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

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Background: 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, in deciding when and how best to irrigate, growers have relied increasingly on gauging the trees' level of water stress by using a pressure chamber (the "bomb") to measure midday stem water potential (SWP). Although this method is reliable, one drawback is that it requires time and labor, and is not amenable to automation. It is also important to determine whether there are varietal differences in SWP under the same orchard environment conditions, and whether the SWP corresponding to tree stress is the same or different in all varieties.

Objectives:

- Determine whether different almond varieties exhibit differences in midday 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.

Results: 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 of the three varieties tested, and similar to that expected, with maximum stomatal opening 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 it's 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.

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.

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**). 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 (**Figure 6**). In Arbuckle, there was better agreement between the psychrometer and SWP, and both indicated a substantial difference from baseline (**Figure 7**). 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 (**Figure 7**), suggesting that it may be possible to "calibrate" stem diameter changes with psychrometer measurements.

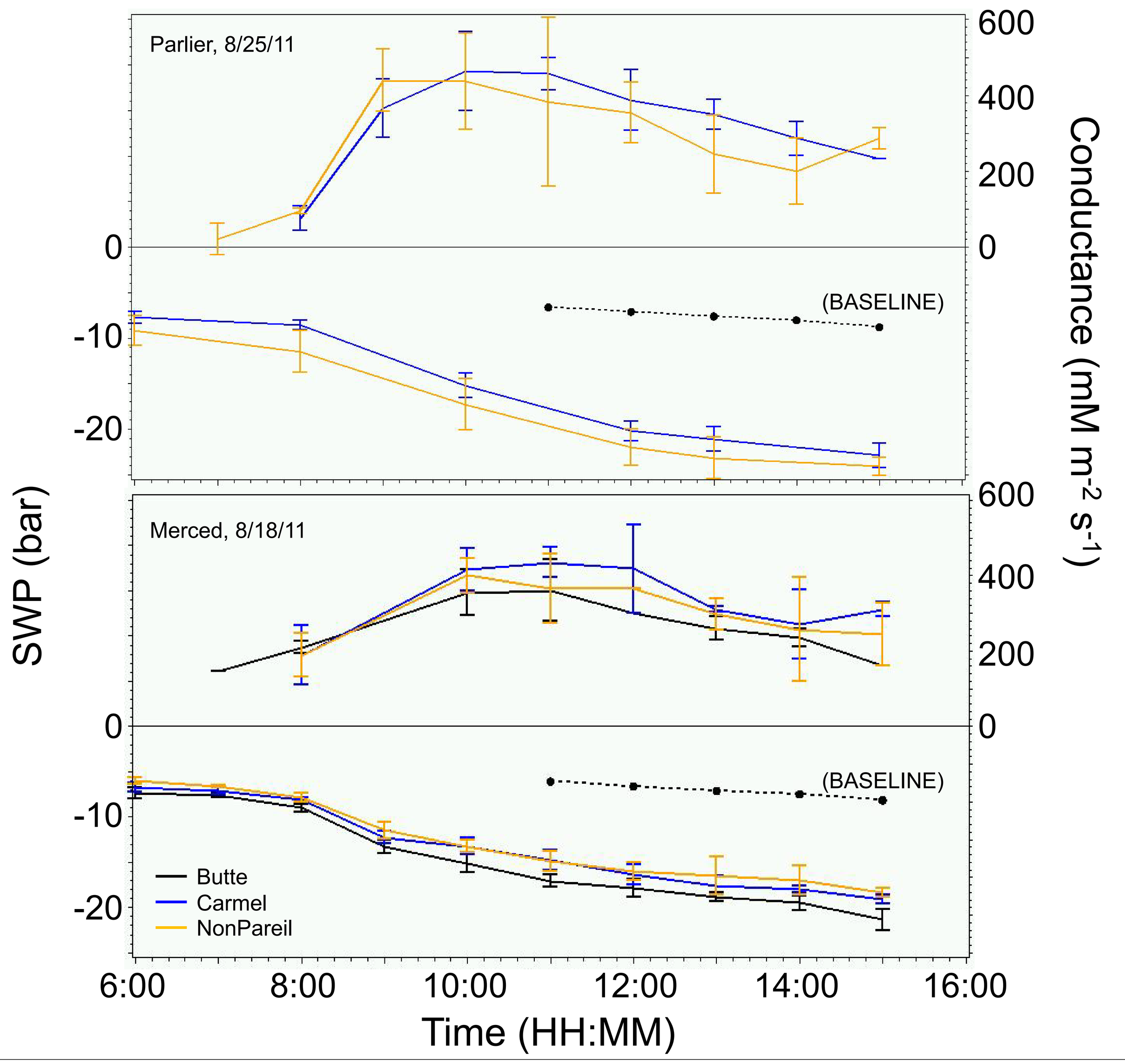


Figure 1. Daily pattern of stomatal opening (conductance) and SWP for three almond varieties in two locations in 2011.

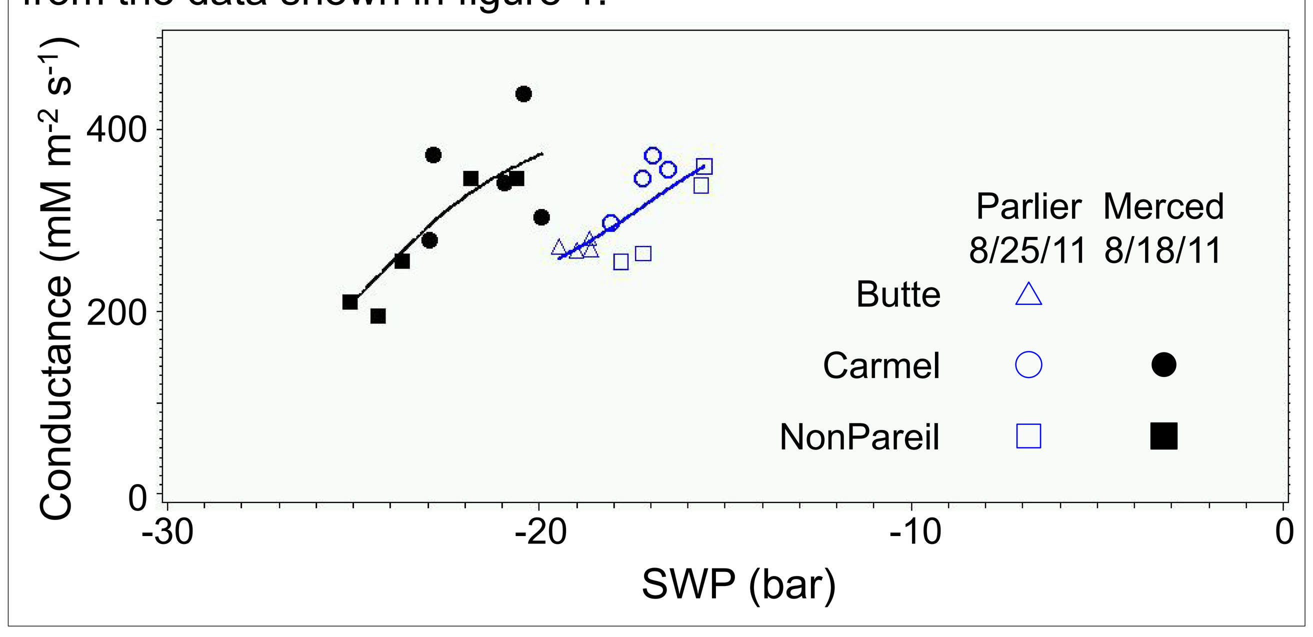
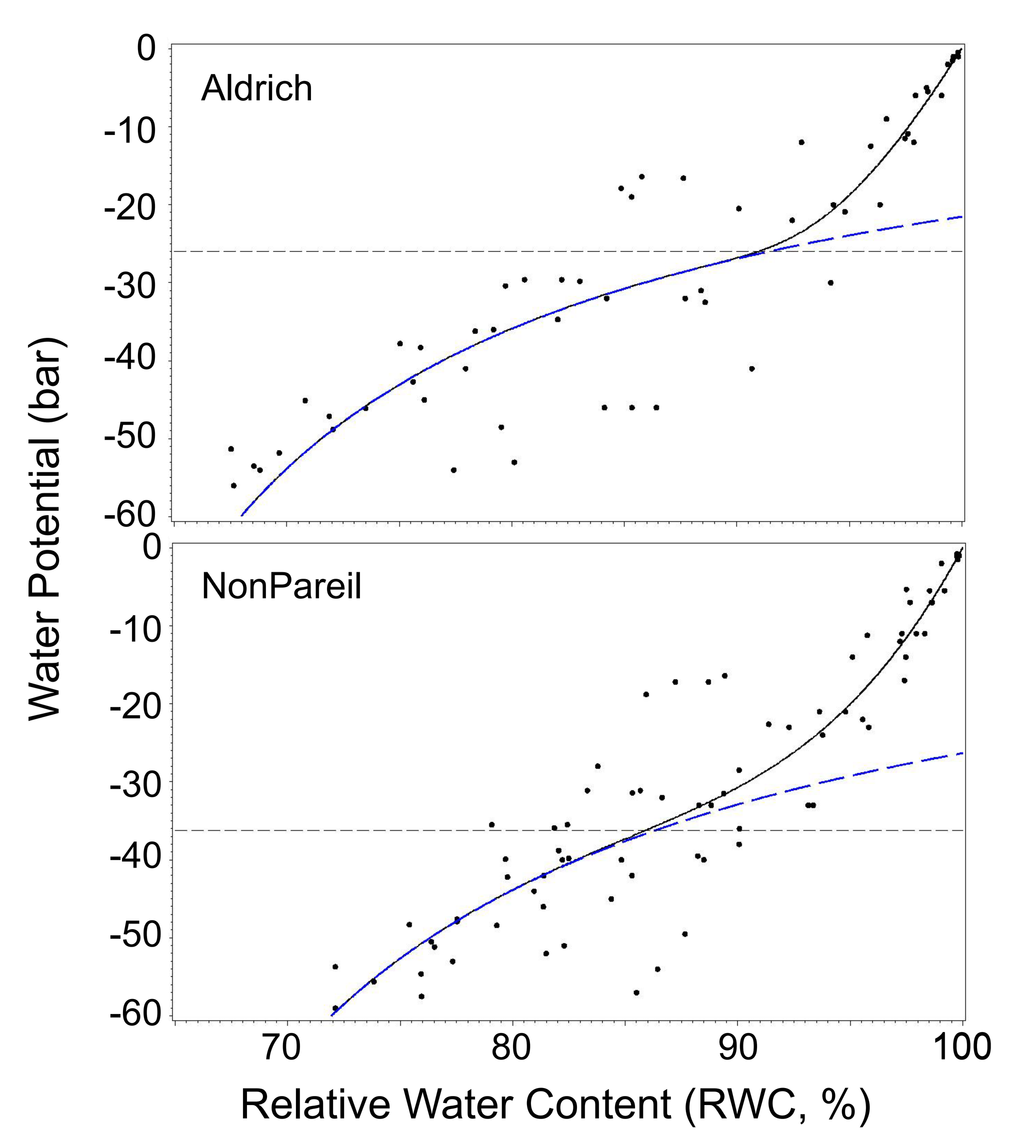


Figure 2. Relation of average stomatal conductance to average SWP for individual trees during the midday period (10:00 – 15:00) from the data shown in figure 1.

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.

	Osmometer data (bars)			Leaf moisture release data (bars)	
Variety	2010 survey	2010 3 var.	2011 3 var.	2010 3 var.	2011 3 var.
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)**

Figure 3. Moisture release curves for leaves collected from FPMS 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 tolerant than Aldrich.



Tentative conclusions:

1. **Some almond varieties (NonPareil, Carmel, Butte) may have physiologically similar stress responses, and others (Aldrich) may be more sensitive.**
2. **The psychrometric method shows promise as a commercially available method for the automated measurement of SWP.**

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.

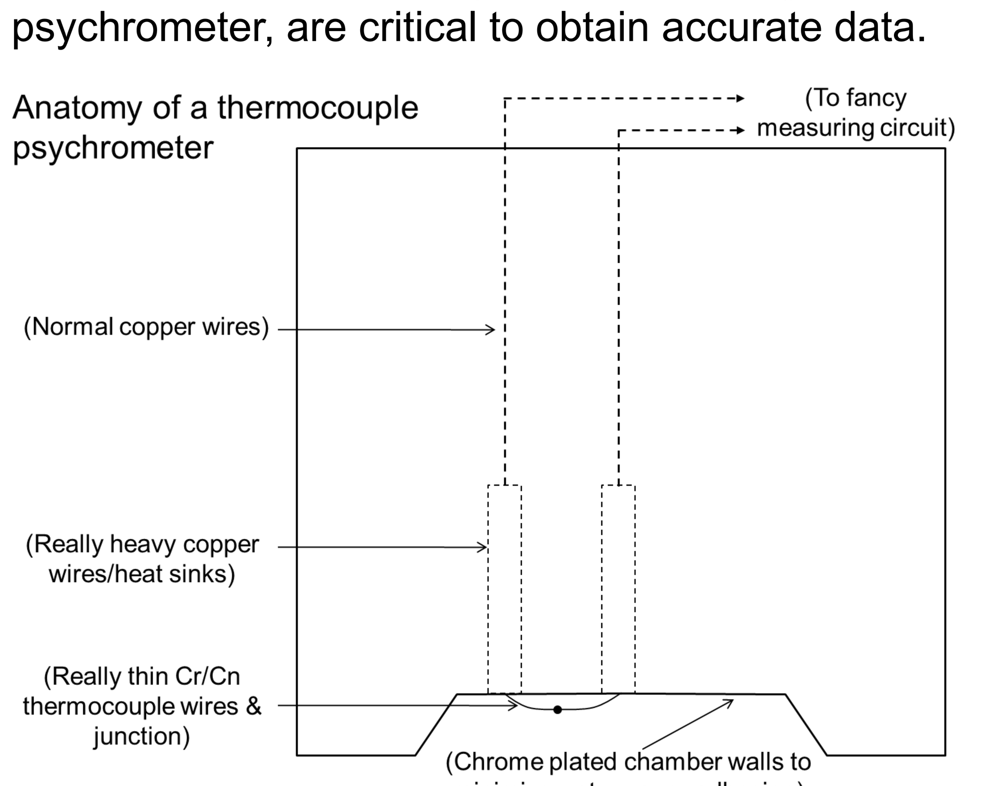


Figure 5. Example of automated measurements of SWP on a cherry tree in the field using the psychrometer, and periodic measurements of SWP on the same tree with the pressure bomb.

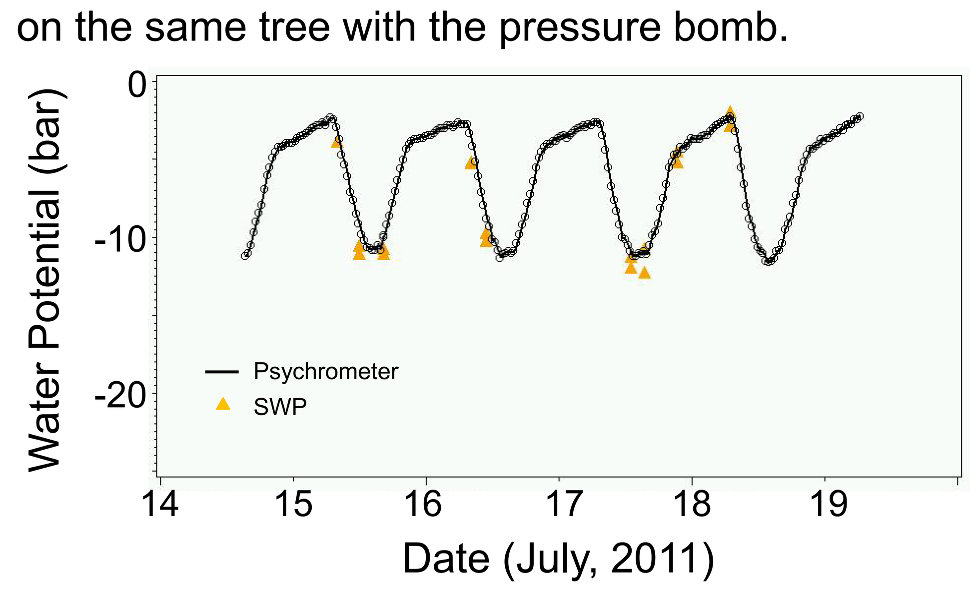


Figure 6. Psychrometer and SWP measurements, as in figure 5, for a single tree in a commercial NonPareil almond orchard in Belridge, CA. Also shown for reference is the calculated baseline value between 10:00 and 16:00 each day. The orchard was irrigated on July 21.

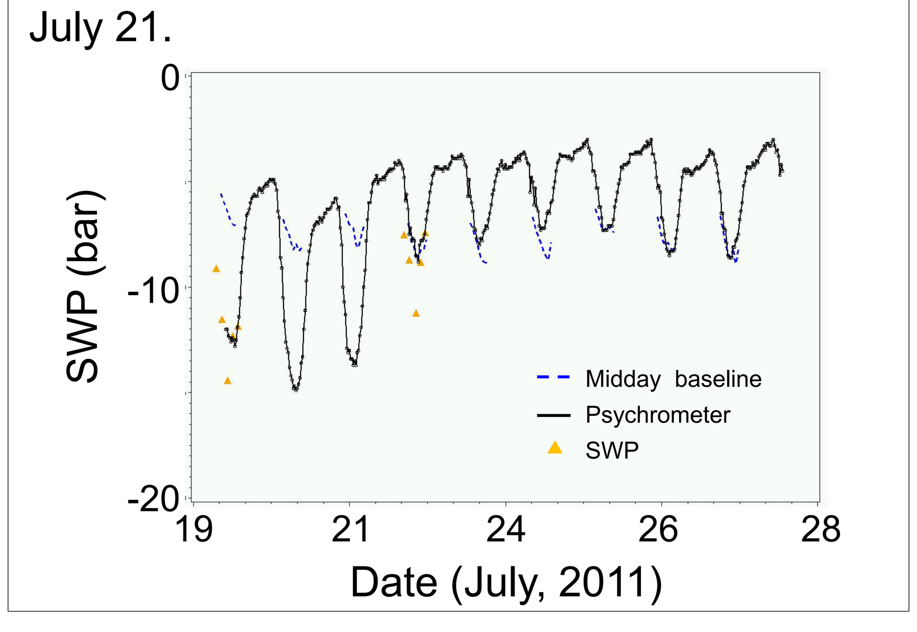


Figure 7. Psychrometer and SWP measurements (top panel), as in figure 6, for a tree at Nickels ranch in Arbuckle, CA, and the changes in diameter for three branches of different size on the same tree (bottom panel). The orchard was irrigated on August 16 and 20.