Almond Water Production Function

Project No.: **13-HORT17-Shackel/Sanden/Fulton/Doll**

Project Leader: Ken Shackel
Department of Plant Sciences
UC Davis
One Shields Ave.
Davis, CA, 95616
530.752.0928
530.752.0122 (fax)
kashackel@ucdavis.edu

Project Cooperators and Personnel:
David Doll, UCCE – Merced County
Bruce Lampinen, UC Davis
Allan Fulton, UCCE – Tehama County
Blake Sanden, UCCE – Kern County

Objective:

Develop a water production function (WPF) for almonds grown in California that will relate potential yield to water applied, accounting for the site-specific effects of orchard cover, soils, varieties, and physiological level of stress experienced by the tree.

Interpretive Summary:

The 2013 season was the first year of imposing a range of water applications to determine a WPF at three locations in the state (Kern, Merced, and Tehama counties). Since many important effects of water stress are carryover effects, only tentative conclusions can be reached at this time. Irrigation treatments resulted in orchard water use from about 60% to 110% of calculated ETc, corresponding to a substantial range of 30” to 56” total water use, depending on location. All sites showed a clear increase in tree water stress (midday SWP) with reduced irrigation, but thus far these levels have not been associated with a clear reduction in yield. Treatment average nutmeat yields ranged from 2,140 to 3,450 pounds per acre, depending on location, mainly due to differences in crop load (nuts per acre), with a smaller effect attributable to kernel size. For two sites (Kern and Merced) the overall relation between yield and canopy light interception (PAR) was similar to that found in other almond orchards and reported by B. Lampinen, at about 50 lbs/ac nutmeats for each 1% of PAR. However, at the same level of PAR, as well as the same level of water use and SWP, the Tehama location had about 30% less yield than the other locations, indicating that the yield in Tehama maybe limited by factors other than water. It is also interesting to note that for the same PAR, the Merced location had the lowest water use (%ETc) of all sites, but the same yield as the Kern location, resulting in the highest water use efficiency (pound nutmeats per acre per inch of ET) for this site. It will be important to confirm these trends after carryover effects have been well established in these orchards.

Materials and Methods:

A randomized complete block experiment was set up in commercial almond orchards in three counties (Tehama, Merced, and Kern). At each site, 4 to 5 irrigation treatments, with target levels ranging from 70% - 110% ETc, in 3 to 6 blocks (**Table 1**) were established by modifying the existing irrigation system. Applied irrigation amounts were measured approximately weekly in at least half of the experimental plots using water meters, and periodic measurements of soil water to 9' were made with a neutron probe throughout the season in order to estimate soil water use in each plot. For plots without water meter or neutron probe data, the treatment averages were used as estimates. Periodic (at least weekly) measurements of midday stem water potential (SWP) were made on individual monitoring trees in each plot. Mid-season canopy cover (% PAR Interception) was measured using the light bar technique developed by Bruce Lampinen, and plot yields as well as individual tree yields for SWP monitored tress were obtained.

Table 1. Numbers of blocks and target levels of irrigation treatments at each location of the study.

Location	# of blocks	Treatment targets (% ET)
Kern	6	70, 80, 90, 100, 110
Merced	3	70, 80, 90, 100, 110
Tehama	6	74, 86, 100, 116

Results and Discussion:

As a result of working under commercial orchard conditions, there was some plot-to-plot variability in applied water amounts, and while there were some instances of statistical overlap between adjacent treatments, treatment mean applied water always ranked in the same order as the target amounts (**Table 2**).

Table 2. Treatment mean values and statistical comparison (means followed by different letters are significantly different at P<0.05) for seasonal applied water, soil water depletion and tree ET (expressed in inches as well as the corresponding % of full ET) for each location. Negative values for soil water depletion indicate soil recharge over the season (i.e., excess of irrigation over tree water use).

Location	Applied water (inch)		Soil water depleted (inch)		ET_c (inch) (and %ET)	
	Treatment	Mean	Treatment	Mean	Treatment	Mean
Kern	110	55.9a	90	1.6	110	56.1a (102)
	100	53.2b	70	1.4	100	54.4a (99)
	90	50.4c	100	1.3	90	51.9b (94)
	80	49.8c	80	0.3	80	50.1b (91)
	70	42.7d	110	0.2	70	44.1c (80)
Merced	110	41.1a	90	3.3	110	40.8a (81)
	100	38.2ab	70	3.0	100	38.2a (76)
	90	33.5bc	100	-0.1	90	36.8a (73)
	80	31.3cd	110	-0.2	70	30.2b (60)
	70	27.2d	80	-1.7	80	29.7b (59)
Tehama	116	50.5a	86	7.7	116	55.5a (109)
	100	46.9a	74	7.6	100	53.1ab (104)
	86	41b	100	6.2	86	48.7bc (95)
	74	39.1b	116	5.0	74	46.7c (92)

In evaluating a water production function however, the contribution from stored soil water, which is beyond our control, must also be considered. While there was no statistical difference in soil water contribution across treatments within a location, a substantial amount of soil water (on the order of 6”) was used at the Tehama location compared to the other two locations (on the order of 1” with, in some cases, soil recharge), and in all cases, soil contribution increased the variation in the calculated seasonal tree water use (applied water plus the contribution from soil water, **Table 2**). Hence, there was increased overlap between treatments in the actual amount of tree ET compared to the applied water amounts, and in one location (Merced) a slight change in the order of the treatments themselves (**Table 2**). These problems will be addressed by analyzing treatment effects either based on the actual ET for each treatment and block, or based on plant-indicators of stress (SWP).

At all sites, lower irrigation amounts resulted in lower (more stressed) SWP levels (**Figure 1**), but for most of the season at all sites, even the highest water application level did not result in baseline values of SWP. This is interesting and may indicate that there are soil or root system limitations to water uptake in these orchards, but this is not uncommon in commercial almond orchards. The overall yields in 2013 were reasonable and ranged from 2,140 to 3,450 kernel pounds per acre depending on irrigation treatment and location (**Table 3**), but in only one location (Kern) was there a statistically significant effect of irrigation treatment, and at this and the other locations there was no clear ranking of the treatments related to the amount of water applied (**Table 3**). There was also no statistical separation or consistent treatment ranking of %PAR in these orchards (**Table 3**), consistent with the expectation that the first year effects of water deprivation in almonds will not be as clear as the carryover effects.

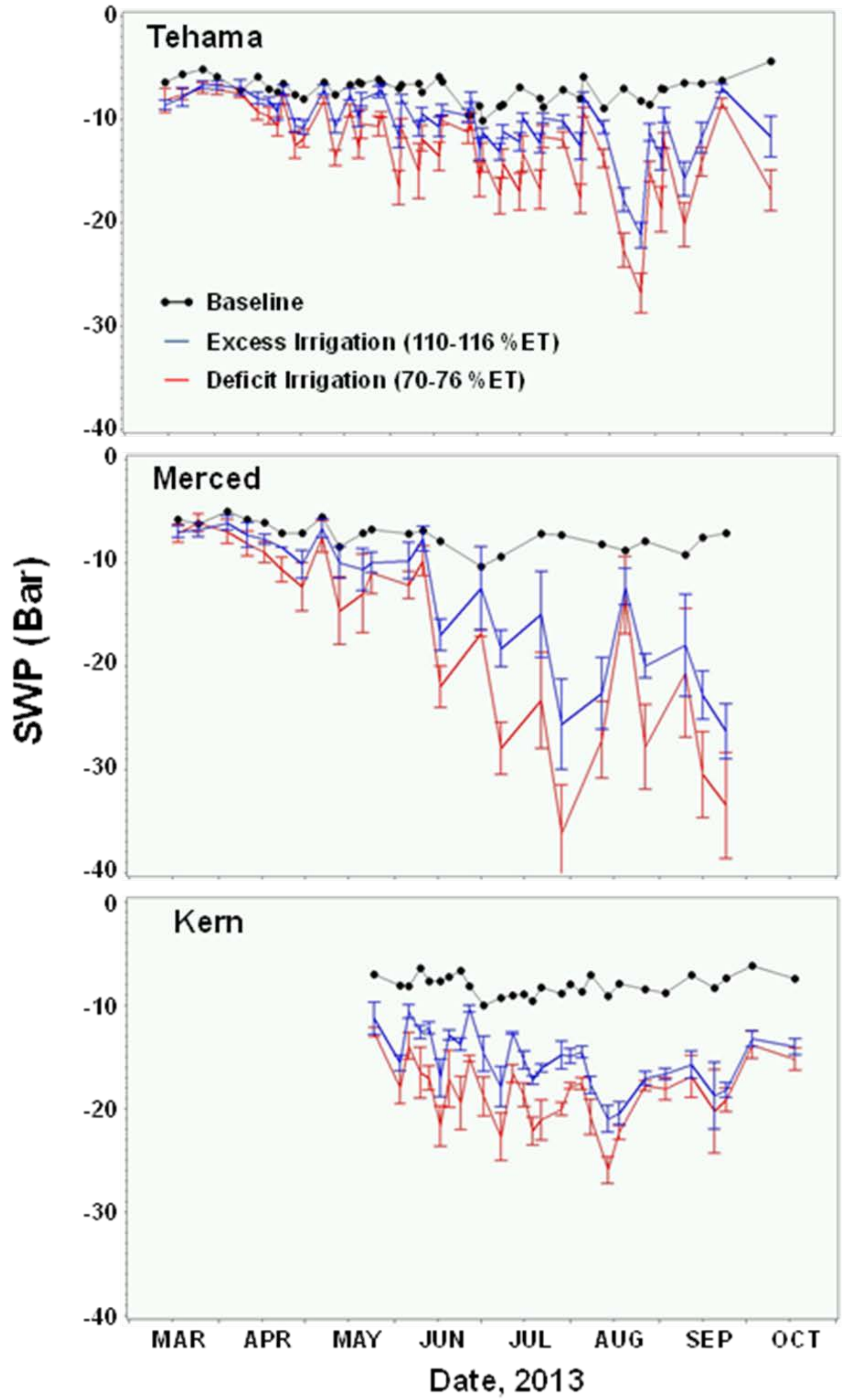

Figure 1. Seasonal pattern of stem water potential (SWP) for the driest and wettest treatments at each location. Also shown for reference is the fully irrigated (non stressed) baseline SWP.

Table 3. Treatment mean values and statistical comparison (means followed by different letters are significantly different at P<0.05) for kernel yield, midsummer % PAR, and season long SWP for each location.

Location	Yield (Lbs nutmeats/ac)		% PAR		SWP (Bar)	
	Treatment	Mean	Treatment	Mean	Treatment	Mean
Kern	90	3450a	110	70	110	-15.3a
	110	3340ab	80	69	100	-16.2b
	100	3320ab	100	69	90	-17.1c
	80	3140ab	70	68	80	-17.3c
	70	2840b	90	68	70	-18.6d
Merced	100	3240a	100	63	110	-13.4a
	110	3040a	110	61	100	-13.6a
	70	2900a	70	59	80	-14.3a
	80	2720a	80	55	90	-14.4a
	90	2620a	90	55	70	-17.2b
Tehama	86	2310a	113	67	116	-10.7a
	74	2210a	74	66	100	-12.6b
	100	2150a	100	65	86	-13.0b
	116	2140a	86	64	74	-13.7b

It is interesting to note that at all locations there was a substantial range (>10") in the quantity of water applied (**Table 2**), and a significant and consistent response to irrigation in tree SWP (**Table 3**). Hence we can anticipate that future yields and possibly PAR will be impacted. Across all sites, there were clear tree-to-tree differences in yield, and these differences were mainly due to differences in nut load, with a similar relation between load and yield across all sites (**Figure 2**). Even though kernel size did not have a strong influence on yield, across all sites as well as within each site there was a clear positive relation of kernel size to SWP, with more stressed trees showing a reduction in kernel size (**Figure 3**). This is a similar result as has been found in previous studies, and presumably indicates that current season stress influences kernel growth. For the Tehama and Merced sites, the strongest linear relation (highest r-square) between SWP and kernel size was for SWP during the months of April and May (data not shown), and probably indicates that the effect of stress on reducing kernel size is most important during early kernel development. Hence, while the first year effects of water deprivation on yield are difficult to detect at the plot level, we are able to see changes in one of the components of yield at the tree level using SWP.

It has been well established that potential almond yield is determined by canopy light interception, with a yield of about 50 kernel pounds per acre for each 1% increase in PAR. The yields obtained at the Merced and Kern locations were consistent with this value, but the yields in Tehama were less than expected based on the PAR at that location (**Figure 4**). There was a trend for decreasing yields with decreasing orchard water use in Kern and Madera, but not in Tehama (**Figure 5**), and the Kern and Madera locations also similarly grouped together compared to the Tehama location in kernel yield and SWP (**Figure 6**). These grouping patterns were mainly determined by the lower yields at Tehama compared to the other two sites, and if confirmed in later years it is possible that the water production function will be different for the Tehama location compared to the Kern and Madera locations, which will be an important finding. One relationship that should not be dependent on location is the relation between canopy size (measured by %PAR) and water use (measured as the % of full ET), but surprisingly, each location showed a unique relation between these two measures, with the Kern and Tehama locations grouping more closely and contrasting to the Merced location (**Figure 7**). This is a very interesting result which must be confirmed in later years, because it will have a strong influence on our interpretation of the water production function (WPF) from different sites. One result of having a WPF is that the water use efficiency (WUE) of crop production (i.e., kernel pounds produced per inch of water used, both expressed on a per acre basis) can be calculated.

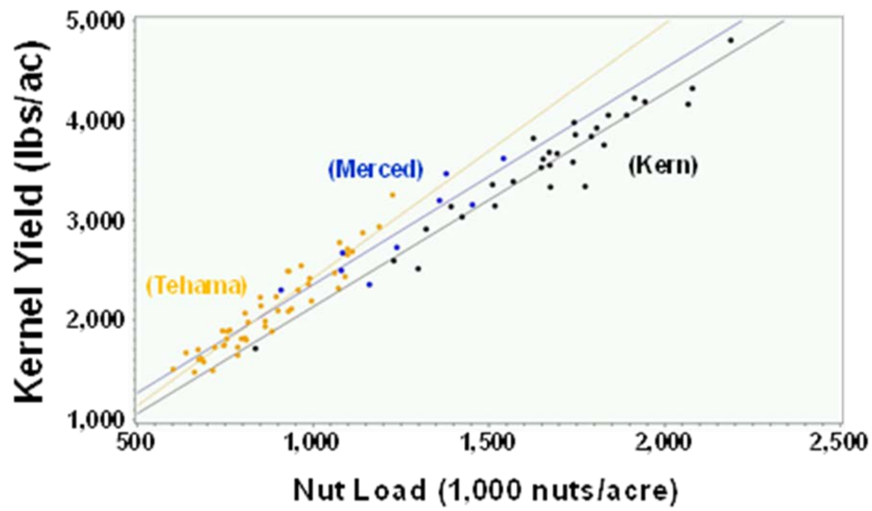

Figure 2. Relation of yield to nut load for individual trees, expressed on a per acre basis. Lines fit to the data are linear regressions.

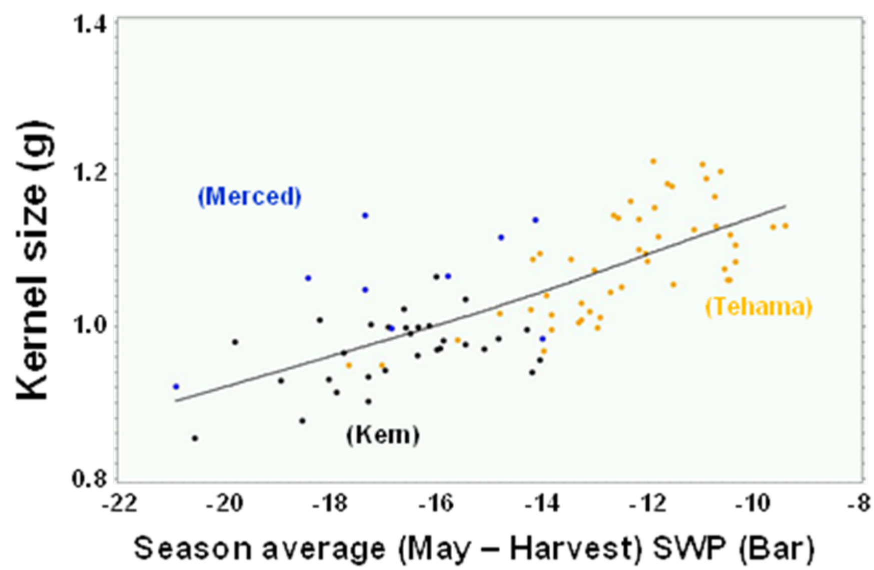

Figure 3. Relation of kernel size to SWP for all individual trees. The line fit to the data is a smoothed spline.

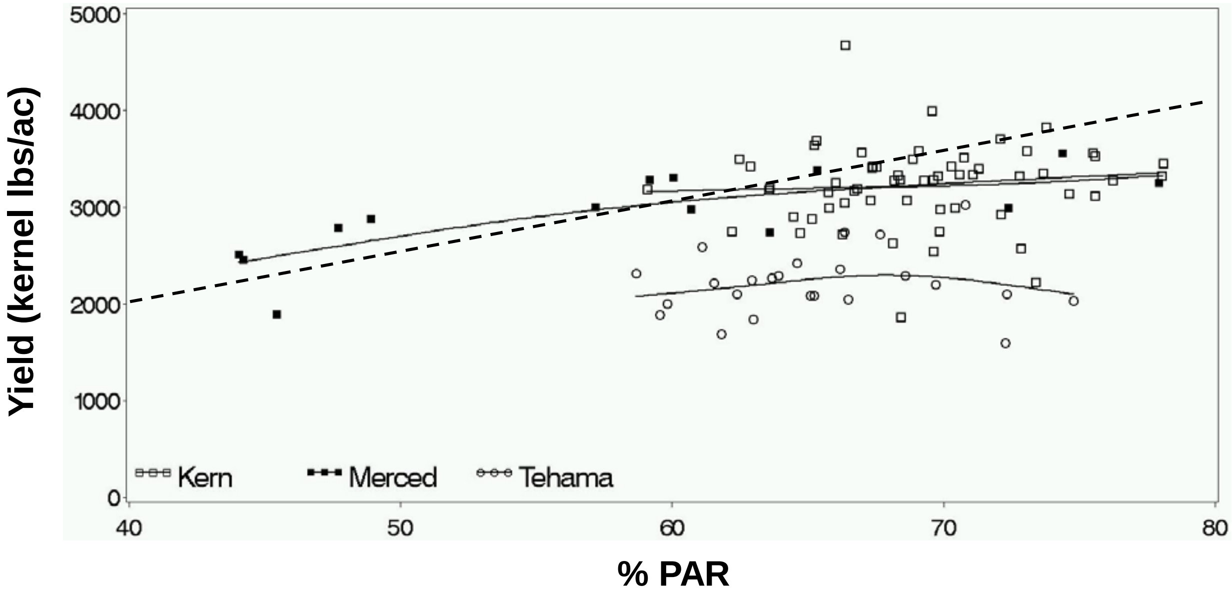

Figure 4. Kernel yield at each location compared on the basis of canopy size, as measured by midsummer % sunlight intercepted (%PAR). Solid lines fit to the data of each site are smoothed splines, and the dashed line shows the value expected based on a value of 50 lbs. yield for each 1% increase in PAR.

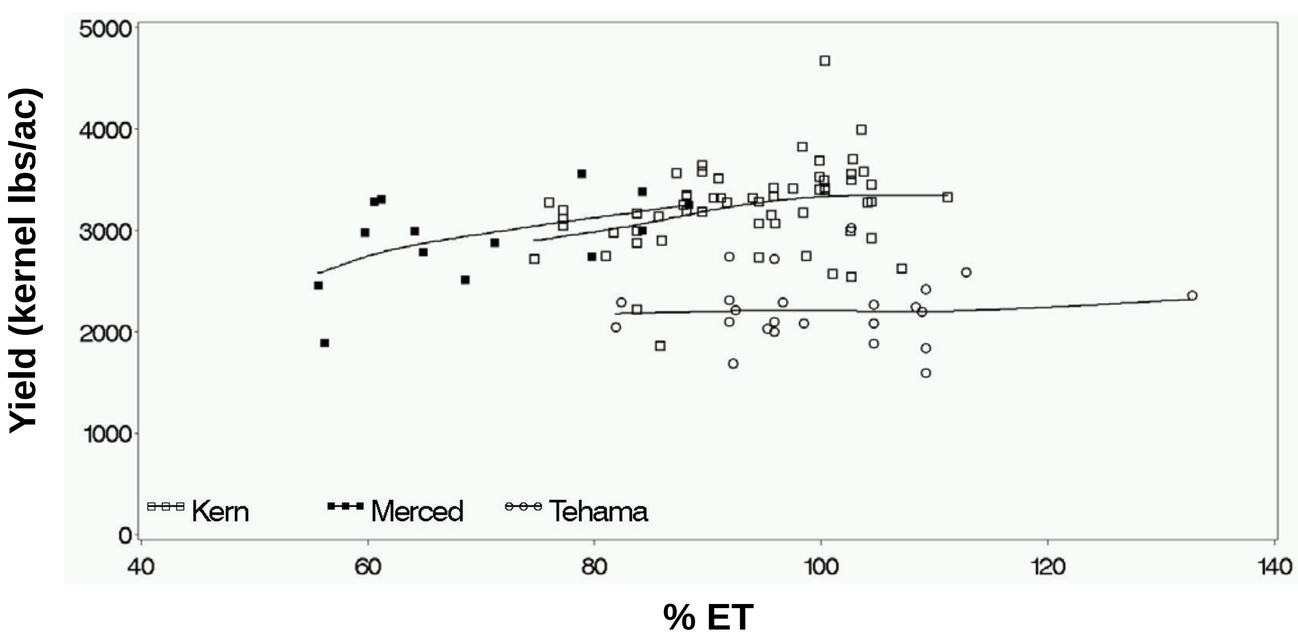

Figure 5. Kernel yield at each location compared on the basis of the % calculated full water use (% ET) for that location. Solid lines fit to the data of each site are smoothed splines.

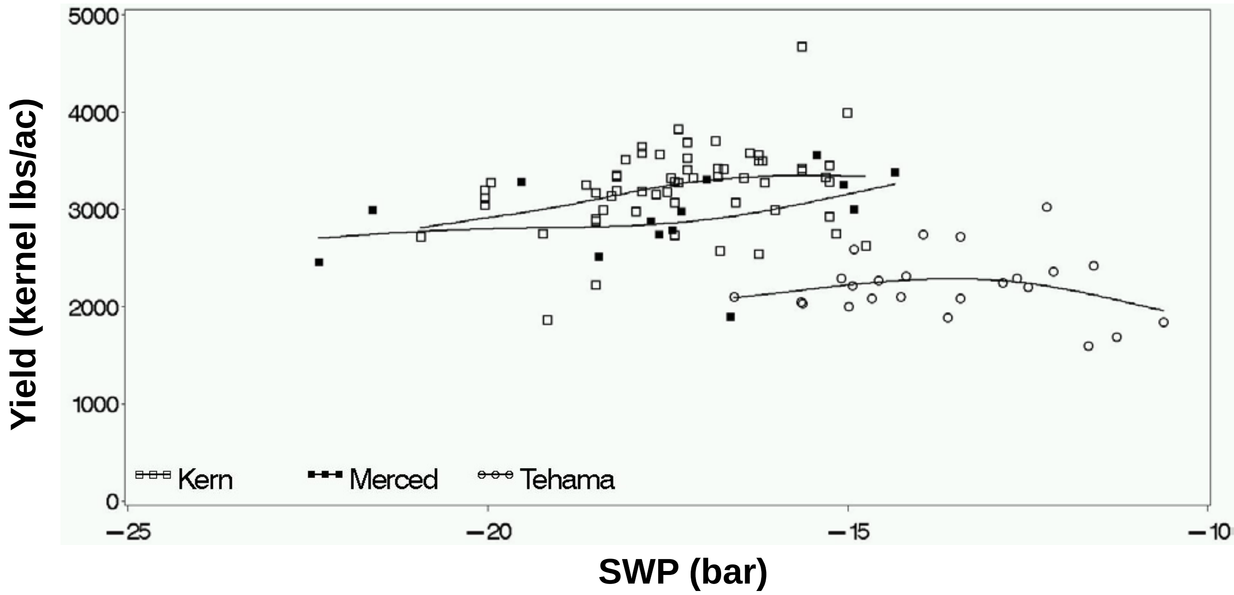

Figure 6. Kernel yield at each location compared on the basis of average mid-summer (June – August) stem water potential (SWP). Solid lines fit to the data of each site are smoothed splines.

However, based on the similarity between Kern and Merced in the yield/PAR relation (**Figure 4**), and the dissimilarity between these locations in the %ET/PAR relation (**Figure 7**), we might expect a strong location effect on WUE. For the data of our study there was both a strong within- as well as between-location effect on WUE, with a parallel increase in WUE as canopy water use (%ET) declined for all sites, and a generally higher WUE for a given level of canopy water use in Merced, followed by Kern, followed by the Tehama location (**Figure 8**). Given the

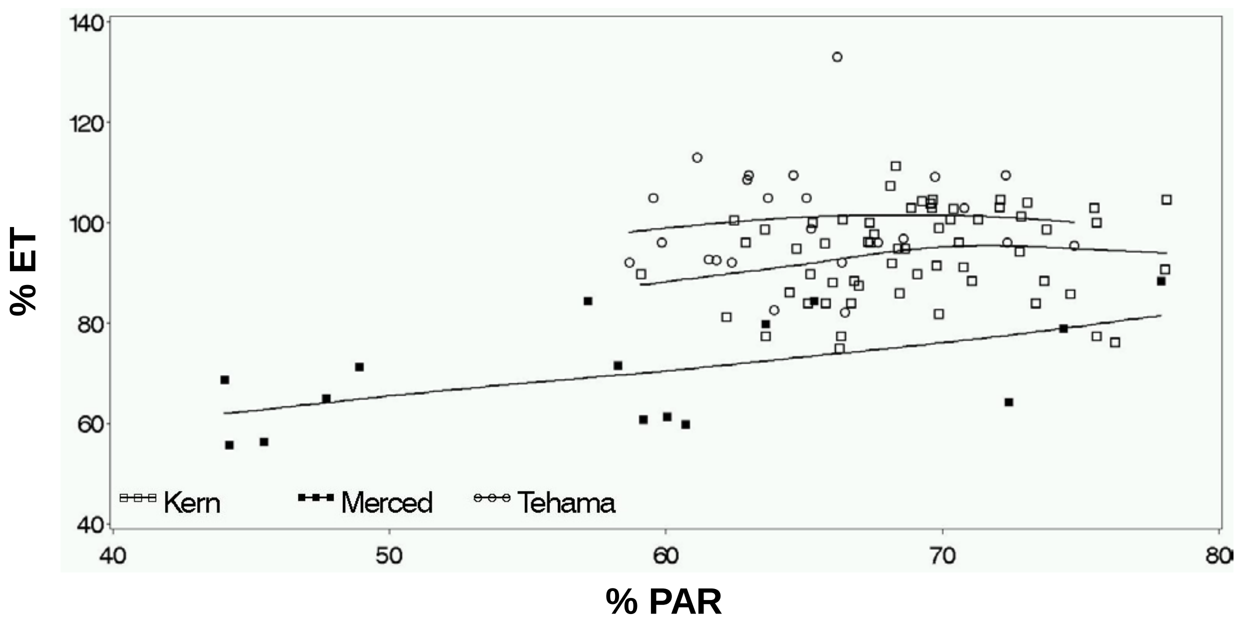

Figure 7. Tree water use at each location, expressed as a the % of calculated full water use, compared on the basis of canopy size, measured as the % of PAR intercepted at midsummer. Solid lines fit to the data of each site are smoothed splines.

parallel increase in WUE as %ET declines for all sites, the appropriate statistical analysis to compare WUE between locations is an analysis of covariance, and **Table 4** shows that each location exhibited a significantly different WUE. It will be important to confirm whether or not these results are consistent in later years, and if so, what factor(s) are responsible for the substantial differences in WUE from different locations.

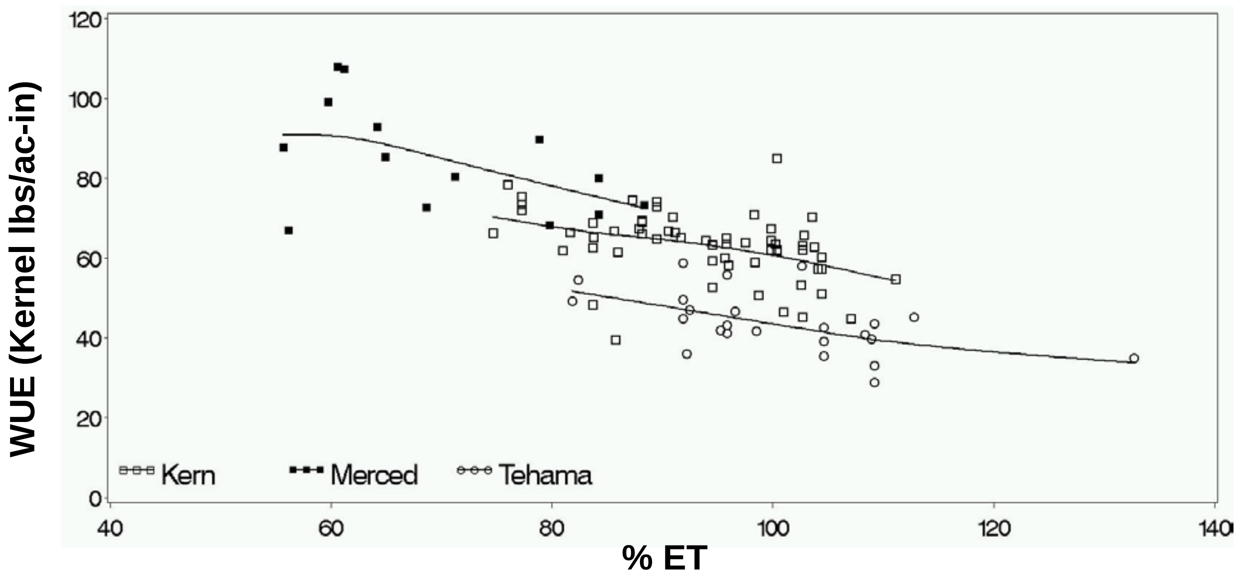

Figure 8. Estimated water use efficiency (WUE) at each site, compared on the basis of the % calculated full water use (% ET) for that location. Solid lines fit to the data of each site are smoothed splines.

Table 4. Least-squares mean estimates of water use efficiency (WUE) at each location. These means are adjusted to compare them at the same level of water use (% ET, **Figure 8**), and each location is different from the other at a level of P<0.0008).

Location	WUE (kernel lbs/ac-in)
Merced	75a
Kern	64b
Tehama	47c

Research Effort Recent Publications:
None at this time.