A Leaf Monitoring System for Continuous Measurement of Plant Water Status to Assist in Irrigation Management of Specialty Crops

Project No.: **15-HORT24-Upadhyaya**

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Objectives:

The objectives of this study are to (i) quantify the benefits of plant water stress based site-specific irrigation management scheme that employs a wireless mesh network for almond crop in comparison to ET based irrigation management scheme, and (ii) demonstrate the technology to growers. While the soil moisture content will be monitored, a newly developed continuous leaf monitoring system that detects the plant water status in real-time will be the key sensor used for decision making and precision irrigation management.

Interpretive Summary:

Two management zones were created in an approximately 5-acre almond plot in Nickel's Soil Laboratory based on soil and plant characteristics. Soil characteristics considered were soil texture, digital elevation, and surface (shallow) and subsurface (deep) soil electrical conductivity (EC). The plant characteristics included were canopy light interception and shaded leaf temperature. Within each management zone two irrigation treatments were implemented – (i) grower practice; and (ii) plant water stress (PWS) based irrigation that utilized a network of leaf monitors. The results indicated that the leaf monitors detected PWS quite well with a coefficient of multiple determinations (R^2) value of 0.75. The preliminary results of field tests conducted just before harvest indicated that one of the management zones required about 80% ET or 70% of what the grower was applying and the other zone required about 105% ET or 90% of what the grower was applying. We plan to implement this irrigation management scheme during the whole season during the 2016 growing season.

Materials and Methods:

Creation of management zones and testing of the suitability of leaf monitors for detecting stress in almond crop were performed during the 2015 growing season. Management zones were created based on soil and plant characteristics using an unsupervised Fuzzy classification. The soil characteristics considered were digital elevation (obtained using RTK

GPS units), soil texture, and surface (shallow depth) and subsurface (deep layer) electrical conductivities. Plant characteristics considered were canopy cover (as measured by an UAV) and leaf temperature. This information was used to create maps using a kriging technique. After maps were created, samples were obtained using an inverse distance technique at locations that represent a tree. The idea behind these zones was that they represent relatively homogeneous management units. Based on these management zones, we made modifications to irrigation water supply systems, selected optimal locations to install leaf monitors, soil moisture sensors, pressure sensors, hubs or nodes and latching solenoid valves. In each location, a wireless data acquisition and communication system was installed. The system consisted of soil moisture and plant water status sensors (leaf monitors) to monitor soil, plant, and ambient conditions continuously. Moreover, the system was capable of actuating latching solenoid valves for a desired duration to implement site-specific water management.

Two treatments were implemented in each management zone, grower based (rows to the left in **Figure 1**, which are shown in blue) and LM based (rows to the right in **Figure 1**, which are shown in yellow). The position of each leaf monitor was chosen by carefully analyzing stem water potential maps created on three different occasions. The positions of the nodes are shown in **Figure 1**. Plant water status was estimated using Crop Water Stress Index (CWSI) and compared with Deficit Stem Water Potential (DSWP). The CWSI is defined as:

$$CWSI = \frac{(T_l - T_a) - (T_l - T_a)_{sat}}{(T_l - T_a)_{dry} - (T_l - T_a)_{sat}} \qquad (1)$$

where, T_l is the leaf temperature, T_a is the ambient temperature, and subscripts 'sat' and 'dry' indicate well-watered and severely stressed conditions.

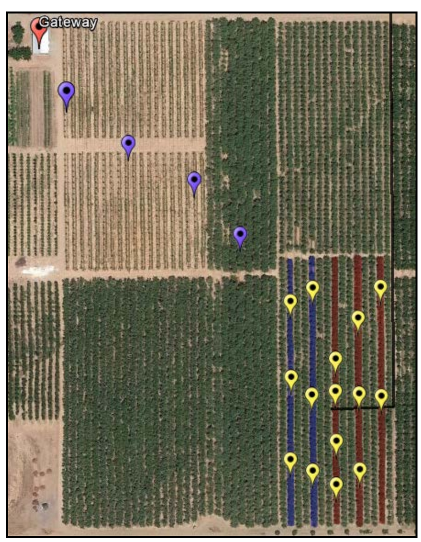

Figure 1. Wireless mesh network located at Nickels Soil Lab., where the red mark corresponds to the gateway, blue marks correspond to the repeaters and yellow marks correspond to ekonodes to which leaf monitors and latching solenoid valves are connected.

Plant water status was monitored by comparing the performance of selected trees with respect to a well-watered tree and a simulated dry tree. The well-watered condition was created by watering a group of three trees with additional amounts of water (i.e., an extra drip line was placed to overwater these trees). The dry or severely stressed condition was simulated by breaking the stem of the leaf being monitored (- initially, we created severely stressed condition by applying antiperspirant to the leaf surface. However, we found that a leaf with a broken stem worked in the exact same way. So we decided to use this technique in all our experiments). Moreover, we found that calibration was needed to account for discrepancies in slope and intercept values between the leaf monitors mounted on various trees. To accomplish this, leaf temperature and air temperature sensors in each of the leaf monitor were calibrated with respect to the saturated and dry leaf monitors, respectively. A day when the selected trees were saturated (i.e. one day after irrigation) was chosen to calibrate each of the leaf temperature sensors (i.e. IR temperature sensor).

Midday stem water potential values were obtained periodically to determine the relationship between DSWP and CWSI values. Moreover, attempts were made to manage irrigation based on plant water stress between July 25th and August 6th. In each management zone, when the average CWSI values exceeded the stress value of 5 bar DSWP (i.e. CWSI value of 0.3), zone based precision irrigation management was implemented to maintain the stress level within a desired range.

Results and Discussion:

The krigged maps developed using plant and soil characteristics, and the management zones created from these maps are shown in **Figure 2**. As seen in these plots, the soil characteristics had a greater contribution in the classification than plant characteristics. Among the soil characteristics considered, digital elevation was the feature that contributed the most.

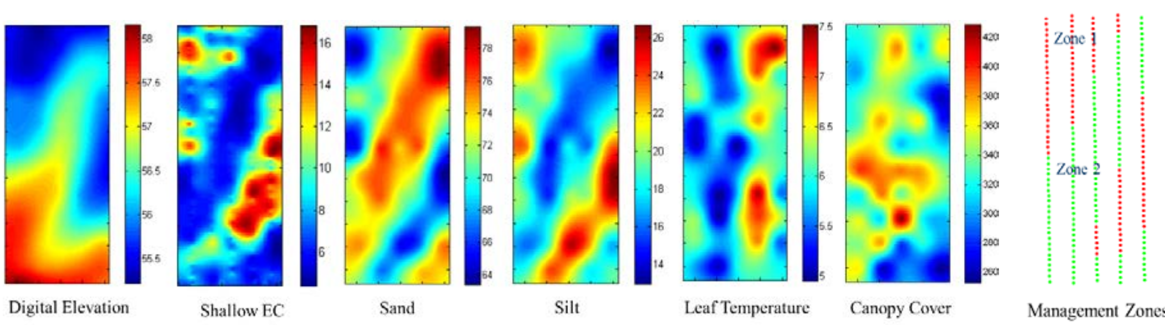

Figure 2. From left to right: krigged maps of (a) digital elevation, (b) shallow EC, (c) sand, (d) silt, (e) leaf temperature and (f) canopy cover, and (g) classification result for of almond plot.

An example, of the behavior of temperature difference (i.e., Air temperature – Leaf temperature) for the period of July 25th to August 4th for three almond trees are shown in **Figure 3a**, where the curves corresponding to the dry (red) and well-watered (green) conditions are displayed together with the curves of each selected leaf monitor (blue); the horizontal axis represents time in Julian days. The estimated CWSI values are shown in **Figure 3b**. In these plots a value of 1 corresponds to the dry or highly stressed condition and 0 corresponds to the saturated or well-watered condition. Note that temporal variability in PWS was different for different management zones, indicating that management zone based precision irrigation management that utilizes plant water status as a stress indicator could be a useful tool.

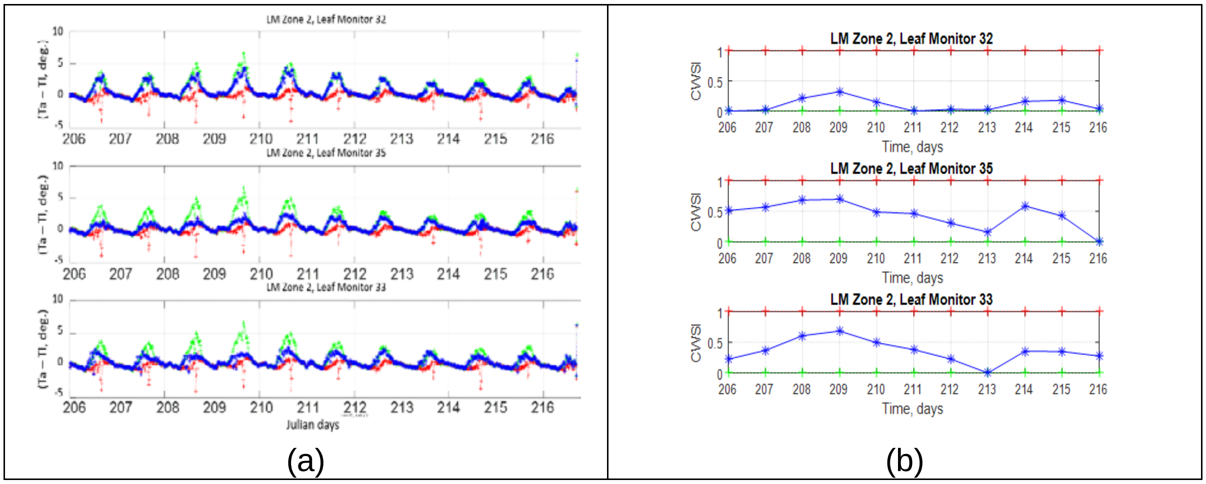

Figure 3. Continuous leaf monitor data for almond crop – (a) Display of temperature difference between the ambient and the leaf for a well-watered (green), simulated dry (red), and monitored tree (blue), (b) Computed daily CWSI values.

Midday DSWP data were compared with their corresponding values of CWSI. CWSI and DSWP values were found to be strongly correlated, with a second order relationship (**Figure 4**). The results were very similar to our previous results (Dhillon et al., 2014). The relationship between CWSI and DSWP was found to be quadratic with a coefficient of determination value of 0.75. Moreover, almonds were not sensitive to stress for CWSI values less than 0.3 or DSWP values of less than 5 bars.

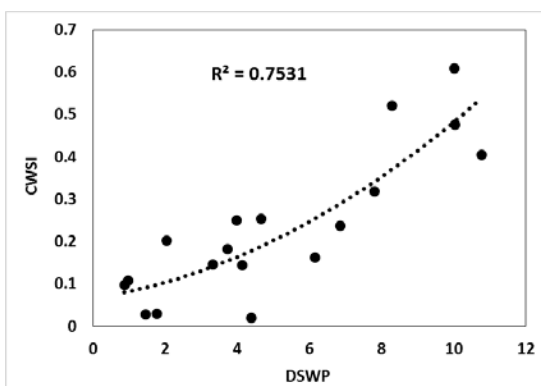

Figure 4. Comparison between CWSI versus DSWP in almond crop.

Figure 5 shows the results of plant water stress based precision irrigation in the two management zones. It shows that when we started with 85% of ET, trees in zone #1 were within the acceptable stress range (CWSI values of about 0.3) and even required less water (about 80% of ET). When we applied 85% ET equivalent, we were able to skip some irrigations compared to the grower practice. However, the situation in zone #2 was very different. We had to keep increasing the amount of water applied (**Figure 5b**) and finally at 105% ET, acceptable plant water stress level was achieved. In terms of amount of water applied, zone #1 required 70% of grower application amount and zone #2 required 90% of grower application amount. These results are very encouraging. However, they should be regarded as preliminary results. By the time we got to this point (establishing management zones, installing irrigation lines, deciding sensor locations and making sure the system was working well), it was already the last week of July. When we finished our preliminary experiments, grower was getting ready to harvest Nonpareil almonds. Once these almonds were harvested and picked up, grower started getting ready to harvest pollinators. So basically harvesting operations dictated irrigation practice (not plant water status) for most of the rest of the season. Based on what we have observed; we believe that the main period where precision irrigation can be implemented in almonds is prior to Nonpareil harvest. This covers the peak transpiration periods of June, July and part of August.

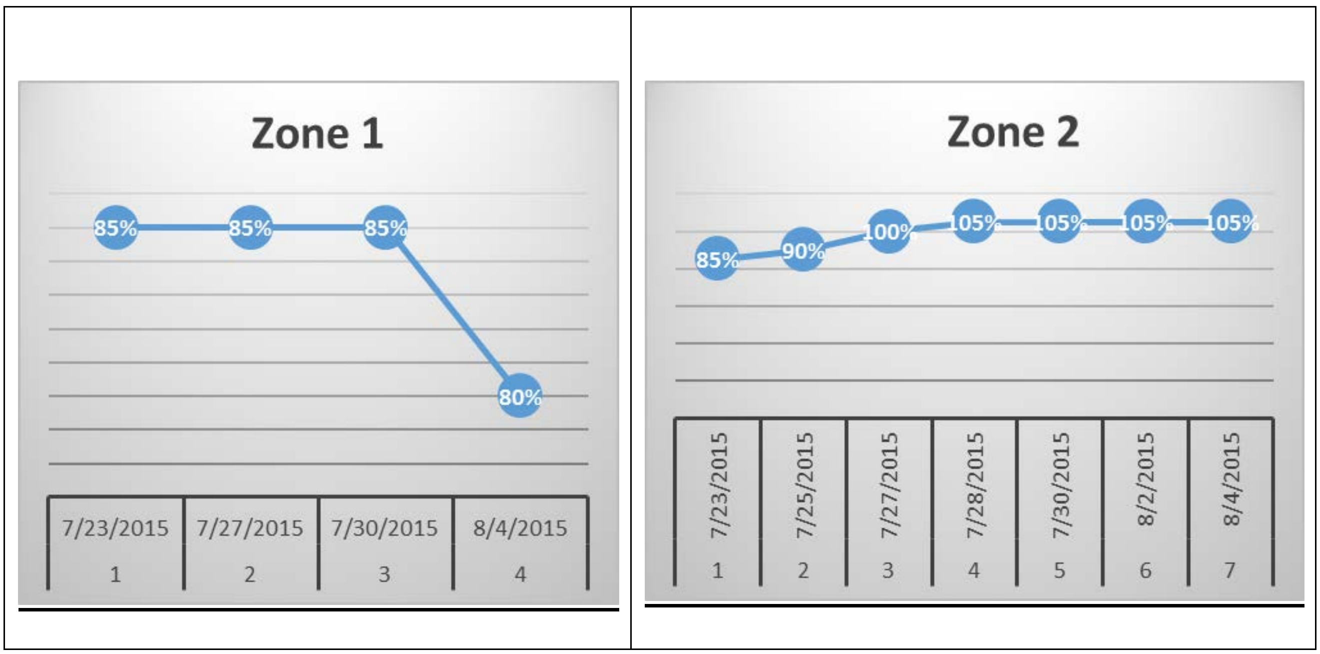

Figure 5. Precision irrigation management scheme in management zones # 1 and # 2 in a 5-acre section of almond orchard in Nickels Soil Lab, Arbuckle, CA.

Our goal for the 2016 growing season is to implement precision irrigation from the beginning of the season. Since the management zones which are primarily governed by soil characteristics and digital elevation have been established and irrigation setup are already in place, we should be able to implement plant water stress based precision irrigation scheme from the very beginning to quantify its benefit for almond crops.

Research Effort Recent Publications:

Rojo, F., E. Kizer, S. Upadhyaya, S. Ozmen, C. Ko-Madden, Q. Zhang. 2016. Precision irrigation in almonds and grapes based on plant water status. Proceedings of California Plant & Soil Conference, Visalia, CA. February 2, 2016.

Kizer, E, F. Rojo, F. Rojo, C. Ko-madden, Q. Zhang and S. Ozmen. 2016. Proximal sensing of leaf temperature and microclimatic variables to implement precision irrigation in almond and grape crops. Proceedings of the 13th International Conference of Precision Agriculture, St. Louis, MO., July 31 – Aug 4, 2016.

Upadhyaya, S., F. Rojo, E. Kizer, Q. Zhang, J. Meyers, M. Delwiche, R. Coates, B. Lampinen, and F. Niederholzer. 2016. Precision irrigation in almonds and grapes based on plant water stress. A 2-page Extension flyer distributed to nearly 150 participants of Nickels Soil Lab Field Day, May 19, 2016.

References Cited:

Dhillon, R., F. Rojo, J. Roach, S. Upadhyaya, and M. Delwiche. 2014. A continuous leaf monitoring system for precision irrigation management in orchard crops. J. Agr. Machinery Sci. 10(4):267-272.