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.

Background:

Previous irrigation research in almond has suggested that there is a maximum possible yield for any given level of irrigation, corresponding to about 70 kernel pounds per inch of water. In any particular orchard however, an increase in applied water may not give this level of yield response if there are other factors limiting yield. This water production function (WPF) project was established in three commercial orchards across the state, in order to determine obtain data on the response of yield to applied water under different commercial production conditions. The target levels of applied water ranged from about 70% ET to 110%ET, but the actual level has been determined for each treatment as the sum of irrigation, rain, and soil moisture depletion. This is the fifth and last year of this research project. We have previously reported that the yield responses we have observed have been much less than 70 kernel pounds per inch of water. In addition, we have found that canopy size (i.e., interception of sunlight, % PAR) is not limiting the yield in these orchards. Recently, Goldhamer and Fereres (2017, Irrig. Sci. 35:169–1790) have published the results of a 5 year study in a Kern Co. production almond orchard, indicating that the primary cause of increased yields with increasing irrigation amounts was via increases in kernel weight, rather than crop load (i.e., the number of nuts per tree or per land area).

Results and Discussion:

Table 1. Summary of the yield, kernel weight, and crop load effects (Nonpareil variety) of applying 5 years of deficit irrigation regimes in three commercial almond orchards. Statistically significant treatment differences are shown in bold. Mean values followed by the same letter are not different at the 5% level of Tukey's test.

Site (average annual calculated ETc)	Target	5 year average Actual %ET (inch)	Yield (kernel pounds/acre) Year: 2013	2014	2015	2016	2017	5 Year Average: Yield	M Kernels/ acre	Grams/ kernel	Highest to Lowest Water Treatment Percent Change in: Water	Yield	# Nuts	Grams/ kernel
Tehama (49")	116%	116% (57")	2143	2260	2440	1860	**1940b**	2130	0.783	**1.24a**	-24.5%	-1.9%	+7.7%	-8.1%
	100%	107% (52")	2150	2315	2230	1600	**2200ab**	2100	0.802	**1.20ab**				
	86%	93% (45")	2310	2260	2380	1650	**2310a**	2180	0.844	**1.19b**				
	74%	89% (43")	2210	2340	2170	1610	**2150ab**	2090	0.843	**1.14c**				
Merced (52")	110%	104% (54")	3040	2910	2220	2580	2120	2570	1.052	1.13	-24.1%	-11.7%	-3.3%	-8.0%
	100%	96% (50")	3240	2900	2410	2370	1890	2560	1.024	1.12				
	90%	89% (46")	2620	2540	2080	2350	1820	2260	0.945	1.09				
	80%	82% (43")	2720	2640	1820	2190	1751	2220	0.938	1.09				
	70%	79% (41")	2900	2420	1750	2280	1980	2270	1.017	1.04				
Kern (56")	110%	107% (60")	**3200ab**	1890	**2770a**	**3560a**	**2510a**	**2790a**	**1.175ab**	**1.09a**	-31.7%	-19.0%	-9.1%	-9.2%
	100%	93% (52")	**3310ab**	1870	**2410b**	**3470a**	**2520a**	**2720a**	**1.144ab**	**1.10a**				
	90%	94% (52")	**3540a**	1960	**2350b**	**3230ab**	**2180ab**	**2650ab**	**1.177a**	**1.03b**				
	80%	85% (47")	**3060ab**	1840	**2370b**	**2920b**	**2120b**	**2460bc**	**1.119ab**	**1.02b**				
	70%	74% (41")	**2670b**	1610	**2140b**	**2830b**	**2040b**	**2260c**	**1.068b**	**0.99b**				

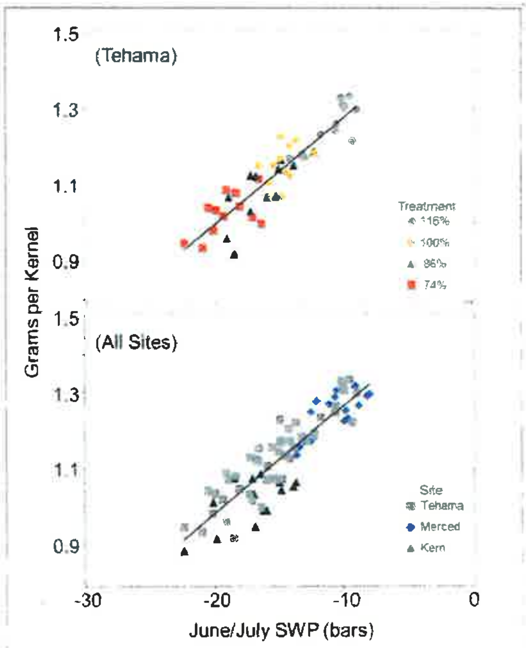

Figure 1. Relation between individual tree kernel weight (g/kernel) and average SWP during June and July, 2015, for one site showing individual treatments (top) and all sites pooling treatments (bottom).

- Substantial irrigation deficits (25-30%) have been imposed across sites and years, representing a 13 to 19" water differential (Table 1).
- Increases in yield with increasing water has only been statistically significant at Kern, but a trend in this direction has occurred in Merced (Table 1), and in the Monterey (pollenizer) variety (data not shown), but not the Nonpareil variety, at Tehama (Table 1).
- Considering the lowest to highest irrigation level at each site, all sites have shown a similar response of increasing kernel weight to increasing applied water, but contrasting crop load and hence final yield responses (table 1).
- Kernel weight was positively and similarly related to SWP across treatments within a site and also across sites within a year (Figure 1).
- Increased kernel weight has positively influenced yields across the sites in this study, as well as the site reported by Goldhamer and Fereres, but sites are very different in the relative effect of irrigation on crop load, ranging from positive (Kern) to negative (Tehama) to neutral (G&F) effects (Table 2).

Conclusions:

Our results indicate that, across sites, June/July is a key period when water stress has a strong influence on kernel weight accumulation and ultimate orchard yield. Future research should focus on the sensitivity of kernel weight and kernel number to water stress at different times of the season.

Table 2. Change in yield obtained by increasing water applied, based on the 5-year average yields and corresponding average water applied at each site. For each site, the relative importance of kernel weight effects and crop load effects are noted. "Kern (G&F)" refers to the results of Goldhamer and Fereres, 2017.

Site	Observed increase (+) or decrease (-) in yield (kernel pounds/ac) per: Inch of water	% ET	Interpretation
Tehama	-0.7	-0.3	Positive kernel weight effects are being canceled by negative nut load effects.
Merced	28	15	Yield increase coming mainly from an increase in kernel weight, and a small increase in nut load.
Kern	30	17	Yield increase coming equally from increases in kernel weight and nut load.
Kern (G&F)	42	22	Yield increase coming entirely from increases in kernel weight – possible drop in load at the highest irrigation.