Plant-Based Measures of Water Stress for Irrigation Management in Multiple Almond Varieties

Project No.: **11-HORT9-Shackel**

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Objectives:

- Determine whether different almond varieties exhibit differences in stem water potential (SWP) across a range of soil and orchard conditions.
- Determine whether there are differences in response to water stress among selected almond varieties, and whether any observed differences are related to inherent physiological differences among the varieties.
- Determine whether there is a reliable and consistent relationship between SWP and other candidate plant-based and soil-based measures of water stress, particularly those that can be automated.

Interpretive Summary:

Accurate and timely irrigation management is a key to both successful almond production and appropriate environmental stewardship, especially in times of protracted water shortages. In recent years, growers increasingly relied on gauging the trees' level of water stress by using a pressure chamber (the "bomb") to measure midday stem water potential (SWP). Varietal differences in SWP under equivalent orchard environmental conditions have not been apparent to date, but some almond varieties (Nonpareil, Carmel, Butte) appear to have physiologically similar stress responses, while others (Aldrich) may be more sensitive. Even though the pressure chamber method for measuring SWP has been demonstrated to be robust and reliable, one drawback is that it requires time and labor, and is not amenable to automation. Commercial devices are available for monitoring stem diameter automatically, and this measurement has been suggested as being a more sensitive index of stress than SWP (Goldhamer et al, 1999), but we have found that different branches on the same tree give inconsistent results, and hence this approach may not be reliable. A commercially available

device for automated measurement of SWP has recently been developed (the ICT psychrometer) and in many cases this device has shown clear responses to irrigation and good agreement with pressure chamber measured SWP. At present, the installation and maintenance of this device is technically demanding, but it shows promise as a reliable method for the automated measurement of SWP.

Materials and Methods:

Varietal differences in SWP were measured in commercial orchards in the Merced and Parlier areas, and varietal differences in leaf water relations were measured on samples from commercial orchards and from trees at the Foundation Plant Services (FPS) in Davis. At each orchard site, 10-15 representative trees of each variety were selected and over the course of the growing season, midday SWP and porometer measurements were made, taking advantage of both the normal irrigation cycle, as well as temporarily increasing or decreasing irrigation to individual trees, in order to obtain a range of water stress levels. Leaves were collected from commercial orchards and FPS trees to document any seasonal or varietal differences in leaf moisture characteristics (leaf moisture release curves), including possible differences in leaf physiological properties such as osmotic adjustment. In all cases, local CIMIS weather data was used to determine if the baseline relation established for Nonpareil is the same as that exhibited by all other varieties.

Results and Discussion:

The daily pattern in SWP and leaf stomatal opening (required for photosynthesis, but also the main route for leaf water loss and canopy evapotranspiration, ET) was similar in all three varieties tested. , As expected, the maximum stomatal opening was around 12:00 and minimum SWP around 15:00 (**Figure 1**, although measurements were not collected after 15:00 to confirm that SWP was at its minimum). At both sites the trees had substantially lower (more stressed) SWP than predicted by the baseline for most of the day (**Figure 1**), indicating a deficit in irrigation. Within each site there were relatively small differences between varieties in both conductance and SWP, although the general trend at each site was that the variety with the lowest SWP also had the lowest conductance. On a tree-average basis, there was a common relation of conductance to SWP, but a different relation was exhibited at different sites (**Figure 2**). Differences between the sites in conductance may have been caused by site differences in weather, but the fact that there was a common relation for all varieties within a site suggests a common physiological sensitivity to stress in these varieties. Based on this, we can tentatively conclude that the same SWP values will apply across varieties.

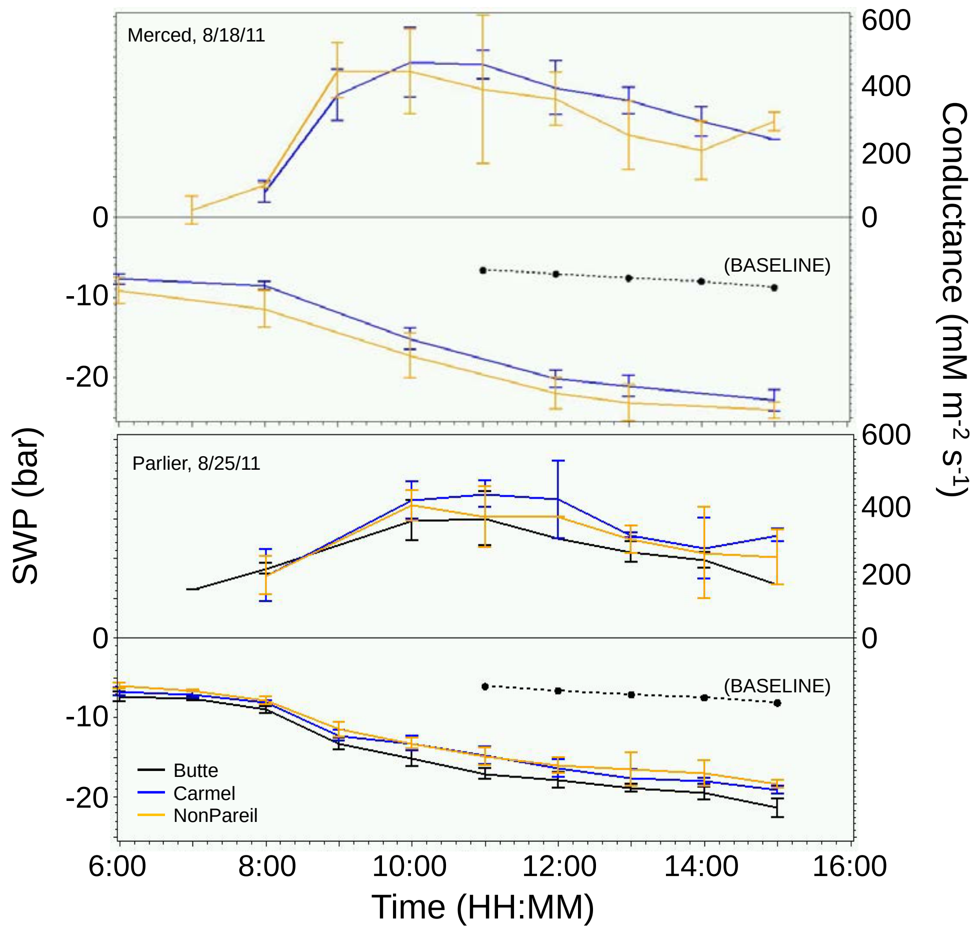

Figure 1. Daily pattern of stomatal opening (conductance) and SWP for three almond varieties in two locations in 2011.

Across a wide selection of scion and rootstock varieties, previous research has shown that there is a difference in leaf osmotic potential (**Table 1**), and with the exception of one test in 2011, subsequent tests have confirmed the pattern of Nonpareil < Aldrich = Carmel in osmotic potential (**Table 1**). An extensive sampling of leaves to generate moisture release curves for these three varieties (only 2 are shown in **Figure 3**) indicated that there was substantial leaf-to-leaf variation, but suggested that there was a systematic difference between Aldrich and Nonpareil, both in osmotic potential (**Table 1**) as well as the rate of decline in turgor with SWP (Nonpareil had a slower rate of decline than Aldrich). Both observations indicate that Nonpareil maybe more drought tolerant than Aldrich. A study such as that shown in **Figures 1** and **2** comparing these varieties will be needed to confirm this hypothesis.

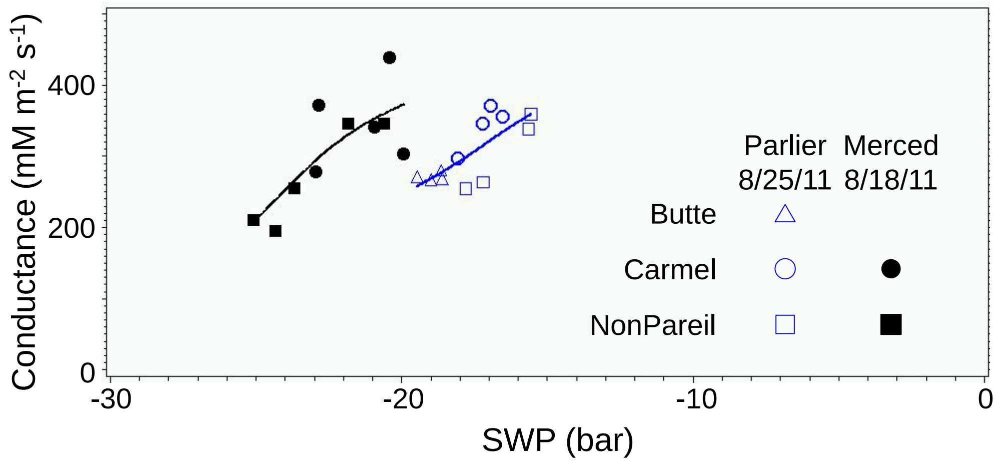

Figure 2. Relation of average stomatal conductance to average SWP for individual trees during the midday period (10:00 – 15:00) from the data shown in **Figure 1**.

Table 1. Summary of leaf osmotic potential values at full turgor that were obtained using contrasting methods (osmometer and moisture release) on multiple almond varieties and rootstocks in 2010, and three contrasting scion varieties in 2010 and 2011. Means within a column followed by the same letter are not different at p=95%. Also shown are the overall probability values for the significance of varietal differences.

Variety	Osmometer data (bars)			Leaf moisture release data (bars)	
	2010 survey	2010	2011	2010	2011
Marianna	-21.7 a				
Aldrich	-22.1 a,b	-22.3 a	-23.1b	-25.9 a	-21.5 ± 1.5
Peerless	-23.3 a,b,c				
Lovell	-24.2 a,b,c,d				
Winters	-24.5 a,b,c,d,e				
Sonora	-25.0 a,b,c,d,e				
Padre	-25.0 a,b,c,d,e				
Carmel	-25.1 b,c,d,e	-22.2 a	-22.5b	-25.5 a	-23.2 ± 3.2
Nemaguard	-25.3 b,c,d,e				
Titan	-25.6 c,d,e				
NE Plus Ultra	-25.6 c,d,e				
Fritz	-26.0 c,d,e				
Mission	-26.3 c,d,e				
Butte	-26.3 c,d,e				
Hansen 536	-26.9 d,e				
Nonpareil	-27.2 d,e	-24.2 b	-20.4a	-28.7 b	-26.3 ± 1.5
Price	-27.9 e				
Probability	**0.02**	**0.04**	**0.0008**	**0.009**	**(± 95% CI)**

Encouraging results using a commercially available device called a psychrometer (**Figure 4**) for the automated measurement of SWP were obtained during 2011. Initial field tests were performed on a cherry tree, and after modifying the commercially recommended insulation and mounting system (details not shown), we obtained a reasonable daily pattern in psychrometer values and good agreement with SWP measured by a pressure bomb (**Figure 5**).

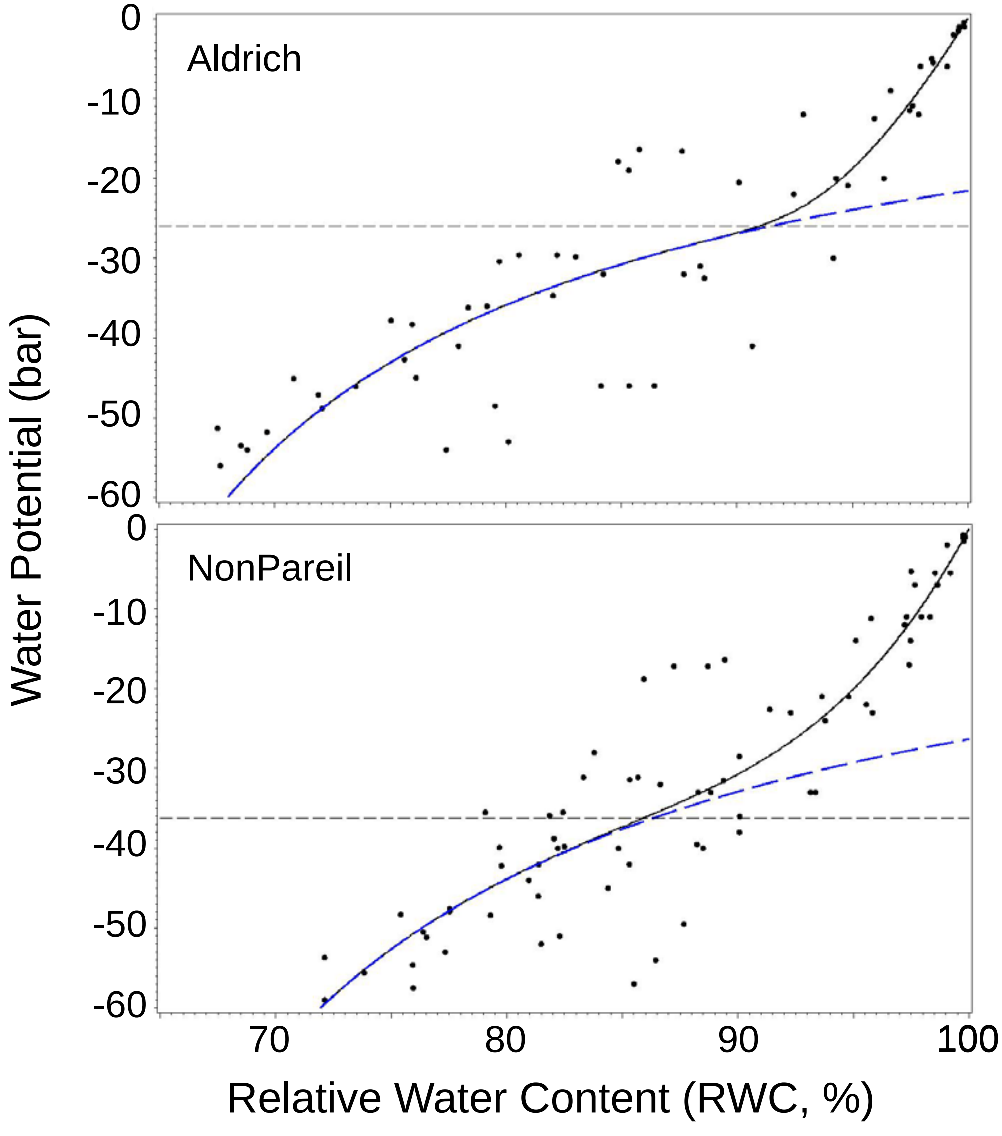

Figure 3. Moisture release curves for leaves collected from FMS or FMS? Field trees of two almond varieties. The solid black line shows how SWP changes with RWC, and the blue dash line how osmotic potential (OP) changes. The space between the OP and SWP lines represents cell turgor. The horizontal dashed lines indicate the predicted SWP for the cells to drop to a turgor close to 0 (no difference between OP and SWP). This value is lower for Nonpareil (-36 bars) than Aldrich (-25 bars), theoretically meaning that Nonpareil may be more drought resistant than Aldrich.

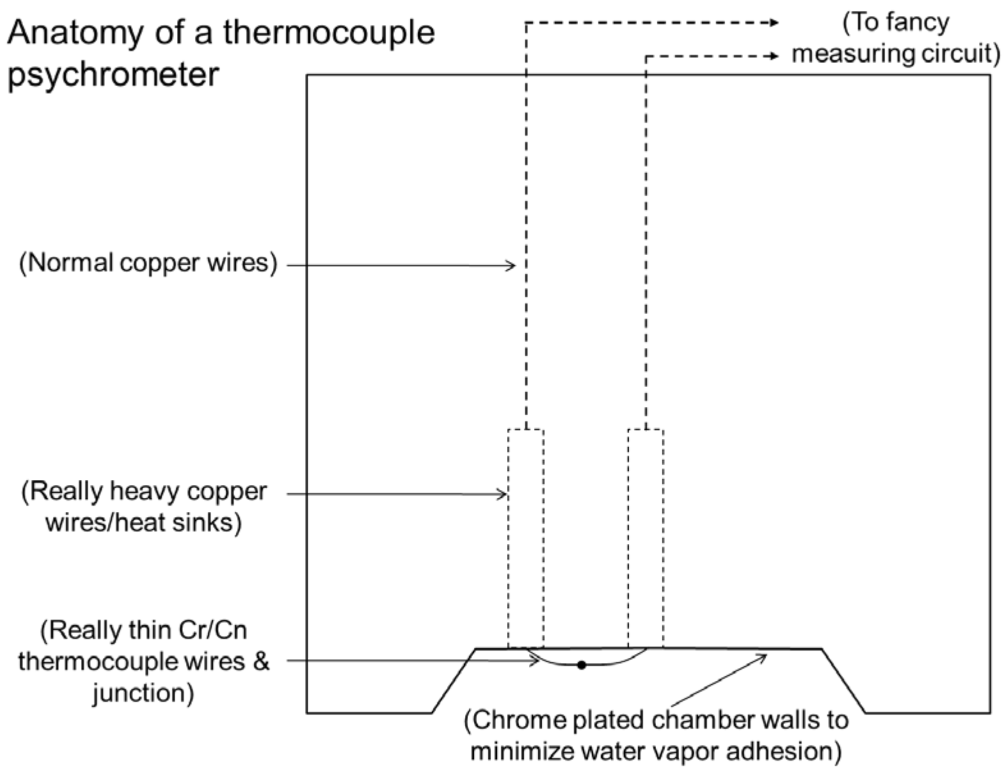

Figure 4. Schematic diagram of a thermocouple psychrometer, used to measure SWP automatically. The lower chrome plated surface of the psychrometer is sealed against a leaf or stem, creating a small chamber above the tissue, and a data logger measures the relative humidity of the chamber every 10 - 30 minutes using a thin wire thermocouple junction. Maintaining a clean junction, and a uniform temperature throughout the psychrometer, are critical to obtain accurate data.

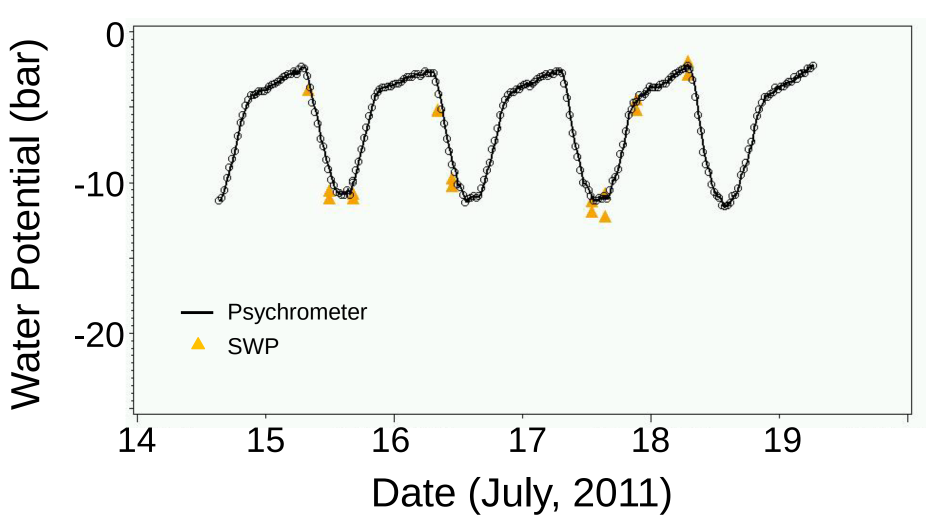

Figure 5. Example of automated measurements of SWP on a cherry tree in the field using the psychrometer, and periodic measurements of SWP on the same tree with the pressure bomb.

Additional field tests were performed on commercial almonds to test for the response of the psychrometer to irrigation. In Belridge, the psychrometer clearly responded to irrigation, and was a close match to the baseline following irrigation, although agreement with SWP (bomb) was variable, with some instances of pressure chamber SWP being 2 to 3 bars below the SWP measured by the psychrometer (**Figure 6**). In Arbuckle, there was generally better agreement between the psychrometer and SWP, with both indicating that the trees were substantially below (more stressed than) the baseline value (**Figure 7**). Irrigation on August 16 and 20 showed a very clear pattern of recovery followed by decline in the psychrometer measured SWP, particularly the irrigation on August 20, which showed increasing SWP for 2 days followed by a progressively declining SWP after that. Automated measurements of stem diameter were also performed in Arbuckle, and at least for the largest branch (3.7" diameter), the daily pattern in stem diameter was similar to that shown in the psychrometer, with the same pattern of increases and declines following the irrigation on August 20 (**Figure 7**). These data suggest that it may be possible to "calibrate" stem diameter changes with psychrometer measurements in order to obtain SWP from stem diameter, but since different branches gave different results, with the two smaller branches showing very little response to irrigation (**Figure 7**), it is not clear whether this approach can be used reliably.

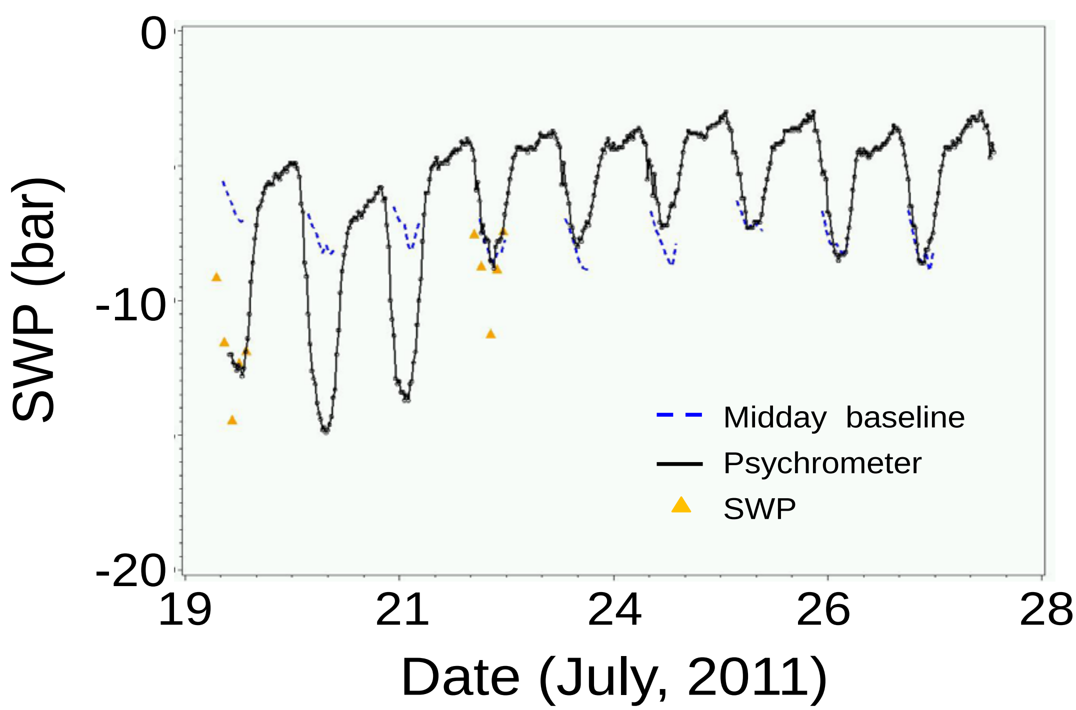

Figure 6. Psychrometer and SWP measurements, as in **Figure 5**, for a single tree in a commercial Nonpareil almond orchard in Belridge, CA. Also shown for reference is the calculated baseline value between 10:00 and 16:00 each day. The orchard was irrigated on July 21.

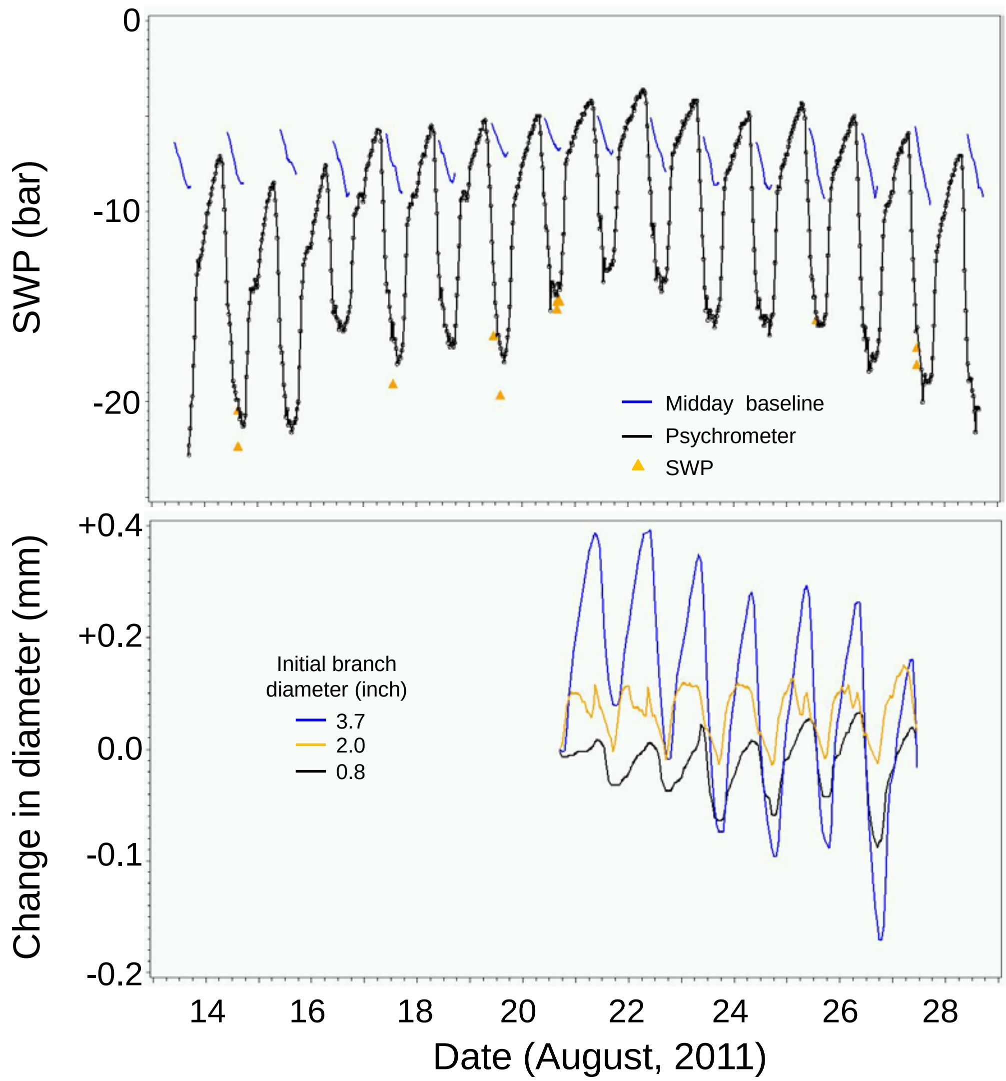

Figure 7. Psychrometer and SWP measurements (top panel), as in **Figure 6**, for a tree at Nickels ranch in Arbuckle, CA, and the changes in diameter for three branches of different size on the same tree (bottom panel). The orchard was irrigated on August 16 and 20.

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, Fereres E, Mata M, Girona J, Cohen M. 1999. Sensitivity of continuous and discrete plant and soil water status monitoring in peach trees subjected to deficit irrigation. JASHS 124:437-444.