Drought Survival Strategies for Established Almond Orchards on Shallow Soil

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Primary questions of this research effort:
1) If there is a drought year, how much water will it take to keep my trees alive?
2) If I have no, or very little water, is there any cultural practice that will help the trees survive and/or reduce the negative carryover effects on tree yield?

Background: This drought study was performed on mature (19 years old in 2009), single line drip irrigated NonPareil almonds at the Nickels experiment station. In 2009, three irrigation and two canopy modification treatments were imposed (Table 1), in order to evaluate the ability of these strategies to reduce tree mortality under a single year drought scenario. This site was chosen based on previous research showing that the active root-zone of these trees was limited to about 3', and the soil had a low water holding capacity, both factors contributing to a potentially lethal level of drought stress. For some trees in 2009 the level of drought stress (midday stem water potential (SWP) was severe, with one non-irrigated tree reaching more than -60 bars and entirely defoliating by late July, 2009, but all trees survived. Soil water uptake was found to occur at the deepest depth measured (10'), and after one year there was little canopy dieback apparent. Some of the non-irrigated pollinator varieties (Monterey, Carmel) did show substantial canopy dieback.

Specific Objectives for 2011

1. **Determine the second year carryover effects on almond production and tree survival of either reducing the tree canopy by 50% or treating it with kaolin (Surround) spray, under nonirrigated (rainfed) conditions.**
2. **Determine the second year carryover effects on almond production and tree survival of restricting irrigation to 5" and 10" of water applied to both kaolin (Surround) sprayed trees and nonsprayed trees (control), compared with fully irrigated control trees.**
3. **Relate shoot growth and spur survival patterns in the different treatments to the carryover effects observed.**

Results: Treatment effects on yield and kernel size (Table 1)

- Kaolin sprays had essentially no effect on yield or nut size in any year
- A 50% reduction in canopy (0" irrigation) resulted in a slightly improved yield compared to non-pruned trees in 2010, but no overall effect.
- For non-canopy modified trees, the clearest progressive reduction in nut size with reduced irrigation occurred in the drought year (2009), with no carryover effects after that, whereas for yield, there were both drought year (2009) and carryover (2010) effects, with carryover effect s being the larger of the two.

Table 1. Observed yield **(A)** and kernel size **(B)** effects of drought and canopy modification treatments in 2009, and the carryover effects of these treatments in 2010 and 2011.The target irrigation level was 40" for the control, but actual levels for 2009 are shown. In 2010 and 2011 all trees were irrigated at control levels. Statistically significant differences in bold.

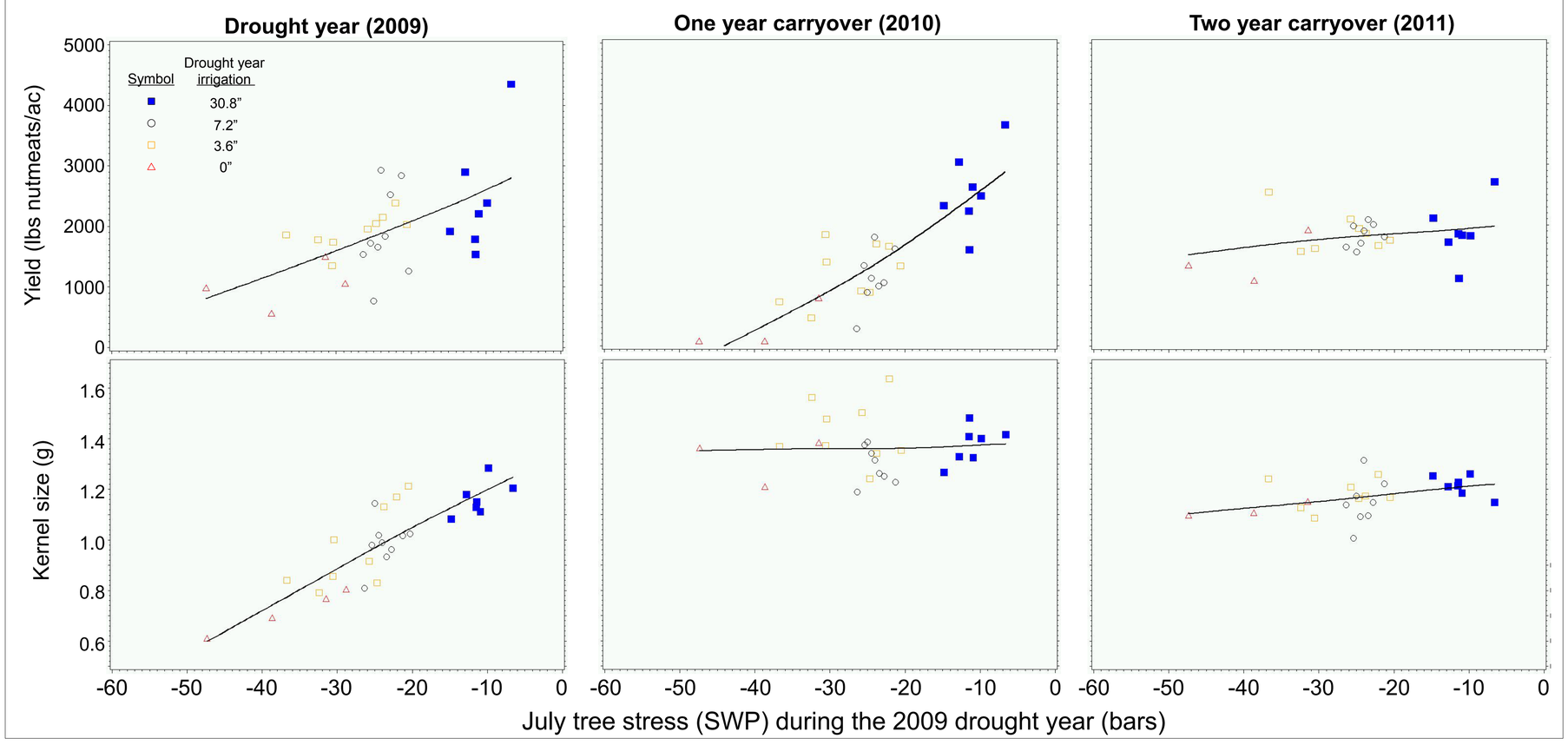
(A) Canopy Modification Treatment	Irrigation Treatment	Year						3 Year Cumulative
		2009 Yield		2010 Yield		2011 Yield		
		Lbs/ac	% control	Lbs/ac	% control	Lbs/ac	% control	% control
(None)	30.8"	2440	100	**2260 a**	100	1880	100	100
(None)	7.2"	1890	78	**1350 ab**	53	1740	93	76
(None)	3.6"	2020	83	**1010 b**	39	1890	100	75
(None)	0"	1030	42	**320 b**	12	1440	76	42
Kaolin spray	7.2"	1910	78	910	34	1930	103	72
Kaolin spray	3.6"	1800	74	1450	55	1860	99	78
50% pruning	0"	860	35	770	29	1360	72	45
50% pruning + spray	0"	590	24	430	16	980	52	31

(B) Canopy Modificatoin Treatment	Irrigation Treatment	Year					
		2009 Kernel Size		2010 Kernel Size		2011 Kernel Size	
		g/kernel	% control	g/kernel	% control	g/kernel	% control
(None)	30.8"	**1.16 a**	100	1.38	100	1.21	100
(None)	7.2"	**1.03 a**	90	1.32	96	1.20	99
(None)	3.6"	**0.96 a**	84	1.43	104	1.19	98
(None)	0"	**0.71 b**	62	1.32	96	1.12	93
Kaolin spray	7.2"	0.90	78	1.2	87	1.10	91
Kaolin spray	3.6"	0.97	83	1.4	101	1.16	96
50% pruning	0"	0.79	68	1.39	101	1.21	100
50% pruning + spray	0"	0.77	66	1.39	101	1.20	99

Results: Relation of tree stress to yield and nut size (Figure 1)

- Consistent with the statistical results shown in Table 1, in the drought year, reductions in both yield and nut size were related to SWP in individual trees, but the relationship was strongest for nut size.
- Similarly consistent with Table 1, the one-year carryover effect on yield (2010) was more strongly related to SWP in 2009 than was the yield of 2009.

Figure 1. Relation between tree yield and nut size in non-pruned trees from 2009 – 2011 to the level of stress experienced in July, 2009.



Results: Carry-over effects on flowering and fruit set (Figure 2)

- Branch-level measurements in the spring of 2010, on trees selected to cover the range of 2009 SWP, indicated that reductions in both flowering (Figure 2A) and fruit set (Figure 2B) were important components of the observed carry-over effect on 2010 yield (Table 1 and Figure 1).
- These limited data also suggested that the stress effect on flowering may have a threshold of about -15 bars (average July SWP), but that there may be no threshold for the stress effect on fruit set.

Results: Comparison of branch-level and irrigation treatment-level carryover effects on yield (Table 2)

- Based on the July treatment mean values of SWP in 2009, the number of flowers and percent fruit set was predicted for each treatment from the best fit lines shown in Figure 2, and each was expressed as a percent of the control irrigation treatment value.
- Since there was no carryover effect on kernel size (Table 1 and Figure 1), a percent of control yield was calculated by multiplying flowering percent by fruit set percent, and this calculated value was in very good agreement with the observed value, indicating that essentially all of the carryover effects could be attributed to the combined effect of SWP on flowering and fruit set .

Results: Predicted carryover effects of water stress on yield (Figure 3)

- Based on the close agreement between the predicted and the observed yield shown in Table 2, a model was developed for the entire range of SWP observed in 2009.
- This model indicates that carryover water stress effects on yield may be most pronounced at high levels of water availability.

Figure 2. Branch-level carryover effect of 2009 stress level (SWP) on 2010 flowering (A), and percent fruit set (B) on selected trees.

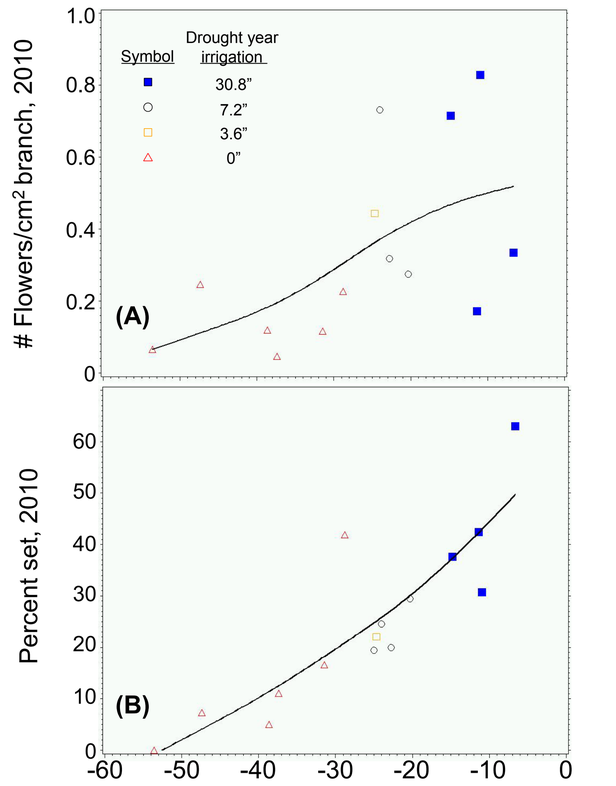
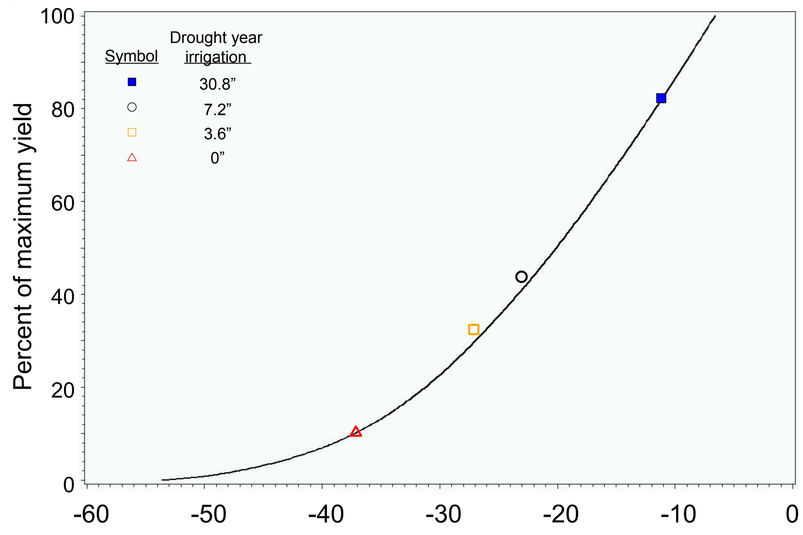


Table 2. Treatment average July, 2009 SWP, the corresponding flowering and fruit set values from the curves shown in figure 2, and predicted and observed reductions in yield in 2010 based on the product of percent control flowering and fruit set.

Irrigation treatment	Observed 2009 July SWP (Bars)	Branch-level observations corresponding to July SWP values (from figure 2)				Predicted carryover yield (% of control)	Observed 2010 yield (% of control)
		Flowering		Fruit set			
		#/bxsa	% control	%	% control		
30.8"	-11	0.518	100	34.5	100	100	100
7.2"	-23	0.445	86	22.1	64	55	53
3.6"	-27	0.370	71	20.0	58	41	39
0	-37	0.185	36	12.8	37	13	12

Figure 3. Predicted (line) and observed (symbols) carry-over effects of 2009 drought treatments on 2010 yields, based on the flowering and fruit set effects shown in figure 2 and table 2.



Summary and conclusions:

- Severe drought reduced kernel size to 62% and yield to 42% of control in the drought year, but caused an even stronger reduction to 12% of control yield in the year following drought, due to reductions in flowering and fruit set.
- All trees have survived, with the extreme trees only showing a 20% canopy dieback at two years, indicating that neither a reduction in canopy size by pruning nor an application of kaolin to protect against heat were effective cultural practices under these drought conditions for NonPareil.
- Water stress reduced yield through current year reductions in nut size and nut number (increased sticktights), but the most severe reductions were caused as carryover effects on flowering and fruit set. These carryover effects, and hence long term orchard yield, may be most pronounced at high levels of water availability.