Development and Testing of a Mobile Platform for Measuring Canopy Light Interception and Water Stress in Almond

Project No.: **14-HORT13-Lampinen**

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Objectives:

- Objective 1. The first component of this project involves using the mobile platform lightbar to measure light interception and corresponding yield in almond orchards throughout the almond growing area of California. The goal of this aspect of the work is to help establish the upper limit to the light interception/yield relationship for almond (shown in **Figure 1**) as well as to use these data to investigate the relationship between productivity and productivity per unit light intercepted.
- Objective 2. The second component of the project involves continuing work on new methods of measuring water stress in almond.
- Objective 3. An application to allow farm advisors and growers to estimate canopy light interception using an iPhone is being developed and tested.

Interpretive Summary:

A mobile platform for measuring midday canopy light interception and a sensor suite for measuring leaf/canopy temperature as a means of assessing plant water status has been developed.

Mobile platform – Data collected by the authors over the past several years has provided a rough upper limit to productivity in almond based on the percentage of the available midday canopy photosynthetically active radiation (PAR) that is intercepted and the age of the trees. However, most of the data that was collected previously had limitations. The methods of measuring percent PAR interception using a handheld lightbar (Decagon Devices, Pullman, WA 99163) were relatively slow and labor intensive. For this reason, much of the lightbar data that was used to develop the relationship was based on sampling of relatively small samples of trees. Often the area for the yield and PAR interception data did not match (i.e. PAR data from 5 trees and yield data from either one tree or from an entire row). We have outfitted a Kawasaki Mule with a light bar that is able to measure light across an entire row (up to 32 feet wide). The data can be stored on a datalogger at intervals of less than 1 foot down the row at a travel speed of about 4.5 mph giving us a much better spatial resolution in much less time than was possible in the past.

The mobile platform has been used extensively for mapping midday canopy light interception in almond orchards. The 2014 season was the sixth year that data was collected with the mobile platform. Data collected with the mobile platform suggests that there are a number of potential uses for this technology. The first is for providing a baseline for assessing how an orchard is performing relative to other orchards of similar age and variety. Another is for separating out the effects of rate of canopy growth from productivity per unit canopy light intercepted in different clones or varieties. A third potential use is for assessing the efficacy of different fumigants by again separating out the effects of canopy size from productivity per unit light intercepted. A fourth use is for evaluating the impacts of different pruning regimes on canopy growth, light interception and productivity per unit light intercepted. This technology also allows the elimination of canopy size differences from any type of trial.

Sensor suite – In 2012, the sensor suite was upgraded to a more compact design. The device uses an IR spot sensor to measure leaf temperature while accounting for windspeed, leaf orientation, and incident PAR to provide a potential means of detecting plant water status. Results from the 2012 through 2014 seasons continued to show promise for this technique to predict stem water potential. Data again showed that shaded leaves give better results than sunlit leaves.

Leaf monitor – The leaf monitor for continuously measuring leaf to air temperature difference in the lower canopy was refined and tested. The leaf monitor is able to track almond tree water stress over an irrigation cycle with the results comparing well with midday stem water potential measurements using the plant pressure chamber suggesting the device could be used for continuous monitoring of plant water status.

Development of the iPhone app is ongoing with an initial trial release to farm advisors and select growers accomplished in the summer of 2015.

Materials and Methods:

Objective 1. Refine light interception/yield relationship in almond. Twenty two almond orchard sites of varying ages and varieties from throughout the almond growing area of California were selected for measurements in 2014 (**Table 1**). An emphasis was placed on orchards with Nonpareil but other varieties were also included. Light bar measurements were done in 10-20 rows (depending on orchard size and variability) in representative areas of the orchard during June to August. In addition, measurements were done in various research plots around the state as described below. A portable weather station with temperature, relative humidity and photosynthetically active radiation sensors was set up outside of each orchard to provide reference data (on a one minute basis) during the period measurements with the light bar were being taken.

The photosynthetically active radiation data from this station was used to calibrate the sensors on the Mule lightbar throughout the measurement period. The data rows were then flagged and at harvest time, rough field weights were taken from the Nonpareil or other primary variety in the orchards. Subsamples from each variety were taken and dried and shelled to estimate kernel yield. In some cases measurements were done in orchards that are being used for other almond trials including sites from the USDA-ARS Area Wide Methyl Bromide Alternatives trials, as well as projects funded under a federal

Site #	County	Trial	Date Mapped	Site #	County	Trial	Date Mapped
1	Colusa	Nickels organic almond	6/12/2014	11	Colusa	Nickels Niederholzer	7/18/2014
2	Colusa	Nickels almond rootstock	6/12/2014	12	Tehama	ETPF Fulton	7/19/2014
3	Colusa	Nickels almond pruning/training trial	6/13/2014	13	Colusa	Nickels RSI	7/24/2014
4	Kern	Kern WPF	6/18/2014	14	Colusa	Nickels precision irrigation	7/24/2014
5	Yolo	Scheuring rootstock	7/2/2014	15	Stanislaus	Duncan almond pruning, spacing and rootstock	8/2/2014
6	Kern	Spur Dynamics	7/4/2014	16	Merced	Browne Littlejohn almond	8/7/2014
7	Kern	SCRI-Belridge	7/7/2014	17	Merced	Doll WPF	8/21/2014
8	Kern	Paramount hedging trial Nonpareil	7/9/2014	18	Merced	Arnold rootstock	8/22/2014
9	Kern	Paramount hedging trial Monterey	7/11/2014	19	Merced	Taylor re-plant	8/23/2014
10	Kern	McFarland Variety trial	7/12/2014	20	Merced	Browne Frago trial	8/24/2014

Table 1. Almond orchards sites mapped with Mule lightbar during 2014 season.

SCRI grant focused on fertilization efficiencies. Other orchards were mapped from rootstock as well as pruning and training trials. Using orchards from other studies allows us to utilize the data for multiple purposes.

<u>Objective 2</u>. A mobile sensor suite (**Figure 3**) was developed and evaluated to predict plant water status by measuring the leaf temperature of nut trees and grapevines. It consists of an infrared thermometer to measure leaf temperature as well as sensors to measure air temperature, relative humidity, wind speed, and photosynthetically active radiation (PAR) in the vicinity of the leaf. In 2012, the sensor suite was redesigned to a much more compact format.

In 2013 and 2014, a continuous leaf monitor for measuring shaded leaf temperature on a continuous basis was refined and tested in the field. UC Davis has applied for a patent for this device. Continuous leaf monitors were installed on shaded almond leaves (**Figure 6**) at Nickel's Soil Lab, Arbuckle, CA. Leaf monitors were integrated into an existing eKo wireless sensor network at the field site used for precision irrigation control. Leaf monitor data was collected every 15 minutes from July through early October. These data were stored in a database on the field computer at the base station and were available to access in real-time from the web. Plant water status was also measured to ground-truth data. Midday stem water potential for each tree on which a leaf monitor was installed was measured using the pressure chamber after enclosing a shaded leaf in a Mylar bag for at least 20-30 minutes.

Objective 3- Release trial version of an iPhone application to estimate canopy light interception and PAR interception in walnut and almond. The application estimates the canopy light interception using images with the canopy ground shadow.

Results and Discussion:

Objective 1. Data collected with the Mule lightbar in from 2009-2014 are shown in **Figure 1**. Although many orchards produced yields well above the sustainable upper limit line in 2009 and 2011, in 2010, 2012, 2013 and 2014 they were well below the line, and the overall regression for all years is below the line. Since individual spurs alternate bear, yields can be shifted from a low yield year to the following year. If a low

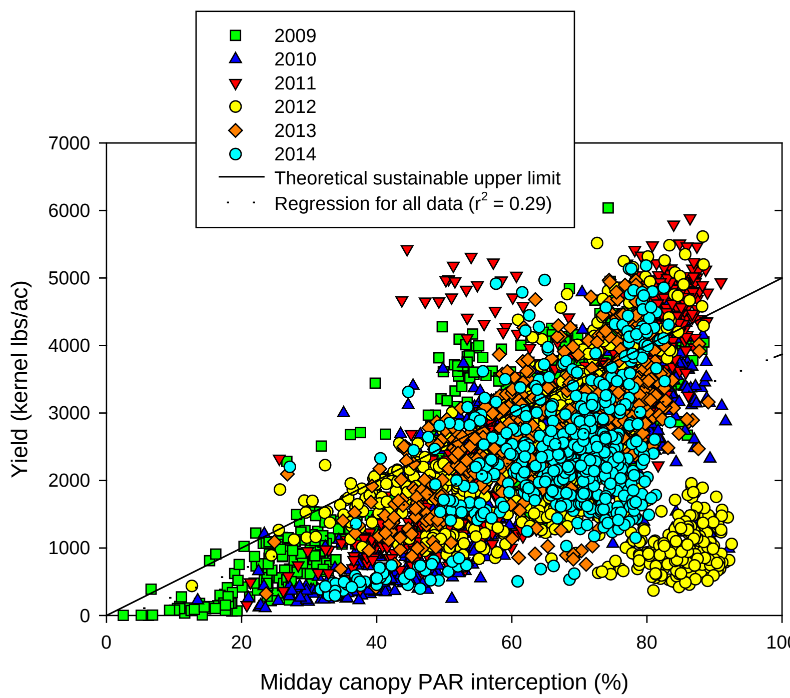

Figure 1. Midday canopy light interception versus yield relationship from mobile platform data for almond sites throughout state for 2009-2014 seasons. Solid line indicates theoretical sustainable upper limit and dashed line indicates regression through all data.

percentage of spurs bear in one year (for example due to poor bloom time weather), the next year a larger percentage of spurs will have a higher percentage chance of bearing.

Since years below and above the line normally alternate, it would have been expected that 2014 would have been a higher yield year that it was since 2013 was generally quite low. This effect may be related to irrigation limitations due to the drought.

The data collected with the mobile platform lightbar has many potential uses. One potential use is to help interpret data from pruning and spacing trials. **Figure 2** shows the midday canopy light interception over years 5 to 15 for a spacing trial in Stanislaus

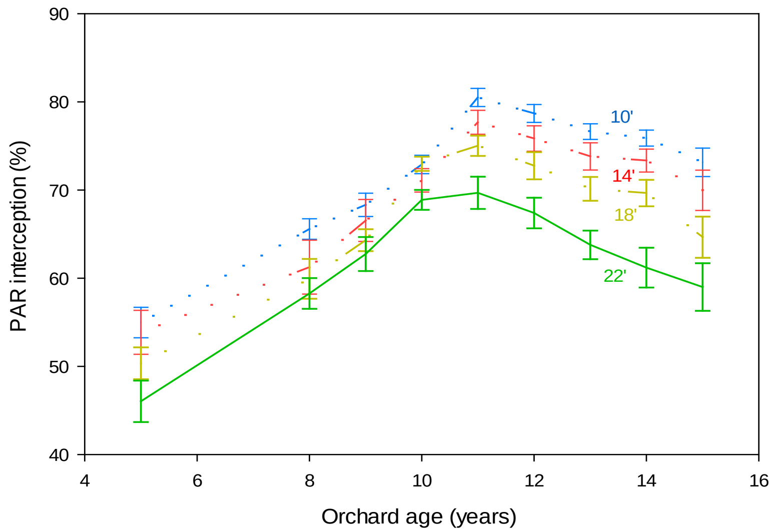

Figure 2. Midday canopy PAR interception from years 5 to 15 for different tree spacings in a variety and tree spacing trial in Stanislaus County conducted by Roger Duncan.

County. These data suggest that the decline in PAR interception (and corresponding yield) that we see in almond orchards starting around year 11 to year 13 are not due to shading related effects from high density plantings since it occurs at all spacings. It is also not due to lack of pruning since pruned and unpruned treatments all show the same pattern (data not shown).

The light bar data combined with the corresponding yield data allow us to look at the productivity of different cultivars or varieties as a function of both canopy size and productivity per unit light intercepted. We have not previously been able to separate out these two factors.

Table 2. Yield per unit light intercepted by Nonpareil source and variety for McFarland Variety trial 2009-2013.

Variety	2009-2014 yield/PAR	2009 yield/PAR	2010 yield/PAR	2011 yield/PAR	2012 yield/PAR	2013 yield/PAR	2014 yield/PAR
Nonpareil-Nico	60.3 a	69.3 abcd	49.7 a	86.7 a	38.2 abc	61.6 a	55.9 b
Nonpareil-3-8-2-70	57.3 a	71.8 abc	47.1 ab	87.9 a	36.2 abcde	56.5 ab	57.5 b
Nonpareil-Driver	56.1 a	76.1 ab	46.2 abc	84.3 a	36.6 abcde	60.2 a	51.2 bc
Nonpareil-5	55.5 a	68.5 abcd	50.8 a	78.0 ab	34.7 abcde	55.4 ab	57.6 b
Nonpareil-Newell	54.1 a	72.8 abc	45.2 abc	81.0 ab	33.4 bcde	58.0 ab	51.9 bc
Nonpareil-6	54.0 a	68.9 abcd	48.7 ab	81.6 ab	32.1 cde	56.8 ab	52.8 bc
Nonpareil-7	52.9 ab	.	49.4 a	76.1 ab	36.7 abcd	58.6 ab	52.1 bc
Winters	51.8 ab	63.8 bcde	38.5 bcde	67.3 bc	38.4 abc	50.3 bc	67.0 a
Nonpareil-Jones	51.6 ab	63.4 bcde	43.8 abc	81.6 ab	38.2 abc	54.7 ab	48.4 c
2-19e	50.1 ab	71.6 abc	33.7 def	73.6 ab	41.8 ab	44.0 cd	49.1 c
Kahl	50.0 ab	79.2 a	43.4 abcd	59.1 cd	43.0 a	57.9 ab	40.6 d
Chips	43.6 bc	55.9 de	48.4 a	51.4 de	37.1 abcd	39.7 de	39.9 d
Sweetheart	40.5 cd	59.6 cde	42.2 abcd	52.5 de	28.8 de	40.4 de	31.5 e
Marcona	36.3 cd	77.7 a	36.7 cdef	51.8 de	12.7 f	49.4 bc	10.3 f
Kochi	32.2 d	52.6 e	23.5 g	43.4 e	28.2 e	33.5 e	26.4 e

Table 2 shows the yield per unit light intercepted for the different Nonpareil sources as well as the varieties included in a variety trial near McFarland, CA for the 2009-2014 seasons. For the 6 year average data, there was not a significant difference in yield per unit light intercepted among the Nonpareil sources. Among the pollenizers, only Winters, selection 2-19e and Kahl had equivalent yield per unit light intercepted compared to Nonpareil sources. The large fluctuations in the yield per unit light intercepted suggest that multiple year light interception and yield data are essential to examine treatment or variety yield impacts.

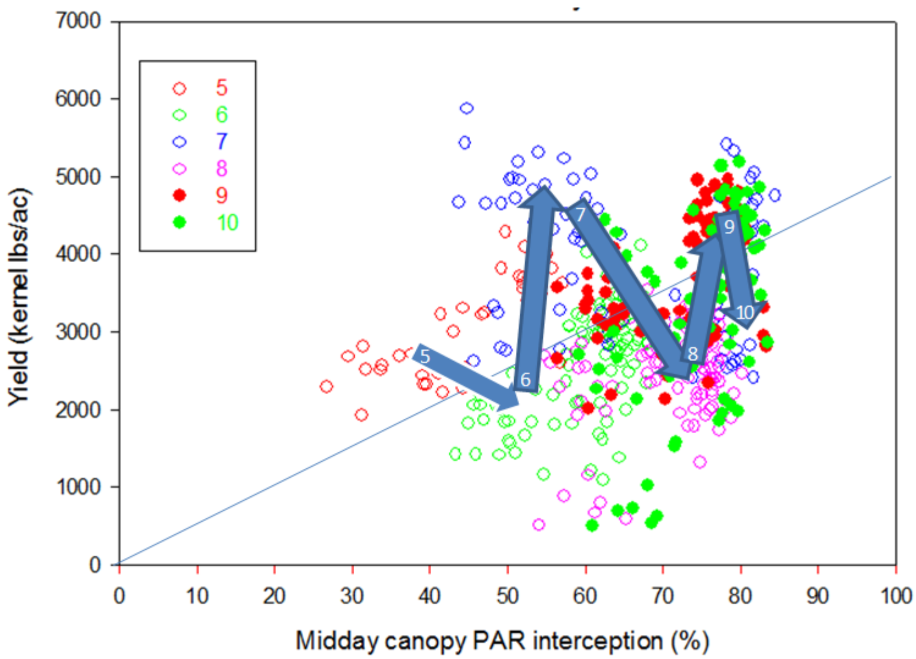

Figure 3. Midday canopy photosynthetically active radiation interception (PAR) versus yield by year at the McFarland Variety Trial. Arrows indicate direction of average yield from year to year and numbers on arrows indicate orchard age.

Figure 3 shows the yearly alternations in yield per unit PAR intercepted. Although there were no significant differences in yield per unit light intercepted among the Nonpareil sources, there were significant differences in cumulative yield (see annual report for Field Evaluation of Almond Verities for details; 14-HORT2-Lampinen). This could be due to small differences in light interception each year adding up to a significant effect on cumulative yield over time.

This study has shown that yield per unit PAR intercepted can vary by variety and rootstock. **Table 3** (left side) shows the average PAR interception, yield and yield per unit PAR intercepted for another variety trial at Nickels Soil Laboratory. Nonpareil has had significantly higher yield per unit PAR intercepted for 4 years that data have been collected from this trial. The variety with the highest PAR interception (Sonora) did not have the highest overall yield since its yield per unit PAR intercepted was lower. This information is very useful for new varieties since a lower yield per unit PAR intercepted will result in lower long term yields. This should allow an earlier evaluation on yield efficiency (as expressed as yield per unit PAR intercepted) in new varieties. **Table 3** (right side) shows the PAR interception, yield and yield per unit PAR intercepted over the past 4 years for a rootstock trial at Nickels Soil Lab. Again, it is clear that rootstock can influence not only tree size but also yield per unit light intercepted. In this study, the highest yield was obtained on Nickels rootstock while the highest yield per unit PAR intercepted was obtained on Atlas rootstock (**Table 3**, right side). This would suggest that under the conditions of this study, if the trees on Atlas had been planted closer together they could potentially have yielded higher than at the current spacing.

Table 3. Average photosynthetically active radiation (PAR) interception, yield, and yield per unit PAR intercepted for 4 years of data from a variety trial (left) and for Nonpareil on different rootstocks (right) Nickels Soil Laboratory in Arbuckle, CA. Each table is sorted by yield and highest value in each column is circled.

Variety	PAR interception (%)	Yield (kernel lbs/ac)	Yield per unit PAR intercepted
Nonpareil	71.6 b	3214 a	45.4 a
Monterey	71.3 b	2557 b	36.7 b
Sonora	73.8 a	2473 b	33.1 b
Carmel	70.4 b	2349 b	32.8 b
Aldrich	67.4 c	2299 b	33.5 b

Rootstock	PAR interception (%)	Yield (kernel lbs/ac)	Yield per unit PAR intercepted
Nickels	68.02 b	3275 a	49.4 a
Brights extra	74.2 a	3203 a	43.5 b
Hansen 536	73.7 a	3168 a	43.3 b
Brights	62.8 b	2924 ab	50.1 a
Atlas	53.0 e	2613 bc	51.0 a
Nemaguard	63.1 a	2501 c	40.3 b
Lovell	57.9 d	2464 c	43.8 b
Viking	62.5 c	2330 c	38.3 b

Comparisons were also made between mule light bar PAR data and data processed from camera images of orchard floor shadows. Digital images were processed to obtain an orthogonal projection of the canopy shadow using the open source software program GIMP 2.8 (The GIMP Development Team 2013, http://www.gimp.org/) and included lens distortion correction, image clipping of the area of interest, perspective correction and image resizing. The next step was clipping the area of interest (AOI) in the picture, which was delimited by the four closest tree trunks (two on the left and two on the right side of the image for the case of a rectangular orchard design) or two left or right closest tree trunks (for offset orchard design) to the Mule light bar (MLB). The resulting trapezoidal area of the projected shadow on the floor was then perspective-corrected to obtain a rectangular area, which was later resized to get an ortho-corrected image of the AOI, with dimensions proportional to actual tree and row spacing. The color ortho-projected images were further processed to finally obtain the canopy light interception by transforming them to binary images. Data from this comparison is shown in **Figure 4**. This is very similar to the process that the iPhone app uses to process images. For further details on this method, see (Zarate-Valdez et.al, 2015b).

Another potential use of these data is to look at the effects of different fumigation treatments on productivity based on separating out canopy size effects from effects of productivity per unit light intercepted. It is clear from these data that different fumigants can have an effect on yield by influencing canopy size as well as by influencing productivity per unit canopy light intercepted since some treatments led to both smaller tree size and less productivity per unit light intercepted (see 2012 season report for data). It is possible that the lower productivity per unit light intercepted is a result of pruning since growers tend to prune smaller trees more vigorously.

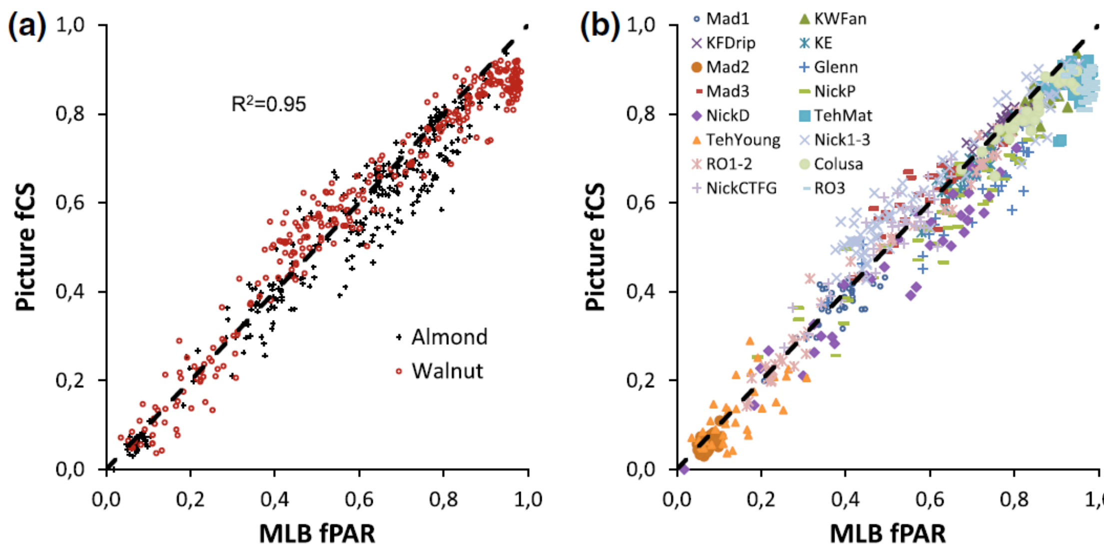

Figure 4. Canopy light interception in almond and walnut as measured by the Mule light bar (MLB) and digital photography techniques in 20 different orchards in California. The regression equation for the trend line of all data in (a) is fCS = 0.9064 x fPAR + 0.0339; R^2 = 0.95. The dashed line corresponds to the 1:1 line.

Objective 2. The sensor suite (**Figure 5**) was successfully evaluated in three crops (almonds, walnuts and grapes) for both sunlit and shaded leaves. Stepwise linear regression models developed for shaded leaf temperature yielded coefficient of multiple determination values of 0.88 for almond. An infra-red thermal camera was used to capture images for comparison measurements of shaded leaf temperature. Stem water potential (SWP) and air temperature (T_a) were found to be significant variables in all models. Regression models were used to classify trees into stressed and unstressed categories with critical misclassification error (i.e., predicting a stressed tree as unstressed) for sunlit and shaded leaf models of 8.8% for almond.

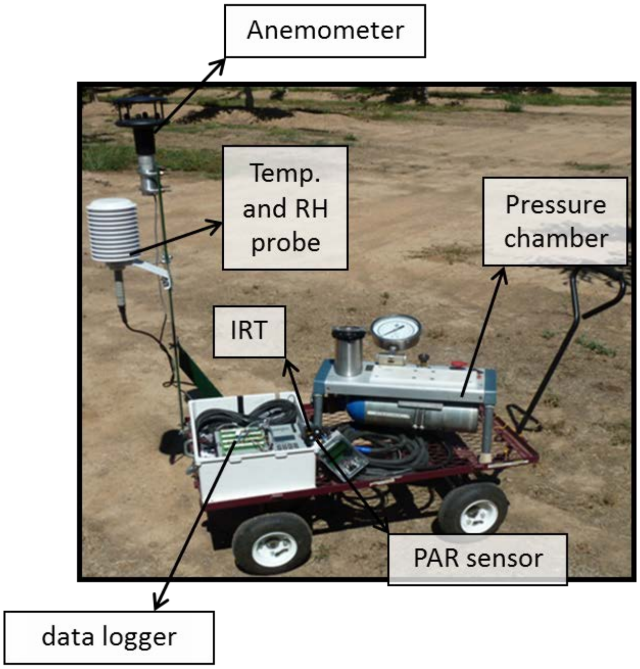

Figure 5. Mobile sensor

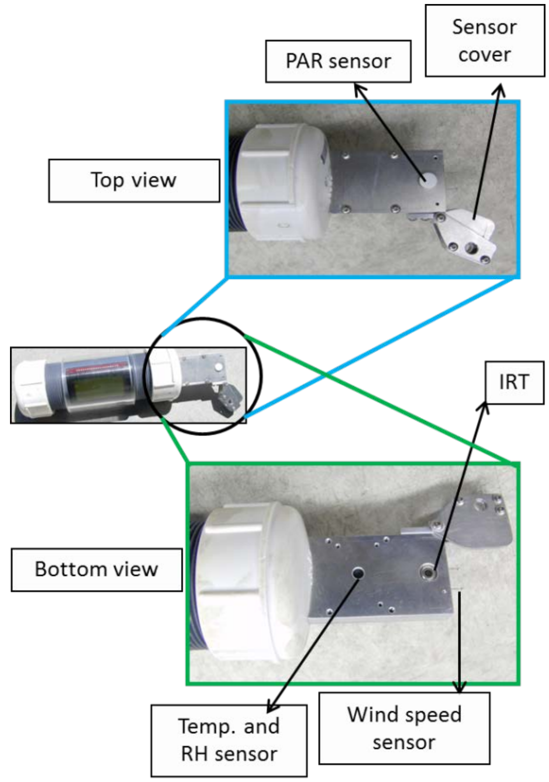

Figure 6. 2nd generation hand-held sensor suite.

The results suggest it is feasible to use the sensor suite to determine plant water status for irrigation management for almond. However, regression models were found to be specific to the time during the season, and the mobile sensor suite system cart was bulky to take in the orchard for frequent data collection. Based on these observations, a much more compact sensor suite was developed and tested (**Figure 6**). This unit is convenient to use and it measures leaf temperature and microclimatic variables using similar sensors as were used in the mobile sensor suite except the sensors are miniaturized. This handheld unit is working well. Data from this device is shown in **Figure 8**. The sensor suite is described in more detail in the publication by Dhillon et.al (2014) listed at the end of this report.

Continuous leaf monitors that were developed and validated as a part of the Specialty Crop grant from USDA, NIFA will be used during these experiments. **Figure 7** shows one of the leaf monitors installed on a shaded leaf of an almond tree in Arbuckle, CA. These leaf monitors will be connected to the wireless mesh network so that the data can be monitored from any convenient location where web access is available. In each management zone, three leaf monitors will be used in stressed based irrigation management treatment. In the other treatments, one leaf monitor per treatment will be used to monitor the trees.

Following Dhillon et al. (2014), the data will be analyzed to determine a modified crop water stress index (MCWSI) as follows:

$$MCWSI = \frac{T_L^{Observed} - T_L^{Saturated}}{T_L^{Dry} - T_L^{Saturatede}} \quad (1)$$

where,

$T_L^{Observed} = Leaf\ temperature\ sensed\ by\ the\ leaf\ monitor,$

$T_L^{Saturated} = Leaf\ temperature\ of\ a\ fully\ saturated\ tree\ under\ the\ current\ environemntal\ conditions,$

$T_L^{Dry} = Leaf\ temperature\ of\ a\ completely\ stressed\ tree\ under\ the\ current\ environemntal\ conditions.$

$T_L^{Saturated}$ is determined by an analysis of the leaf temperature data following an irrigation event. It depends on air temperature and vapor pressure deficit. Optimal value of T_L^{Dry} was found to be (T_a +0.75), where T_a is the ambient temperature, for shaded almond leaves in our previous study.

Figure 8a shows air temperature data measured by leaf monitors over a week in the orchard. **Figure 8b** shows the typical pattern of leaf to air temperature difference (T_{air} – T_{leaf}) data. As expected temperature difference is close to zero at night since there is negligible transpiration. As the sun rises the leaf starts transpiring which results in the leaf being cooler than the air. **Figure 8** shows a typical pattern of MCWSI following an irrigation cycle in almond.

Figure 9 shows a plot of MCWSI as a function of deficit stem water potential (DSWP) for almond trees (Dhillon et al., 2014, Udompetaikul, 2013). This figure shows that almond trees are not as sensitive to stem water potential up to a DSWP value of 0.5 mPa. For the stress based irrigation management, the leaf monitor data will be used as a feedback signal to determine the amount of water that must be applied to maintain deficit stem water potential in the desired range. Other three irrigation management treatments will be based on local ET data. Stem water potential data will be obtained using a pressure chamber to monitor the accuracy and reliability of leaf monitor data as needed. Nutrient management and other cultural practices will follow the standard practices followed at the Nickels Soil Lab.

Figure 7(a): Leaf monitor installed in almond.

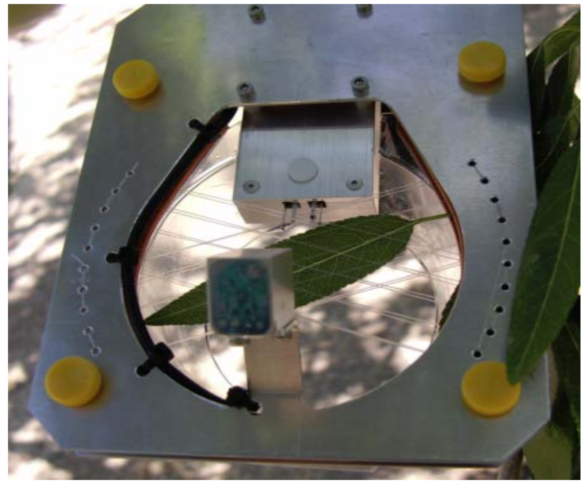

Figure 7(b): Close up of leaf monitor installed on almond leaf.

(a) (b)

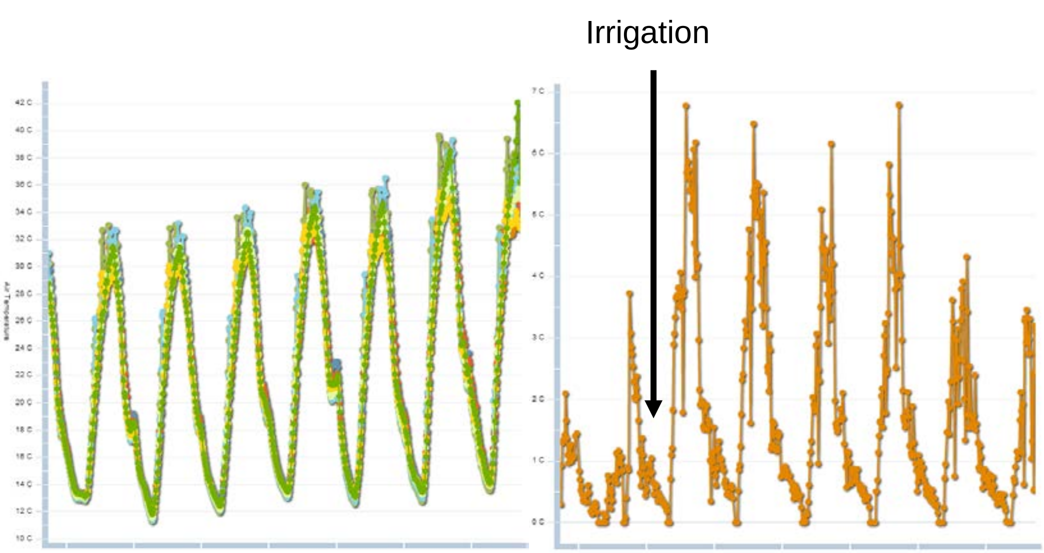

Figure 8. Screen shots of the continuous leaf monitor (a) air temperature (^{0}C) and (b) leaf to air temperature difference (T_a – T_L) for an almond leaf for eight consecutive days with an irrigation event indicated.

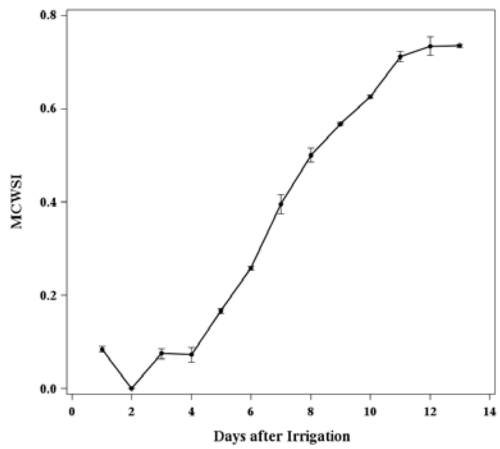

Figure 9: Typical pattern of modified crop water stress index after an irrigation event for an almond tree.

Figure 9 shows the pattern of water stress detected by the continuous leaf monitor following an irrigation event. The continuous leaf monitor appeared to track the development of stress following an irrigation event well suggesting it may be a useful tool for growers continuous monitoring of stress.

Figure 10 shows the relationship between stem water potential deficit (difference from baseline) and the modified crop water stress index. The tree response to stress down to about -0.5 mPa (-5 bars) below the baseline was relatively minor suggesting this might be a good range to target with the continuous tree monitor.

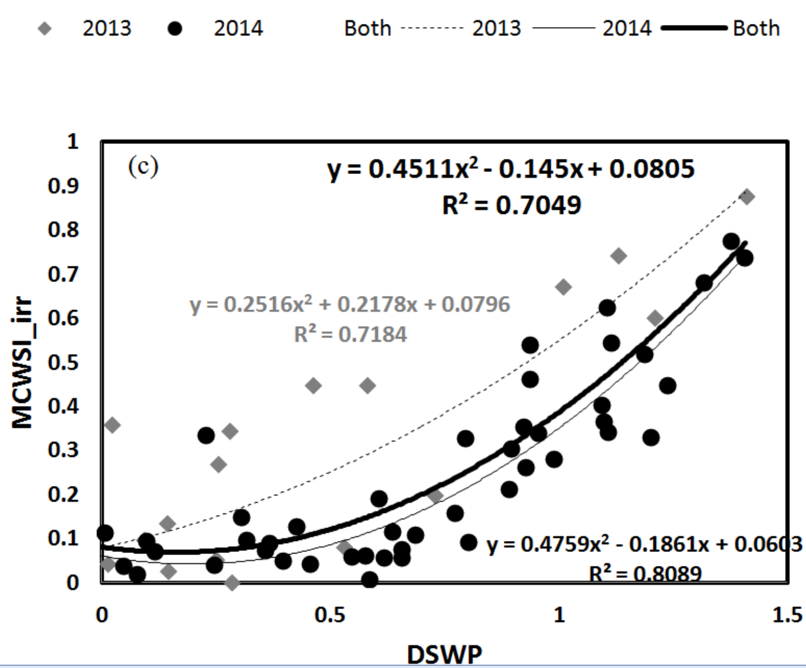

Figure 10. Modified Crop Water Stress Index as a function of the deficit stem water potential (DSWP) measured in mPA (multiply by 10 to get bars).Data collected on Nonpareil almond at Nickels Soil Lab., Arbuckle, CA.

Objective 3. An iPhone application to estimate canopy light interception and PAR interception in walnut and almond is currently in development. The application estimates the canopy light interception using images with the canopy ground shadow, as shown in **Figure 11**.

The user takes a picture of the orchard floor shadows projected by the canopy, and selects the area to make the estimate of light interception (usually either one or two trees down the row). The iPhone app then corrects the image for perspective, converts the area of interest into either shadow or sun and then tabulates the pixels of each. The estimation with the iPhone app is about plus or minus 5% accuracy compared to the

Figure 11. Photo showing the angle of view required by the application to estimate the canopy light interception.

mobile platform light bar data. When branches or leaves hang into the view of the shadow image on the ground, the deviation can be higher. This can be corrected by taking the images from a lower angle, but the image will have less accuracy in the back of the scene due to the narrow angle with the ground. **Figure 12** shows a corrected image from the iPhone app on the left and a screenshot of the report generated on the right side. The iPhone app generates both an expected yield for this level of PAR interception as well as the nitrogen needs for a crop of this size. Of course these numbers have to be taken in context of the fact that even in an optimally managed orchard, large fluctuation in year to year yield and nitrogen needs can occur due to weather events such as poor bloom time weather, etc.

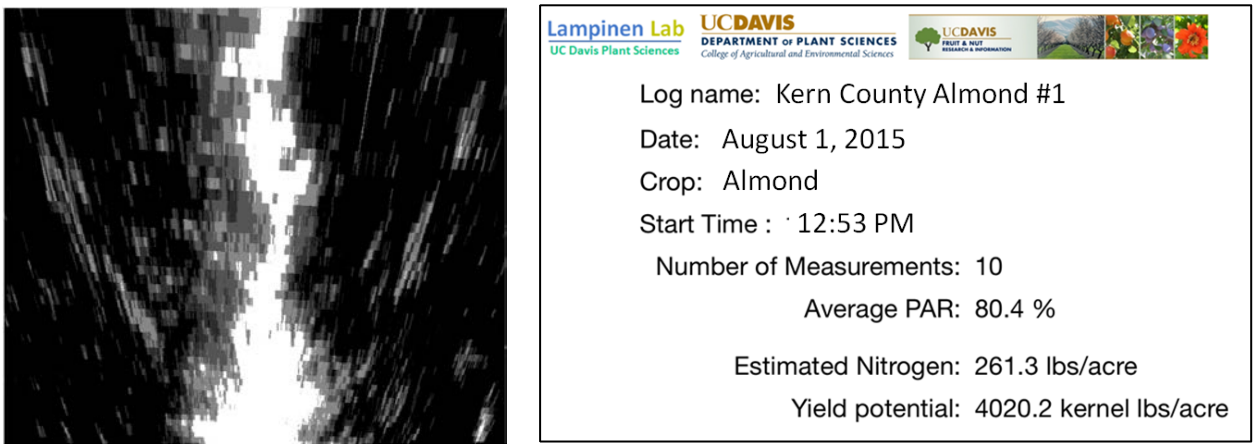

Figure 12. Image showing the image corrected for perspective (left) and the final summary report for orchard (right).

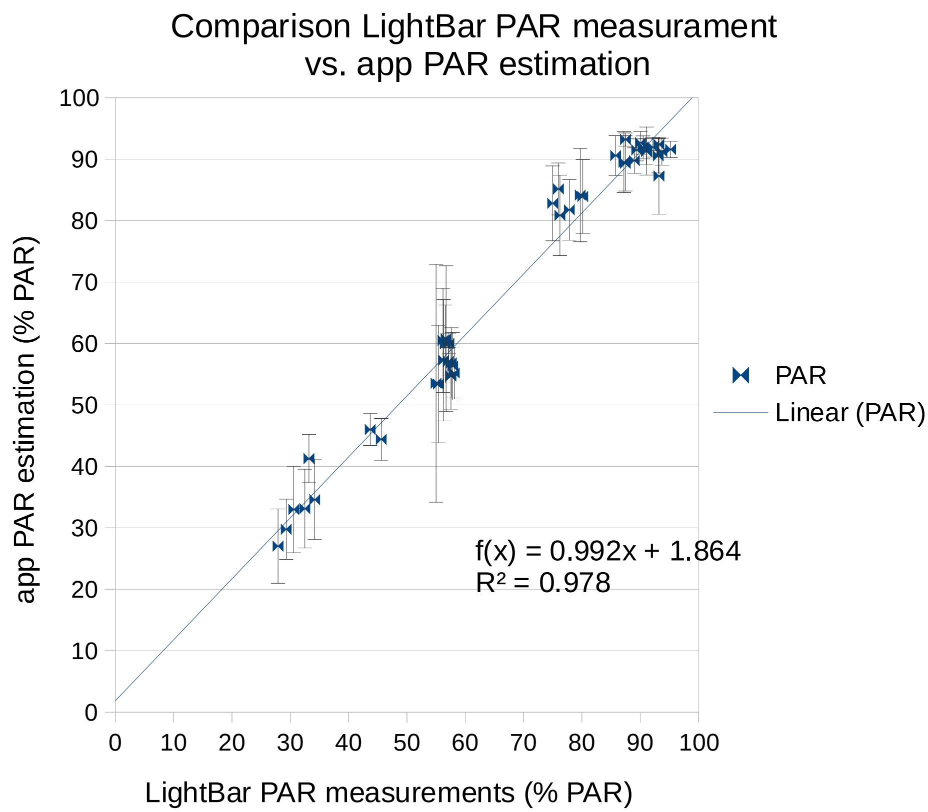

Figure 13. Comparison between the mobile platform light bar PAR and the iPhone app PAR estimation.

The application has been calibrated for almonds and the results are promising as it is shown in **Figure 13**. A more detailed calibration is being done with pictures taken by the GoPro camera on the mobile platform light bar as well as using the iPhone camera in different orchards across California in 2015. This new set will be used to evaluate whether or not the calibration varies over the growing season.

Preliminary Conclusions:

Data on midday canopy light interception collected with the modified mobile platform suggests that there are a number of potential uses for this technology. The first is for providing a baseline for assessing how an orchard is performing relative to other orchards of similar age and variety. Another is for separating out the effects of rate of canopy growth from productivity per unit canopy light intercepted in different clones or varieties. The measure of productivity per unit PAR intercepted is proving to be a very useful tool for analyzing orchard performance. A third potential use is for assessing the efficacy of different fumigants by again separating out the effects of canopy size from productivity per unit light intercepted. This information is very useful in evaluating new selections and varieties for their production potential before they reach full canopy size. Additional investigations using this technology include looking at the effect of tree spacing and orchard age on productivity per unit light intercepted. This technology also allows the elimination of canopy size differences from any type of research trial. These data are being used in a wide range of almond research project statewide as well as for providing ground truthing for remotely sensed (aerial and satellite) imagery. Two publications describing the mobile platform light bar are listed at the end of the report.

A second generation more compact, mobile sensor suite as well as a leaf temperature monitor were developed and evaluated to predict plant water status by measuring the leaf temperature of almond trees. The compact sensor suite consists of an infrared thermometer to measure leaf temperature along with relevant sensors to measure microclimatic variables. See publication by Dhillon et.al. (2014) listed at the end of this report for details on the sensor suite. The compact sensor suite was successfully evaluated in almond on sunlit and shaded leaves. The results suggest that it is feasible to use the sensor suite to determine plant water status for irrigation management of almond. In addition to the compact sensor suite, a leaf monitor was developed that can be used to continuously monitor leaf temperature of a shaded leaf. Refinement of the device was completed in 2013-2014. The leaf monitor is able to track almond tree water stress over an irrigation cycle with the results comparing well with midday stem water potential measurements using the plant pressure chamber suggesting the device could be used for continuous monitoring of plant water status. Results from the 2015 season will be used to further refine the device. UC Davis has applied for a patent on this device.

A preliminary working version of the iPhone application for estimating midday canopy light interception was tested in 2013-14. A trial version was released to farm advisors and select growers in the summer of 2015. A revision is currently being done based on input from the trial users and should be released for the 2016 season.

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