Winter Water Management

Project No.: **15-PREC9-Shackel/Dahlke**

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Objectives:

1) Conduct field studies to test the effectiveness of winter irrigation as a sustainable groundwater recharge strategy
2) Document any negative or positive effects of winter irrigation on almond yield and/or root development
3) Determine the threshold level of dormant tree water stress (SWP) indicating the need for pre-bloom irrigation in dry winters

Interpretive Summary:

This was the first year of a multi-location field trial to test for the effects of winter recharge irrigations on almond tree health and orchard productivity. In addition to about 12” of rain at the Modesto and Delhi sites from November 1, 2015 to March 31, 2016, a total of 24 inches of water was applied in 3-4 flood irrigation events on each orchard in the December/January period. At the Modesto site, recharge irrigation was associated with periods of up to 48h when the soil was saturated, whereas in the sandier soil of the Delhi site, saturated soil conditions following flood irrigation only prevailed for about 12 h. Following the recharge irrigations in Modesto, stem water potential (SWP) readings indicated a slight increase in tree hydration compared to non-irrigated controls, but within about 2 weeks the SWP of control and flooded trees was the same, and remained the same through mid-June. In contrast, the SWP of

flooded trees at the Delhi site have remained higher (more hydrated) than the SWP of control trees through mid-June, indicating that in terms of water, the trees may be benefiting from this practice at the Delhi site. There were no obvious differences in bloom and no indications of differences in tree health associated with these treatments at either site, but the trees have yet to be harvested. Collection of minirhizotron root images began in January, 2016, but these data can only be interpreted once images are evaluated over a yearly time frame. A potted tree study indicated that plant stress during winter dormancy can result in a delay in bloom and a lower percent bloom, with both effects being more severe at higher levels of stress. On average, trees which experienced SWP levels below -10 bars during dormancy, but were fully irrigated prior to bloom, had a delay of bloom on the order of 1 week, and were reduced in percent bloom to 80%, compared to the controls (100%). However, even on the most stressed tree (SWP of -25 bars), there appeared to be no damage to the floral or vegetative buds, and flowers were capable of setting fruit with normal embryo and endosperm development. These results suggest that a substantial delay in winter irrigation during dry winters may be possible without concerns about a negative impact on bloom, giving growers more flexibility and potentially representing a savings in water. Similar to the delaying effect of water stress during dormancy on bloom, a preliminary study indicated that water stress may also cause a delay in the normal pattern of xylem sap sugar concentration.

Materials and Methods:

Field Plots. During the 2015/2016 winter, groundwater recharge experiments were conducted on two almond orchards located near Modesto, CA and Delhi, CA, respectively. In each orchard three treatment plots were established: 1) no winter irrigation (in case the grower winter irrigated), 2) winter recharge irrigation with 24 inches of water in addition to rainfall (flood), and 3) grower control. The flood and grower control plots were each instrumented with Decagon 5-TM and 5-TE soil moisture sensors at 0.5 ft and 1.5 ft depth. The deeper sensors also allowed measurement of the soil electrical conductivity. On each plot the control volume applied to the test plots, the infiltration rate of the applied water into the soil and passed the root zone, and the soil water content within the root zone were determined. Three thermal infiltrometers were installed in each plot consisting of temperature sensors installed at predefined depths (4 and 12 inches) in water-filled PVC pipes (Hatch et al, 2006). In-line flow meters were installed in the irrigation water supply system to measure the control volume of water applied in the plot. Soil nutrient concentrations (N, P, K, salt) and soil texture were determined prior to the recharge experiments by extracting 1.5 in diameter soil cores of 10ft length using a Geoprobe push drill. A total of 5 soil cores were extracted from each site. Soil texture, nitrate-nitrogen, phosphorus, salt content, and potassium was determined. Minirhizotron tubes were installed each in the grower and recharge treatments at each location in December, 2015. Scans were performed in each tube prior to, during, and after the recharge treatment. Dormant and growing season midday stem water potential was measured at all sites approximately weekly.

Pot Study. Nonpareil on Nemaguard were grown in large (12g) drip irrigated plastic pots on a concrete slab at the UC Davis field facility. Pots were filled with UC Davis standard mix (1 part coarse sand, 1 part compost, 1 part peat moss, 3 pound/yard Dolomite). Thirty-five trees were planted on 4/21/2015, 6 trees replanted in June, 2015, and a total of 37 trees were used for the experiment. Automatic controlled fertigation was set up to irrigate the trees 5 times each day at

7:00, 11:00, 13:15, 15:15, and 17:30. Decagon EC5 and GS1 soil moisture sensors were installed in 10 pots to monitor soil moisture. Measurements of midday stem water potential (SWP) were taken approximately bi-weekly. The amount of irrigation was adjusted based on weather conditions and the tree's midday SWP. Close to baseline SWP were maintained for all trees during most of the growing season. Before tree dormancy in September, 2015,10 wheat seeds were planted in each pot to establish a cover crop, in order to dry the pots during

Figure 1. Potted trees showing plastic shields covering the wheat cover crop.

Figure 2. Trees under a cover to shield from rain (Dec. 2015).

Figure 3. Trees on a trailer on a sunny day (Jan. 2016).

winter. The cover crop was well established by November, when each tree was also fitted with a plastic rain shield (**Figure 1**). A defoliation solution (1.79% of 36% Zn--mixture of $ZnSO4$ and ZnO, 0.95% Urea) was sprayed on 12/1/2015. Because the plastic rain shields were not effective in high winds, all trees were moved under the cover of a sawdust bin area on 12/18/2015 (**Figure 2**). Unfortunately, on 12/28/2015, all trees were hand watered by an uninformed employee, and being mistaken for weeds, the wheat cover crops were removed from about half of the pots, requiring a revision of the original experiment plan. All trees were loaded on a trailer which was pulled into the sun on non-rainy days in order to dry the pots as quickly as possible (**Figure 3**). For the control, we selected 10 trees without wheat and 2 trees with wheat which were watered twice a week, and did not water the other trees. For this experimental design, dormant twig SWP was used to classify trees as well as serving as a covariate. Flower development was followed by labeling about 20 flower buds from each tree, and the percent of bloom calculated based on the number of flower buds that opened over time. The progress of bloom and vegetative bud development was described using the stages represented in **Figures 4 and 5** (from “Integrated Pest Management for Almonds”).

Results and Discussion:

Field Plots. In addition to about 12” of rain at both the Modesto and Delhi sites from November 1, 2015 to March 31, 2016, a total of 24 inches of water was applied in 3-4 irrigation events on each orchard (**Table 1**). Recharge experiments were conducted between mid-December and mid-January at the Delhi site and throughout the entire month of January at the Modesto site. At the Modesto site the initial soil water content prior to the recharge experiment was between 26 and 29 %, while the sandier Delhi site showed initial soil water contents between 8 and 12%. At the Modesto site the soil water content increased to saturated conditions during each water application event (**Figure 6**). During each event, 6 inches of water were applied via flood irrigation over a period of 4-6 hours. Based on the soil moisture data, saturated conditions prevailed for up to 48 hours after each water application, after which the soil moisture content dropped back to pre-event values. As shown in **Figure 6** some of the higher intensity rainfall events that occurred mid-February and mid-March caused short-lived spikes to saturated conditions in the soil water content. After March the soil moisture data show a steady depletion in soil water content throughout the growing season, to values as low as 17% interjected by the flood irrigation conducted every 16-18 days.

Figure 4. Bloom stages of almond flowers from Dormant Bud to Petal Fall.

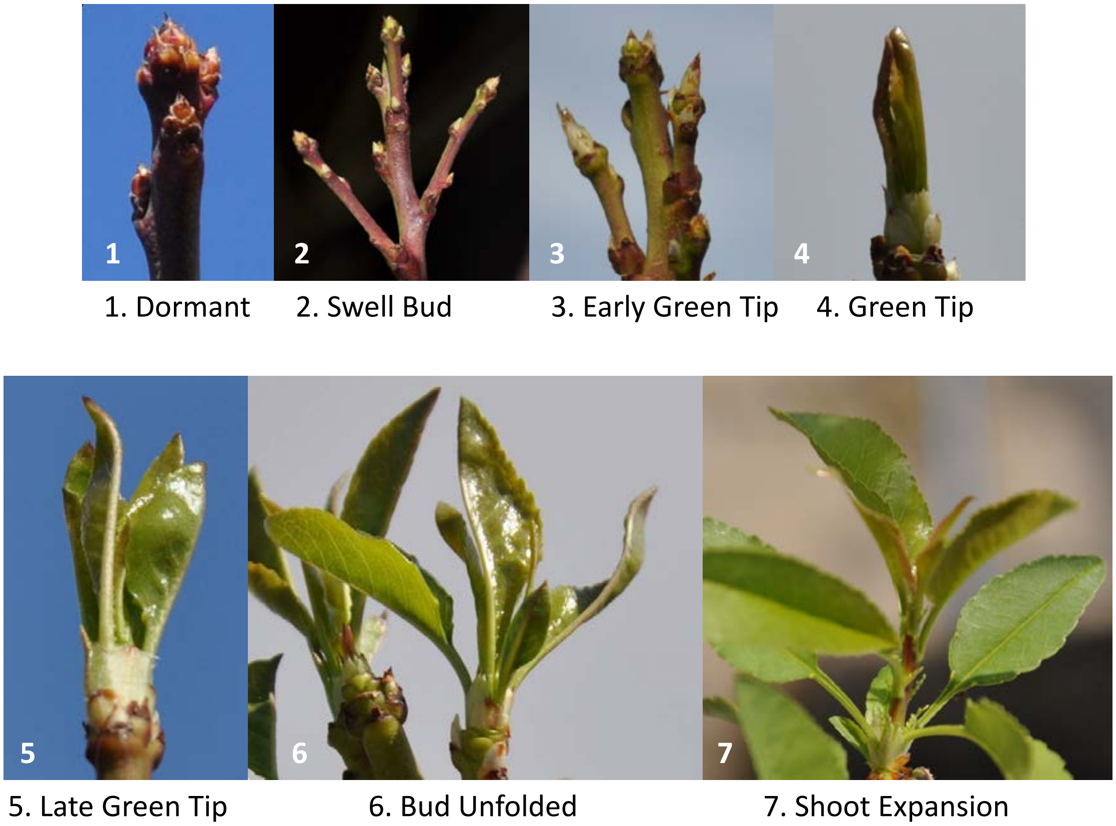


Figure 5. Vegetative bud stages of almond from Dormant to Shoot Expansion.

Table 1: Irrigation events and total applied water amounts for the winter recharge experiments conducted in Delhi and Modesto, CA

Modesto		Delhi	
Date	Inches Applied	Date	Inches Applied
1/4/2016	6	12/23/2015	6
1/11/2016	6	12/29/2015	9
1/19/2016	6	01/12/2016	10
1/25/2016	6		

In contrast to the Modesto site, the sandier Delhi site showed much quicker infiltration of the applied groundwater recharge water. As shown in **Figure 7a** and **Table 1** the total 24 inches of recharge water were applied in three events of 6, 9 and 10 inches of total applied water. While the shallow soil moisture sensor showed an immediate response to the first water application on December 23, 2015, the applied water did not seem to be enough to fill the deeper soil profile (**Figure 7a**). Only during the second and third water application event did both the shallow and deep soil moisture sensors indicate saturated conditions in the soil profile. In the recharge plot both the shallow and deep soil moisture sensors dropped to pre-irrigation water contents within 12 hours after the water was applied. Overall the sensor data indicates that the volumetric water content stayed around 10-15% throughout the growing season.

Three soil cores were drilled in each treatment plot at each site prior to (October 2015) and after (February 2016) the winter recharge experiments. The 1.5 inch diameter soil cores were extracted with a department-owned Geoprobe push drill. Soil cores were drilled to a depth of 14-16 ft. **Figure 8** is showing an example of the soil stratigraphy, biogeochemical and textural data extracted from a core in the recharge plot in Modesto, CA. The soil type at the Modesto site is classified as a Dinuba fine sandy loam. Based on the soil core stratigraphy the soil profile contains three clay-rich layers at 70, 260 and 360 cm depth. Soil nitrate-N in the root and deeper vadose zone was relatively low (3-15 ppm) prior to the recharge events and mainly concentrated in the deeper soil profile. In contrast electrical conductivity (EC) was higher in the upper part of the soil profile but overall low (40-640 µS/cm). Comparison of the soil nitrate-N and soil EC before and after the recharge events indicates mobilization of solutes into the deeper vadose zone and accumulation above a cemented clay layer at 360 cm depth. Total mobilized mass still needs to be estimated. However, the before and after soil biogeochemical data clearly indicate that the applied recharge water essentially removed residual nitrate and salts from the root zone.

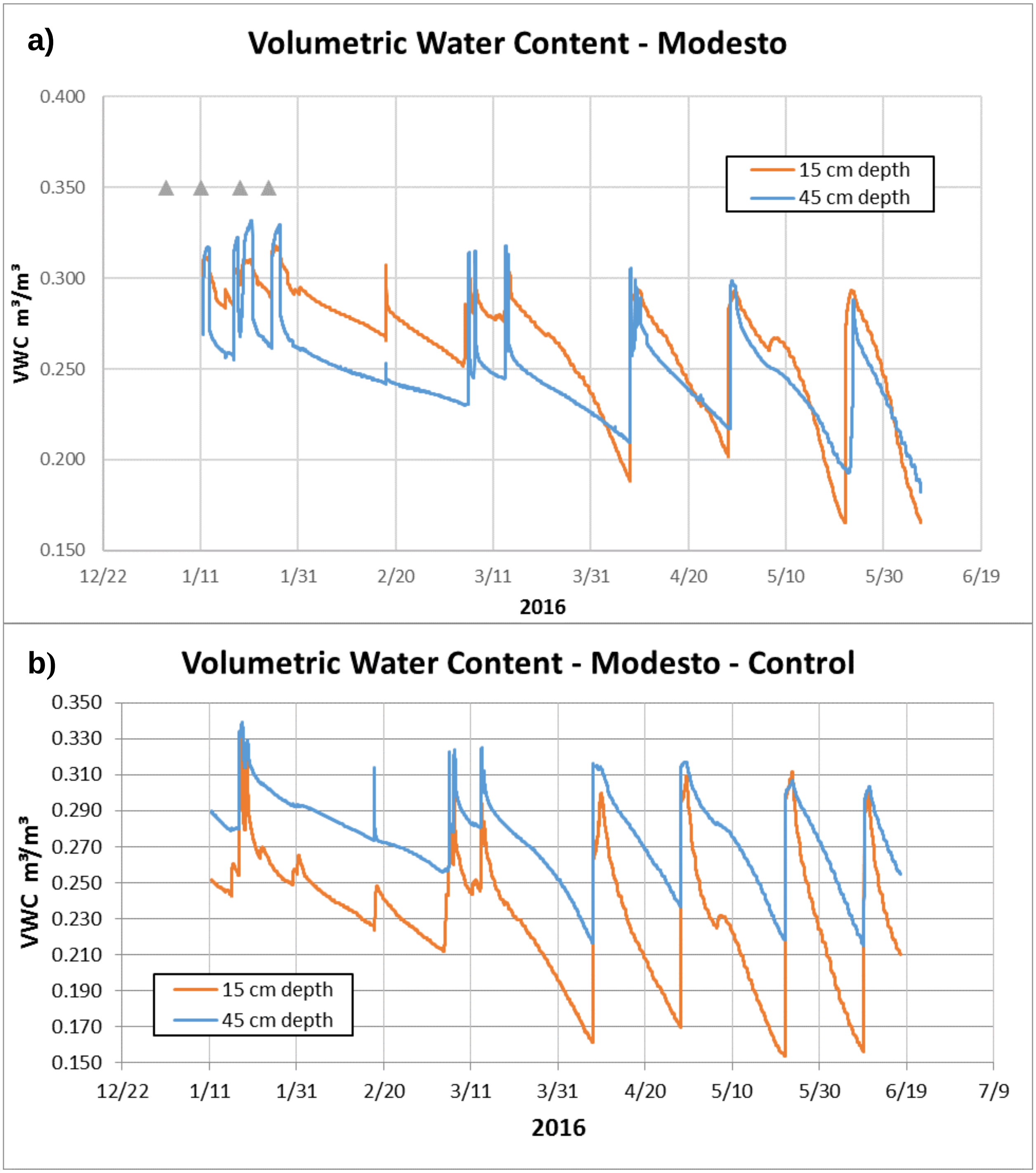


Figure 6: Volumetric soil water content measured at 15cm and 45 cm depth in the flood (a) and control (b) plot in Modesto, CA. Green triangles indicate the recharge events.

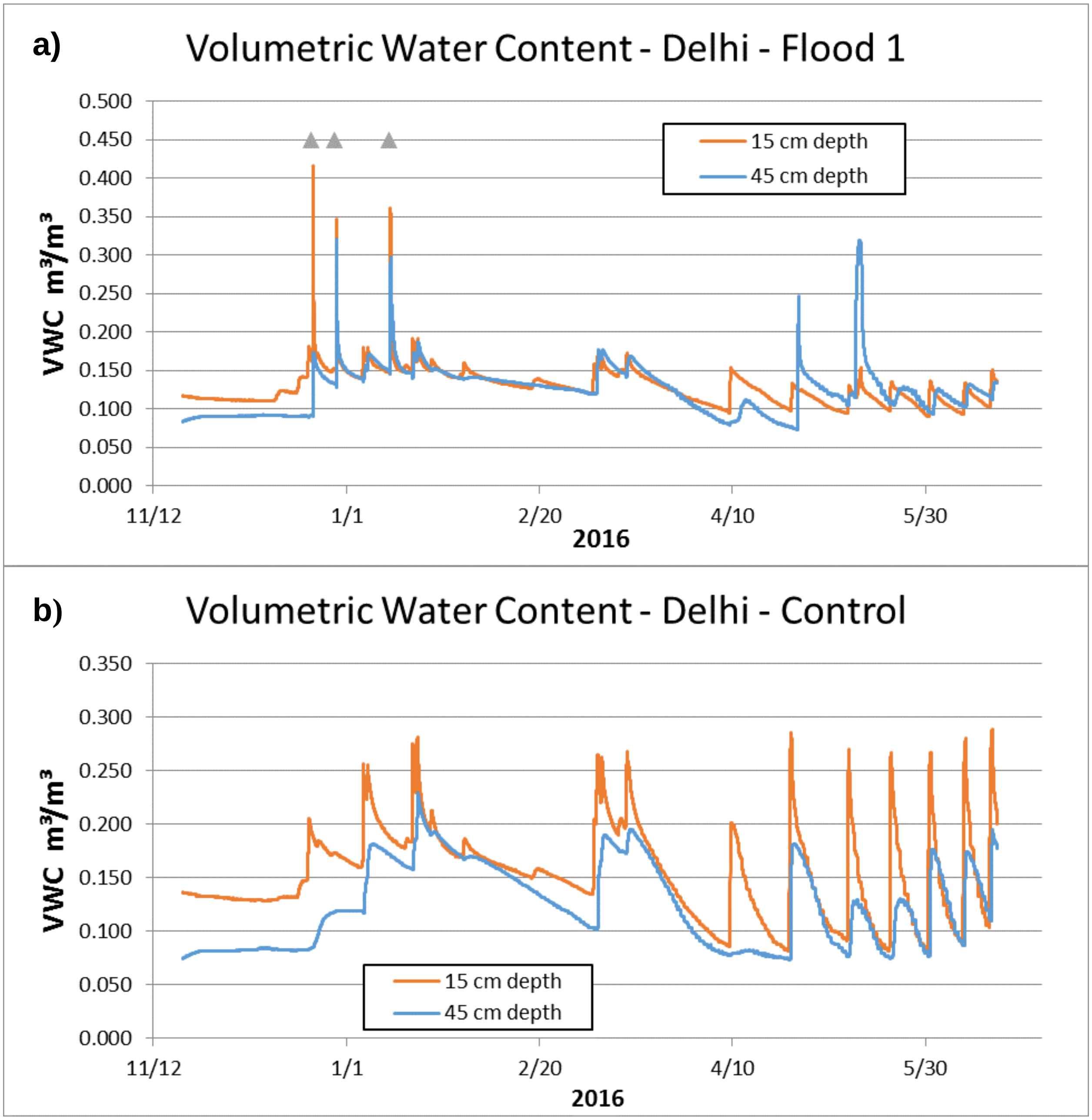


Figure 7: Volumetric soil water content measured at 15cm and 45 cm depth in the flood (a) and control (b) plot in Delhi, CA. Green triangles indicate the recharge events.

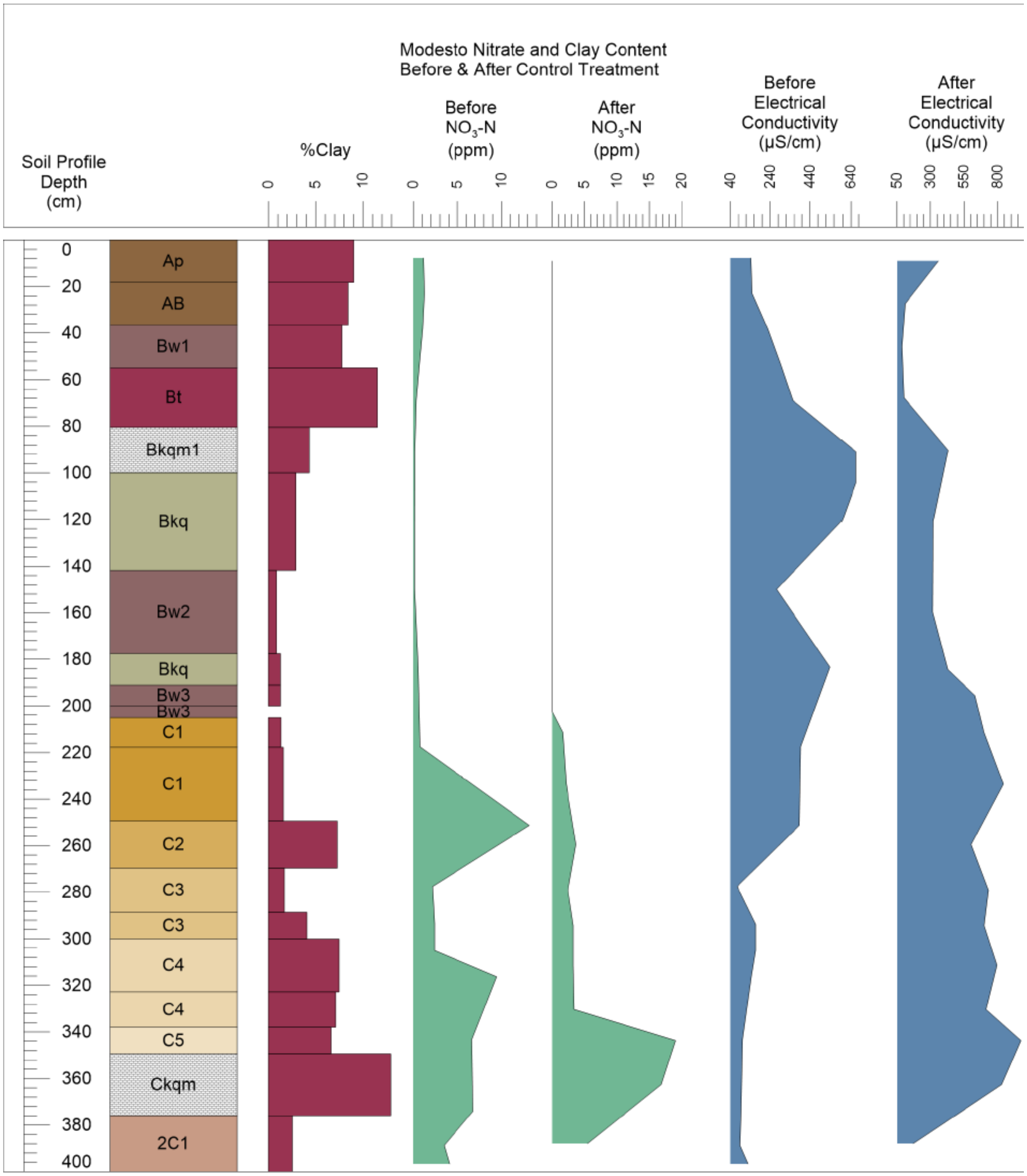


Figure 8: Soil stratigraphy, percent clay content, and soil nitrate-N and soil electrical conductivity before (October 2015) and after (February 2016) the flood water application near Modesto, CA.

Following the January recharge irrigations at the Modesto site, the SWP of the trees in the recharge treatment was slightly higher (wetter) than the SWP of trees in the grower control treatment, and both measured wetter than the baseline, which is typical in almonds for dormant and early spring conditions (**Figure 9**). By mid-February however, and for the rest of the season, there was no apparent long term effect of the winter recharge irrigations on tree SWP, as the Grower and recharge values were essentially identical, staying very close to the baseline through mid-June (**Figure 9**). At the Delhi site, there was no difference between the Grower and the 'Dry Winter' treatments because of sufficient rainfall, and prior to applying any recharge irrigations, all treatments had essentially identical SWP values, which, as in Modesto, were above the baseline (**Figure 9**). However, unlike the Modesto results, following the first two recharge irrigations in December, trees in the recharge treatment of the Delhi site had consistently higher (wetter) SWP values compared to the other treatments, and while the size of this effect varied through the season, the improvement in SWP due to the recharge irrigations lasted through mid-June (**Figure 9**). Whether or not this difference in SWP will be associated with any short or long term orchard health or productivity differences will be determined with further monitoring.

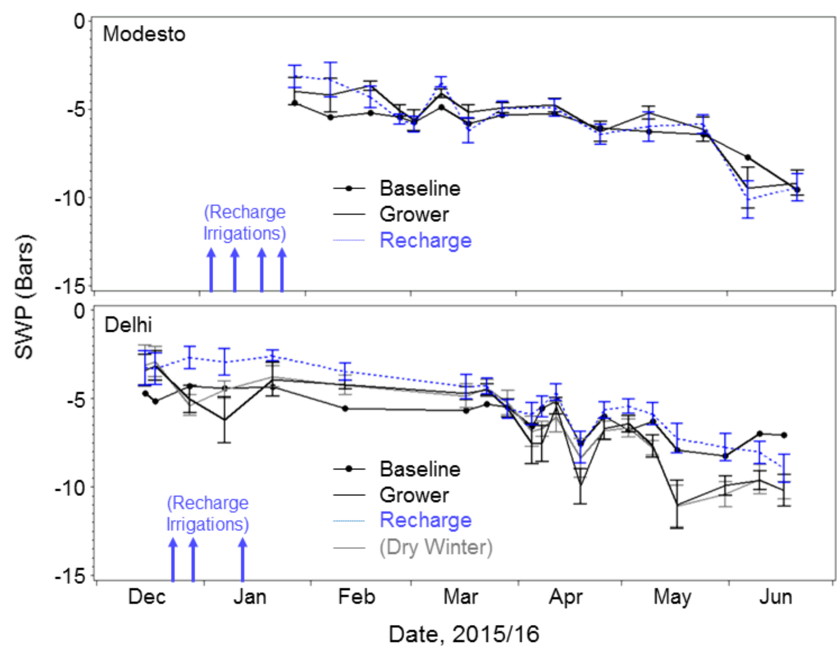


Figure 9. SWP for all treatments at the Modesto (top) and Delhi (bottom) sites in 2015/16. Recharge (flood) irrigations in December/January are indicated by the upward arrows.

Root images have been collected (**Table 2**) and are being analyzed. Images indicate that even at the 45-60 cm depth, soil settling around the minirhizotron tubes is evident after many months, but roots can be identified (**Figure 10**). It is interesting to note that more roots are apparent in the grower treatment compared to the recharge (flood) treatment at the Modesto site, but all root images will need to be analyzed to determine if this is a consistent pattern. The sandier texture of the soil at the Delhi site is also apparent (**Figure 10**).

Pot study. Following accidental watering, SWP showed that all trees were in a relatively wet condition, with SWP around -3 bars (**Figure 11**). However, during January, trees with a wheat cover crop (N=17), were able to reach SWP values of from -4.2 to -25 bars. The drought treatment trees without wheat (N=10) had about the same average SWP at the end of January as they did at the start even though no water was applied, demonstrating the importance of a cover crop to establish stress in these pots. The control trees (N=10), watered twice a week, ranged from -0.9 bar to -3.9 bars with average SWP of -2.1 bars. This result is consistent with the pilot experiment that was performed in 2014/15, which showed that dormant tree SWP changes very little for volumetric soil water contents ranging from 50% to about 10% in this potting soil. Hence, a cover crop is an effective and necessary method to establish a range of dormant tree SWP values and simulate dry winter conditions. Based on the MS thesis of Luke Milliron, who found that most field almond trees have dormant SWP values above -5 bars, whereas in the dry winter of 2015, some reached -10 bars, the trees of this pot study were divided into three categories according to their final SWP (**Table 3**). All trees showed a rapid recovery in SWP when they were irrigated prior to bloom on February 5, 2016 (**Figure 11**).

Table 2. Dates of root image collection at the Delhi and Modesto sites.

Delhi	Modesto
1/15/2016	1/11/2016
2/5/2016, 2/1/2016	2/1/2016
2/29/2016	2/29/2016
3/28/2016	3/28/2016
4/18/2016	4/18/2016
5/9/2016, 5/13/16	5/9/2016
5/28/2016	5/28/2016
6/20/2016	6/20/2016
7/11/2016	7/11/2016

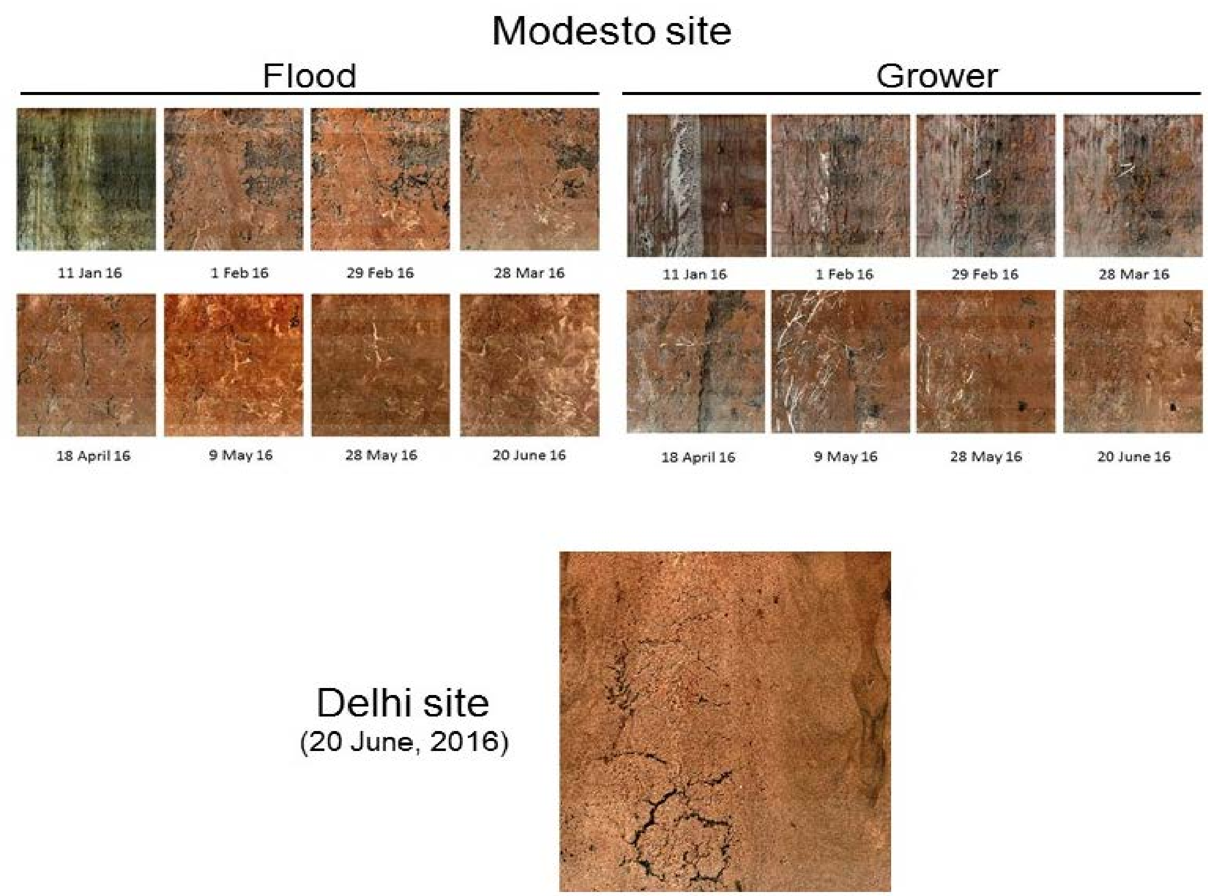


Figure 10. Example root images over time from the flood (recharge) and grower treatments at the Modesto site, and a single example illustrating the sandy texture of the Delhi soil.

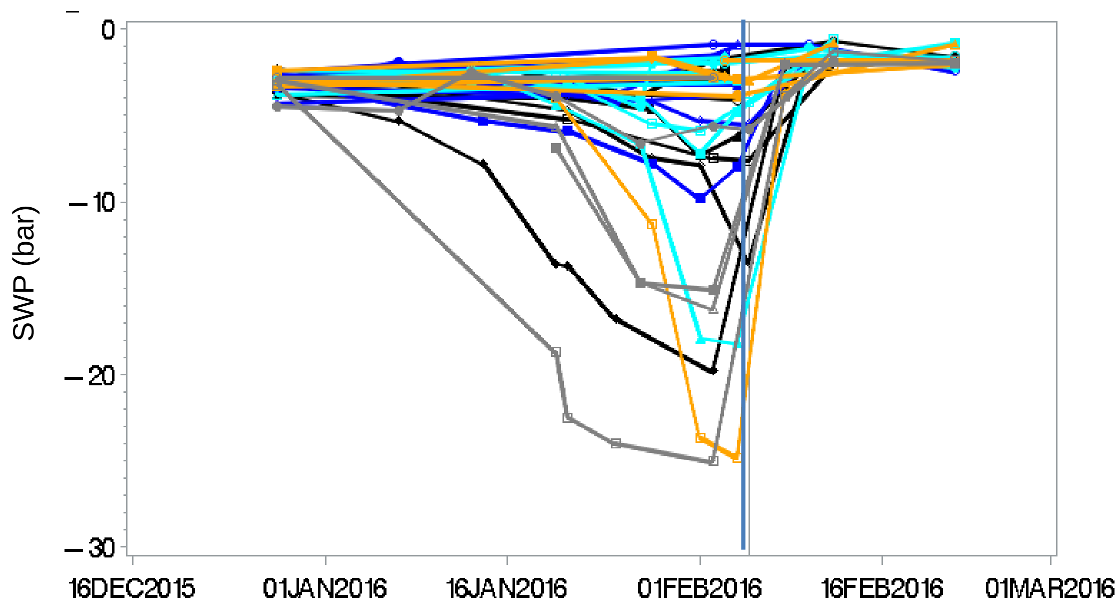


Figure 11. SWP (following accidental watering) over the 2015-2016 winter, with each line representing an individual tree. The blue vertical line indicates the day when all trees were irrigated prior to bloom (Feb. 5th, 2016).

Bloom was delayed by more than a week for a tree that had experienced dry dormant conditions compared to one that stayed wet during dormancy (**Figures 12 and 13**). For these trees, the difference in dormant SWP as well as the progress in percent bloom was very clear (**Figure 14**). After grouping into categories based on the severity of dormant season stress (**Table 3**), the average percent of flowering was always consistent with the severity of dormant season stress, with more stress resulting in a lower percent bloom, and hence a delay in bloom, at all time points (**Figure 15**). It should be noted however, that even for values of dormant SWP lower than -10 bar (more stressed than any field observation thus far) the average final percentage of flowering was still above 80%. Since both the duration as well as the severity of water stress may be important in determining plant growth responses, we calculated the product (BarDay) in order to compare bud development across all individual trees. Both floral and vegetative buds exhibited a later date for the beginning of development (i.e., the transition from stage 1 to stage 2) with increasing stress (**Figure 16**), although it is interesting to note that for all but the most stressed tree, which reached a SWP of -25 bars, the flower buds of all other trees had broken dormancy before being irrigated on February 5. This is consistent with the results of the pilot experiment in 2014/15, and indicates that almond flower buds are capable of beginning development even when the tree is under substantial water stress. For some of the driest trees, the substantial delay in bloom development caused an overlap to occur between bloom and leafing (**Figure 13**).

The control trees set some fruit due to normal bee activity in the area, but the delay in bloom for the dry trees was enough so that hand pollination was required in order to evaluate whether or not the flowers that did bloom on these trees were capable of setting fruit (no obvious anomalies in flower anatomy were observed). Fruit was set on both control and dormant stressed trees and these fruit were harvested in late April/early May. Other than the difference

Figure 12. Images of a control tree from bud break to fruit set

Figure 13. Images of a dry tree from bud break to fruit set

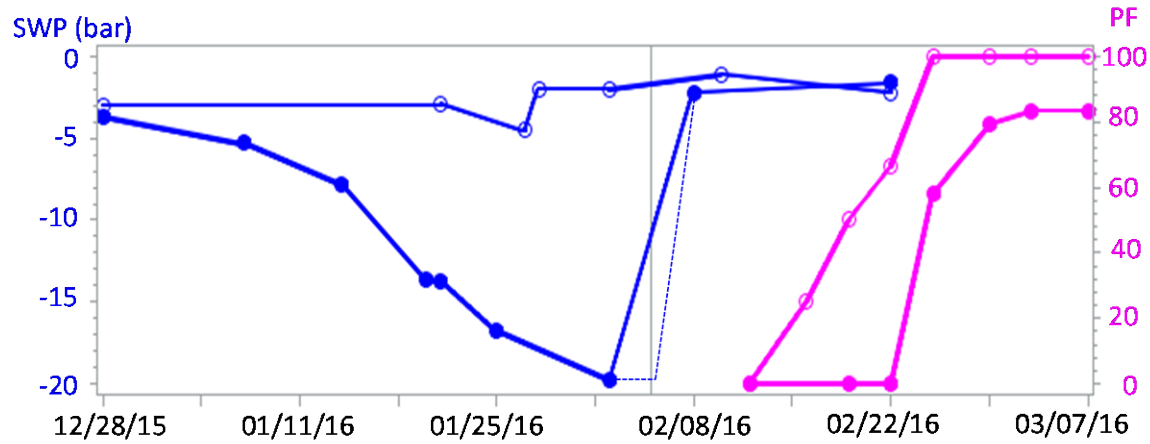


Figure 14. SWP (left axis) and the percent open flowers (right axis) for a control tree (open symbols) and a tree that experienced drought during dormancy (close symbols). A grey vertical line indicates the date of rewatering of the droughted tree, with the dashed blue line indicating that SWP would not have recovered until after watering.

Table 3. Tree categories based on final SWP before re-watering on 02/05/2016. The final SWP indicates the tree drought condition during the 2015-2016 winter season.

Tree Category	SWP range (bar)	Number of trees in this category
Low/No water Stress	0 to -5	23
Medium Water Stress	-5 to -10	7
High Water Stress	Below -10	7

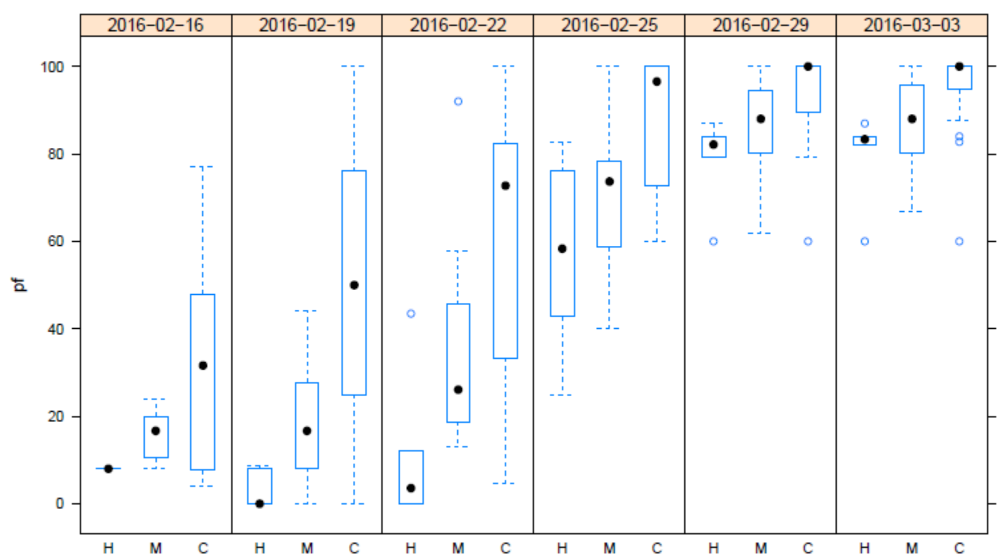


Figure 15. Box plot of the percent of flower buds that opened by the indicated sampling dates (top row) for trees grouped based on high (H), medium (M), and low/no water stress as control (C). Dots indicate the average (mean) value for each group.

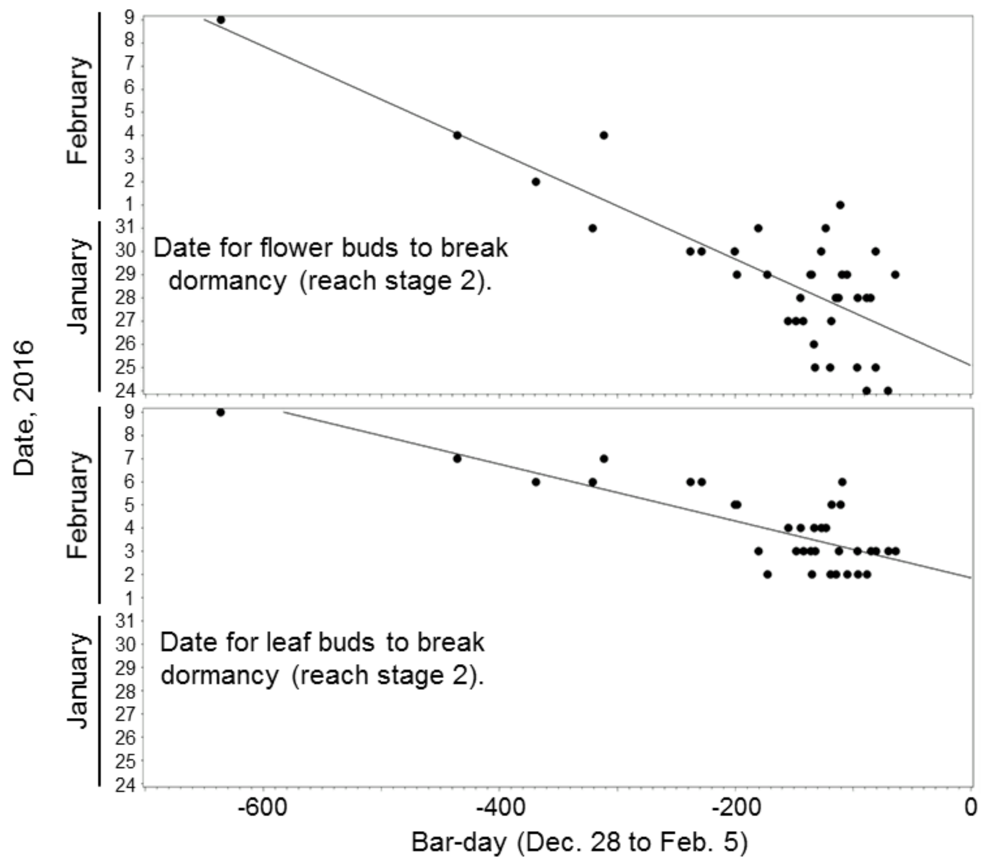
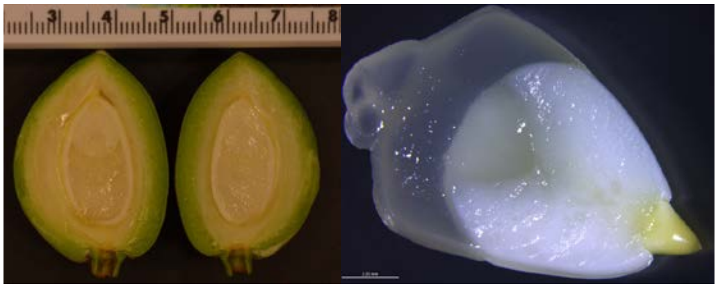


Figure 16. Relation of the date (y-axis) of flower bud break (top) or leaf bud break (bottom) to the integrated level of stress (x-axis) experienced during the dormant period. Each point represents one tree.

associated with the earlier bloom and a somewhat more advanced stage of embryo and endosperm development in the control trees, no difference was found between control and dormant stressed trees (**Figure 17**). Our tentative conclusion from these studies is that water stress during dormancy may delay flower and to some extent vegetative bud development, but appears not to cause damage to the buds themselves. This is an important conclusion because it indicates that a substantial delay in winter irrigation during dry winters may be possible without concerns about a negative impact on bloom, giving growers more flexibility. Also, a longer delay in dry winters should result in water savings in years when winter rains arrive late. We have also developed a reliable method for creating different levels of water stress in dormant almond trees, although in this year we were prevented from establishing the planned replicate levels of stress and stress timing.

A preliminary study was conducted in cooperation with the lab of Maciej Zwieniecki to determine if the dry winter treatment resulted in changes in the concentration of sugars in the xylem sap compared to control trees. Both control and dry treatments exhibited high initial levels followed by declines over time as floral and vegetative buds were beginning development (**Figure 18**). There is some indication that the dry treatment caused a delay in the pattern of xylem sap sugar concentration (**Figure 18**) which is consistent with the observed delay in bloom (**Figure 15 and 16**), but more replication will be required to determine if this effect is consistently observed.

Harvested on 05/02/2016. Nut from a control tree



Harvested on 05/02/2016. Nut from tree with severe drought in winter

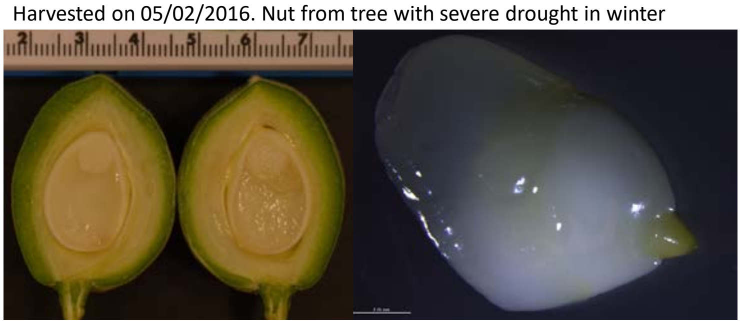


Figure 17. Images of sectioned nuts about 10 weeks old and the embryo and endosperm from the nut from a control (top) and a drought stressed tree (bottom).

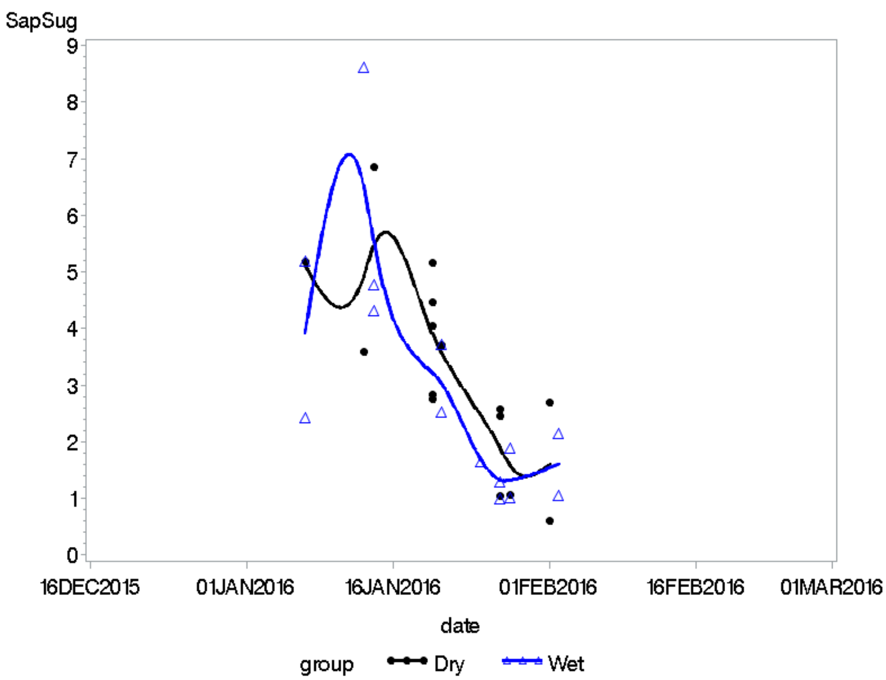


Figure 18. Xylem sap sugar concentration for dry trees and wet trees over time. Data come from 6 of the driest trees and 4 wet trees.

Research Effort Recent Publications:

None.

References Cited:

None.