Fertigation: Interaction of Water Management and Nutrient Management in Almond

Project No.: **10-HORT11A-Sanden/Shackel**

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Objectives:

The broad objective of this combined research effort is to: 1) Better understand the variability of almond tree response to water and fertility inputs, and 2) determine the optimal combination of tree water and nutrient status to achieve high and sustainable almond yields and quality.

(Statewide-Shackel) Document the variability of yield in four production orchards from Colusa to Kern County as a function of tree stress (as measured by midday bagged leaf/stem water potential (SWP)) throughout the season, applied water and nitrogen fertility.

(Kern County-Sanden) For this intensively monitored site, determine:

1) The maximum crop water use (ET) potential of almonds.

2) If N fertilizer rates and crop yield differentially impact tree ET.
3) If these factors behave differently under drip vs. microsprinkler (MS) irrigation.
4) Determine the relationship between available soil moisture and tree SWP

Interpretive Summary:

Kern only. (See Shackel 10-HORT11(A) for other locations):
Many almond irrigation trials have been conducted over the last 30 years in California where the Control treatment has been assumed to represent “non-stressed” or “100% evapotranspiration (ET)” conditions. The maximum applied water for these trials rarely exceeded 45 inches even in the southern San Joaquin Valley, and maximum yields were low by today’s standard (Teviotdale, et. al, 1994, Goldhamer and Viveros, 2000, Goldhamer et. al, 2005). The 2002-2008 Spur Dynamics Trial by Bruce Lampinen et. al (2007) was the exception both in higher levels of applied water and achieved yield. However, precise tree ET was not calculated. Personal conversations with some of the involved researchers and cooperators have confirmed that visual signs of stress were often seen in the “100% ET” treatments.

This current project provides for very detailed monitoring of soil moisture levels and actual tree stress to schedule irrigations so that stress is truly avoided. Weekly ET is calculated using applied water and soil moisture depletion. Daily field ET is calculated by an energy balance using very precise meteorological equipment (eddy covariance, EC). All of this is laid over the multi-rate fertility trial of Brown, et. al. to see if varying levels of N fertility (125 to 350 lb/ac) impact tree water use in mature, full cover trees. As of this writing (July 2011), we are in the fourth season of this trial.

Using the energy balance (EC) method, the average January through December measured almond ET for microsprinklers with no cover crop for the southern San Joaquin Valley for 2008 through 2010 was 58.6 inches. This is 39% higher than the old standard of 42.2 inches for April 1 to November 15 published by the University of California more than 20 years ago (Snyder, et. al., 1989. See **Figure 3** following.) The average crop coefficient value (Kc) for 4/1 to 11/15 from this earlier work was 0.81 (basically 81% of what a well-watered pasture grass would use over the same period). The average Kc for this same period calculated by our study is 1.05. **(NOTE: This is not a recommendation that almonds should be irrigated with 58 inches of water, but rather the fact that this is indeed the true potential ET of these trees. As long as salt is not a problem, our best current estimate would be around 50 to 54 inches of in-season irrigation would be sufficient.)**

2010 almond ET across the different rates of nitrogen fertilizer (125 to 350 lb/ac), as measured by tree specific applied irrigation and soil moisture depletion, varied from 54.4 to 57.5 inches. Average ET by fertilizer treatment was not significantly different – indicating that N fertility status did not affect tree ET for this mature orchard. If this were an immature orchard (say 2^{nd} to 6^{th} leaf) this would not be the case as the higher N rates would cause trees to grow more quickly thereby increasing ET over the smaller low N trees. But effective cover in this established orchard has been 85 to 100% from the start of the trial, and, therefore was already at maximum potential energy interception from light and wind for maximum ET. Individual tree ET estimated by this same method, regardless of N fertilizer level, ranged from 48.3 to 63.1 from 2008 to 2010. Individual tree kernel yields over the same period ranged from 1,767 to 5,330 lb/ac. There was no relationship between yield and ET at the individual tree level.

Hull rot was a significant problem in 2009 even though soil moisture was kept around 65% available. Deficit irrigation prior to and during hull split (about 6 weeks prior to harvest) was implemented during 2010, achieving tree stem water potentials (SWP) in the -14 to -18 bar range, but hull rot was still a problem. Hull rot incidence was slightly greater in the double-line drip.

The double-line drip irrigation set has maintained trees at a lower stress level (less negative stem water potential levels) and with a higher average stored soil water content compared to the MS set. This has NOT translated into a consistent yield advantage. For the two higher rates of N fertilizer (275 and 350 lb/ac), average Nonpareil kernel yields for intensively monitored irrigation sites were 4,393 for drip and 3,984 lb/ac in the microsprinkler (MS) for 2010. Average yields for the entire 15 tree plots for these treatments were a bit lower and showed less separation at 3,954 and 3,865 lb/ac for drip and MS, respectively. The MS and double-line drip systems are separate 50 acre sets with identical fertilizer treatments in each and, therefore, do not allow for a statistical comparison of the two irrigation methods.

Comparing hundreds of tree SWP measurements to the tree specific soil moisture at the same time was a confirmation of the old standard that plants start to experience water stress when available soil moisture is depleted to 50%. For this site, the average on-set of early stress would actually start at about 60% available soil moisture but the on-set of stress for individual trees varied anywhere from 75% to 35% available. As soil moisture depleted even more, tree stress would increase more rapidly in the MS system than in the drip.

Materials and Methods:

The 151 acre orchard comprising the experimental site was planted in 1999 on a 21 x 24 foot spacing with 50% Nonpareil and 50% Monterey and irrigated with 2, A-40 Bowsmith Fanjets applying 10.8 to 11 gph each. There are 3 irrigation sets. The orchard is on the Westside of Kern County about 10 miles south of Lost Hills with a Panoche sandy clay loam predominating in the western 50 acre set and a cross between a Panoche and Milham fine sandy loam in the eastern two sets. (The official NRCS soil survey classification specifies a Kimberlina fine sandy loam, but I disagree!) The soil has no infiltration problems and excellent water holding capacity. At the start of the trial in February 2008 the eastern set was converted to double-line drip with emitters spaced and sized to apply the same 22 gph as the Fanjets.

This trial is designed to document, as close as possible, non-stressed almond ET, and any interaction with N fertilizer rates by using high frequency meteorological monitoring equipment (similar to CIMIS) and detailed weekly measurements of applied water and soil moisture depletion in 40 locations throughout the orchard. Midday tree stem water potential (SWP) is measured for 2 trees/location weekly using the pressure chamber and shaded, bagged leaves to insure uniform measurements. These data are combined into a weekly custom irrigation schedule provided to the cooperator to minimize stress in the trees while not leaching out of the rootzone. Soil salinity and fertility is also monitored at the end of every season. This water/fertigation trial is superimposed over Patrick Brown's extensive fertility trial with 12 different fertilizer treatments, each having 5 to 6 replicated plots in a given irrigation set. All fertility treatments and water monitoring sites are set up in identical fashion in the two eastern 50 acre sets (set 2 with the original microsprinkler FANJETs and set 3 with the new double-line DRIP). Yield and tissue data are taken from a total of 768 individual trees for the Brown fertility trial. A subset of 70 of these trees is used for plant water status stem water potential (SWP) and soil moisture monitoring. 2010 was the third season for this trial. All data are from the Nonpareil variety. We will attempt to also take Monterey yields by treatment for 2011.

Almond crop evapotranspiration (ETc) is determined using two meteorological methods (eddy covariance (EC) and surface renewal (SR)) with instruments placed on a 28 foot tower located in the FANJET block. These instruments collect data several times a second to provide an overall ET measurement every ½ hour for the block. Daily ET is totaled and compared to the nearby Belridge CIMIS station 1.5 miles due West, which calculates the daily potential evapotranspiration (ETo). The almond ETc is divided by the ETo to calculate daily/weekly crop water use coefficients (Kc).

ET is also calculated weekly using tree specific measurements of applied water and soil moisture depletion using a neutron probe (NP) to a depth of 9 feet for 20 sites in the FANJET set and 20 sites in the DRIP set. Individual water meters in the hoses irrigating these trees measure the water applied to that site. Due to the intensive effort of installation and weekly monitoring of these sites only 5 fertilizer treatments with 4 replications are monitored. These treatments are 125, 200, 275 and 350 lb/ac N from UAN32 fertigation with 200 lb/ac K (125 lb/ac from winter broadcast potassium sulfate and 75 lb/ac from fertigated potassium thiosulfate), and a fifth treatment with the same 275 lb/ac N but 300 lb/ac K (125 broadcast, 175 K thiosulfate). These treatments appear in the following figures and table as "125, 200, 275, 300 and 350".

Results and Discussion:

Figure 1 shows weekly crop water use (evapotranspiration, Etc) over the entire year from the meteorological estimates of latent heat flux (evaporation of water, which is basically ET) and soil moisture depletion by neutron probe (NP) plus applied water estimates of ET. You'll notice the meteorological estimates closely follow the curve of the CIMIS ETo (potential evapotranspiration) while the NP estimates of ET jump up and down from one week to the next. This "saw tooth" pattern is due to the fact that the neutron probe does not adequately measure the moisture change in the top 3 to 5 inches of soil and, therefore, it doesn't record the additional stored water shortly after an irrigation when this zone is very wet, or the depletion of this moisture when it is very dry just before an irrigation. So when you add in the depth of applied water (measured by a small flowmeter in the hose and calculated over the wetted area) this method overestimates ET when soil moisture readings are made just after irrigation and underestimates ET when readings are taken just before the irrigation.

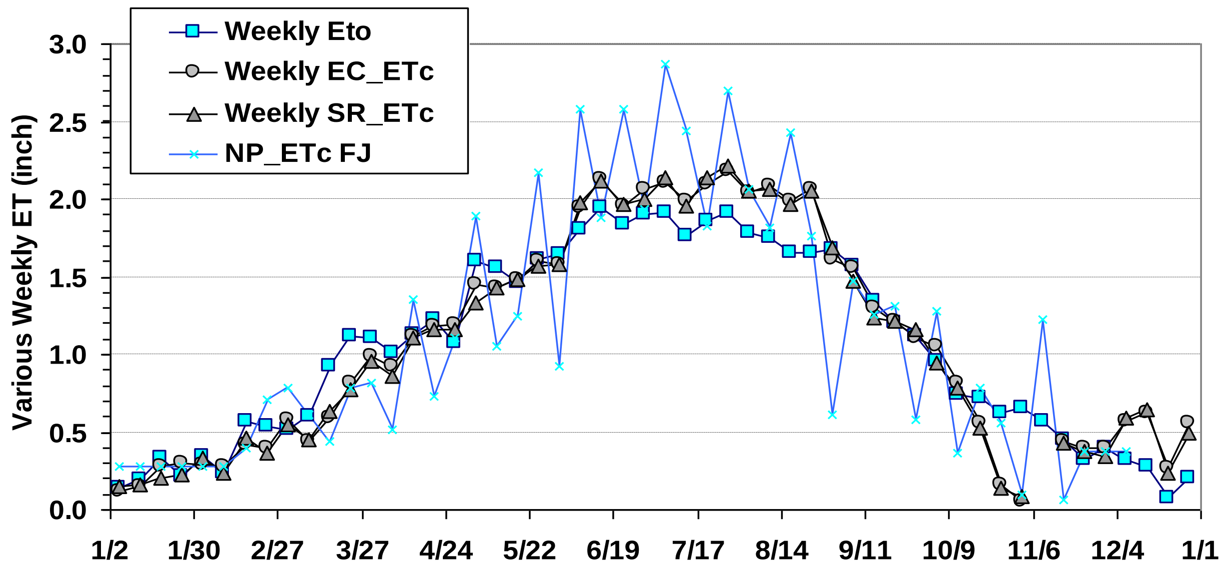

Figure1. Weekly Fanjet ETc from meteorological estimate of heat flux (eddy covariance (EC), surface renewal (SR) methods) and neutron probe soil moisture depletion and applied water (NP) compared to the Belridge CIMIS ETo for 2009.

However, if these weekly estimates are used as a cumulative sum over time and there is virtually no percolation of water below the rootzone at the measurement site (which is the case in this study area as shown by the lack of leaching of salts) then the cumulative NP estimate of ET should basically equal the applied irrigation plus additional moisture depletion and agree with the meteorological estimates of crop ET, which it does very nicely as shown in **Figure 2**. (During the season there is virtually no leaching past the 5 foot depth in the Fanjet block and none past 7 feet in the Drip block, with the average water content at these depths showing a slow decline over the season.

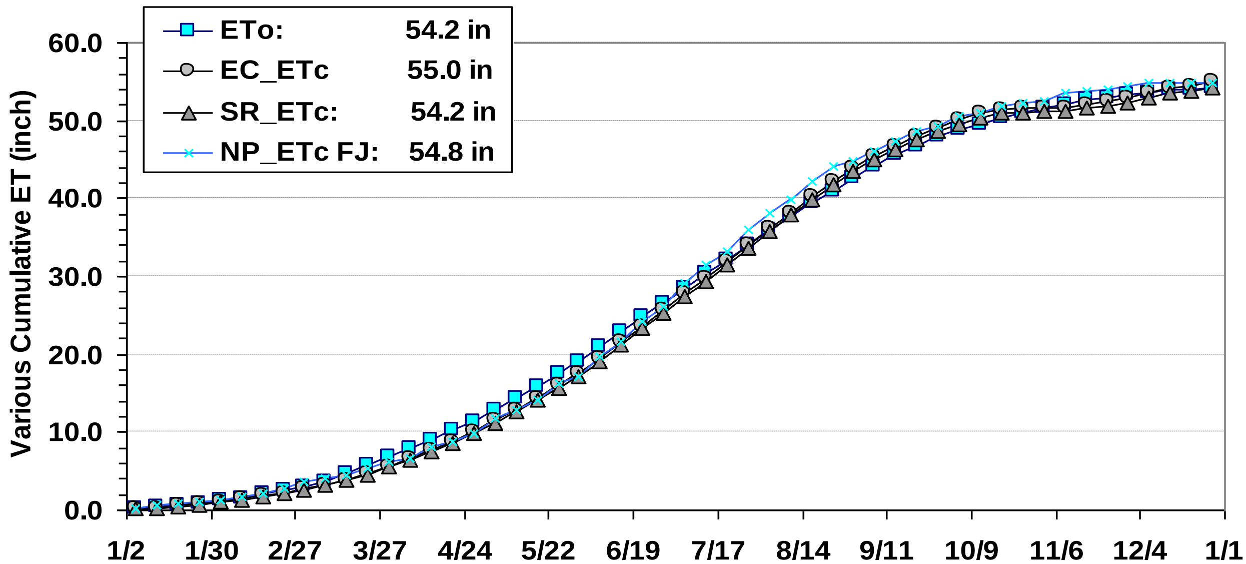

Figure 2. Cumulative CIMIS ETo, crop ET and applied irrigation for the 2009 season.

One of the important goals of crop water use research for arid irrigated climates like the Central and San Joaquin Valley is the determination of “crop coefficients”, (Kc) for various crops. The idea is that this coefficient for a given crop is constant for that species for a given growth stage and canopy cover. So if you have appropriate Kc values over the season you can estimate the expected crop ET based on weather data for that particular area. For example: the California Irrigation Management Information System (CIMIS) has divided CA into 18 climate zones with “historic (average) ETo” (basically pasture grass ET) that ranges from a yearly total of 33 inches on the north coast to 72 inches in the Imperial Valley. Just multiply the local historic average ETo, or the real-time CIMIS ETo, by the right Kc for a given week to get a reasonable estimate of the crop ET for a particular zone.

For more than 20 years the published Kc values for almonds on micro irrigation systems with minimum cover have peaked at 0.95 (95% of pasture ET. Snyder, et.al., 1989). This study has recorded weekly peak season Kc values of 1.15 and higher with no cover crop on the orchard floor using microsprinklers with about a 50% wetted area. Looking again at **Figure 1**, the EC and SR ET are slightly lower than the CIMIS Belridge ETo (Kc <1) until April, about equal (Kc = 1) till June and then exceeding ETo (Kc > 1) until September. **Figure 3** illustrates the year to year variability in these Kc values in the spring and fall as a function of the time of year due to changes in heat units and micro climate differences that affect this number more severely during these low ETo periods, but shows that for the critical June through August period this Kc value of water use potential is virtually the same at around 1.15.

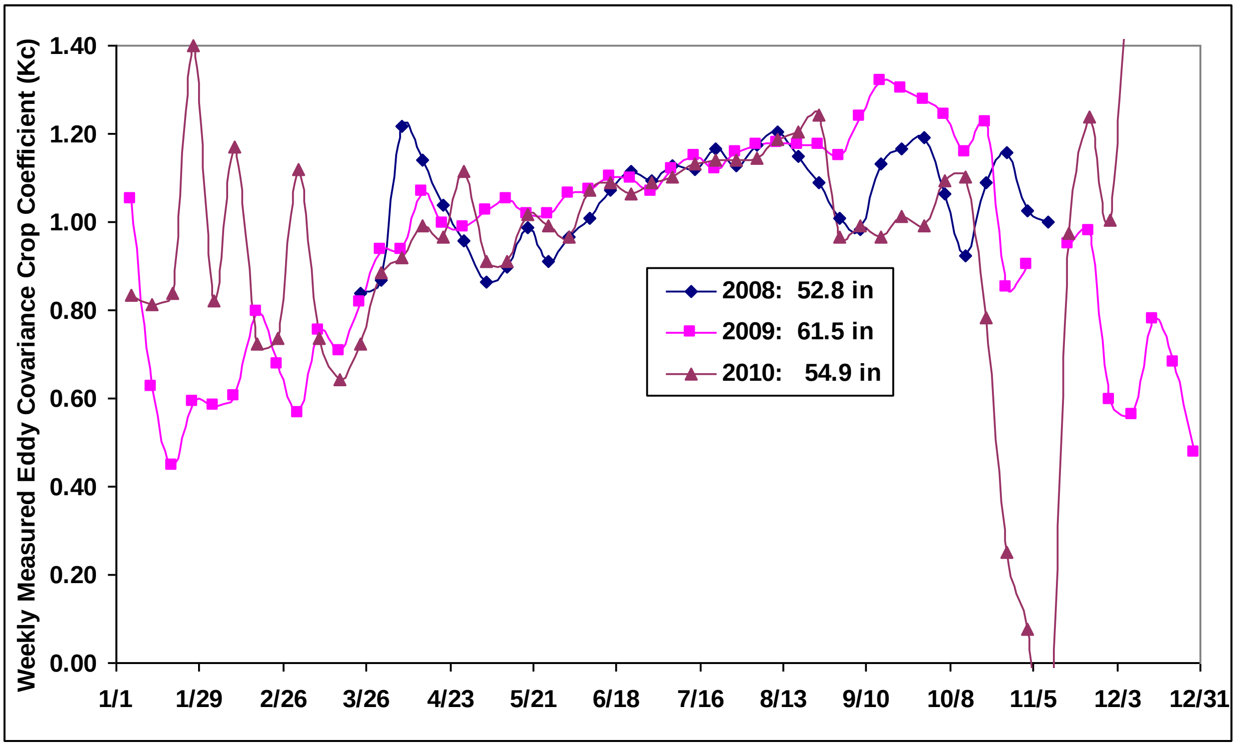

Figure 3. Comparison of 3 years of mature almond crop coefficients calculated from EDDY COVARIANCE heat flux estimates of crop ET divided by the modified Penman ETo from the Belridge CIMIS station #146 1.5 miles due west of orchard. (2008 ET measured 3/19to 11/11. 2009 and 2010 are full year.)

Figure 4 compares the older published values of almond Kc with Kc's developed by me through irrigation demonstrations and observations in high yielding orchards (first released by me to local growers starting 2002) and finally with average measured Kc's from the last 3 seasons of this project from **Figure 3**. These values represent a 39% increase over the old water use numbers. Average almond yields in Kern County, however, have doubled over that same time period, giving a net increase in "crop per drop" water use efficiency.

Disclaimer:

This is not to say that optimum almond yield requires 60 inches of water. Thus far, this study claims only to document that almonds can use this much water under low to no stress conditions. This figure includes a few weeks with SWP < -15 bars (i.e. more negative, more stress) in both 2009 and 2010. We had no hull rot problems in 2008, but significant strikes in 2009 in both drip and fanjet blocks, which is consistent with high water and N status in production almonds. (The low N rates did have fewer strikes.) 2009 yields were also lower than 2008 (**Table 1**), but this was generally true for the industry. We practiced partial regulated deficit irrigation prior to hull split during 2010 in an attempt to reduce hull rot, but still had a high number of strikes and higher levels of stress than desirable during August in the Fanjet set (**Figure 5**). For 2011, as much as possible, we will continue to irrigate with minimal stress.

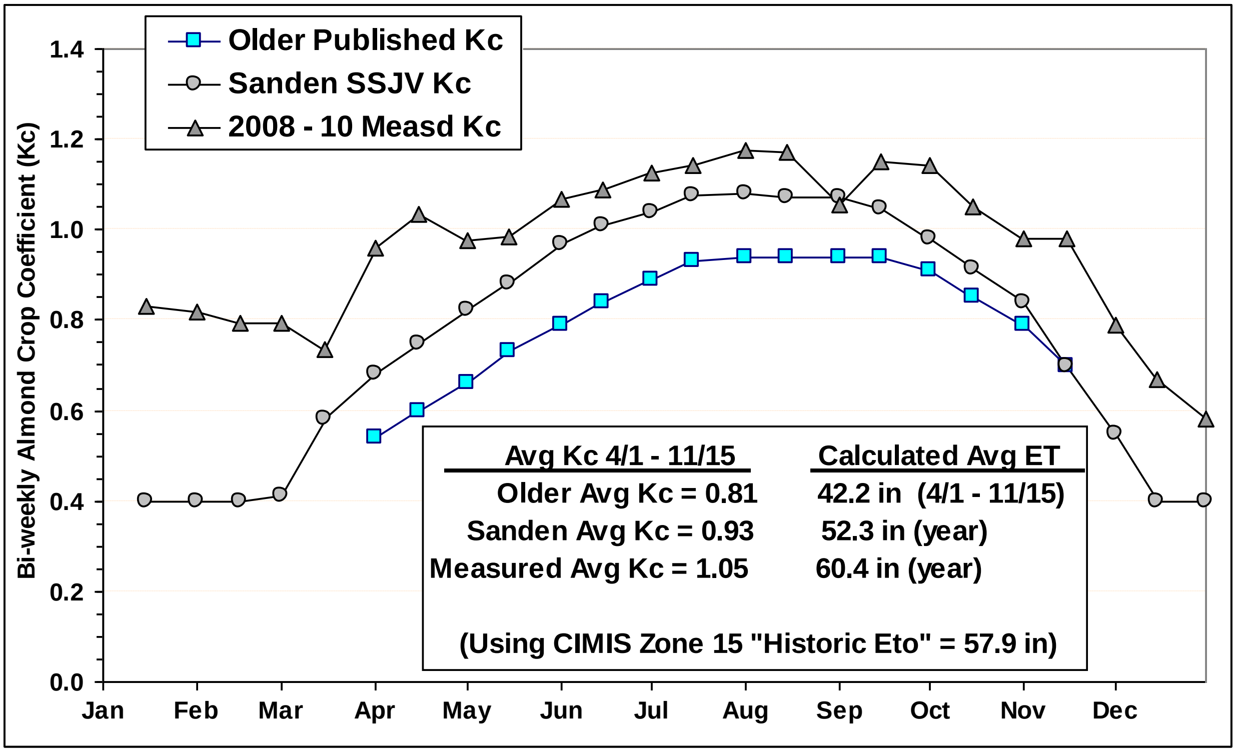

Figure 4. Comparison of Kc values for almonds over the season.

Season-long average soil water content to 9 feet was 17 to 22% greater under drip irrigation compared to fanjet under essentially the same irrigation schedule. This is of course due to the larger surface wetting and evaporation under the fanjets compared to

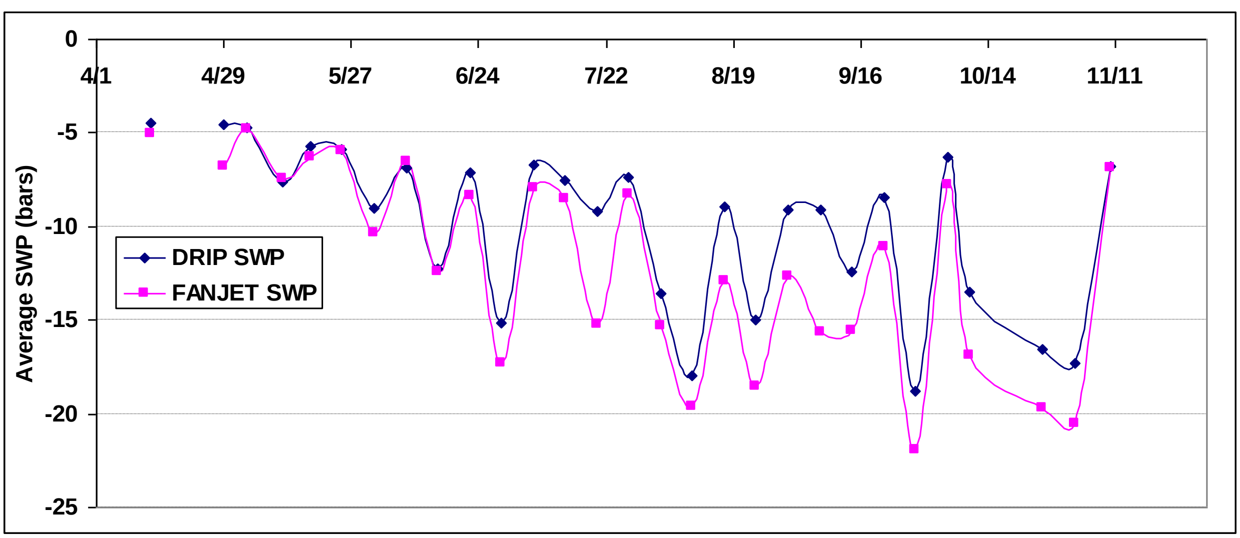

Figure 5. Average SWP over all fertilizer treatments for 2010. Season long drip average, -9.9 bars, Fanjet, -11.9 bars.

the small wetted areas under drip emitters. This higher average soil water content also resulted in tree stem water potential (SWP) being less negative for drip irrigation as opposed to fanjet irrigation. As a ratio, fanjet SWP was 11 to 17% more negative (more potential stress) than the drip (**Figure 5**).

Figure 6 shows the relationship between available soil moisture and SWP, illustrating that somewhere between 50 to 60% available soil moisture (40 to 50% depletion) in this fine sandy loam soil moisture can become limiting to plant uptake and increase plant stress (i.e. more negative SWP readings).

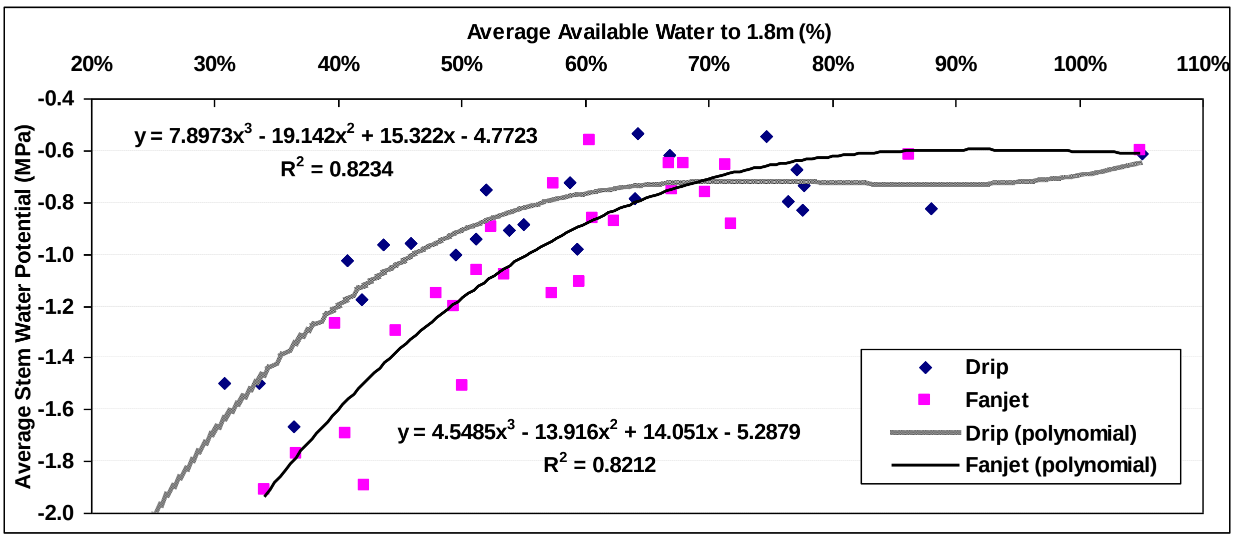

Figure 6. Third order polynomial regression of weekly SWP and available soil water content averaged over 15 sites over the entire season for both drip and microsprinkler sets.

Finally, **Table 1** lists fertilizer treatment and Drip vs. Fanjet averages for a variety of factors for replicated plots with intensively monitored soil moisture and tree SWP. Yields for the various N treatments are, therefore, different from the more complete set reported by Brown. Soil tests have shown nitrate to be very low, but it took two years to show a statistically reduced yield for the two lower N rates. (Brown's data for all 768 data trees shows a mixed response.) However, higher N rates have not resulted in significantly different NP estimates of individual tree ET and, therefore, not resulted in any differences in average soil water content in either year. Season long irrigation distribution uniformity for the Fanjet set is 94.8% and 93.1% for the Drip, which is exceptionally uniform. However, this still allows for a 7 to 8 inch applied water difference from the "low pressure" to "high pressure" sites. Tracking this allows us to measure differences in individual tree ET from 51 to 63 inches and see if there is any relation to kernal yield for these high levels of water use. The season long NP ET in **Table 1** and **Figure 7** show that individual tree ET above 52 inches did not increase kernal yield, nor did fertilizer rate have an impact on ET.

Table 1. Season long average stem water potential and soil water content and cumulative NP ET as measured by weekly soil water depletion and applied water. Nonpareil kernel yield using final turnouts for neutron probe and SWP data trees only.

(NP ET for 2008 is for 2/7 to 11/17)

2008 Treatment (N-K lb/ac)	Stem Water Potential (bars)		Soil Water Content to 9 feet (in)		Neutron Probe ET (in)		Final Kernal Yield NP Trees (lb/ac)	
	Drip	Fanjet	Drip	Fanjet	Drip	Fanjet	Drip	Fanjet
125-200	--	-10.2 ab	--	12.6 a	--	55.3 a	--	3301 ab
200-200	-9.6 a	-9.7 b	16.8 a	14.9 b	54.5 a	56.1 a	3260 a	3360 b
275-200	-8.5 ab	-10.1 ab	17.4 ab	14.7 ab	57.3 a	57.7 a	3997 b	3338 ab
275-300	-8.4 b	-10.3 a	16.8 b	12.9 ab	55.9 a	55.3 a	3839 ab	3370 a
350-200	-9.5 ab	-10.0 ab	15.4 ab	13.9 ab	56.2 a	55.6 a	3518 ab	3963 ab
AVERAGE	**-9.0**	**-10.0**	**16.6**	**13.8**	**55.9**	**56.0**	**3653**	**3467**
LSD 0.05	*1.1*	*0.6*	*2.3*	*2.3*	*4.8*	*2.5*	*715*	*517*

(NP ET for 2009 is for 1/27 to 12/2)

2009 Treatment (N-K lb/ac)	Stem Water Potential (bars)		Soil Water Content to 9 feet (in)		Neutron Probe ET (in)		Final Kernal Yield NP Trees (lb/ac)	
	Drip	Fanjet	Drip	Fanjet	Drip	Fanjet	Drip	Fanjet
125-200	-9.6 a	-10.5 ab	18.0 a	14.2 a	54.9 a	56.9 a	2722 a	3027 ab
200-200	-9.3 ab	-10.4 b	18.2 a	17.1 b	58.2 a	57.6 a	2642 a	3005 a
275-200	-8.9 b	-11.1 a	18.8 a	15.8 ab	60.5 a	58.3 a	3524 b	3164 abc
275-300	-8.3 c	-11.0 ab	18.6 a	14.2 a	59.2 a	57.0 a	3572 b	3783 c
350-200	-9.7 a	-11.0 ab	15.3 a	14.9 ab	58.3 a	56.5 a	3727 b	3858 bc
AVERAGE	**-9.2**	**-10.8**	**17.8**	**15.2**	**58.2**	**57.3**	**3237**	**3367**
LSD 0.05	*0.6*	*0.7*	*6.2*	*2.7*	*6.9*	*3.5*	*752*	*844*

(NP ET for 2010 is for 1/1 to 12/6)

2010 Treatment (N-K lb/ac)	Stem Water Potential (bars)		Soil Water Content to 9 feet (in)		Neutron Probe ET (in)		Final Kernal Yield NP Trees (lb/ac)		Trial Whole Plot Kernal Yield (lb/ac)	
	Drip	Fanjet	Drip	Fanjet	Drip	Fanjet	Drip	Fanjet	Drip	Fanjet
125-200	-9.8 a	11.1 a	15.9 ab	14.4 a	56.8 a	55.5 a	3565 a	3280 a	2865 a	2909 a
200-200	-9.7 a	11.9 b	17.2 b	15.1 a	57.0 a	54.4 a	3779 ab	3591 ab	3453 b	3405 b
275-200	-9.7 a	12.5 b	17.7 b	16.2 a	56.6 a	55.0 a	4266 bc	3914 bc	3765 bc	3813 bc
275-300	-10.1 a	12.1 b	16.7 ab	14.5 a	57.5 a	55.1 a	4069 cd	3804 bc	3844 bc	3806 bc
350-200	-9.7 a	11.9 b	14.6 a	15.3 a	56.4 a	55.0 a	4717 d	4165 c	4064 c	3924 c
AVERAGE	**-9.8**	**11.9**	**16.4**	**15.1**	**56.9**	**55.0**	**4079**	**3751**	**3598**	**3571**
LSD 0.05	*0.5*	*0.6*	*2.5*	*2.9*	*3.7*	*3.3*	*457*	*415*		

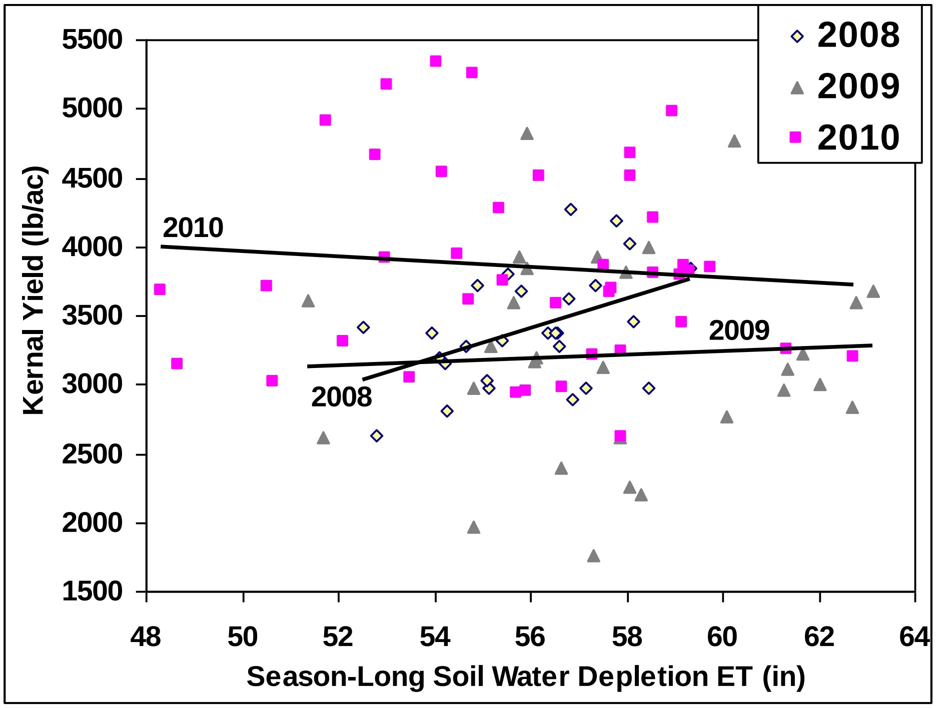

Figure 7. Individual tree kernel yield as a function of tree ET estimated by applied irrigation and soil moisture depletion.

Research Effort Recent Publications:

Sanden, B., K. Shackel, P. Brown. 2010. Correlation of soil water content determination by neutron backscatter and almond tree stem water potential for microirrigation scheduling in almonds. 5th National Decennial Irrigation Conference, Dec. 5-8, 2010, Phoenix, AZ Amer. Soc. Agric. and Bio. Eng., 2950 Niles Road, St. Joseph MI 49085-9659. www.asabe.org. ASABE Pub. No. 711P0810cd, Paper No. IRR10-9870, 12 pp.

Boman, B., B. Sanden, T. Peters, L. Parsons. 2010. Status of microsprinkler design, operation and maintenance in 2010. 5th National Decennial Irrigation Conference, Dec. 5-8, 2010, Phoenix, AZ Amer. Soc. Agric. and Bio. Eng., 2950 Niles Road, St. Joseph MI 49085-9659. www.asabe.org. ASABE Pub. No. 711P0810cd, Paper No. IRR10-9639, 12 pp.

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Snyder, R.L., Lanini, B. J., Shaw, D. A., and Pruitt, W. O. 1989. Using reference evapotranspiration (ETo) and crop coefficients to estimate crop evapotranspiration (ETc) for trees and vines. Leaflet No. 21428, 8 p. UC Cooperative Extension, Department of Land, Air and Water Resources, 113 Veihmeyer Hall, University of California, Davis, CA 95616-8628.

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