Almond ET/Yield Production Function

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Problem and its Significance:

Water is a critical resource for Californian agriculture and much of California suffers from periodic shortages and persistent threats of reduced allocations. Water is also the primary means of delivery of nitrogen and the primary driver for nitrogen loss. One of the major challenges faced by irrigated agriculture is to optimize the use of water with respect to production (i.e., more "crop per drop"). It is well known in almonds and most other crops that production increases with increasing water availability up to a point, but for almonds a relation between water availability and crop production, the "Water Production Function" (WPF), has not been established. It has long been assumed that production will be maximized by applying water to match orchard evapotranspiration (ETc), but we do not know the shape of this relation, and the shape of the relation is an important basis for determining the optimum irrigation approach. It is imperative that the almond industry have the best available information on the relation of almond tree yield to different levels of irrigation in mature orchards.

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.

Results and Discussion:

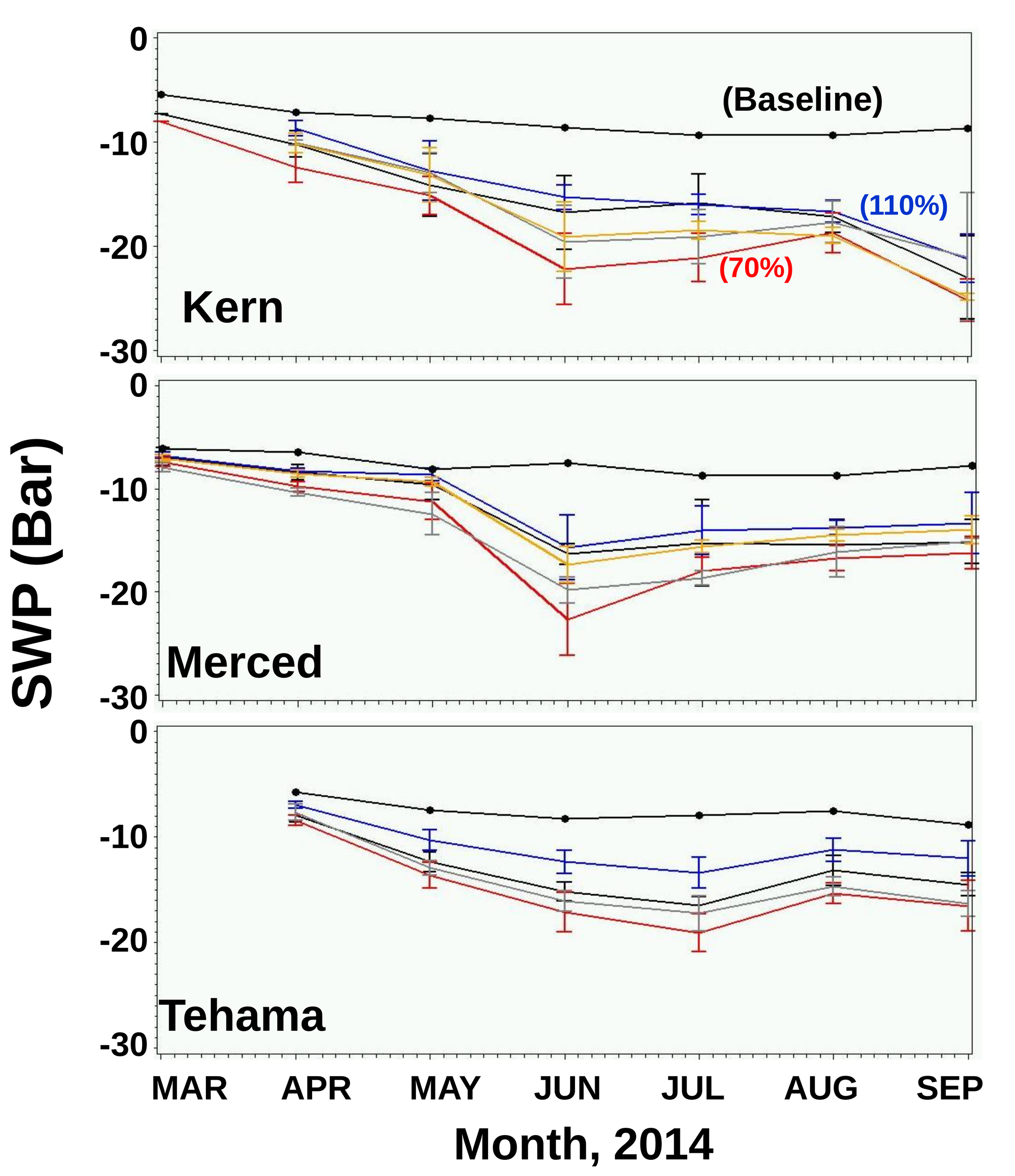

Figure 1. Monthly average stem water potential (SWP) values for each treatments at each study site. Only the 110% [blue] and 70% [red] treatments are indicated for clarity, with the others being 100% [black], 90% [yellow], and 80% [grey]. Also shown for reference is the fully irrigated (non-stressed) baseline SWP for each month and site.

This is the second year of applying different amounts of water, approximating 70 – 110 % ET, in a randomized complete block design at three orchard sites across the state. At all sites, the imposed irrigation treatments have been successful in causing consistent differences in the levels of water stress, as measured by SWP, for the majority of the growing season (**Figure 1**). At all sites there was also a general trend of increasing stress from spring to midsummer, even at the highest level of irrigation. The SWP of the three highest irrigation levels (90-110%) at the Merced site stayed closest to the non-stressed baseline through May compared to all other sites. This is particularly interesting because the Merced site had the lowest applied water amounts of any site (see below).

Statistical tests always showed a significant to highly significant separation in the midsummer average SWP at all sites, with treatments essentially always ranking in the order of applied water **(Table 1)**. In contrast, kernel yield was not statistically different at any site, although in Merced, the yields ranked largely in the order of applied water. At the Merced site, even though there were no statistically significant treatment effects for yield, kernel weight, or PAR, in all cases the mean ranking was consistent with the amount of applied water. The Kern site exhibited significant treatment effects in kernel weight and PAR, but only PAR showed a ranking consistent with applied water. In Tehama there was no consistency in ranking. At all sites and for most measures, there were significant block effects (not shown), suggesting the need for a regression approach to interpret these data.

Table 1. Orchard yields, Kernel weight, % light interception, and average midsummer tree SWP (June-August) for the different sites and irrigation treatments (70 – 110 %ET) in 2014. All means are ranked in numerical order (means which appear to be identical are due to rounding), but means followed by the same letter are not significantly different. An absence of letters also indicates that there was no significant treatment effect.

Site	Kernel Yield (lbs./ac)		Kernel weight (g)		PAR (%)		SWP (bar)	
	Treatment	Mean	Treatment	Mean	Treatment	Mean	Treatment	Mean
Kern	90	1960	100	1.17a	110	73a	110	-16a
	110	1890	70	1.15ab	100	70a	100	-17a
	100	1870	110	1.08ab	90	69a	80	-19ab
	80	1840	80	1.08ab	80	68ab	90	-19ab
	70	1610	90	1.01b	70	64b	70	-21b
Merced	110	2910	110	1.04	110	68	110	-14a
	100	2900	100	1.00	100	68	100	-15ab
	80	2640	90	1.00	90	64	90	-16ab
	90	2540	80	0.97	70	63	80	-18bc
	70	2420	70	0.90	80	62	70	-19c
Tehama	74	2340	116	1.35	116	71	116	-12a
	100	2315	86	1.29	86	68	100	-15b
	116	2260	100	1.27	74	68	86	-16b
	86	2260	74	1.24	100	67	74	-17b

At each site there was significant block-to-block variation in the amount of water applied, even for the same irrigation treatment (data not shown). However, this variation was useful in establishing a good range of applied water both between and within sites. There was a clear positive correlation of applied water to both PAR and SWP **(Figure 2)**. For PAR, all sites were similarly distributed around one fit line, but for SWP, there were clear differences, with Merced showing generally higher SWP for the same level of irrigation compared to Kern, and Tehama being intermediate **(Figure 2)**. For instance, an SWP of about -17 bars (moderate stress) was associated with about 43" of irrigation in Kern but only about 26" in Merced and 30" in Tehama. Presumably, this can be attributed to greater soil moisture reserves in Merced and Tehama compared to Kern, but it also raises the possibility that the almond water production function may not be the same for different almond growing regions/soils. A parallel difference between the three sites can also be seen in the relation of yield to applied water, with Merced showing the highest yields but also the lowest applied water amounts compared to the other two sites **(Figure 3a)**. All three sites had similar calculated values of ETc (data not shown), and while the higher irrigation levels at Kern and Tehama approached 100% of calculated ETc, at Merced the maximum applied water (about 35") was only about 85% of calculated ETc. The reason for this difference in SWP and yield at the same level of applied water (**Figures 2 and 3a**) is not yet clear, but a parallel difference was also exhibited in the relation of yield to PAR (**Figure 3c**), suggesting that there may be factors other than light and irrigation that are limiting yields in these sites. A more 'unified' approach has been to express yields as a % of the control yield at in each block (e.g., **Figure 3b**), but in this case the same slope (about 1.1% per inch of water for the regression shown) would mean different yield effects for different orchards. The slopes of the lines in **Figure 3a** range from about 20 to 70 kernel pounds per inch of water, but these values must be confirmed with additional years of data from these sites. One hypothesis we are testing is that the most appropriate basis for a water production function may be SWP, and even though that approach (**Figure 3d**) did not unify the data, it did eliminate the overall negative trend between sites (Merced had the lowest applied water but the highest yields) indicated in **Figure 3a**.

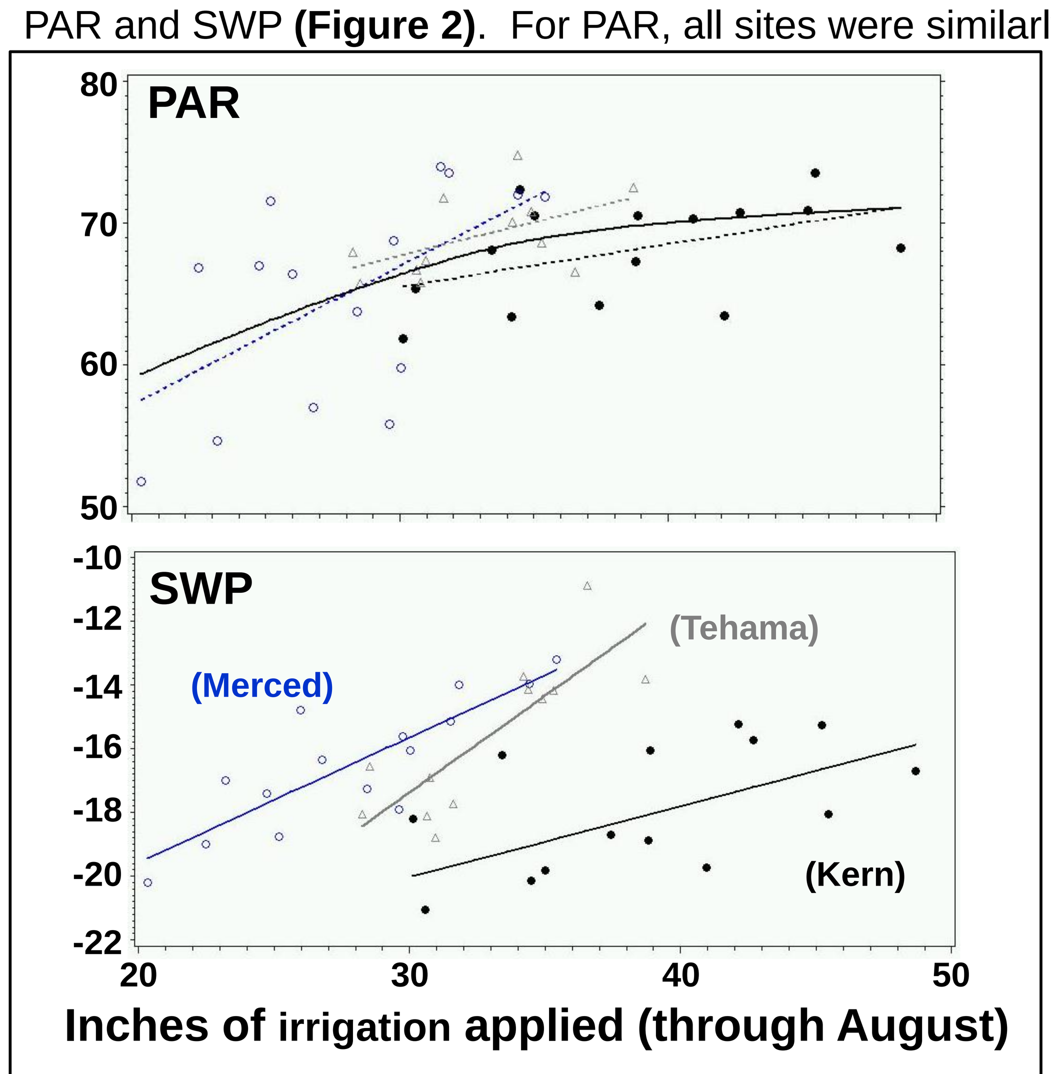

Figure 2. Influence of applied water amounts on midsummer canopy light interception (PAR) and midsummer (June – August) stem water potential (SWP). Linear regressions are shown for each individual site, but in the case of PAR only the Merced site was statistically significant, and a solid spline fit to all sites is also shown. In the case of SWP, all sites showed significant (Kern) to very highly significant (Merced) r-square values (0.32 to 0.71).

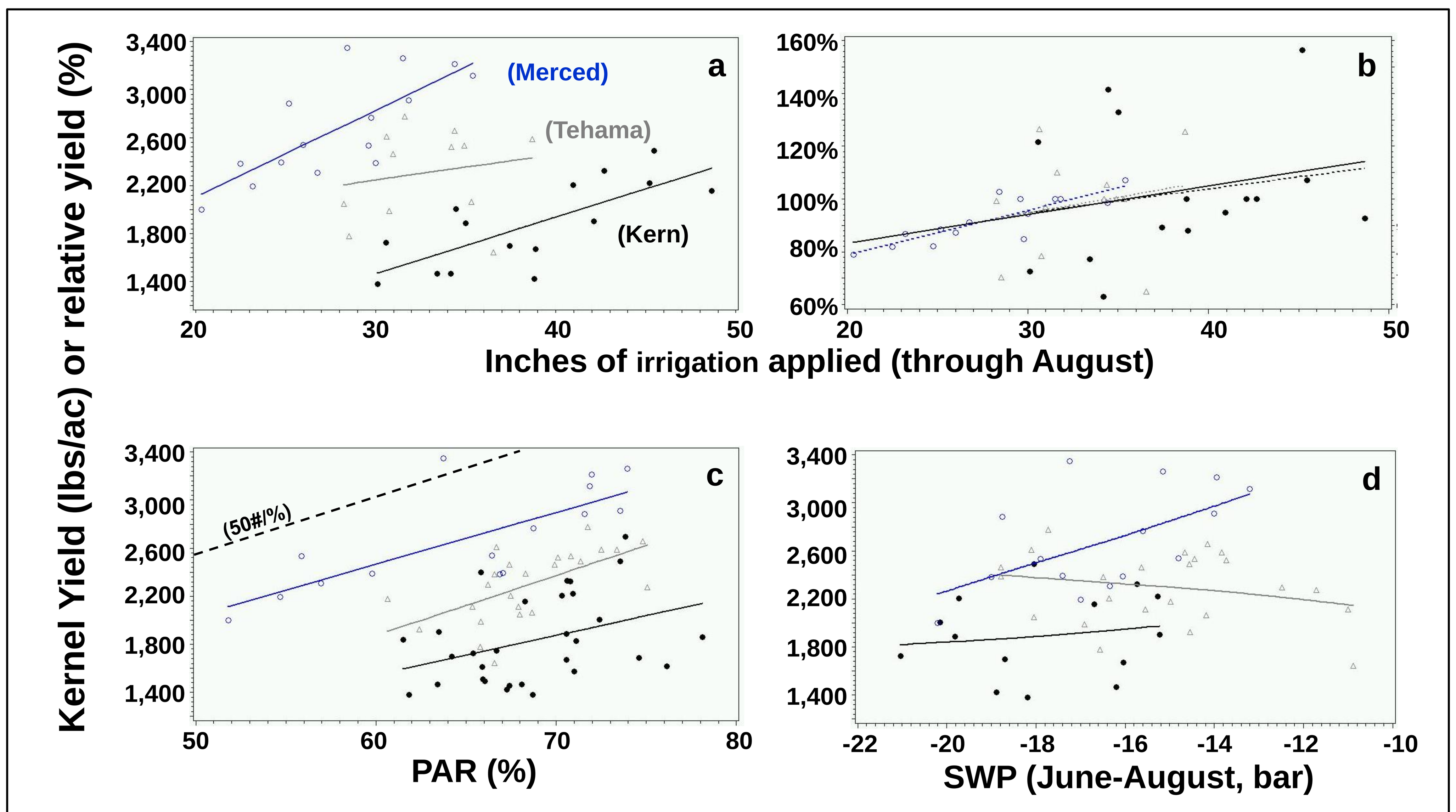

Figure 3. Alternative approaches to expressing a water production function. Yield is expressed either as actual kernel pounds per acre (a, c, d), or as a % of that found for the 100% ET treatment in each block (b). Water is expressed directly as inches of water applied (a, b), indirectly as SWP (d), or as percent PAR intercepted (c). In all cases, the range in the x-axis is established by the range of irrigation treatments imposed. The dashed line in c indicates the almond relation proposed by Lampinen (50 kernel ponds per percent PAR).

Conclusions:

Reducing irrigation has caused a clear increase in tree water stress (lower SWP) and reduction in canopy light interception (PAR) and yield across all sites, but there also appear to be site-specific effects on yield that are independent of the influence of SWP and PAR. The overall change in yield with PAR is consistent with the relationship proposed by Lampinen (50 kernel pounds per percent), but with a different overall level of yield for each site. The reason for this difference is not yet clear, but substantially different applied irrigation amounts (26" in Merced and 43" in Kern) were also associated with the same moderate level of tree water stress (-17 bars SWP), indicating that some of the site effects may still be attributable to differences in water availability and/or factors not yet considered, such as root health, other environmental factors (e,g, temperature) or specific developmental processes/periods (e.g., springtime tree water status and nut development).