Drought Survival Strategies for Established Almond Orchards

Project No.: 10-HORT8-Shackel

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Objectives:

1) Determine the effects of 3 levels of canopy modification (none, 50% scaffold thinning in the spring, and 50% scaffold thinning in the spring plus spring/summer Kaolin spray) under non-irrigated (rainfed) conditions on tree production and survival.
2) Determine the effects of an irrigation restriction to 5" and 10" of applied water at 2 levels of canopy modification (none, and spring/summer Kaolin spray) on tree production and survival.
3) Estimate the total quantity of water required for survival of almond trees under these conditions.
4) Determine the critical level of tree water stress necessary for tree death or dieback.
5) Document the degree of water stress occurring in a properly managed rainfed orchard, and the physiological mechanisms that allow trees to survive on rain alone. (Note: it was not possible to complete this objective as we were unable to obtain grower permission to conduct the study).

Interpretive Summary:

This experiment was conducted on single line drip irrigated trees on a very low water holding capacity soil, and it was anticipated that non-irrigation would result in tree death or at least extensive tree dieback. The most surprising result to date is that all trees continue to survive, two years after the simulated “drought” year (2009). The results continue to support earlier conclusions that 7.6” of water may be sufficient for almond tree survival under these conditions, and that even under drip irrigated conditions, the roots of these trees can be functional to depths on the order of 10 feet. Carryover effects on yield were more severe as stress increased, and were about equally attributable to reductions in flowering and fruit set, leading to a lower number of nuts per

tree and lower yield. It appears that flowering may be somewhat less sensitive to stress than fruit set, at least until the July stem water potential (SWP) reaches about -30 bars. Canopy management (pruning, spraying) had no effect on tree survival, and no statistically significant effect on yield, although removing 50% of the canopy numerically reduced yields. A SWP value of -63 bars was exhibited by one tree in the study without tree death. This fact indicates that this value is not lethal and is consistent with the belief that almond trees are very drought resistant. Twig dieback occurred in both stressed and non-stressed trees, but was not severe in any treatment. More dieback was observed in guard trees of the Monterey and Carmel varieties, indicating that these varieties may not be as drought resistant as Nonpareil.

Materials and Methods: The 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, with 2 of the rows being Nonpareil, bordered on each side by one of three other varieties (Butte, Carmel, Monterey), serving as guards. Each plot consisted of 8 treatments as described in **Table 1**. The irrigation treatments were based on recent work by Goldhamer, showing that deficit irrigation appears best when spread throughout the growing season. The 5" and 10" irrigation levels were established by replacing drippers in the existing system, but using the same schedule of irrigation timing as used in the control. Applied water is being measured with water meters and direct flow measurements on each dripper, as well as automated sensors for measuring system on time. Grids of 9 neutron access tubes were installed in a single quadrant of one tree in each drought treatment in 4 of the 5 plots. Measurements of midday stem water potential (SWP) are being taken approximately weekly, and soil moisture with neutron probes monthly. Periodic measurements of canopy light interception are also being made. SWP is measured on one central tree in each rep of each treatment (total of 40 trees). Yield was measured at the end of the first season, and dieback, bloom status, and yield were measured in subsequent years. In years #2 and 3, the intensity of measurement of soil moisture and SWP will be reduced, unless there are indications that the year #1 treatments have caused root system dieback. Nuts harvested in 2009, from trees that representing the entire range of stress experienced in that year, were also submitted to the Almond Board of California for compositional analysis.

Table1. Irrigation and canopy modification treatments applied in 2009 in order to simulate a drought condition and contrasting grower management alternatives. Irrigation was restored to control levels in 2010.

Irrigation Treatment	Canopy modification
0" (rainfed)	None
	50% reduction once SWP reaches -15 bars
	50% reduction + Kaolin spray
5" in-season	None
	Kaolin spray
10" in-season	None
	Kaolin spray

Results and Discussion:

Stem water potential (SWP). The amounts of applied water in 2009 at this site were somewhat less than those normally applied, with the control treatment receiving about 80% of full ET (**Table 2**).

Table 2. Applied irrigation amounts for each treatment, and the corresponding range in minimum SWP (maximum stress) exhibited by individual trees in that treatment in 2009.

Irrigation Treatment	Inches of water applied in 2009	Range in minimum SWP observed for all trees within each irrigation treatment (Bar)
0 (rainfed)	0”	-29 to -63
5" in-season	3.6”	-24 to -42
10" in-season	7.2”	-24 to -35
Control	30.8”	-19 to -22
≅100% ETc	38.7"	-9

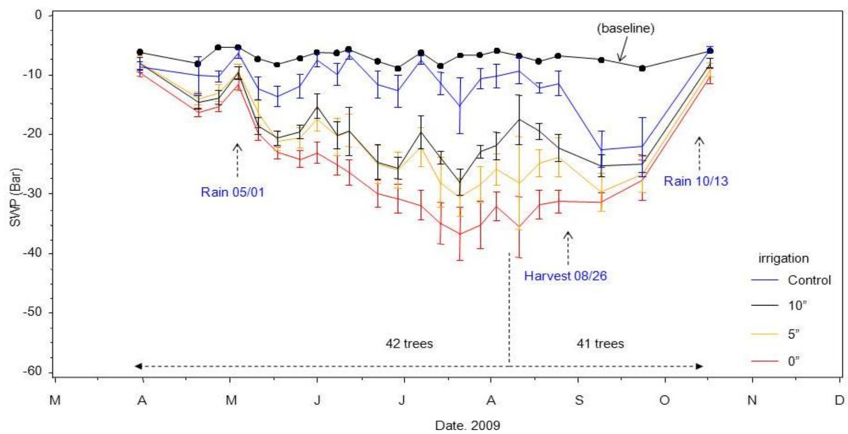

Figure 1. SWP observed for all irrigation treatments in 2009.

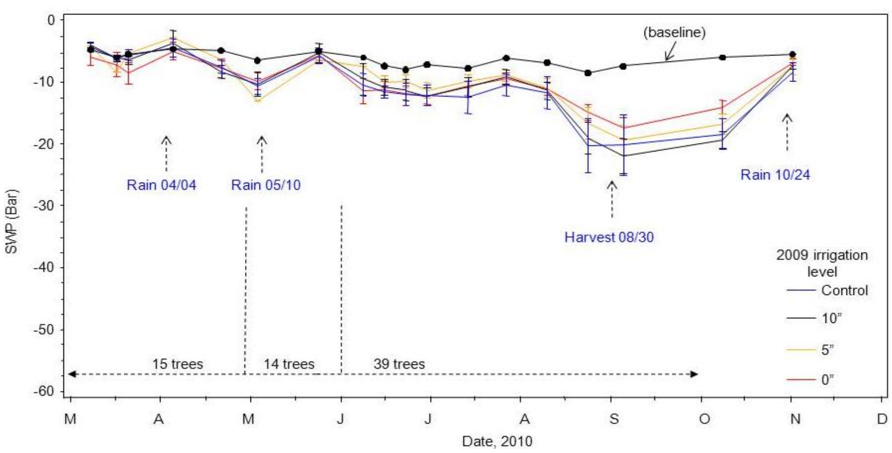

Figure 2. SWP observed under normal (control) irrigation conditions in 2010, for the same 2009 treatments as shown in figure 1. A sample of study trees was monitored until mid-June, after which all study trees were monitored.

Most of this deficit occurred after harvest. The substantially different irrigation amounts used in 2009 resulted in clear differences in SWP over the season, with the lowest SWP (most stress) occurring in the non-irrigated plots, highest SWP in the fully irrigated plots, and intermediate levels in the 5" and 10" irrigated plots (**Figure 1**). In 2010, when all trees were irrigated at the same level, all treatments recovered to the level of control, indicating that there were **no carryover effect on SWP**, particularly in the early season, when a carryover effect from 2009 might have been anticipated (**Figure 2**).

Tree survival. One surprising result in 2010 was that there was **no tree death as a result of stress in 2009**, including a non-irrigated tree that was entirely defoliated by late July. Together with the observations made in 2009, these facts illustrate two important points: 1) given a gradual development of stress during the season, **Nonpareil trees are able to survive very low water potentials** (on the order of -60 bars), and 2) **the root systems of drip irrigated trees may extend well beyond the zone generally considered as "active."** In 2009 we reported that a clear increase in soil moisture tension occurred at all depths measured to 8 ft for one tree in the 10 inch irrigation, indicating water uptake at that depth. This particular tree was blown over and removed in May, 2010, and after that time, water depletion was only observed to a depth of 3 ft, with deeper depths remaining around field capacity (10 – 20 cb for this soil) for the entire season (**Figure 3**). This is a clear illustration that the root system of this particular tree extended to 8ft, and probably beyond, and suggests that these **deep roots are a very important factor in the ability of almonds to survive drought.** Even though all trees survived, by the spring of 2011 there was some evidence of dieback in some small branches and limbs (**Figure 4**). Dieback was much more severe for some of the guard trees (Monterey and Carmel) in the 0" plots, and in some cases entire scaffolds were lost, but such severe effects were not observed in Nonpareil trees. Since we did not measure water potentials in guard trees, we do not know if the more severe dieback was the result of extremely low water potentials, perhaps related to shallower rooting, or an increased sensitivity of these varieties to the same level of stress. More research on this question is needed. Dieback on all of the Nonpareil trees was estimated by measuring the diameter of branches with dead portions and expressing the dead branch

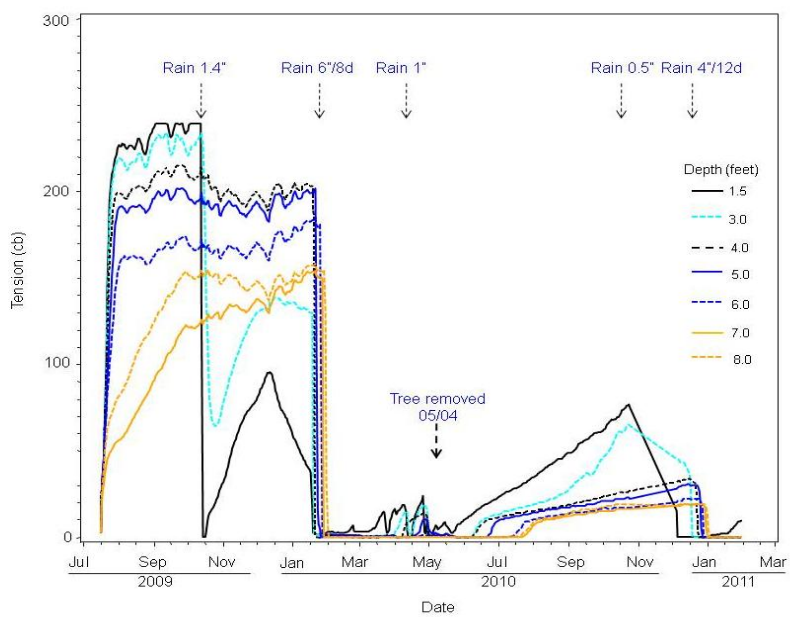

Figure 3. Soil moisture tension from 1.5 to 8 ft for one tree in the 10" irrigation treatment throughout the course of the experiment. High values indicate dry soil, and values of 0 indicate saturated soil.

cross sectional area as a percent of the total cross sectional area of the rest of the tree. In the control treatment this value ranged from about 1% to 7%, but across all trees in the study **there was a significant increase in dieback with stress, although the most severely stressed tree only reached a value of about 23% (Figure 5).** One individual tree exhibited a value of 36% dieback (**Figure 5**), but other trees at the same level of stress did not show this amount of dieback, and hence it is possible that some of this dieback may have been due to other causes. Yields in 2011 will be used to evaluate the importance of these differences in dieback.

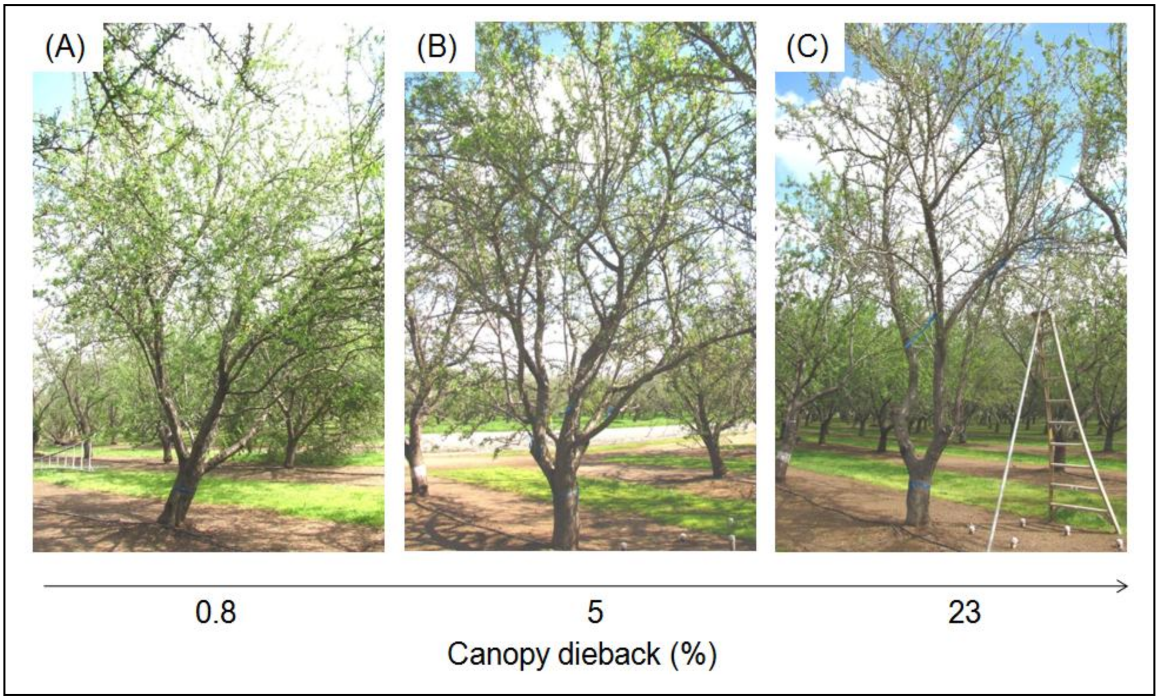

Figure 4. Examples of experimental trees with canopy dieback observed on March 22nd, 2011 for three different levels of midday stem water potential measured in July 2009; (A) Control, -7 Bars; (B) 0 mm, -31 Bars; (C) 0 mm -54 Bars. Dead branches are indicated by blue flagging.

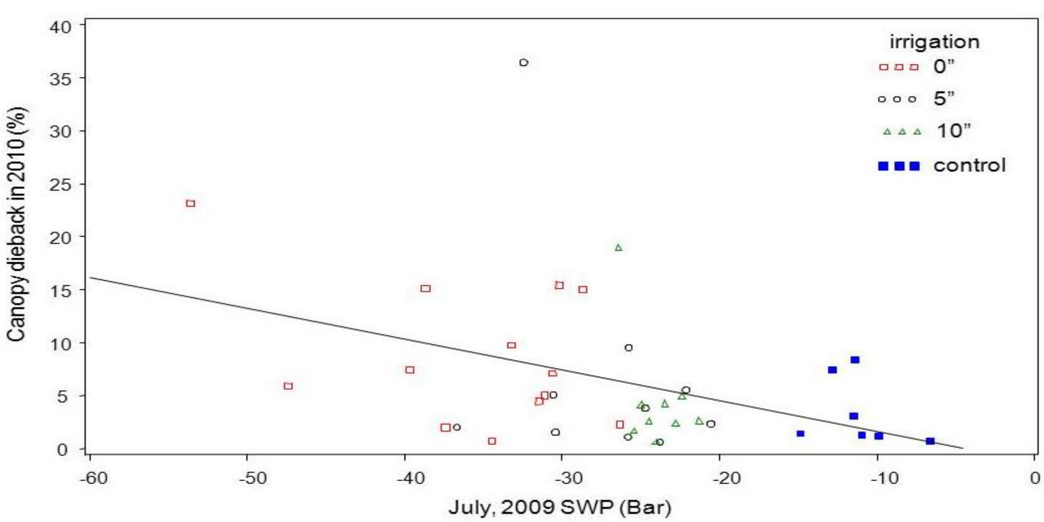

Figure 5. Relationship between canopy dieback observed in 2010 and July average SWP that occurred in 2009 for all trees in the study.

<u>Yield effects</u>. As reported earlier, yields in the deficit treatments were numerically reduced compared to control in 2009, but the only statistically significant treatment effect was a **reduction in nut size in the year of stress** (**Table 3**). In contrast, **the strongest carryover effects were in the number of nuts/tree and yield**, with the 0" treatment causing a reduction of 88% from control levels (**Table 3**). In addition to

Table 3. Nut weight, # nuts/tree, yield and statistical results for 2009 and 2010 (non-pruned trees only).

2009						
Irrigation	Nut weight		Nuts / tree		Yield	
	(g/nut)	(% control)	(#)	(% control)	(lbs/ac)	(% control)
40	1.16 a	100	7649	100	2441.3	100
10	1.03 a	90	6807	89	1892.2	78
5	0.96 a	84	7804	102	2021.8	83
0	0.71 b	62	5235	68	1030.0	42
2010						
Irrigation	Nut weight		Nuts / tree		Yield	
	(g/nut)	(% control)	(#)	(% control)	(lbs/ac)	(% control)
40	1.38	100	8148 a	100	2257.7 a	100
10	1.32	96	4404 ab	54	1349.3 ab	53
5	1.43	104	3217ab	40	1006.4 b	39
0	1.32	96	852 b	10	319.4 b	12

describing current year and carryover effects in terms of irrigation treatments, one of the key objectives of this research is to describe carryover effects in terms of tree stress, and as a benchmark value, we found that the average SWP in the month of July was well correlated to yield and other plant responses. **Current year stress (SWP) generally decreased yield (Figure 6A) but markedly decreased nut size (Figure 6B).** In the year following stress, **yield was markedly reduced as a carryover effect**, and was clearly linear with the degree of stress experienced by the tree in the prior year (**Figure 6C**), whereas there was **no carryover effect on nut size (Figure 6D).** Another factor that reduced yield in the year of stress was an **increase in stick tights with stress**, although there appears to be a threshold stress of about -25 bar before stick tights are increased (**Figure 7**).

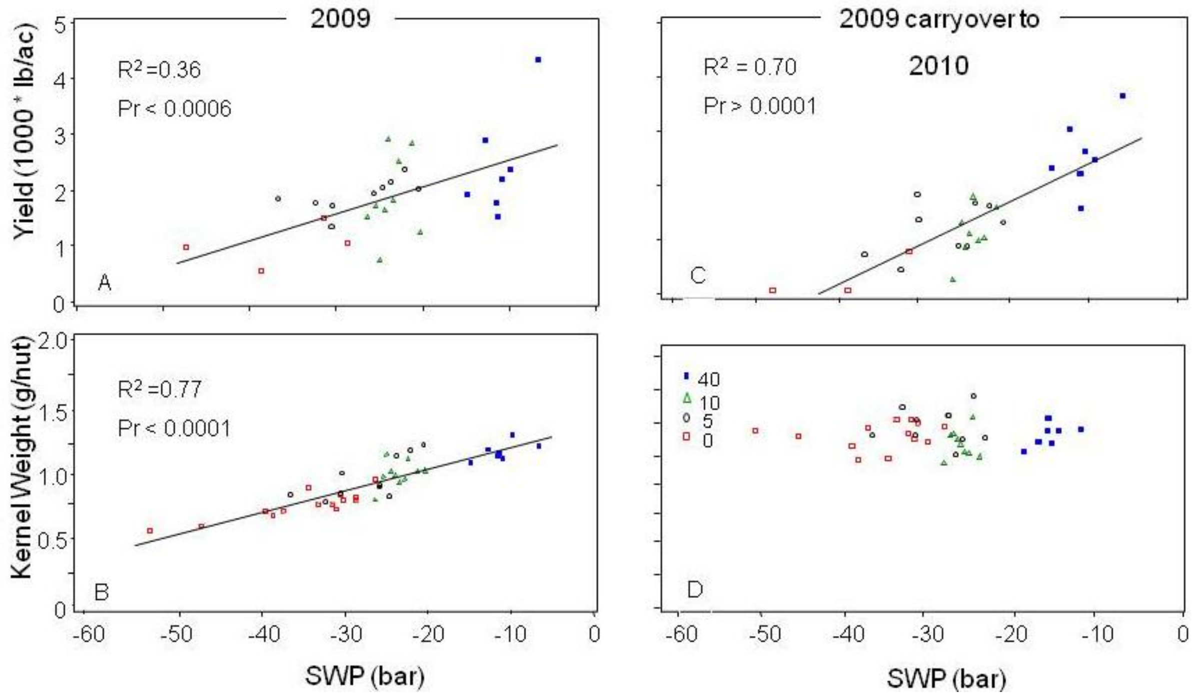

Figure 6. Effects of 2009 (current year) stress level on yield (A) and nut size (B) in 2009, compared to stronger carryover effects on yield (C) and no carryover effect on nut size (D) in 2010.

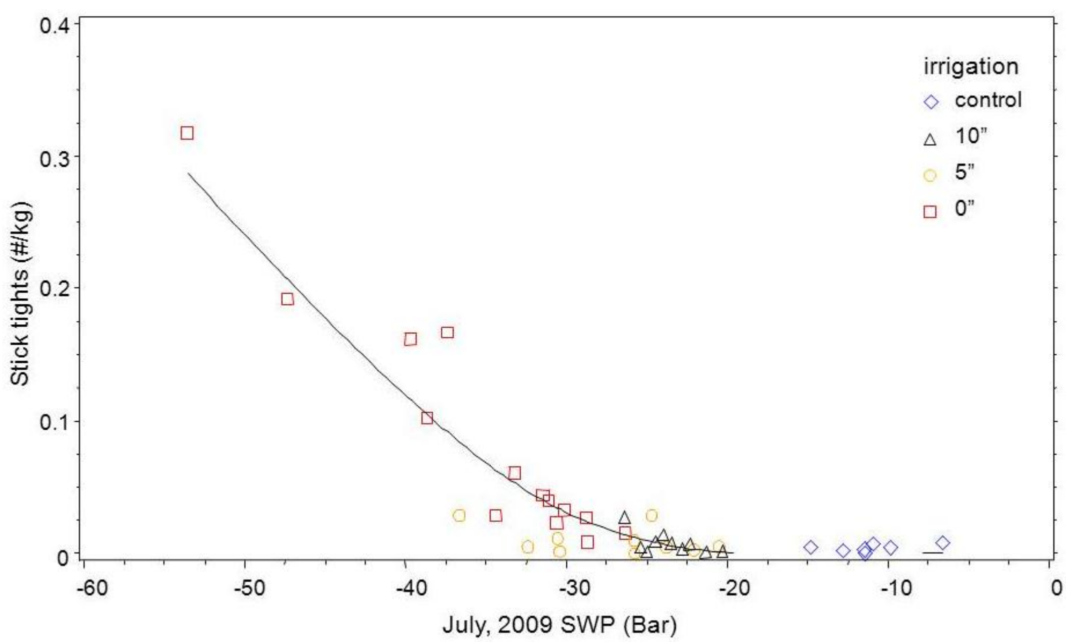

Figure 7. Effects of 2009 (current year) stress level on stick tight (un-harvested) nuts in each tree of the study. Stick tight nuts are expressed per kilogram of nutmeats harvested.

Nut quality effects. There were strong current year effects on nut composition. Increasing stress was associated with increases or no change in some components (**Figure 8**) and decreases in other components (**Figure 9**). **Table 4** summarizes all of the nut components that were evaluated, and in general shows that a **decrease in fat content under stress was balanced by an increase in carbohydrates and protein.** The increase in moisture content with stress is counter intuitive, but **Figure 8** shows that the nut moisture levels were generally low (around 4%), and so the increase in moisture was probably just reflective of the increase in carbohydrate levels.

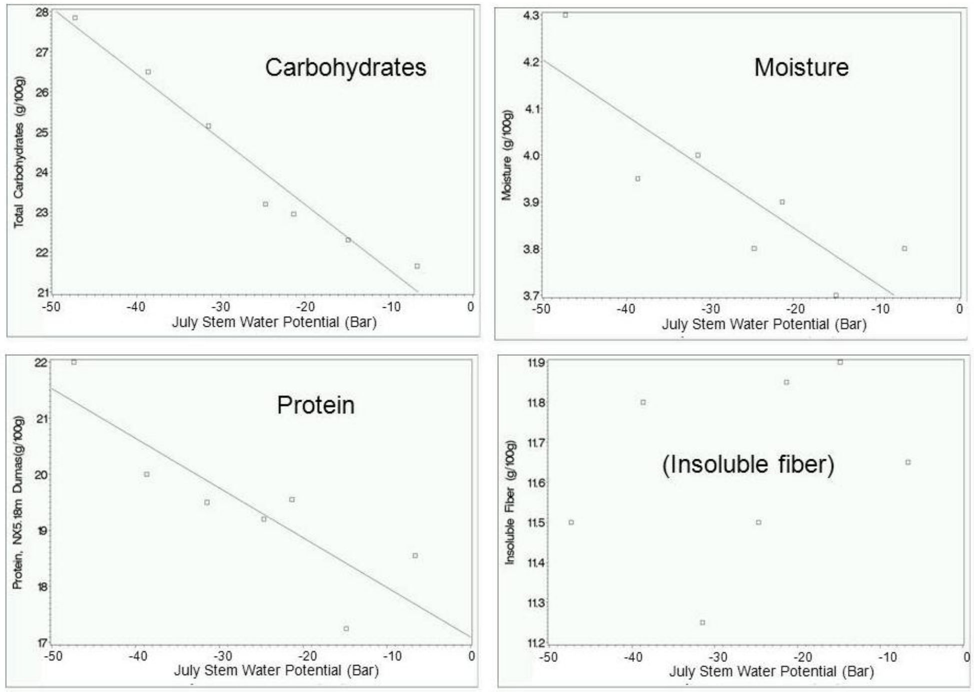

Figure 8. Nut components that showed an **increase or no change** in level with increases in stress (lower SWP) in 2009.

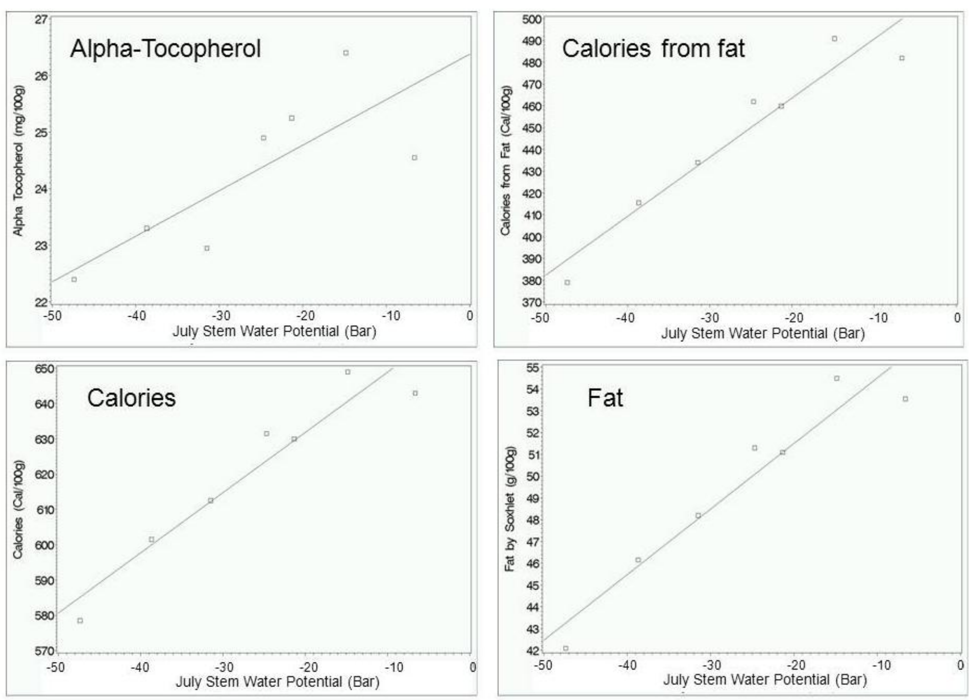

Figure 9. Nut components that showed a **decrease** in level with increases in stress (lower SWP) in 2009.

Table 4. Nut composition as influenced by tree water stress.

Components showing a significant **increase** with stress	Components showing a significant **decrease** with stress	Components showing **no significant change** with stress
Total Carbohydrates	Calories from fat	Soluble Fiber
Protein	Calories	Insoluble Fiber
Ash	Fat	Total Dietary Fiber
Moisture	Alpha Tocopherol	Gama Tocopherol

<u>Bloom and other carryover effects</u>. As reported by other researchers, in the spring of 2010 we observed a progressive **delay in flower development** with increasing stress experienced in 2009 (**Figure 10**). Bloom was rated subjectively on a 0 – 5 scale for all trees in the study by two individuals on 2/22/10, and while there was a clear trend for higher bloom rating with less stress (**Figure 11**) only the most severely stressed tree (completely defoliated by late July) rated a 0 (no bloom), with a wide range of bloom ratings for all other levels of stress. These data indicate that **severe stress may be required to completely eliminate bloom in Nonpareil**. Winter wood carbohydrate reserves (TNC, mainly starch) and spring bloom counts were made on a select group of trees representing the range of stress levels observed, to test the hypothesis that stress may lead to lower flowering due to a depletion in carbon reserves. There was a decrease in both flowering (# flowers/branch cross-sectional area) and TNC with stress (**Figure 12**), but **neither flowering nor TNC appears to be affected until stress becomes relatively severe -30 bars July SWP).** In contrast, there was a **progressive decline in % set with stress** (**Figure 13**). **Table 5** summarizes these two effects (flowering effects and % set effects), and shows a remarkable agreement between the predicted yield effects and the observed yield effects. Hence **we can tentatively conclude that the observed carryover effect on yield is caused by reductions in both flowering and set, with both effects being of about equal importance**, although at moderate stress levels it appears that set may be more strongly reduced than bloom.

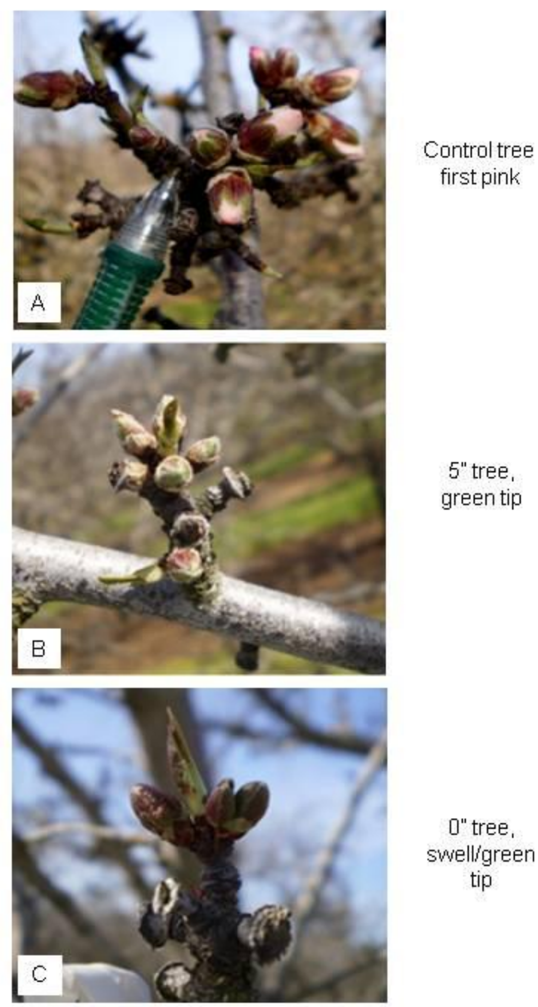

Figure10. Flower development on 02/16/10 for three trees representing a range of average SWP experienced during the 2009 season: A, -11 Bars; B, -24 Bars; C, -32 Bars.

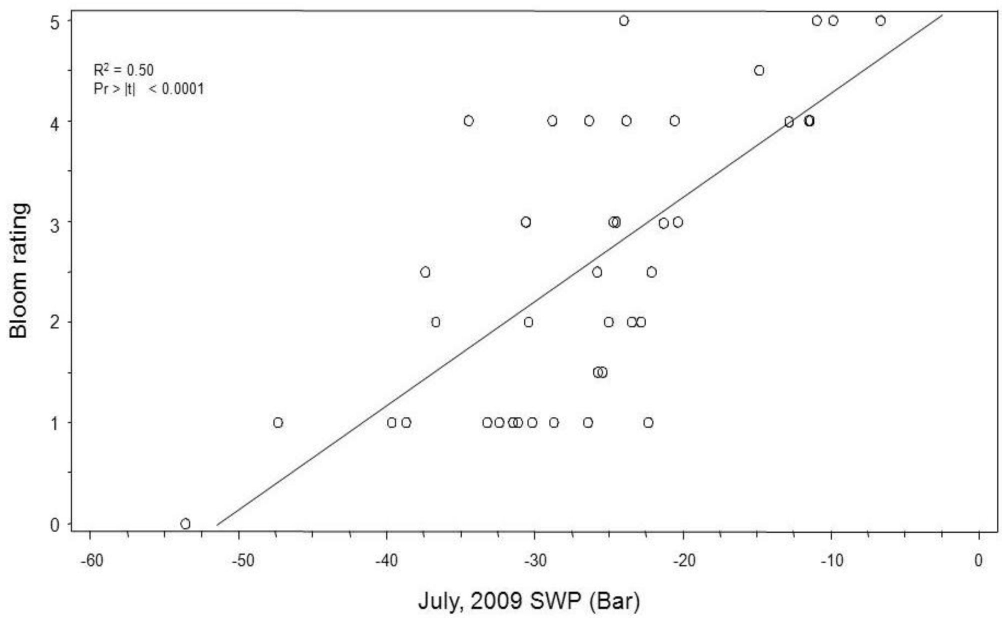

Figure 11. Subjective bloom rating (0 – 5 scale) of all study trees on 2/22/10 as a function of the degree of stress experienced in July, 2009. Also shown is a linear regression through the data.

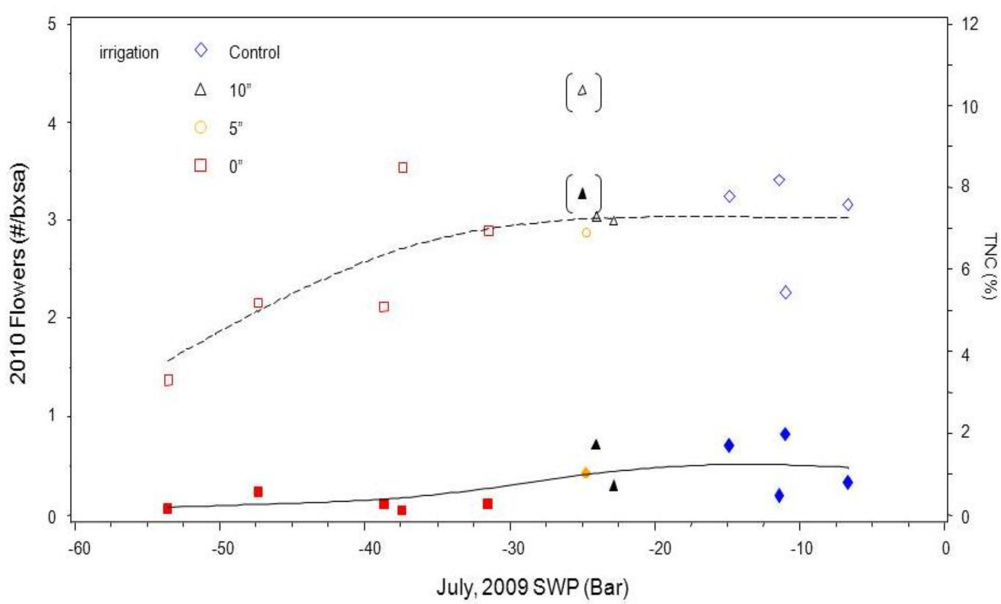

Figure 12. Relation of flowering (lower line, solid symbols) and total non-structural carbohydrate (TNC, upper line open symbols) at the branch level in 2010, to the degree of stress experienced in July, 2009. Lines are a statistically fitted smoothed spline, but do not include one tree (symbols in brackets) that had an extremely high branch level of flowering compared to all other sampled trees.

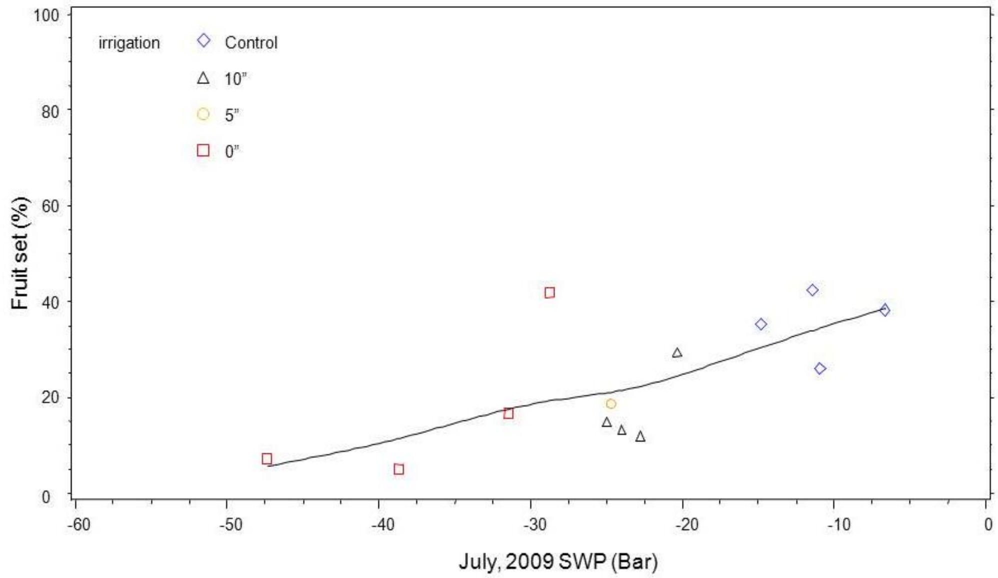

Figure 13. Relation of fruit set at the branch level in 2010, to the degree of stress experienced in July, 2009. The line is a statistically fitted smoothed spline, as in Figure 12, but illustrates that the relationship is essentially linear.

Table 5. Summary of the carryover effects of the average stress experienced in the irrigation treatments of 2009, on yield determinants (flowering and % set) in 2010.

Irrigation Treatment	Observed 2009 July SWP (Bar)	Branch-level observations corresponding to July SWP values					
		# flowers /BXSA	(% control)	% set	(% control)	Predicted % control yield	Observed 2010 yield (% control)
Control	-11	0.518	100	34.5	100	100	100
10"	-23	0.445	86	22.1	64	55	53
5"	-27	0.370	71	20.0	58	41	39
0"	-37	0.185	36	12.8	37	13	12

<u>Canopy modification</u>. Two of the grower approaches that were hypothesized to mitigate the effects of stress on tree mortality were to reduce the canopy by 50%, or to spray with kaolin (surround) or both, with the combination treatment only being tested under 0" (rainfed) conditions. Since there was no tree mortality in any treatment, we have no evidence that these treatments were beneficial. In addition, **in the 5" and 10" treatments, kaolin spraying alone had no beneficial effects on 2009 or 2010 yields** (**Table 6**). As expected and as reported previously, under 0" irrigation, pruning or pruning and Kaolin spraying reduced yields compared to the control treatment in 2009, but there was a trend of increased yields compared to the control treatment in 2010 (**Table 6**). Hence, at this point, **there is no evidence of a substantial beneficial effect of kaolin spraying or canopy pruning on tree survival or yield** under any of the drought treatments tested.

Table 6. Yield and nut size in 2009 and 2010 under different canopy modification treatments imposed in 2009 in the 0", 5", and 10" treatments. None of the differences were statistically significant.

Canopy modification	Irrigation treatment		
	10"	5"	0"
	2009 yield (Lbs/ac)		
Control	1,890	2,020	1,030
Kaolin Sprayed	1,910	1,800	------
Pruned	------	------	860
Pruned&Sprayed	------	------	590
	2009 Nut size (g/nut)		
Control	1.0 a	0.96	0.7
Kaolin Sprayed	0.9 b	0.97	------
Pruned	------	------	0.7
Pruned&Sprayed	------	------	0.7
	2010 yield (Lbs/ac)		
Control	1,350	1,010	320
Kaolin Sprayed	910	1,450	------
Pruned	------	------	770
Pruned&Sprayed	------	------	430
	2010 Nut size (g/nut)		
NP	1.3	1.4	1.3
S	1.2	1.4	------
P	------	------	1.3
PS	------	------	1.3

Research Effort Recent Publications:

(None for this project)

References Cited:

(None)