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Drought Survival Strategies for Established Almond Orchards on Shallow Soil

Project No.: **08-HORT13-Shackel**

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Objectives:

1) Determine the effects of 50% canopy reduction or kaolin (Surround) 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 on control (unsprayed) and kaolin (Surround) sprayed tree production and survival, compared to fully irrigated control trees.
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.

Interpretive Summary:

Because the soil at this site has a low water holding capacity, we anticipated that there would be some tree mortality the first year, particularly under non-irrigated conditions. However, only one tree in the non-irrigated treatment exhibited complete defoliation in late July, after reaching a stem water potential (SWP) of -63 bars. Following harvest, this tree was inadvertently irrigated and exhibited some re-foliation (although no bloom), so it appears to have survived, although the production and overall health effects for this and the other trees will not be known until the 2010 season. The lowest SWP achieved by any other tree in the study was -58 bars. There was a clear reduction in yield and nut size in all water deficit treatments, but also substantial tree-to-tree variation within each treatment in the degree of water stress experienced. This indicates that orchard performance during a single season of severe water restriction will be determined by the level of water stress experienced by the trees, rather than on the specific level of water applied to the orchard.

Kaolin spray did not improve SWP in the reduced irrigation treatments, but there was some evidence that both Kaolin spray and a 50% reduction in canopy size had additive effects in improving SWP mid- to late season in the non-irrigated treatment. After adjusting for the tree-to-tree effects of SWP on yield and nut size, Kaolin sprayed trees had numerically higher yields compared to non-sprayed trees, but the difference was not statistically significant.

The only significant effects from these treatments were a substantial (about 50%) reduction in yield and number of nuts per tree by a 50% reduction in canopy size. There was no spray or pruning effect on nut size or kernel % moisture. Patterns of soil matric potential indicated that water uptake was occurring to 8', well below the estimated 3-4' active root zone which has been previously documented for the almond trees at this site. This result is consistent with the relatively gradual development of stress that was observed in these trees. Gradual stress development may be a key factor in the ability of almonds to acclimate to drought conditions. Estimates of soil water uptake using neutron access tubes indicated that almond trees may be able to survive on as little as 7.6" of water, but the long term effects of this on yield will not be known until further research is conducted. Some wood dieback was observed on 1-2 year old shoots, but none of the Nonpareil trees monitored showed substantial dieback. Shoot growth and yield measurements will be made in the 2010 and 2011 seasons to quantify these effects.

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 will be 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.

Results and Discussion:

Because of difficulties managing irrigation during harvest, 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**). Most of this deficit occurred after harvest.

The substantially different irrigation amounts used in this study however, resulted in clear differences in SWP over the season, and as expected, the most stress was exhibited in the non-irrigated plots, least in the fully irrigated plots, and intermediate levels in the 5" and 10" irrigated plots (**Figure 1**). SWP was very responsive to individual tree conditions, for instance, a 1" rainfall event near the end of April allowed some recovery in all treatments (**Figure 1**). Following harvest, the irrigation to one plot of control trees was also temporarily discontinued and irrigation to one plot of 0" trees was temporarily re-established, and these events were reflected by a sudden decrease in SWP in the control and increase in SWP in the 0" at this time (**Figure 1**). Despite the clear effect of deficit irrigation on treatment average SWP (**Figure 1**), substantial tree-to-tree variation in SWP was also observed within each treatment, with some trees in the 0" treatment showing less stress than some trees in the 5" or 10" treatment (**Table 2**).

It was expected that kaolin spray and pruning might mitigate the effects of deficit irrigation and that SWP would be higher (less stressed) in these treatments. In the 5”and 10” irrigation regimes, kaolin spray had no detectable effect on SWP (**Figure 2**), but in the 0” (non-irrigated) treatment, both kaolin and pruning did improve the SWP compared to the controls from June – September, and in combination, their effects appeared to be synergistic (**Figure 3**). Whether or not these differences in SWP will be associated with meaningfully less carryover effects in yield will be determined in the 2010 and 2011 seasons.

A separate statistical analysis of the yield and nut size data was performed for each canopy modification, since it was anticipated that severe pruning (50% canopy reduction) would itself reduce yields substantially. **Table 3** shows the results of this analysis, with the only statistically significant results being substantial reductions in both tree yield and nut size in the non-modified canopy trees under deficit irrigation, and a slight reduction in nut moisture content in the fully irrigated trees as compared to the irrigation deficit trees. The latter result was somewhat surprising, but the nuts from all treatments had less than 7% moisture content, and hence moisture was not an issue in any treatment. Since the selection of canopy modification treatments were necessarily different in the different irrigation treatments, **Table 3** can also be used to evaluate the effects of pruning and kaolin spraying for the same irrigation, but there were no statistically significant effects of canopy modification within an irrigation treatment, and in no case was there any evidence of an improvement due to canopy modification. The only indication of a trend in benefit was that nut size was improved slightly (but not significantly) in the 0” irrigation by pruning, but this was at the expense of lower number of nuts per tree, and so yield was lower.

One advantage of recording SWP for individual trees over the season is that yield and nut size can be related to SWP for all treatments collectively. **Figure 4** shows the relation of yield and nut size to SWP for all irrigation treatments, and it is clear from this figure that yield and nut size were more related to individual tree SWP than to the irrigation treatment itself. That is, there were some trees which had the same SWP and same yield and size, even though they were subject to different irrigation treatments. A large influence of SWP on nut yield and size may be one reason why many of the differences in **Table 3** were not significant, particularly that pruning did not significantly affect yield. In order to account for the effects of canopy modification independent of SWP, **Table 4** shows the "least squares means," which are adjusted to the average level of SWP across treatments. These results clearly show that, as expected, pruning reduced yield, but that spraying had no effect.

In order to evaluate the range of stress experienced by the trees of this study, as well as the tree physiological responses to stress, SWP and leaf stomatal conductance were measured over one daily cycle on August 11, 2009, in a group of 13 trees representing the full range of tree stress in the study orchard. In this group there were 3 control trees, and **Figure 5** illustrates the tree-to-tree variability that occurred in the control treatment, despite the fact that all trees in this treatment were receiving the same amount of irrigation. Tree-to-tree differences in SWP were consistent throughout the day, but with larger differences at midday than at predawn, indicating that the midday period gives a more sensitive indication of mild stress. For the wettest of the control trees there was very good agreement between the observed SWP around the midday period and that predicted for a non-soil water limited tree (**Figure 5**). The daily pattern for the 13 trees representing all treatments and the range of stress experienced in this study is shown in **Figure 6** and the corresponding measurement of stomatal conductance for these trees shown in **Figure 7**. The ranking of the irrigation treatments in SWP (**Figure 6**) was consistent throughout the day and the SWP patterns were more-or-less parallel, indicating that for moderate to severe stress levels, both predawn and midday SWP values may be of value. For stomatal conductance (**Figure 7**), all treatments showed the expected increase in the morning to maximum values near midday, although the most severely stressed trees reached their maximum somewhat earlier than midday. Stomatal conductance is a measure of the degree of stomatal opening, with values around 300 typical for fully open stomata and values of around 5-10 typical of completely closed stomata in almond. Since stomatal closure inhibits the uptake of carbon dioxide needed for photosynthesis, **Figure 7** shows that the stress that was measured in all deficit treatments (**Figure 6**) was also reducing photosynthesis in these treatments.

SWP and stomatal conductance were also measured in two non-irrigated almond orchards in the Capay Valley region, in order to determine whether drip irrigated trees exposed to only one year of deficit irrigation had the same basic response to stress as trees exposed to stress throughout development, and to what extent the values of SWP we measured would be considered "extreme." There was a clear relation of conductance to SWP for all trees measured (**Figure 8**), and it appears that SWP in the -20 to -30 bar range for rainfed trees may not be unusual. The higher conductance values in the Paddock orchard compared to the Gordon orchard were interesting, because the trees in the Gordon orchard appeared to be much healthier (very little defoliation) than the Paddock trees or the trees of the same SWP in our study site. This may indicate that the ability to close stomata effectively is a key component of almond tree acclimation to water stress, and suggests that enhancement of this acclimation response may be one method of dealing with drought years, but more research on this specific question will be required in order to recommend cultural practices that would achieve this goal.

Watermark soil matric potential sensors were installed mid-July in one plot of the 10" irrigation regime to a depth of 8'. After a 10-15 day equilibration period, soil matric potential clearly showed significant drying at the 7'-8' depth, indicating that root water uptake was occurring (**Figure 9**). This is well below the root zone typically considered as "active" for almonds on this soil type, but variable access to deep water would explain the differences in SWP that were observed for these trees.

Neutron soil moisture measurements allowed an estimate of the total water used by the trees under different levels of irrigation deficit, by adding the amount of irrigation, rainfall and soil water uptake. These data showed (**Table 5**) that on average, the trees in the non-irrigated (0") treatment were able to survive on a total of 7.6" of water (21% ETc), substantially below the current estimate of 12". As for the other 1-year effects observed in this study, a clearer picture of the medium- to long-term effects will require further study. Near the end of the season (September) some wood dieback was observed in trees of the 0" treatment, with the pattern of dieback starting at the shoot apex and progressing down until a shoot with some green leaves was reached (**Figure 10**). Shoot dieback was not extensive however, and for the Nonpareil variety was only observed on the most stressed of the 0" treatment trees. The effects of this dieback should be evident in the yields obtained in 2011 and 2012.

Table1. Combination of irrigation and canopy reduction treatments. These treatments will only be imposed in year #1, followed by normal irrigation and cultural practices in years #2 and 3.

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
Control (100% ETc)	None

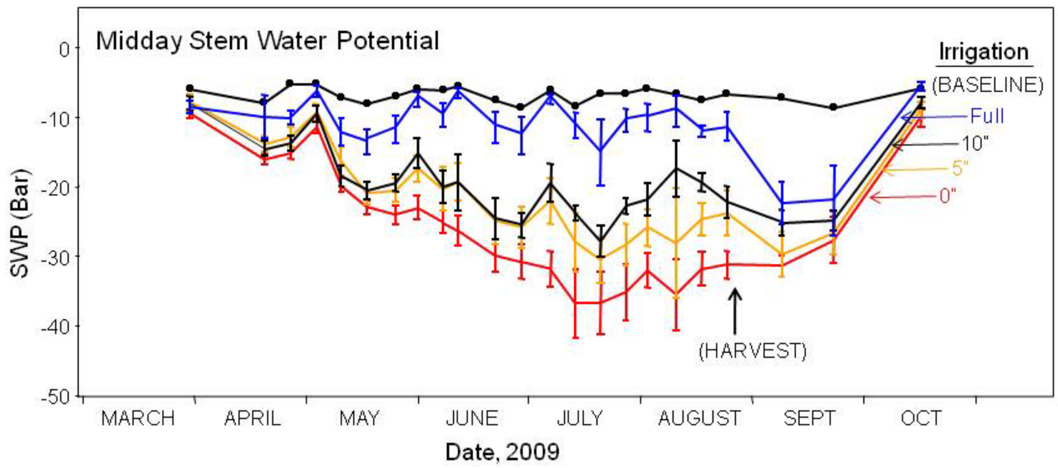

Figure 1. Seasonal pattern in average midday stem water potential (SWP) for non-stressed (baseline) conditions, and for each of the irrigation regimes imposed in 2009. Error bars are approximate 95% confidence limits.

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

Irrigation Treatment	Inches of Water Applied in 2009	Range in Minimum SWP Observed for all Trees Within Each Irrigation Treatment
0 (rainfed)	0”	-29 to -63 bars
5" in-season	3.6”	-24 to -42 bars
10" in-season	7.2”	-24 to -35 bars
Control	30.8”	-19 to -22 bars
100% ETc	38.7"	-9 bars

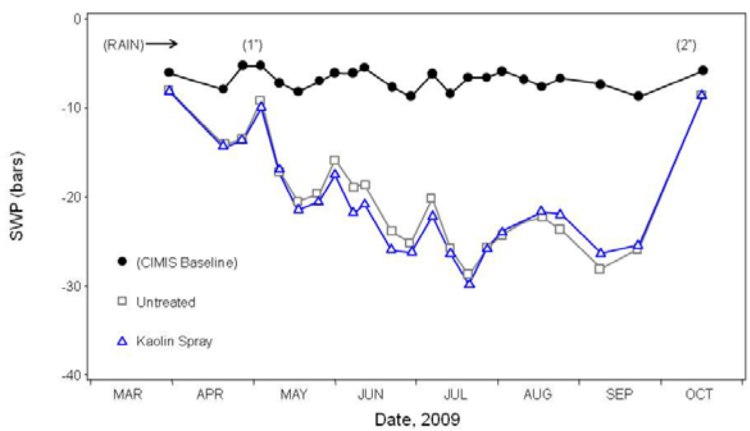

Figure 2. Midday stem water potential (SWP) of Untreated and Kaolin Sprayed trees in the 5" and 10" irrigation treatments showing no reduction in stress due to spraying.

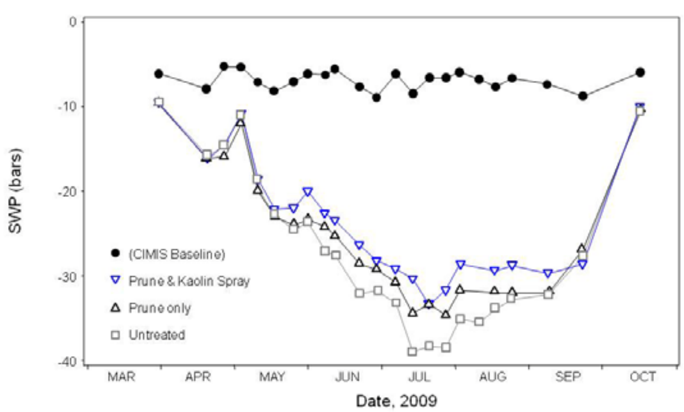

Figure 3. Midday stem water potential (SWP) of Untreated, Pruned (50% canopy reduction), and Pruned & Sprayed trees in the 0" (rainfed) treatment showing some reduction in stress in the June – September period due to pruning and spraying.

Table 3. Final yield and nut size analysis (corrected to 7% moisture) and calculated number of nuts per tree and kernel % moisture after bin drying of whole harvest samples. Means followed by different letters are significantly different at the 5% level. No following letters indicates no significance. Numbers in parentheses are values for single trees in the 5" and 10" irrigation plots that were pruned inadvertently.

Irrigation		Canopy Modification			
		None	Sprayed	Pruned	P+S
Yield (Lbs/ac)	Full	2224 a			
	10"	1890 ab	1860	(1290)	
	5"	2020 ab	1760	(1160)	
	0"	1030 b		860	590
Nut Size (g/nut)	Full	1.16 a			
	10"	1.04 ab	0.90	(1.11)	
	5"	0.97 b	0.95	(0.90)	
	0"	0.72 c		0.79	0.77
Nuts per Tree	Full	7650			
	10"	6810	7560	(4230)	
	5"	7800	6740	(4710)	
	0"	5240		3980	2850
Kernel % Moisture	Full	3.68 a			
	10"	4.29 b	4.39	(4.21)	
	5"	4.41 b	4.45	(4.10)	
	0"	4.38 b		3.96	4.27

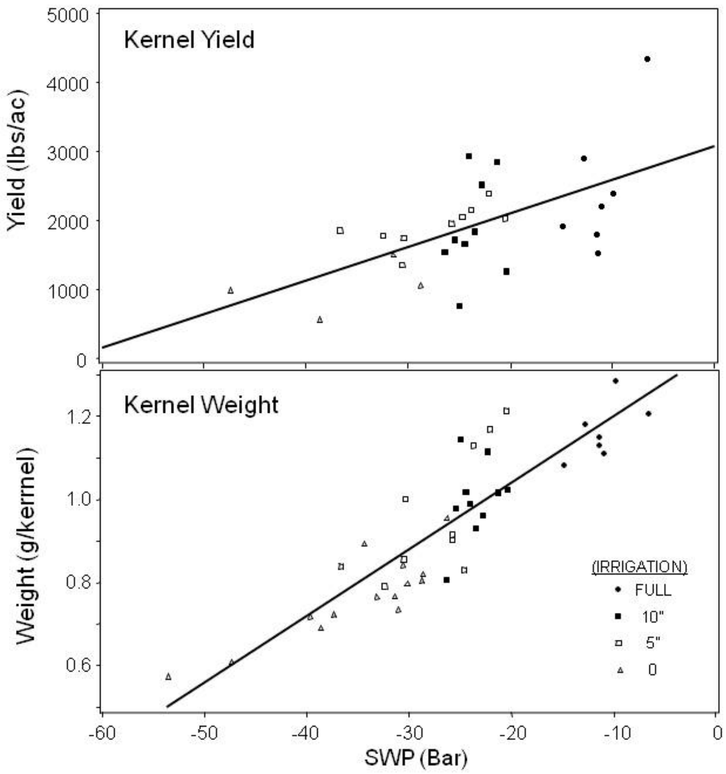

Figure 4. Relation of yield and kernel weight to the average SWP during July for each individual tree of the study. For the kernel weight analysis all trees were included, but for the yield analysis only non-pruned trees were included.

Table 4. Least squares means (adjusted to the same level of SWP) for each canopy modification treatment. Means followed by different letters are significantly different at the 5% level. No following letters indicates no significance.

Canopy Modification	Yield (lbs/ac)	Nut Size (g/nut)	Nuts/Tree	Kernel % Moisture
None	1760 a	0.95	6740 a	4.25
Sprayed	1890 a	0.95	7240 a	4.40
Pruned	1120 b	0.96	4260 b	4.11
Pruned & Sprayed	630 b	0.91	2580 b	4.00

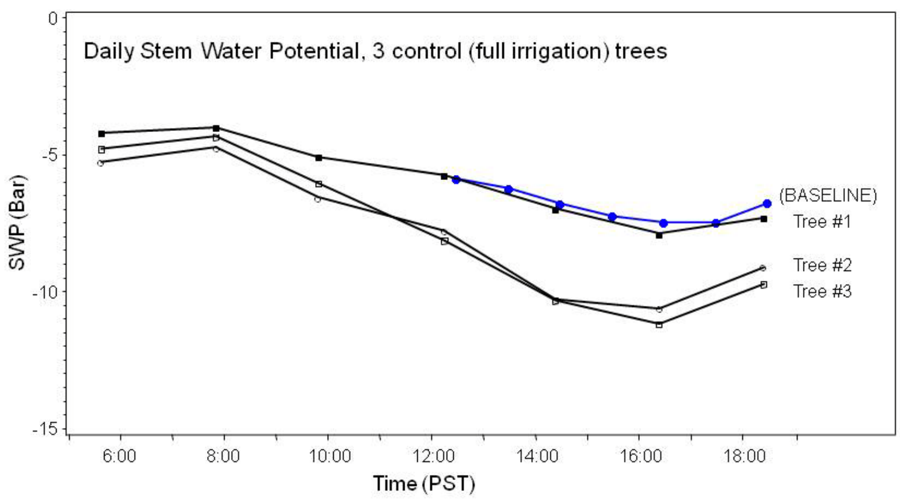

Figure 5. Daily pattern of SWP in 3 control trees on August 8. Also shown for reference is the SWP predicted for a fully irrigated (no soil water limitation) tree from 12:30 to 18:30.

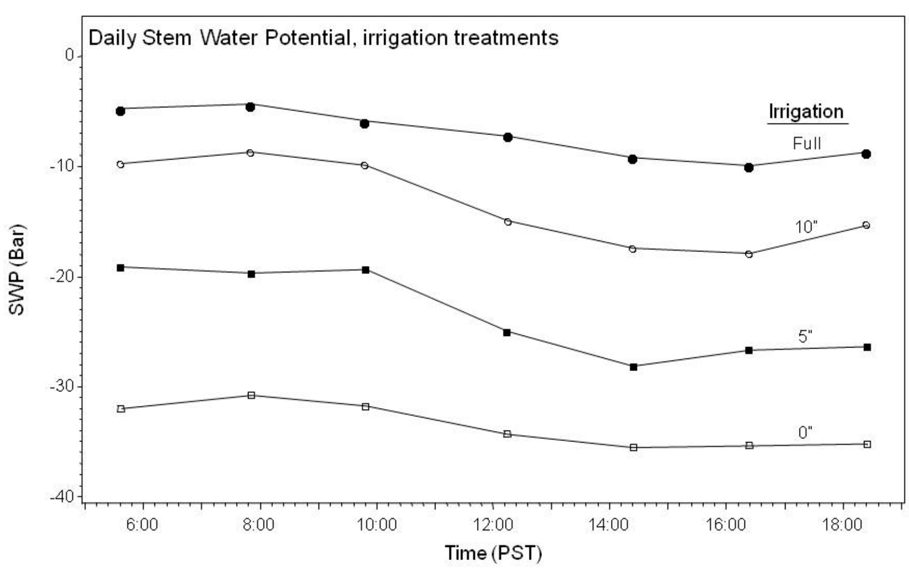

Figure 6. Daily pattern in SWP on August 8 for trees representing all treatments.

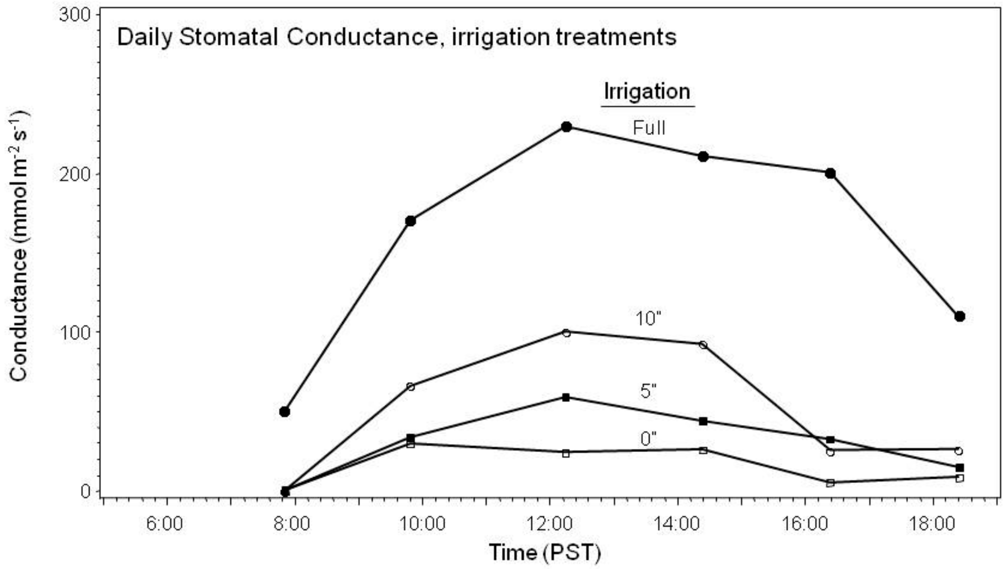

Figure 7. Daily pattern in stomatal conductance on August 8 for trees representing all treatments.

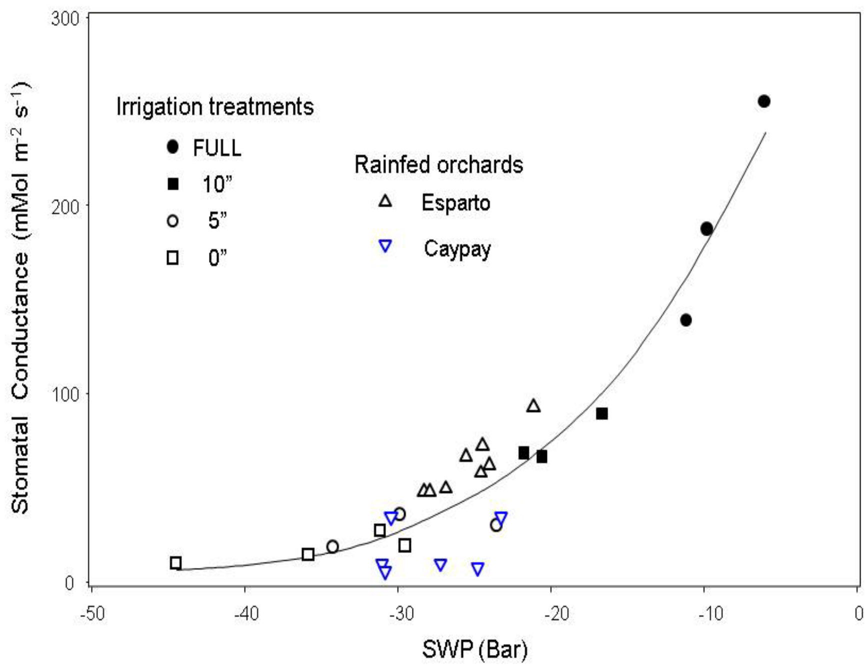

Figure 8. Relation of leaf stomatal conductance to midday stem water potential for selected study trees, as well as for trees in two additional rainfed orchards.

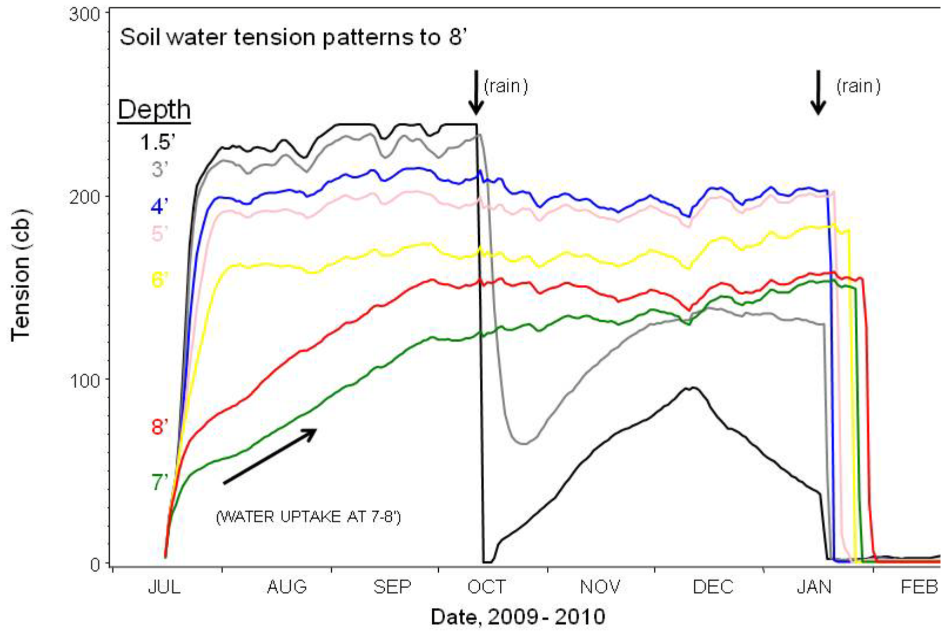

Figure 9. Soil water tension observed after installation of 7 sensors at various depths near one tree in the 10" irrigation treatment. Increases in soil water tension indicate water loss from the soil, presumably due to root water uptake, particularly at depths below 3'.

Table 5. Water budget analysis based on neutron measured soil water uptake from the different treatments.

Treatment	Irrigation applied	Rain	Soil uptake	Total	%ETc
0"	0"	2.1"	5.5"	7.6"	21%
5"	3.6"	2.1"	6.7"	12.4"	35%
10"	7.2"	2.1"	5.9"	15.2"	42%
Control	30.8"	2.1"	(?)	(32.9")	(92%)

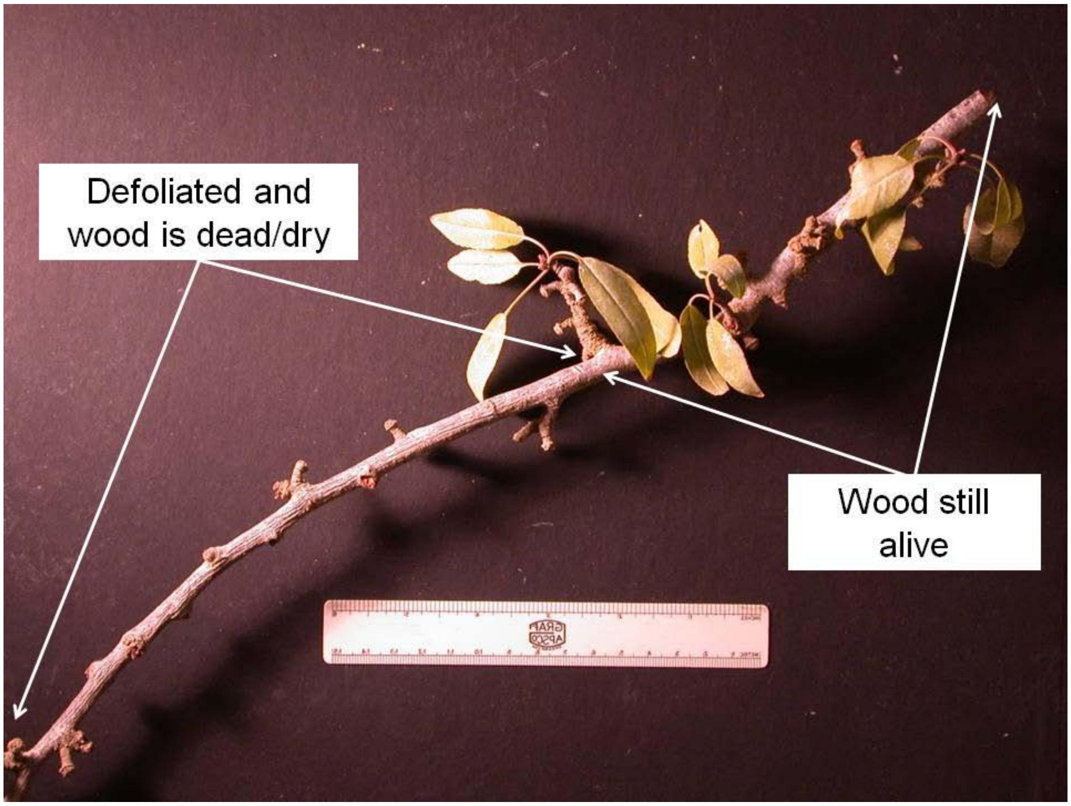

Figure 10. Pattern of shoot dieback observed in the most severely stressed Nonpareil trees of the 0" (non-irrigated) treatment.

Research Effort Recent Publications:

None for this project

References Cited:

None