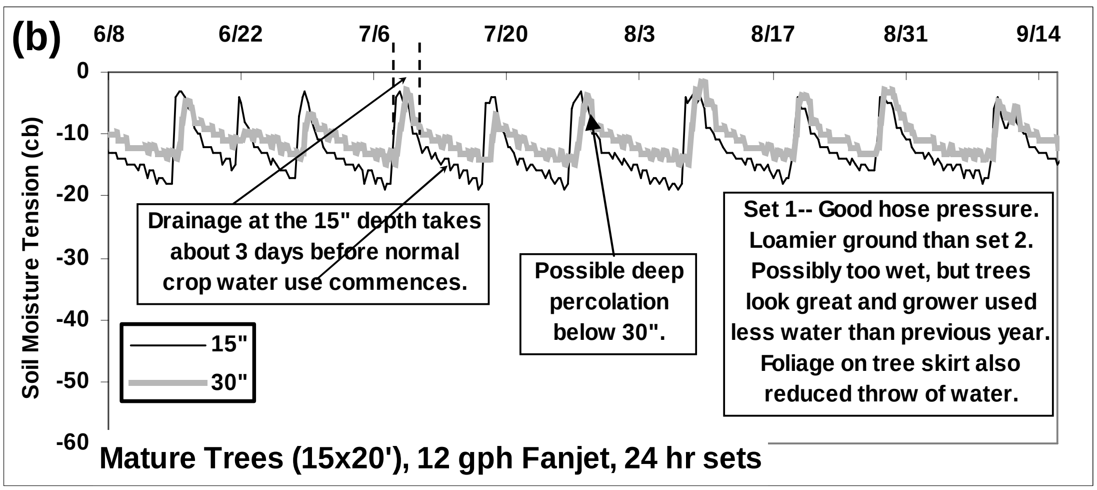
After pushing, twisting, pounding and digging thousands of holes in hundreds of fields around the San Joaquin Valley I can testify to the fact that this is only slightly more fun than shoveling manure, and it's a whole lot harder on your shoulders and wrists. The result is that it's not done very often, if at all, and farmers tend to stick to a traditional irrigation schedule. Given all the other decisions and details growers have to see to on a daily basis it's not surprising this activity gets pushed to the side. At the same time, the years of experience a farmer has with a crop and with a particular field often give him an intuitive sense of how to run the water and end up being 75 to 90% efficient anyway! So if you're already this efficient why check moisture anyway?

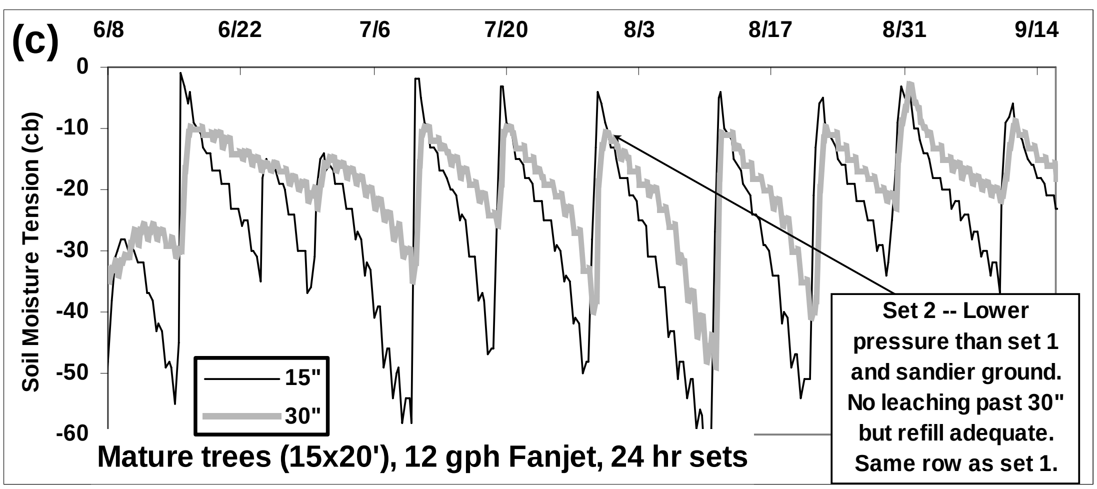
There are two reasons: 1) You're not really sure that you're at the optimum point of the crop water use curve until you check, and 2) The simple math of cost versus benefit. Water monitoring consulting services run around $15/acre/season depending on total acreage and what degree of technology and reporting you want done. If this is the only cost you incur to get the extra 5% out of a 3-bale cotton crop then you've made an extra $22/acre even if cotton is only 50 cents/lb. Even at just $2 net/box, an extra 15 boxes of grapes or extra fancy oranges is a 100% return on your $15 investment.

Many growers have tried tensiometers in the past and usually get fed up with the maintenance. A new generation of medium and high technology sensors are now available to growers and consultants. The huge diversity sensors can be intimidating at first glance but these systems can make this job easier, more accurate and even more affordable. The biggest advantage to the new technology is the use of a continuously recording data logger coupled to responsive soil moisture sensors.

A series of irrigation management/monitoring demonstrations by UC Cooperative Extension over the last 3 years in Kern County has looked at using a combination of 6 granular matrix electrical resistance blocks (Watermark®) coupled to a logger with a graphic display (Hansen AM400®, pictured above) to allow growers a "push button" look at 5 weeks of soil moisture history at any time during the season. The cost of this system is about $600 and should be good for 3 to 5 years. This gives growers a look at the dynamic changes in soil moisture due to actual crop water use and subsequent recharge of the profile during irrigation. The pattern of the peaks and rate of change of these readings is more useful than the actual numbers themselves. Many different sensors and loggers provide this type of information but the AM400/Watermark system is the only combination providing a graphic display in the field without having to download to a computer. Computer downloads can also be done anytime during the season to develop charts such as those shown below.







Charts (a), (b) and (c) show the changes in soil moisture for 2 different blocks of early navels in the Edison area of Kern County for summer 2003. Comments are placed in boxes connected to explain what these patterns mean.

Even though all 3 of these monitoring locations are within 800 feet of each other we see very different changes in soil moisture. The hedgerow block (a) has many skips as the grower has begun pulling trees and he wants to avoid over watering the whole block.

Charts (b) and (c) are for trees in the same row but different sets. Slightly higher hose pressures and loamier ground keep (b) moister than (c), which shows almost a perfectly efficient pattern of crop water use and recharge. To keep the trees in (c) from looking "hot" required an irrigation frequency for this block that resulted in the wetter condition at location (b). But the bottom line for the grower is these trees have never looked better, he used less water in 2003 and had a better packout than in 2002.

Irrometer, Onset and Spectrum companies also make inexpensive loggers (<$400) that can be used with Watermark blocks. The Watermark block is currently the least expensive, fairly reliable sensor. An excellent website for explaining soil moisture sensors is: **http://www.sowacs.com/sensors/index.html** (Note: use of any product names is not intended as a commercial endorsement.)

GENERAL COMPARISON OF SOIL MOISTURE SENSORS AND LOGGERS

(All prices are an approximation for comparison only)

Sensor Type	Advantages	Disadvantages	Cost
Tensiometer (Irrometer, Soil Moisture Equip)	Mechanical, no power required, not affected by salinity, good for veg crops, easy installation, can be hooked to a logger if pressure transducers substituted for pressure gauge on instrument	Requires maintenance, not good for drier soil moisture levels, must read gauge at site, manual record keeping of occasional readings, reads soil water "tension" and not actual content	$60 – 90, depending on length, pressure transducer $210
Modified Electrical Resistance (Watermark)	No maintenance, least cost sensor, can be buried and remotely monitored with logger or checked with hand meter, good in dry conditions, easy installation	Can have problems with good contact in coarse sandy soil, can be affected by high salinity (>5 mmhos/cm), reads "tension" and not water content	$30 – 60, depending on logger adapter, $240 hand meter
Capacitance (Aquatel, Aquapro, Echo, Enviroscan, PureSense)	Can be calibrated to read actual soil water content, long-lasting sensors-some hermetically sealed, some can detect very small changes in water content	Signal strength/accuracy variable from one model to another, wire run length maybe limited, can be highly influenced by salinity and heavy soil, can require more power, some only "%" moisture	$100 – 6000, plus logger or hand meter reqd & misc $200-4000
Time Domain Reflectometry TDR (FDR) (Trime, Tektro-nic, Gro-Point)	Potential for greatest accuracy over a wide range of soil types on high end models with site specific calibration, access tube types read multiple depths	Requires most power, factory calibration in %moisture, **movable access tube type not suitable for automated readings**	$250 – 7500, proprietary logger/meter/ tubes reqd $1000 - 6000
Neutron Probe	Most adaptable to wide range of soil types, accuracy increases with local calibration, gives actual water content, least sensitive to installation precision, use cheap 2" PVC Class 125 pipe for site	Needs radiation license and monitoring, **not suitable for automated readings**	$6,000 for unit, ~$2 for 6 foot PVC tube

LOGGERS: A huge selection of loggers are out there. Some sensors are adaptable to numerous loggers, some can only be used with proprietary loggers/meters. Several consultants operate in the Valley that use one or more of the above devices: providing all the way from field visits, hand recording and processing moisture readings to radio/cell phone uploads of remote sensors to the Internet and office computers. Yearly fees are required for Web-based monitoring ranging from $25 to $150 per site. The Hanson AM 400 logger is the only one with a graphic display on the logger that does not require downloading to view.

Watchdog logger can take 3 Watermark Blocks and a pressure switch. $314

8 channel Irrometer logger for Watermark sensors. $389

AM 400 logger can accept 6 Watermarks and Temp sensor. $389

Weather station hookups and/or soil moisture sensors can be either bounced from station to station or connected via cell phone. Costs for the installation site: $500 – 2500 plus yearly fees for download via Internet.

SCHEDULING IRRIGATIONS USING CIMIS & SOIL MOISTURE

THE TOOLBOX: Fortunately, we have a number of tools to help us on the water front: **1) Weather records** of our very stable climate in the San Joaquin Valley that allow us to estimate the **"historic or normal year" potential evapotranspiration (ETo), 2) Crop coefficients (Kc)** for most of our important crops that relate crop ET to changes in crop development over the season, **3) Statewide CIMIS weather stations** (California Irrigation Management Information Service) that can be accessed through the internet to tell you when current ET is significantly different from "normal", and **4) Soil moisture monitoring technology and consulting services** to optimize the above estimates to a specific orchard site. Using only two or three of these tools is like driving a car without all four wheels – the ride will not be smooth, or efficient.

To Access CIMIS for Potential Evapotranspiration (ETo) data follow below steps:

Website Address: **http://www.cimis.water.ca.gov/**

Non-Members – last 7 days only:

1. Select Data tab on header
2. Sample Daily or Monthly report
3. Select County
3. Submit – gives last 7 days for all stations in county

KERN COUNTY CIMIS STATIONS

5	Shafter/USDA
54	Blackwell's Corner
125	Arvin-Edison
138	Famoso
146	Belridge
172	Lost Hills NW

Signing up for membership is free, can be done on the website and allows many more options for data access.

CURRENT DEBATE OVER "HISTORIC ETo": The science of crop water/weather monitoring continues to change. Fifteen years ago the "historic ETo" for the San Joaquin Valley was put at 49 inches/year. New calculations using CIMIS data now put this number at 57 inches/year. Wow, 8 inches more … is this global warming? Not really. We now have many more weather stations and some changes in the way ETo is calculated, but which number is right? That's why you need **Tool (4)**, because the "right" number is the one that keeps your trees well watered without wasting water and you won't know unless you have a way to check the moisture status of the rootzone.

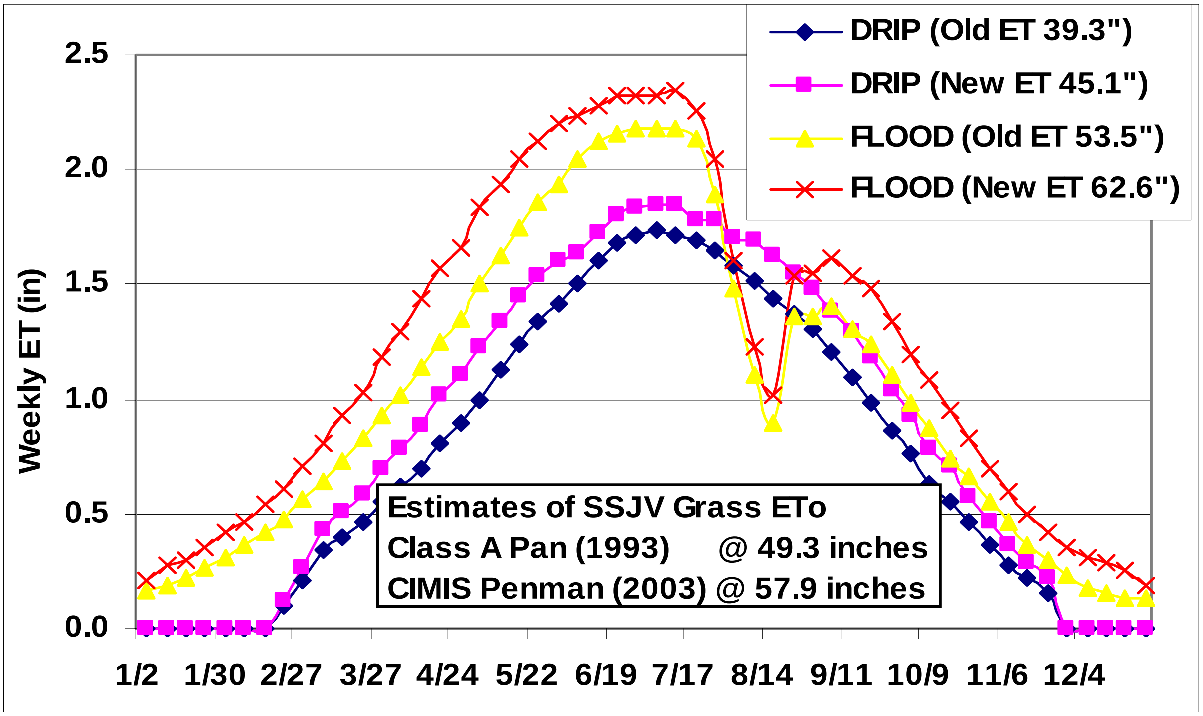
CALCULATING CROP ET USING CIMIS ETo and CROP COEFFICIENTS (Kc): use the below formula with the appropriate Kc for the time of year multiplied by the CIMIS ETo for your region to calculate "normal year" crop ET.

$$ET_{crop} = ET_o * K_c * E_f$$

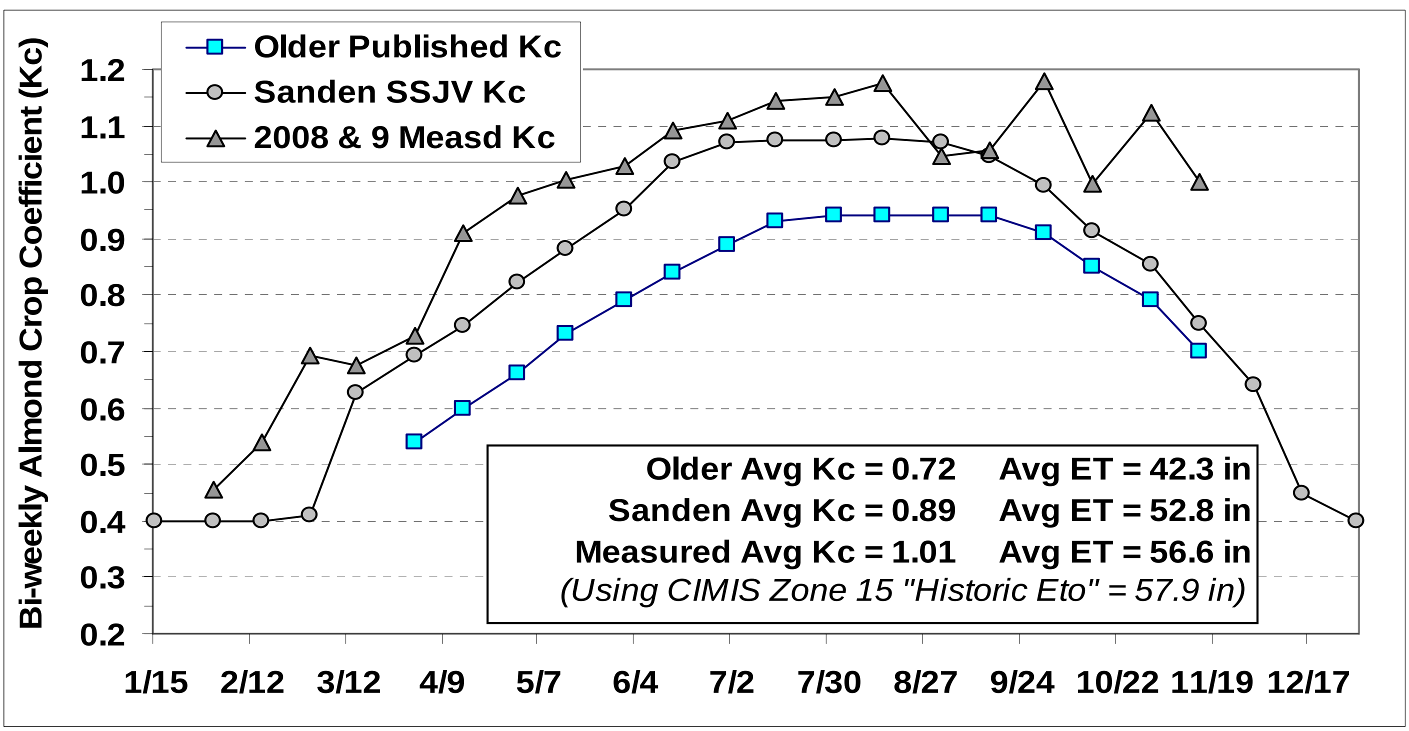
ET_o = **reference crop** (tall grass, CIMIS) ET

K_c = **crop coefficient** for a given stage of crop growth as a ratio of crop/grass water use. May be 0 to 1.3, standard values are good starting point.

E_f = an "**environmental factor**" that can account for immature permanent crops and/or impact of salinity. May be 0.1 to 1.1, determined by site.



Comparing 1993 and 2003 estimates of Potential Evapotranspiration (ETo) for SJV and changes in estimated almond ET for drip to flood systems. The dip in the curve for flood irrigation represents significant stress and reduced ET by the crop due to harvest cutoff and drying of nuts before pickup. This stress can be avoided in micro systems as water can be run at low pressure even with nuts on the ground. The old estimate of 39.3 inches for drip system ET is not enough water for high production almonds.



These curves compare the older published Kc curve (39 to 42 inches/year ET) for mature almonds on micro irrigation to Kc numbers developed by Blake Sanden in Kern County through irrigation demonstration monitoring and the 2 year average of a current large-scale field trial. The middle curve is recommended and is used for the next table.

“NORMAL YEAR” WEEKLY CALCULATED ET FOR ALMONDS IN SSJV

CIMIS ET Estimates Using Zone 15 Southern SJV "Historic" ETo							
	Normal Year Grass ETo	Mature Crop Coef-ficient	Almond ET -- Minimal Cover Crop, MIcrosprinkler (S. San Joaquin Valley)				
Week	(in)	(Kc)	1st Leaf @ 40%	2nd Leaf @ 55%	3rd Leaf @ 75%	4th Leaf @ 90%	Mature
1/6	0.21	0.40	0.03	0.05	0.06	0.08	**0.09**
1/13	0.28	0.40	0.03	0.06	0.08	0.10	**0.11**
1/20	0.30	0.40	0.04	0.07	0.09	0.11	**0.12**
1/27	0.36	0.40	0.04	0.08	0.11	0.13	**0.14**
2/3	0.42	0.40	0.05	0.09	0.13	0.15	**0.17**
2/10	0.47	0.40	0.06	0.10	0.14	0.17	**0.19**
2/17	0.54	0.40	0.06	0.12	0.16	0.19	**0.22**
2/24	0.61	0.40	0.07	0.13	0.18	0.22	**0.24**
3/3	0.69	0.42	0.09	0.16	0.22	0.26	**0.29**
3/10	0.79	0.61	0.14	0.27	0.36	0.43	**0.48**
3/17	0.89	0.64	0.17	0.31	0.43	0.51	**0.57**
3/24	0.98	0.67	0.20	0.36	0.49	0.59	**0.65**
3/31	1.09	0.72	0.23	0.43	0.59	0.70	**0.78**
4/7	1.19	0.74	0.26	0.48	0.66	0.79	**0.88**
4/14	1.32	0.75	0.30	0.55	0.74	0.89	**0.99**
4/21	1.41	0.81	0.34	0.63	0.85	1.03	**1.14**
4/28	1.49	0.83	0.37	0.68	0.93	1.12	**1.24**
5/5	1.59	0.86	0.41	0.75	1.03	1.23	**1.37**
5/12	1.66	0.90	0.45	0.83	1.13	1.35	**1.50**
5/19	1.73	0.94	0.49	0.89	1.22	1.46	**1.63**
5/26	1.78	0.96	0.51	0.94	1.29	1.54	**1.72**
6/2	1.85	0.98	0.54	0.99	1.35	1.62	**1.80**
6/9	1.86	0.99	0.55	1.01	1.38	1.65	**1.83**
6/16	1.90	1.02	0.58	1.06	1.45	1.74	**1.93**
6/23	1.93	1.05	0.61	1.11	1.52	1.82	**2.03**
6/30	1.93	1.06	0.62	1.13	1.54	1.85	**2.05**
7/7	1.93	1.08	0.62	1.14	1.56	1.87	**2.07**
7/14	1.93	1.08	0.62	1.14	1.56	1.87	**2.07**
7/21	1.86	1.08	0.60	1.10	1.50	1.80	**2.00**
7/28	1.86	1.07	0.60	1.10	1.50	1.79	**1.99**
8/4	1.78	1.07	0.57	1.05	1.44	1.72	**1.91**
8/11	1.75	1.08	0.57	1.04	1.42	1.70	**1.89**
8/18	1.69	1.08	0.55	1.00	1.36	1.64	**1.82**
8/25	1.62	1.07	0.52	0.96	1.30	1.57	**1.74**
9/1	1.55	1.07	0.50	0.91	1.24	1.49	**1.66**
9/8	1.47	1.06	0.47	0.85	1.17	1.40	**1.55**
9/15	1.40	1.04	0.43	0.80	1.08	1.30	**1.45**
9/22	1.31	1.02	0.40	0.73	1.00	1.19	**1.33**
9/29	1.19	0.97	0.35	0.64	0.87	1.04	**1.16**
10/6	1.10	0.95	0.31	0.57	0.78	0.94	**1.04**
10/13	1.00	0.88	0.26	0.48	0.66	0.79	**0.88**
10/20	0.90	0.88	0.24	0.43	0.59	0.71	**0.79**
10/27	0.77	0.83	0.19	0.35	0.48	0.58	**0.64**
11/3	0.67	0.78	0.16	0.29	0.39	0.47	**0.53**
11/10	0.57	0.71	0.12	0.22	0.31	0.37	**0.41**
11/17	0.48	0.68	0.10	0.18	0.25	0.30	**0.33**
11/24	0.42	0.60	0.07	0.14	0.19	0.22	**0.25**
12/1	0.36	0.50	0.05	0.10	0.13	0.16	**0.18**
12/8	0.31	0.40	0.04	0.07	0.09	0.11	**0.12**
12/15	0.29	0.40	0.03	0.06	0.09	0.10	**0.11**
12/22	0.25	0.40	0.03	0.06	0.08	0.09	**0.10**
12/29	0.21	0.40	0.03	0.05	0.06	0.08	**0.09**
Total	**57.90**		**15.68**	**28.75**	**39.20**	**47.05**	**52.27**

"NORMAL YEAR" WEEKLY CALCULATED ET FOR CITRUS IN SSJV

CIMIS Average Citrus ET by Crop Age -- Zone 15 SSJV

Week	Normal Year Grass ETo	Mature Crop Coefficient (Kc)	--Weekly Citrus ET (inches/week)-- Wide Spaced, No Cover Crop, Fanjet 1st Leaf @ 15%	3rd Leaf @ 40%	5th Leaf @ 70%	7th Leaf @ 90%	Mature
1/7	0.21	0.75	0.02	0.06	0.11	0.14	**0.16**
1/14	0.28	0.75	0.03	0.08	0.14	0.19	**0.21**
1/21	0.30	0.75	0.03	0.09	0.16	0.20	**0.22**
1/28	0.36	0.75	0.04	0.11	0.19	0.24	**0.27**
2/4	0.42	0.75	0.05	0.13	0.22	0.28	**0.31**
2/11	0.47	0.74	0.05	0.14	0.24	0.31	**0.35**
2/18	0.54	0.74	0.06	0.16	0.28	0.36	**0.40**
2/25	0.61	0.73	0.07	0.18	0.31	0.40	**0.44**
3/4	0.69	0.73	0.08	0.20	0.35	0.45	**0.50**
3/11	0.79	0.71	0.08	0.22	0.39	0.50	**0.56**
3/18	0.87	0.70	0.09	0.24	0.43	0.55	**0.61**
3/25	0.98	0.70	0.10	0.27	0.48	0.62	**0.69**
4/1	1.09	0.70	0.11	0.31	0.53	0.69	**0.76**
4/8	1.19	0.70	0.13	0.33	0.58	0.75	**0.84**
4/15	1.32	0.70	0.14	0.37	0.64	0.83	**0.92**
4/22	1.41	0.70	0.15	0.39	0.69	0.89	**0.98**
4/29	1.49	0.70	0.16	0.42	0.73	0.94	**1.04**
5/6	1.59	0.70	0.17	0.45	0.78	1.00	**1.11**
5/13	1.66	0.70	0.17	0.47	0.81	1.05	**1.16**
5/20	1.73	0.70	0.18	0.49	0.85	1.09	**1.21**
5/27	1.78	0.69	0.18	0.49	0.86	1.10	**1.23**
6/3	1.85	0.68	0.19	0.50	0.87	1.12	**1.25**
6/10	1.88	0.66	0.19	0.50	0.87	1.12	**1.25**
6/17	1.91	0.65	0.19	0.50	0.87	1.12	**1.24**
6/24	1.93	0.65	0.19	0.50	0.88	1.13	**1.25**
7/1	1.94	0.65	0.19	0.50	0.88	1.13	**1.26**
7/8	1.94	0.65	0.19	0.50	0.88	1.13	**1.26**
7/15	1.93	0.65	0.19	0.50	0.88	1.13	**1.25**
7/22	1.89	0.65	0.18	0.49	0.86	1.11	**1.23**
7/29	1.86	0.65	0.18	0.48	0.84	1.09	**1.21**
8/5	1.80	0.65	0.18	0.47	0.82	1.05	**1.17**
8/12	1.75	0.65	0.17	0.46	0.80	1.03	**1.14**
8/19	1.69	0.65	0.17	0.44	0.77	0.99	**1.10**
8/26	1.62	0.65	0.16	0.42	0.74	0.95	**1.05**
9/2	1.55	0.68	0.16	0.42	0.74	0.95	**1.06**
9/9	1.47	0.73	0.16	0.43	0.75	0.96	**1.07**
9/16	1.40	0.78	0.16	0.44	0.76	0.98	**1.09**
9/23	1.31	0.65	0.13	0.34	0.59	0.76	**0.85**
9/30	1.19	0.66	0.12	0.32	0.55	0.71	**0.79**
10/7	1.10	0.69	0.11	0.30	0.53	0.68	**0.76**
10/14	1.00	0.70	0.10	0.28	0.49	0.63	**0.70**
10/21	0.90	0.70	0.09	0.25	0.44	0.57	**0.63**
10/28	0.77	0.70	0.08	0.22	0.38	0.49	**0.54**
11/4	0.67	0.70	0.07	0.19	0.33	0.42	**0.47**
11/11	0.57	0.70	0.06	0.16	0.28	0.36	**0.40**
11/18	0.48	0.70	0.05	0.13	0.23	0.30	**0.34**
11/25	0.40	0.70	0.04	0.11	0.20	0.25	**0.28**
12/2	0.34	0.70	0.04	0.10	0.17	0.21	**0.24**
12/9	0.29	0.70	0.03	0.08	0.14	0.18	**0.20**
12/16	0.26	0.70	0.03	0.07	0.13	0.16	**0.18**
12/23	0.23	0.70	0.02	0.06	0.11	0.14	**0.16**
12/30	0.21	0.73	0.02	0.06	0.11	0.14	**0.16**
Total	**57.90**		**5.93**	**15.82**	**27.68**	**35.59**	**39.54**

“NORMAL YEAR” WEEKLY CALCULATED ET FOR PISTACHIO IN SSJV

CIMIS ET Estimates Using Zone 15 Southern SJV "Historic" Eto PISTACHIOS

> **Note:** the below numbers are a guide only. There are some areas of Kern County where elevated soil/water salinity reduces pistachio ET by as much as 15 to 25%. There are other locations where adjacent canals and sand layers allow shallow groundwater to move out under fields and be taken up by pistachio roots -- reducing the need for surface applied irrigation water. Augering/probing for current soil moisture levels in the orchard rootzone is the only way to insure that you are not deficit or overirrigating.
>
> 4,000 lb/ac pistachios have been grown in Kern County with as little as 30 inches to as much as 52 inches of water.

Week Ending	Normal Year Grass ETo	[1]Pistachio Crop Coef-ficients	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	Year 9 (>65% cover)
	Adjustment Factor		**0.10**	**0.15**	**0.22**	**0.30**	**0.40**	**0.65**	**0.78**	**0.90**	**1.00**
1/7	0.21										
1/14	0.28										
1/21	0.30										
1/28	0.36										
2/4	0.42										
2/11	0.47										
2/18	0.54										
2/25	0.61										
3/3	0.69										
3/10	0.79										
3/17	0.89										
3/24	0.98	0.07	0.01	0.01	0.02	0.02	0.03	0.04	0.05	0.06	0.07
3/31	1.09	0.10	0.01	0.02	0.02	0.03	0.04	0.07	0.09	0.10	0.11
4/7	1.19	0.20	0.02	0.04	0.05	0.07	0.10	0.16	0.19	0.21	0.24
4/14	1.32	0.30	0.04	0.06	0.09	0.12	0.16	0.26	0.31	0.36	0.39
4/21	1.41	0.40	0.06	0.08	0.12	0.17	0.23	0.37	0.44	0.51	0.56
4/28	1.49	0.50	0.07	0.11	0.16	0.22	0.30	0.48	0.58	0.67	0.74
5/5	1.59	0.60	0.10	0.14	0.21	0.29	0.38	0.62	0.74	0.86	0.95
5/12	1.66	0.70	0.12	0.17	0.26	0.35	0.47	0.76	0.91	1.05	1.16
5/19	1.73	0.90	0.16	0.23	0.34	0.47	0.62	1.01	1.22	1.40	1.56
5/26	1.78	1.00	0.18	0.27	0.39	0.54	0.71	1.16	1.39	1.61	1.78
6/2	1.85	1.10	0.20	0.30	0.45	0.61	0.81	1.32	1.58	1.83	2.03
6/9	1.86	1.15	0.21	0.32	0.47	0.64	0.85	1.39	1.66	1.92	2.13
6/16	1.90	1.17	0.22	0.33	0.49	0.67	0.89	1.44	1.73	2.00	2.22
6/23	1.93	1.17	0.23	0.34	0.50	0.68	0.90	1.47	1.76	2.03	2.25
6/30	1.93	1.19	0.23	0.34	0.50	0.69	0.92	1.49	1.79	2.06	2.29
7/7	1.93	1.19	0.23	0.34	0.50	0.69	0.92	1.49	1.79	2.06	2.29
7/14	1.93	1.19	0.23	0.34	0.50	0.69	0.92	1.49	1.79	2.06	2.29
7/21	1.86	1.19	0.22	0.33	0.49	0.66	0.88	1.44	1.72	1.99	2.21
7/28	1.86	1.19	0.22	0.33	0.49	0.66	0.88	1.44	1.72	1.99	2.21
8/4	1.78	1.19	0.21	0.32	0.47	0.64	0.85	1.38	1.66	1.91	2.12
8/11	1.75	1.19	0.21	0.31	0.46	0.63	0.83	1.36	1.63	1.88	2.09
8/18	1.69	1.19	0.20	0.30	0.44	0.60	0.81	1.31	1.57	1.81	2.01
8/25	1.62	1.12	0.18	0.27	0.40	0.54	0.73	1.18	1.42	1.63	1.82
9/1	1.55	1.12	0.17	0.26	0.38	0.52	0.69	1.13	1.35	1.56	1.74
9/8	1.47	1.00	0.15	0.22	0.32	0.44	0.59	0.95	1.15	1.32	1.47
9/15	1.40	0.95	0.13	0.20	0.29	0.40	0.53	0.86	1.04	1.19	1.33
9/22	1.31	0.96	0.13	0.19	0.28	0.38	0.50	0.82	0.98	1.13	1.26
9/29	1.19	0.88	0.10	0.16	0.23	0.31	0.42	0.68	0.82	0.94	1.05
10/6	1.10	0.87	0.10	0.14	0.21	0.29	0.38	0.62	0.74	0.86	0.95
10/13	1.00	0.80	0.08	0.12	0.18	0.24	0.32	0.52	0.62	0.72	0.80
10/20	0.90	0.74	0.07	0.10	0.15	0.20	0.27	0.43	0.52	0.60	0.67
10/27	0.77	0.71	0.05	0.08	0.12	0.16	0.22	0.36	0.43	0.49	0.55
11/3	0.67	0.70	0.05	0.07	0.10	0.14	0.19	0.31	0.37	0.42	0.47
11/10	0.57	0.45	0.03	0.04	0.06	0.08	0.10	0.17	0.20	0.23	0.26
11/17	0.48	0.40	0.02	0.03	0.04	0.06	0.08	0.12	0.15	0.17	0.19
11/24	0.42	0.30	0.01	0.02	0.03	0.04	0.05	0.08	0.10	0.11	0.13
12/1	0.36										
12/8	0.31										
12/15	0.29										
12/22	0.25										
12/29	0.21										
Total	**57.90**		**4.74**	**7.11**	**10.43**	**14.22**	**18.96**	**30.81**	**36.97**	**42.66**	**47.40**

[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.

Simplified Stem & Leaf Water Potential Guidelines for Almonds, Citrus and Pistachio

(<u>Note:</u> The following guidelines assume that irrigation water is excellent quality and salinity is not accumulating to damaging levels.)

<u>Using the pressure chamber to determine tree stress:</u>

Before we can begin to understand the best times to reduce water and apply stress to a tree we need to have a means to measure the degree of that stress in the tree. The easiest way to measure this water potential is with the pressure chamber. This device, also called a pressure "bomb", is basically an aluminum chamber capable of applying up to 600 psi (40 atmospheres, or bars) of pressure on a leaf. The petiole of the leaf is sealed in a rubber gasket in the top of the chamber with the cut end sticking out. When the pressure applied to the leaf equals the force with which the xylem sap was under when the leaf was cut then the liquid sap oozes out of the end of the stem. The more stress on the tree (which is actually a negative pressure), the more pressure required to reach the "endpoint" to make the sap ooze out. If a bare leaf is used this is called the leaf water potential (LWP), or if the leaf is first bagged for 15 to 30 minutes or a damp rag placed around the leaf prior to cutting then the leaf reflects more the stem water potential (SWP) of the tree. For almonds the low to no-stress range is around -8 to -10 bars and wilting and some defoliation starts around -18 to -20 bars. A fuller explanation of how to use the pressure bomb, by Allan Fulton, Irrigation Advisor for Tehama County can be found on the web at: http://cetehama.ucdavis.edu/files/37294.pdf.

Table 1, following, lists the various stress levels in bars for almonds, citrus, pistachio and walnut. The ranges are broad as operator method, tree variability and air temperature can vary readings by +/- 1.5 bars. (See below figures, Goldhamer and Fereres (2001). **1 MPa = 10 bars.**)

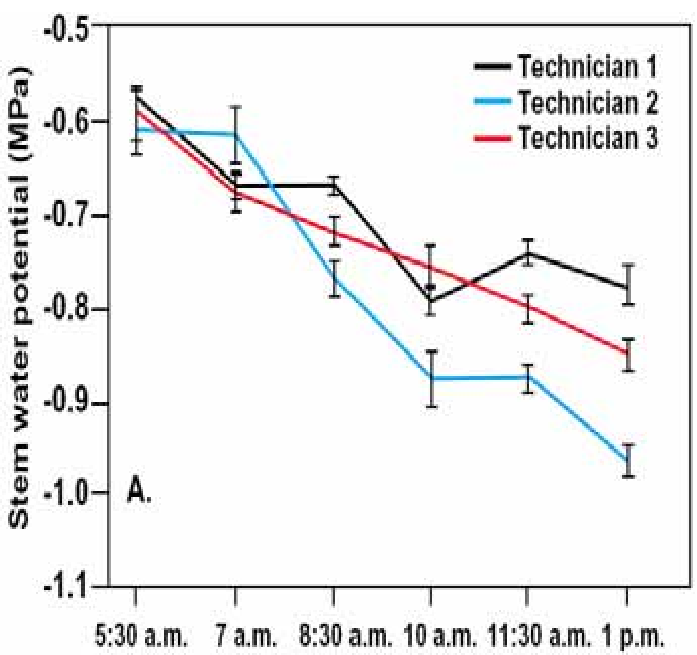


Fig. 1. Diurnal measurements of SWP for the same four trees by technicians using the same sampling technique on Aug. 4, 2000. Each data point is the mean of single measurements on each of 4 trees. Vertical bars represent two standard errors of the mean.

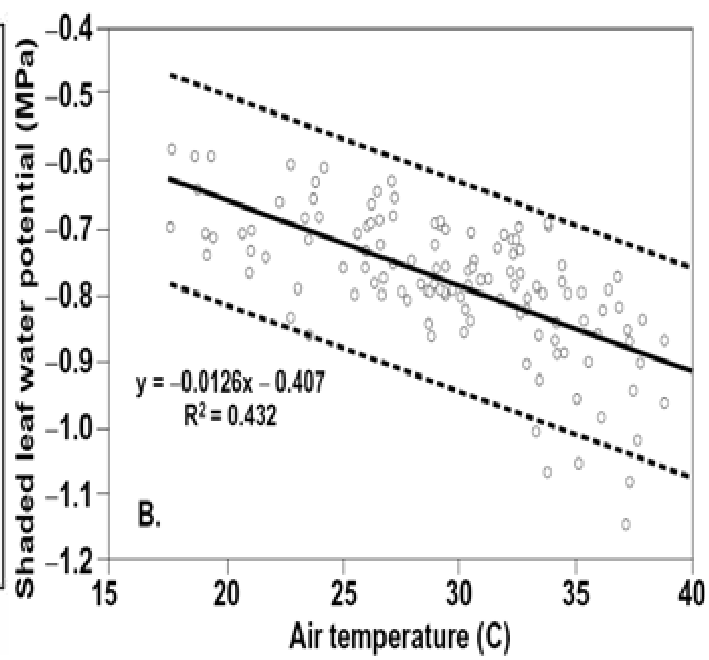


Fig.2. Relationship between shaded LWP using damp cloth and air temperature at the 2 p.m. sampling time for fully irrigated almond trees. Each data point is the mean of four trees. June-October. With 95% confidence limits.

GUIDELINES FOR INTERPRETING PRESSURE CHAMBER READINGS (midday stem water potential (SWP) for almonds, pistahcio and walnuts, and midday shaded leaf water potential (LWP) for citrus)

ALMOND & WALNUT: Allan Fulton/Richard Buchner-UCCE Tehama; Joe Grant-UCCE San Joaquin; Terry Prichard, Bruce Lampinen, Larry Schwankl, Ken Shackel Extension Specialists, UC Davis.

CITRUS & PISTACHIO: Dave Goldhamer-UCCE Kearney Ag Center; Craig Kallsen/Blake Sanden UCCE Kern County

Pressure Chamber Reading (- bars)	ALMOND	CITRUS	PISTACHIO	WALNUT
0 to -2	Not commonly observed	Not commonly observed	Not commonly observed	Not commonly observed
-2 to -4	↓	↓	Fully irrigated, mild spring conditions, rapid shoot expansion. Excellent for early season flush. Avoid saturation on heavy soils.	Fully irrigated using CIMIS ETc estimates, low stress, phytophthora may be a concern, especially on California Black rootstock.
-4 to -6	↓	↓	↓	Low to mild stress, high rate of shoot growth visible, suggested level from leaf-out until mid June when nut sizing is completed.
-6 to -8	Low stress, indicator of fully irrigated conditions, ideal conditions for shoot growth. Suggest maintaining these levels from leaf-out through mid June.	Low stress, indicator of fully irrigated conditions, ideal conditions for shoot growth. Excellent for early season flush.	Low stress, indicator of fully irrigated conditions, ideal conditions for shoot growth.	Mild to moderate stress, shoot growth in non-bearing and bearing trees has been observed to decline. These levels do not appear to affect kernel development.
-8 to -10	↓	↓	Moderate stress, may slightly reduce shoot growth.	Moderate to high stress, shoot growth may stop, nut sizing may be reduced in bearing trees and bud development for next season may be negatively affected.
-10 to -12	Mild to moderate stress, these levels of stress may be appropriate during the phase of growth just before the onset of hull split (late June).	Mild to moderate stress, puff and crease in navels still occurs in this range.	Leaves can "harden" and slightly cup, shell splitting/nut size can be reduced during nutfill (Jul-Aug).	High stress, temporary wilting of leaves has been observed. New shoot growth may be sparse or absent and some defoliation may be evident. Nut size likely to be reduced.
-12 to -14	↓	↓	↓	Relative high levels of stress, moderate to severe defoliation, should be avoided.
-14 to -18	Moderate stress in almond. Suggested stress level during hull split, Help control diseases such as hull rot and alternaria, if present. Hull split occurs more rapidly	Moderate stress, can accelrate color in early Becks (Sep-Oct), control puff and crease/size in Frost Nucellar, Washington (5/16-7/15)	Increasing stress, slight defoliation, may reduce shell hardness/increase splits Stage 2 (May-Jun).	Severe defoliation, trees are likely dying.
-18 to -20	Transitioning from moderate to higher crop stress levels	Stress prominent, leaf cupping obvious and can feel "warm" to the touch. Yield/size loss in early Becks (Sep-Oct). Controlled granulation Lane Late/best packout (Jul-Sep).	Stress prominent, leaf hardening and cupping obvious and can feel "warm" to the touch.	Not observed at these levels in English walnut ↓
-20 to -30	High stress, wilting observed, some defoliation	High stress, severe cupping, some defoliation	High stress, significant defoliation.	↓
Less than -30	Extensive defoliation has been observed	Significant defoliation	↓	↓

Westside Almond Irrigation & N trial – Yields, applied water, & 2003 soil moisture.

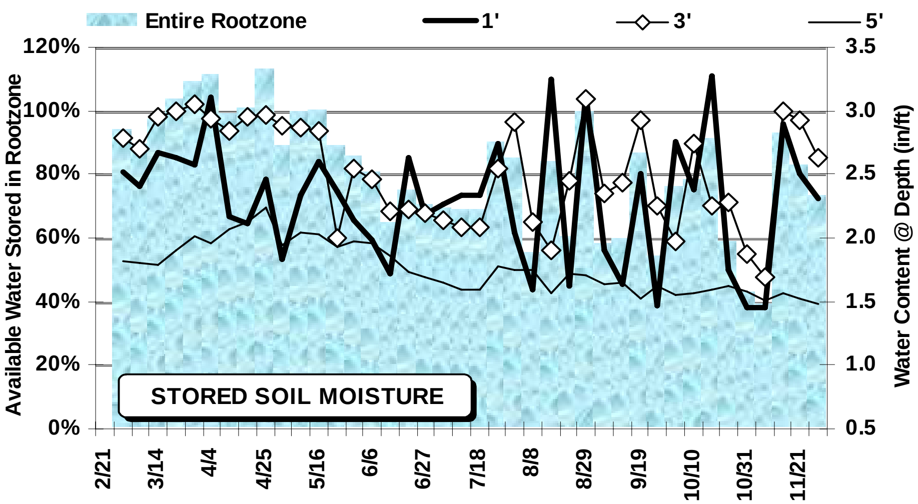
Nonpariel yields (lb/ac) by applied irrigation & N fertilizer (lb/ac) for 5th-9th leaf almonds, NW Kern.

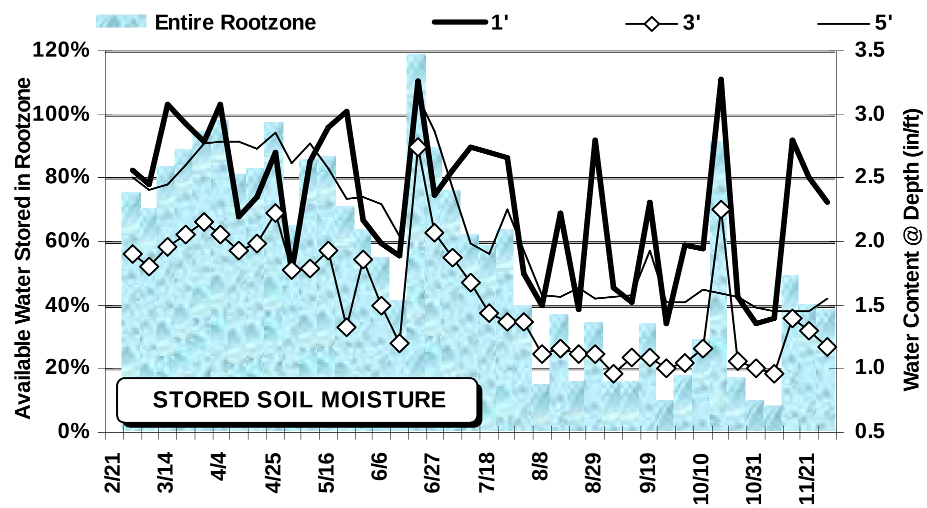
	Full Irrigation			Reduced Irrigation		
	(in)	N~250	N~125	(in)	N~250	N~125
2001	25%	1926	1898	?	1979	1992
2002	48.5	1922	1275	38.8	1593	1215
2003	57.6	3004	2030	47.1	2352	1901
2004	59.7	2838	2752	47.9	2307	2209
2005	53.8	2227	1493	44.5	1758	1538
2006	52.5	3241	2697	41.5	2739	2330
2002-6	**272.1**	**13232**	**10247**	**219.8**	**10749**	**9193**
Wtr Use Eff (lb/in)		**48.6**	**37.7**		**48.9**	**41.8**

*Lampinen, B., T.Dejong, S.Weinbaum, S.Metcalf, C. Negron, M.Viveros, J. McIlvane, N.Ravid, and R.Baker. 2006. Spur dynamics and almond productivity. CA Almond Board 2005 Conference Proceedings, 16pp.

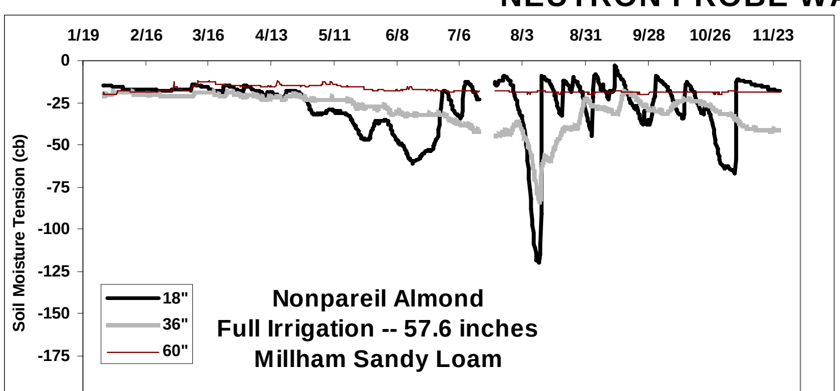
Full Irrigation
57.6 Total for 2003
3.2" Dormant Refill
54.4" In-Season

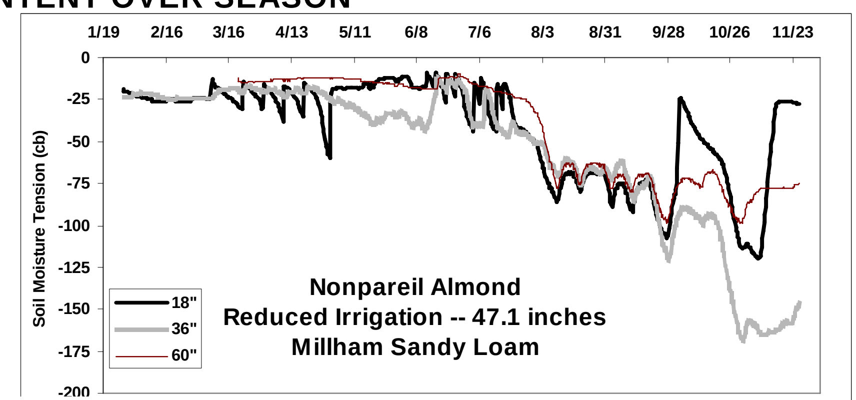
Reduced Irrigation
47.9 Total for 2003
2.9" Dormant Refill
45.0" In-Season





NEUTRON PROBE WATER CONTENT OVER SEASON





WATERMARK® SOIL MOISTURE TENSION OVER SEASON

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Using Reference Evapotranspiration (ET_o) and Crop Coefficients to Estimate Crop Evapotranspiration (ET_c) for Trees and Vines. UC Publication 21428.

(Also unpublished data and personal experience collected by Blake Sanden, Irrigation & Agronomy Advisor, UCCE Kern County.)

Excellent website **explaining soil moisture sensors**:
http://www.sowacs.com/sensors/index.html

New UC DROUGHT MANAGEMENT WEBSITE
http://ucmanagedrought.ucdavis.edu/index.cfm

Soil Probes: Art's Manufacturing **http://www.ams-samplers.com**
Part 401.07 7/8 in. x 33 in. Chrome Soil Probe with Cross Handle and Slide Hammer