Drought Survival Strategies for Established Almond Orchards on Shallow Soil

Project No.: **11.HORT8.Shackel**

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Objectives:

- 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.
- 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.
- Relate shoot growth and spur survival patterns in the different treatments to the carryover effects observed.

Interpretive Summary:

A set of one-year drought conditions (no irrigation, 3.6”, 7.2” and a 30.8” applied water control) were imposed on blocks of experimental trees in 2009, and in that year there was a substantial reduction in yield (58%) compared to the control for the most extreme drought treatment (no irrigation). In the following year, however (2010), despite returning all drought treatments to normal irrigation, there was an even more substantial reduction (88%) in the 2009 no irrigation treatment compared to the control, due to the combined carryover effects of reduced flowering and reduced fruit set. These carryover effects were closely related to the degree of tree water stress measured by midday stem water potential (SWP) across all drought treatments. Carryover effects on yield were still apparent in the no irrigated treatment in 2011, which showed a 24% reduction compared to the control, but by this time the intermediate treatments had returned to 100% of the control yield. These results demonstrate that the most severe drought effects on almond yield are carryover effects, but also that these effects can be substantially mitigated by application of even modest amounts of irrigation during the drought year. When faced with drought conditions, a key factor to consider is the level of tree stress. Based on these data, a 50% reduction in yield can be expected if trees average -20 bars SWP

in July, and a 90% reduction can be expected if trees average -40 bars SWP, compared to trees that are maintained near baseline SWP (typically -7 to -10 bars in July).

Materials and Methods:

The primary trees of this study are located at the Nickels estate (Arbuckle, CA), and are the surface (single line) drip irrigated plots of the Marine Avenue irrigation experiment. A total of 5 replicate plots consisting of 6 rows X 11 trees were established and in 2009, the following treatments applied (**Table M1**).

Table M1. Combination of irrigation and canopy reduction treatments. These treatments were imposed in 2009, and were followed by resumption of normal irrigation as of 2010.

Irrigation level	Canopy reduction or spray	# trees/plot
0 (rainfed)	None	2
	Surround Spray	3
	Pruning (50% scaffold removal) + surround spray	3
5" in-season	None	2-3
	Surround spray	2-3
10" in-season	None	2-3
	Surround spray	2-3
Control (100% ETc)	None	3

Based on recent work by Goldhamer et al. (2006), showing that deficit irrigation is best spread throughout the growing season, the 5" and 10" irrigation levels were accomplished by replacing drippers in the existing system, but using the same schedule of irrigation timing as used in the control. A grid of 9 neutron access tubes were installed (deepest to 10’) in a single quadrant of one tree in each rep of each treatment except for the control treatment. Watermark soil moisture sensors were also installed adjacent to one neutron tube site (to 8’). Measurements of midday stem water potential (SWP) were taken approximately weekly. Soil moisture using Watermark sensors was monitored continuously, and soil moisture using neutron probes was monitored monthly. Periodic measurements of canopy light interception were used to characterize regrowth and defoliation patterns. Yield was measured at the end of the first season, and dieback, bloom status, and yield measured in subsequent years.

Results and Discussion:

Soil conditions and tree survival. 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.

Canopy modification treatment effects on yield and kernel size. Kaolin sprays had essentially no effect on yield or nut size in any year, but a 50% reduction in canopy (0" irrigation) resulted in a slightly improved yield compared to non-pruned trees in 2010, but no overall effect (**Table 1 A**). 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 effects being the larger of the two (**Table 1 B**). 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 50% pruning, nor an application of kaolin to protect against heat, were effective cultural practices under these drought conditions for Nonpareil.

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 to control levels. Statistically significant differences are in bold, with means followed by the same letter being not significantly different at the 5% probability level.

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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 Modification 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*

Relation of tree stress in the drought year to yield and kernel size in all years. Consistent with the statistical results shown in **Table 1**, in the drought year, reductions in both yield and kernel size were related to the SWP experienced during the height of the drought (July), but the relationship was strongest for nut size (**Figure 1, year 2009**). Similarly consistent with **Table 1**, the one-year carryover effect for yield in 2010 was strongly related to the SWP experienced in 2009, but with no relation to nut size in 2010 (**Figure 1, year 2010**). By 2011, there was no clear carryover effect that was related to the degree of stress experienced in the drought year (**Figure 1, year 2011**).

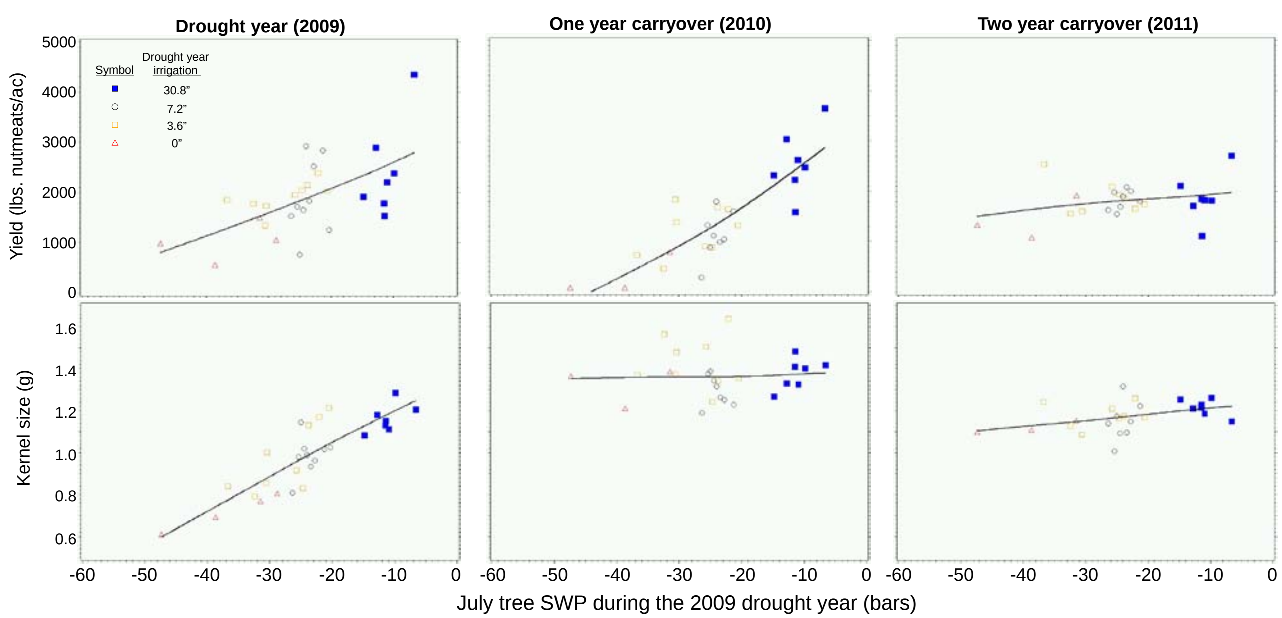

Figure 1. Relation between tree yield and nut size in non-pruned trees from 2009 – 2011 to the level of stress experienced in July, 2009.

Analysis of the relation of SWP to branch- and treatment-level carryover effects. 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 (**Figure 2A**) 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. Based on the July treatment mean values of SWP in 2009 (**Table 2**), 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 (**Table 2**). 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 (**Figure 3, solid line**). This model was in very good agreement with the observed treatment means (**Figure 3, symbols**), and indicates that carryover water stress effects on yield may be most pronounced at high levels of water availability.

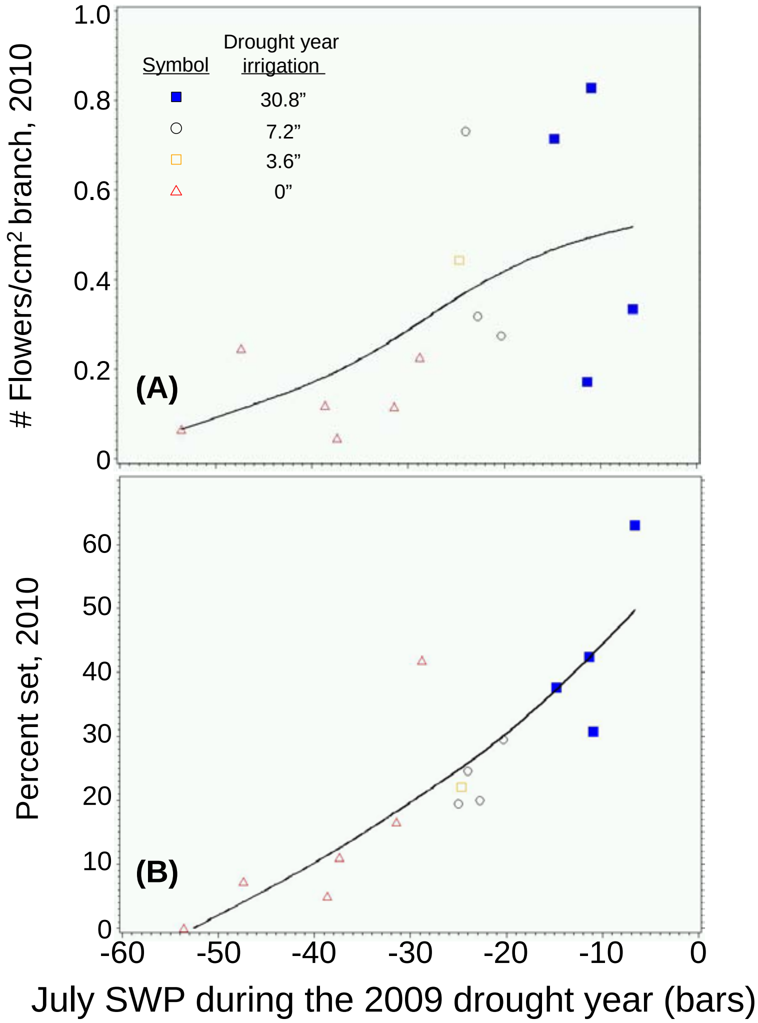

Figure 2. Branch-level carryover effect of 2009 stress level (SWP) on 2010 flowering (A), and percent fruit set (B) on selected trees.

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 (number of flowers per unit branch cross-sectional area, #/bxsa)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**

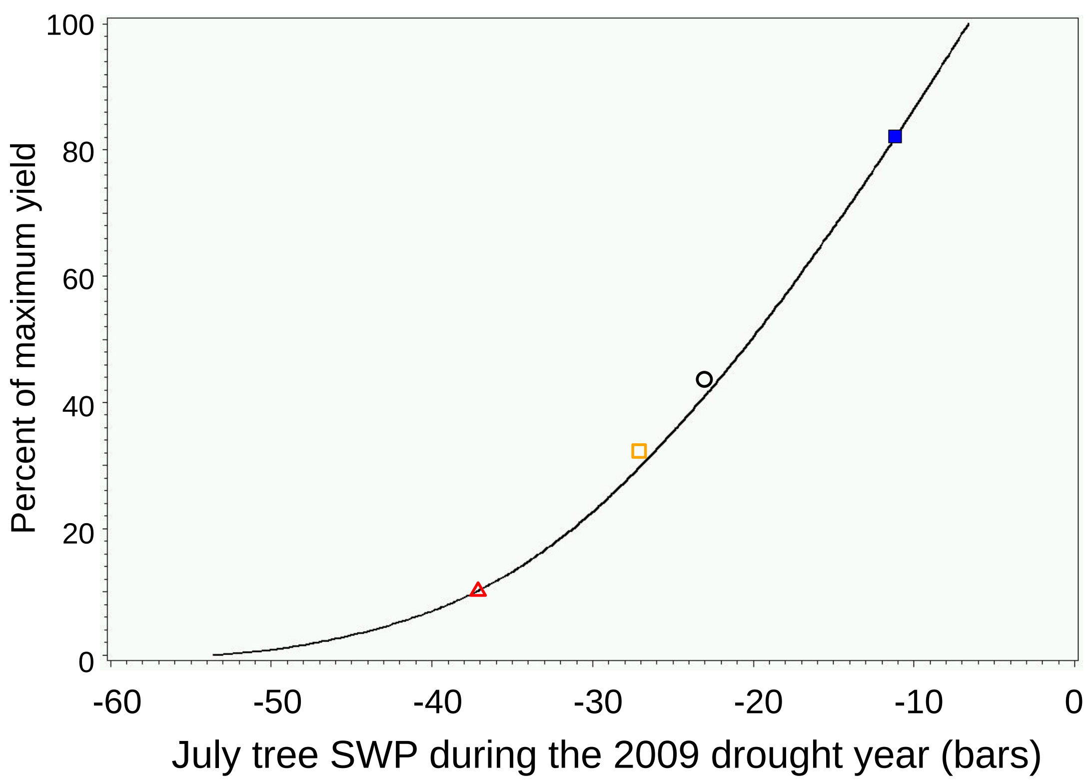

Figure 3. Predicted (line) and observed (symbols) carry-over effects of 2009 drought treatments on 2010 yields, \ based on the flowering and fruit set effects shown in **Figure 2** and **Table 2**.

Research Effort Recent Publications:

Munoz H, 2011. Carry-over effects of water stress in the vegetative development, flowering, fruit set, and yield of almond trees. MS Thesis, UC Davis.

Shackel KA. 2010. A Plant-based Approach to Deficit Irrigation in Trees and Vines. Hort.Sci. 46:173-177.

Stewart WL, Fulton AE, Krueger WH, Lampinen BD, Shackel KA. 2011. Regulated deficit irrigation reduces water use of almonds without affecting yield. Cal Ag. 65: 90-99.

References Cited:

Goldhamer DA, Viveros M, Salinas M. 2006. Regulated deficit irrigation in almonds: effects of variations in applied water and stress timing on yield and yield components. Irrig. Sci. 24(2):101-14.