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

Project No.: 12-HORT13-Lampinen

Project Leader: Bruce Lampinen
Department of Plant Sciences
UC Davis
One Shields Ave.
Davis, CA 95616
530.752.2588
bdlampinen@ucdavis.edu

Project Cooperators and Personnel:
Greg Browne, USDA/ARS
Shrini Upadhyaya, Vasu Udompetaikul, Rajveer Dhillon, Francisco Rojo, David Slaughter, Sam Metcalf, Jed Roach, William Stewart, Ignacio Porris Gómez, and Maria Contador, UC Davis
David Doll, UCCE - Merced County
Roger Duncan, UCCE - Stanislaus County
John Edstrom, UCCE Emeritus - Colusa County
Brent Holtz, UCCE - San Joaquin County
Bill Krueger, UCCE Emeritus - Glenn County
Franz Neiderholtzer, UCCE - Colusa/Yuba/Sutter Counties

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.

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) 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 recently 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 was used extensively for mapping midday canopy light interception in almond orchards. The 2012 season was the fourth 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 if 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 season continued to show promise for this technique to predict stem water potential. Data again showed that shaded leaves give better results than sunlit leaves. Adapting this sensor suite to the mobile platform presents some challenges, but the ability to use shaded leaves will make it somewhat easier.

Materials and Methods:

Objective 1. Refining the light interception/yield relationship in almond was addressed using the following methods. Twenty two almond orchard sites of varying ages and varieties from throughout the almond growing area of California were selected for measurements in 2012 (**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 and 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 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.

Table 1. Almond orchards sites mapped with Mule lightbar during 2012 season.

Site #	County	Trial	Date mapped	Site #	County	Trial	Date mapped
1	Colusa	SCRI Precision Irrigation	05/7/12 05/31/12 07/23/12 09/22/12 10/21/12	12	Madera	Paramount New Columbia Irrigation/fumigation Trial	07/08/12
2	Kern	Belridge Spur Survival	05/30/12	13	Colusa	Shackel Almond Deficit Trial	07/18/11
3	Madera	Madera Growers South	06/21/12	14	Colusa	Nickels Organic Almond Trial	07/22/12
4	Madera	Agriland Fumigation/irrigation Trial	06/22/12	15	Colusa	Nickels Almond Rootstock Trial	07/24/12
5	Madera	Agriland Fumigation Trial	06/23/12	16	Colusa	Nickels Almond Pruning/training Trial	07/26/12
6	Kern	SCRI-Belridge Continuous Fertigation	06/20/12	17	Glenn	Erickson	07/27/12
7	Kern	SCRI-Belridge	06/13/12	18	Tehama	Tehama Water Production Function	07/29/12
8	Madera	Paramount New Columbia Fumigation/irrigation Trial	06/26/12	19	Stanislaus	Duncan Almond Pruning, Spacing and Training Trial	08/10/12
9	Kern	Spur Dynamics	07/01/12	20	Merced	Browne Frago Fumigation Trial	08/11/12
10	Kern	Belridge SCRI Remote Sensing	07/03/12 07/04/12	21	Merced	Merced Water Production Function Trial	08/15/12
11	Kern	McFarland Variety trial	07/05/12 07/06/12	22	Merced	Browne Littlejohn Fumigation Trial	08/31/11

Objective 2. 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 addition, a leaf monitor for measuring shaded leaf temperature on a continuous basis was developed. UC Davis has applied for a patent for this device.

Results and Discussion:

Objective 1. Data collected with the Mule lightbar from 2009-2012 are shown in **Figure 1**. Although many orchards produced yields well above the sustainable upper limit line in 2009 and 2011, in 2010 and 2012 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 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.

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 2011 midday canopy light interception versus the cumulative yield (years 6-12) for a pruning and spacing trial in Stanislaus County (Project 12-HORT5-Duncan). **Figure 2a** shows the data separated out by in row tree spacing treatment. These data suggest that the effect of the different tree spacings can largely be explained by differences in canopy light interception. **Figure 2b** shows the data separated out by the different pruning treatments. Again, the cumulative yield differences can largely be explained by the different levels of light interception. In general, pruned treatments tend to have lower cumulative yields for a given level of light interception due to the fact that the act of pruning generates vegetative growth that is less productive for 1-2 years following pruning.

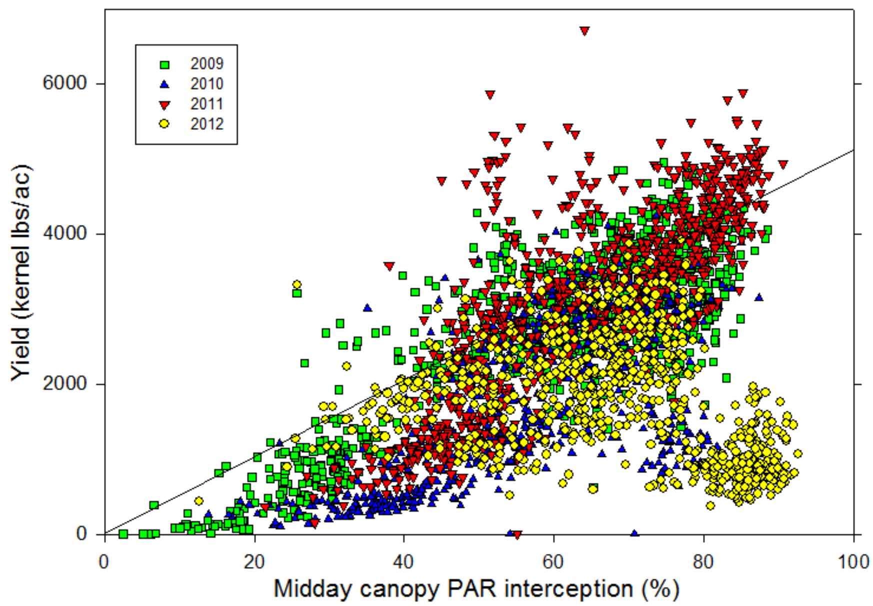

Figure 1. Midday canopy light interception versus yield relationship from mobile platform data for almond sites throughout state for 2009-2012 seasons. Solid line indicates theoretical sustainable upper limit.

The light bar data combined with the corresponding yield data allows 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** 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 2009-2012 seasons. For the 4 year average data, there did not appear to be any difference in yield per unit light intercepted among the Nonpareil sources (Project 12-HORT2-Lampinen). Among the pollenizers, only Kahl, selection 2-19e, and Winters had equivalent yield per unit light intercepted compared to Nonpareil sources. The large fluctuations in the yield per unit light intercepted (particularly notice 2011 versus 2012 values) suggest that multiple year light interception and yield data are essential to examine treatment or variety yield impacts. 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 Varieties12-HORT2-Lampinen for details). This could be due to small differences in light interception each year adding up to a significant effect on cumulative yield over time.

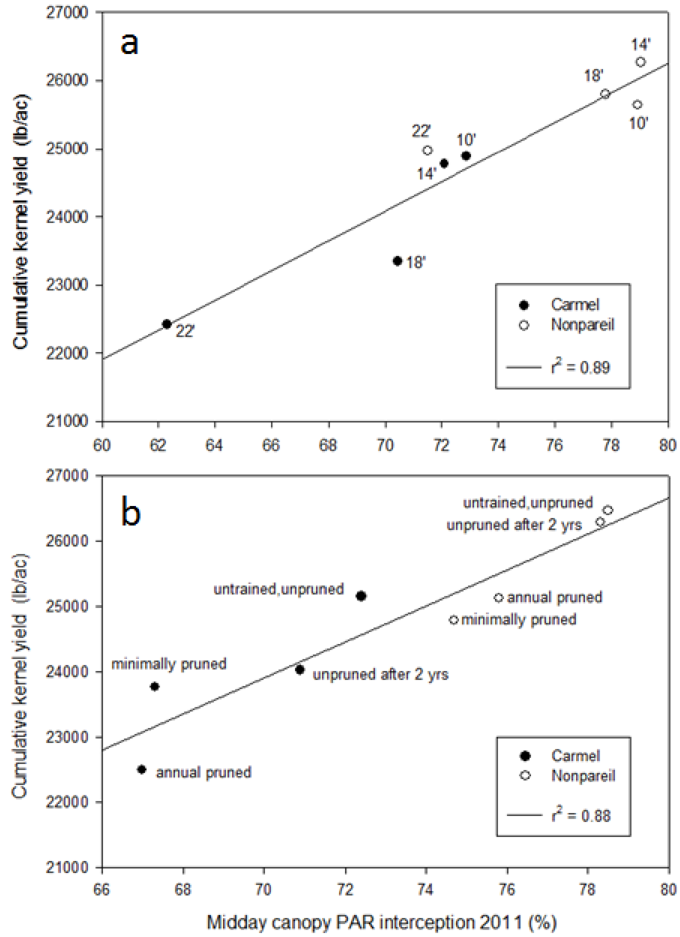

Figure 2. Midday canopy PAR interception versus cumulative yield (through year 12) by (a) variety and tree spacing and by (b) variety and pruning treatment. Trial is in Stanislaus County conducted by Roger Duncan (Project 12-HORT5-Duncan).

Table 2. Yield per unit light intercepted by Nonpareil source and variety for McFarland variety trial 2009-2012 (Project 12-HORT2-Lampinen).

Variety	2009-2012 yield/PAR	2009 yield/PAR	2010 yield/PAR	2011 yield/PAR	2012 yield/PAR
NP-Nico	60.8 a	69.3 bc	49.7 a	90.1 a	38.2 abc
NP-38270	57.5 ab	71.8 bc	47.1 a	79.6 ab	36.2 abcd
NP-driver	56.3 ab	76.1 abc	46.2 abc	72.8 ab	36.6 abcd
NP-Newell	53.6 abc	72.8 abc	45.2 abc	69.4 abc	33.4 bcde
NP-6	53.6 abc	68.9 bc	48.7 ab	74.7 ab	32.1 cde
Kahl	51.5 abc	85.2 a	43.4 abcd	45.6 de	43.0 a
2-19e	51.4 abc	71.6 bc	33.7 e	65.2 bcd	41.8 ab
NP-J	51.4 abc	63.4 cd	43.8 abcd	70.0 abc	38.2 abc
NP-7	51.1 abc	. .	49.4 ab	70.5 abc	36.7 abcd
Winters	48.1 abc	63.9 cd	38.5 cde	56.8 bcde	38.4 abc
Chips	45.7 bcd	55.9 d	48.4 ab	44.7 de	37.1 abcd
Sweetheart	45.0 bcd	69.6 bc	42.1 bcd	47.3 cde	28.8 de
Marcona	39.9 cd	77.7 ab	36.7 de	45.1 de	12.7
Kochi	33.6 d	52.6 d	23.5	39.4 e	27.3 e

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. An example of this is shown in **Table 3**. 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. However, it is possible that this is a result of pruning since growers tend to prune smaller trees more vigorously.

Table 3. Midday canopy light interception, kernel yield, and yield per unit light intercepted by fumigation treatment and coverage, Methyl Bromide Alternatives site, Madera Co., 2010 - 2012.

2010

Fumigant, lbs per treated area	Treated area in tree row (and % of orchard area treated)	Fumigant per orchard acre (lbs)	2010 Midday canopy light interc. (%)	2010 Yield (kernel lbs/acre)	2010 yield per unit light intercepted
Control	8-ft strip (38%)	0	46.1 bc	695.4 e	14.9 d
MB, 400	8-ft strip (38%)	152	45.7 c	822.3 de	17.7 cd
Telone II, 350	8-ft strip (38%)	133	49.6 abc	969.5 cd	19.5 bc
CP, 400	8-ft strip (38%)	152	54.1 a	1155.7 abc	20.6 abc
CP, 300	8-ft strip (38%)	114	51.1 abc	1154.2 abc	22.5 ab
CP, 200	8-ft strip (38%)	76	54.3 a	1329.2 ab	24.6 a
CP, 400	8x8-ft tree sites (17%)	68	50.9 abc	1128.5 abc	22.3 ab
IM:CP 50:50, 300	8-ft strip (38%)	152	56.6 a	1172.2 abc	20.6 abc
Telone C35, 550	8-ft strip (38%)	209	56.0 a	1354.8 a	24.3 a
Telone C35, 550	8x8-ft tree sites (17%)	93	51.3 abc	1066.9 bcd	20.7 abc
Telone C35, 550	Broadcast (100%)	550	55.2 a	1343.4 a	24.5 a
Pic-clor 60, 550	8-ft strip (38%)	209	55.0 a	1378.8 a	25.1 a
Pic-clor 60, 300	8-ft strip (38%)	152	53.1 ab	1297.9 ab	24.4 a

2011

Fumigant, lbs per treated area	Treated area in tree row (and % of orchard area treated)	Fumigant per orchard acre (lbs)	2011 Midday canopy light interc. (%)	2011 Yield (kernel lbs/acre)	2011 yield per unit light intercepted
Control	8-ft strip (38%)	0	58.7 ab	2168 d	36.7 bcd
MB, 400	8-ft strip (38%)	152	53.8 bc	2089 d	38.4 bcd
Telone II, 350	8-ft strip (38%)	133	58.2 ab	2480 bcd	42.8 bcd
CP, 400	8-ft strip (38%)	152	60.7 ab	2588 abcd	42.7 bcd
CP, 300	8-ft strip (38%)	114	56.2 ab	2596 abcd	46.3 abc
CP, 200	8-ft strip (38%)	76	61.0 ab	2621 abcd	43.0 bcd
CP, 400	8x8-ft tree sites (17%)	68	58.2 ab	2734 abc	47.1 abc
IM:CP 50:50, 300	8-ft strip (38%)	152	62.2 a	2987 ab	48.2 ab
Telone C35, 550	8-ft strip (38%)	209	61.7 a	2852 abcd	44.5 bcd
Telone C35, 550	8x8-ft tree sites (17%)	93	59.3 ab	2639 abcd	44.5 bcd
Telone C35, 550	Broadcast (100%)	550	61.1 ab	3079 a	50.4 ab
Pic-clor 60, 550	8-ft strip (38%)	209	60.4 ab	3038 ab	50.4 ab
Pic-clor 60, 300	8-ft strip (38%)	152	59.2 ab	2633 abcd	44.6 bcd

2012

Fumigant, lbs per treated area	Treated area in tree row (and % of orchard area treated)	Fumigant per orchard acre (lbs)	2012 Midday canopy light interc. (%)	2012 Yield (kernel lbs/acre)	2012 yield per unit light intercepted
Control	8-ft strip (38%)	0	65.1 ab	2033 a	31.0 a
MB, 400	8-ft strip (38%)	152	59.4 b	1810 a	30.9 a
Telone II, 350	8-ft strip (38%)	133	65.5 ab	2058 a	31.4 a
CP, 400	8-ft strip (38%)	152	66.6 a	2060 a	30.9 a
CP, 300	8-ft strip (38%)	114	63.5 ab	1888 a	29.8 a
CP, 200	8-ft strip (38%)	76	67.0 a	2254 a	33.6 a
CP, 400	8x8-ft tree sites (17%)	68	66.6 a	1802 a	30.9 a
IM:CP 50:50, 300	8-ft strip (38%)	152	68.0 a	2084 a	30.6 a
Telone C35, 550	8-ft strip (38%)	209	67.9 a	2125 a	29.2 a
Telone C35, 550	8x8-ft tree sites (17%)	93	65.3 ab	1915 a	29.2 a
Telone C35, 550	Broadcast (100%)	550	66.1 ab	2125 a	32.1 a
Pic-clor 60, 550	8-ft strip (38%)	209	67.1 a	1999 a	29.8 a
Pic-clor 60, 300	8-ft strip (38%)	152	64.1 ab	1886 a	29.3 a

Objective 2(New methods of measuring water stress)**.** The sensor suite (**Figure 3**) 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 0.90, 0.86, and 0.86 for almond, walnut, and grape crops, respectively. 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 and 5.2% for almond, 5.4 and 6.9% for walnut, and 12.9 and 8.1% for grape crops, respectively.

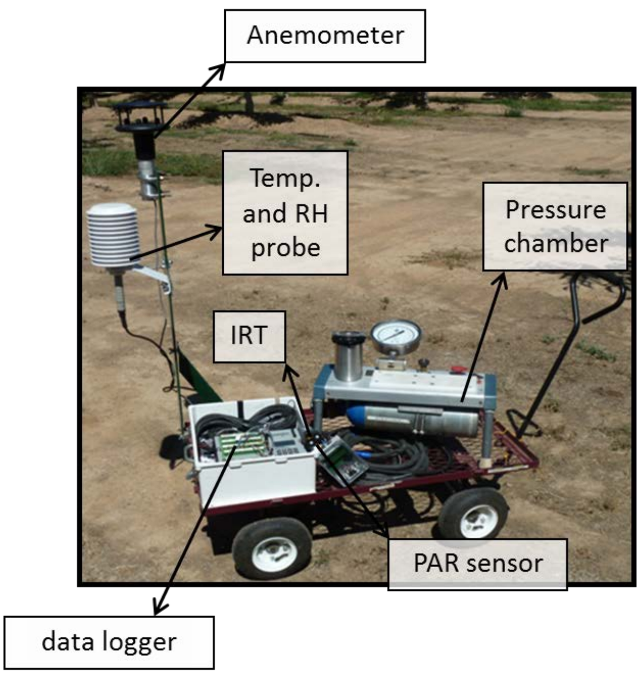

Figure 3. Mobile sensor suite

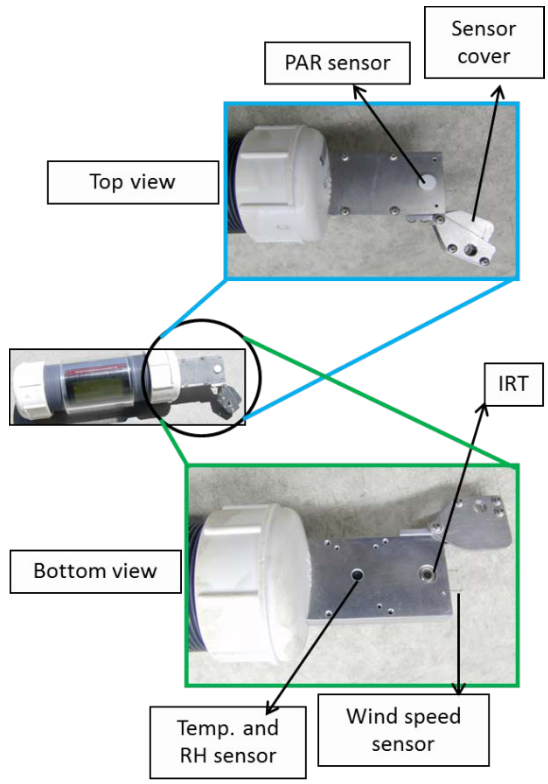

Figure 4. 2nd generation hand-held sensor suite

The results suggest it is feasibile 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, two sensor suites have been developed and are currently being tested. The first one is a handheld sensor suite (**Figure 4**), which is very convenient to use. 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 5**. This unit again requires repeated visits to orchards/vineyards to obtain plant water status data.

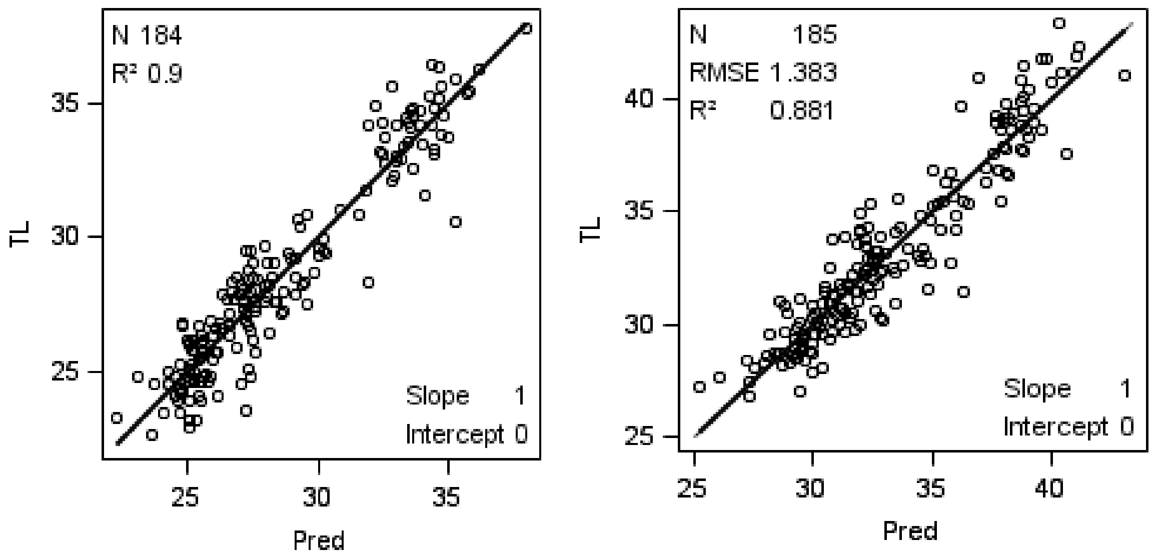

Figure 5. Multiple linear regression data comparing predicted (Pred) to measured leaf temperature (TL) using the new sensor suite for (a) shaded and (b) sunlit almond leaves.

Continuous measurements of leaf temperature and other relevant microclimatic parameters would be helpful to develop plant indices like crop water stress index (CWSI). A sensing system called the "leaf monitor" (**Figure 6**) was developed to continuously measure leaf temperature and microclimatic variables and to transmit measured data over the web. A large number of these leaf monitors have been installed in an almond orchard at Nickels Soil Lab near Arbuckle, CA to continuously monitor leaf temperature, air temperature, relative humidity, wind speed, and PAR to predict plant water status. Data collected from preliminary field experiments was used to calculate a daily crop water stress index (CWSI) value which is independent of light and wind conditions. UC Davis has filed for a patent on the leaf monitor.

Figure 6(a). Leaf monitor installed in almond orchard.

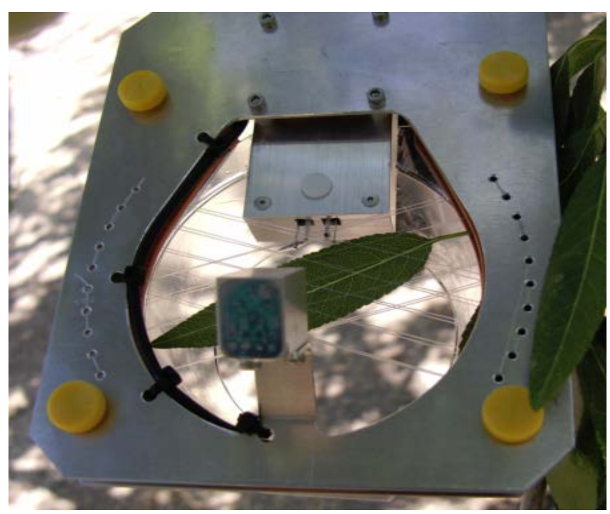

Figure 6(b). Close up of leaf monitor installed on almond leaf.

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. 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. 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.

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. 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. However, there are still many difficulties in putting the sensor suite on to the mobile platform. This is being addressed in the summer of 2013. 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. This device should allow a continuous record of stress to be recorded and accessed remotely. It is also being tested in the summer of 2013.

References Cited:

McCutchan, H., and K. A. Shackel. 1992. Stem-water potential as a sensitive indicator of water stress in prune trees (*Prunus domestica* L. cv. French). *J. Amer. Soc. Hort. Sci.* 117(4):607-611.

Shackel, K. A., H. Ahmadi, W. Biasi, R. Buchner, D. Goldhamer, S. Gurusinghe, J. Hasey, D. Kester, B. Krueger, B. Lampinen, G. McGourty, W. Micke, E. Mitcham, B. Olson, K. Pelletrau, H. Philips, D. Ramos, L. Schwankl, S. Sibbett, R. Snyder, S. Southwick, M. Stevenson, M. Thorpe, S. Weinbaum, and J. Yeager. 1997. Plant water status as an index of irrigation need in deciduous fruit trees. *HortTechnology* 7(1):23-29.