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

Project No.: **15-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 of productivity and productivity per unit light intercepted to other variables.

Objective 2
The second objective will be to complete calibration of the iPhone app for measuring midday canopy PAR interception and release it on a trial basis to farm advisors and select growers.

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 was used extensively for mapping midday canopy light interception in almond orchards. The 2015 season was the seventh 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.

Development of the iPhone app ongoing with an initial trial release to farm advisors and select growers was accomplished in the summers of 2015 and 2016. In September 2016, the iPhone app (named iPAR) was submitted to the Apple App Store for approval.

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 2015 (**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

Table 1. Almond orchards sites mapped with Mule lightbar during 2015 season.

Site #	County	Trial	Date Mapped	Site #	County	Trial	Date Mapped
1	Colusa	Nickels precision irrigation	5/27/2015	11	Tehama	ETPF Fulton	7/6/2015
2	Colusa	Nickels organic almond	6/6/2015	12	Yolo	Scheuring rootstock	7/13/2015
3	Stanislaus	Salida Variety trial	6/7/2015	13	Kern	McFarland Variety trial	7/16/2015
4	Colusa	Nickels almond rootstock	6/14/2015	14	Colusa	Nickels RSI	7/22/2015
5	Colusa	Nickels almond pruning/training trial	6/14/2015	15	Merced	Doll WPF	7/24/2015
6	Kern	Kern WPF	6/18/2015	16	Stanislaus	Duncan almond pruning, spacing and rootstock	7/25/2015
7	Kern	Paramount hedging trial Nonpareil	6/21/2015	17	Merced	Arnold rootstock	7/26/2015
8	Kern	Paramount hedging trial Monterey	6/22/2015	18	Merced	Browne Frago trial	7/27/2015
9	Fresno	Browne Kearney	6/23/2015	19	Madera	Chowchilla Variety trial	7/30/2015
10	Fresno	Browne Avenalis	6/24/2015	20	Merced	Taylor re-plant	9/5/2015
				21	Merced	Browne Littlejohn almond	9/6/2015

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> 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 of the canopy ground shadow.

Results and Discussion:

<u>Objective 1</u> - Complete the collection of light interception and yield data for the orchards that have been followed for 4-5 years to get a final data set to help separate out alternate bearing effects from overall yield trends as well as to assess what happens to this relationship as orchards age. Data collected with the Mule lightbar in from 2009-2015 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 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 midday canopy light interception over years 5 to 15 for a spacing trial in Stanislaus 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).

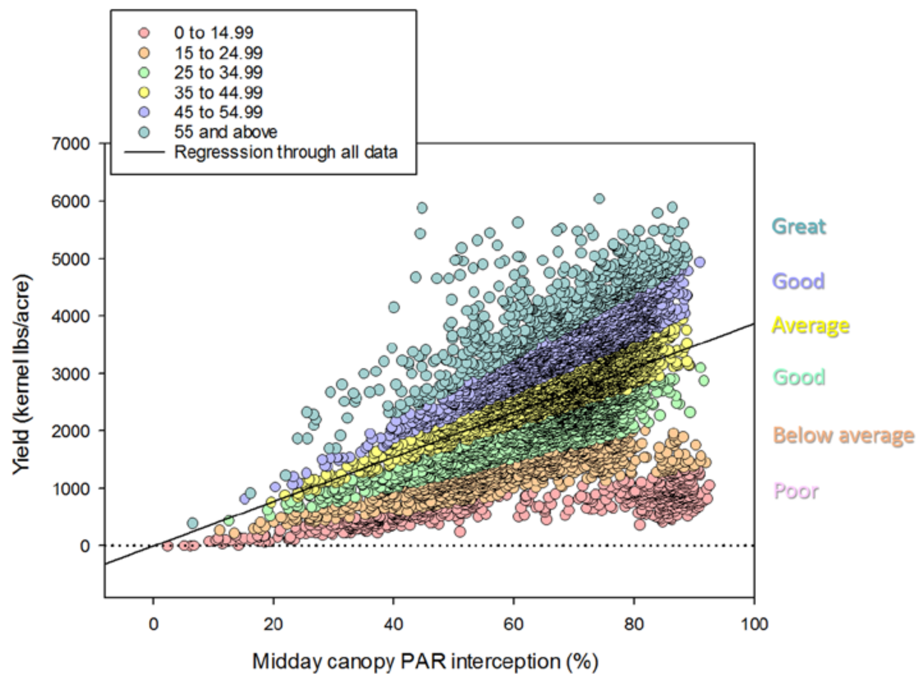

Figure 1. Midday canopy light interception versus yield relationship from mobile platform data for almond sites throughout state for 2009-2015 seasons. Solid line indicates average for all data. Categories are based on yield per unit light intercepted.

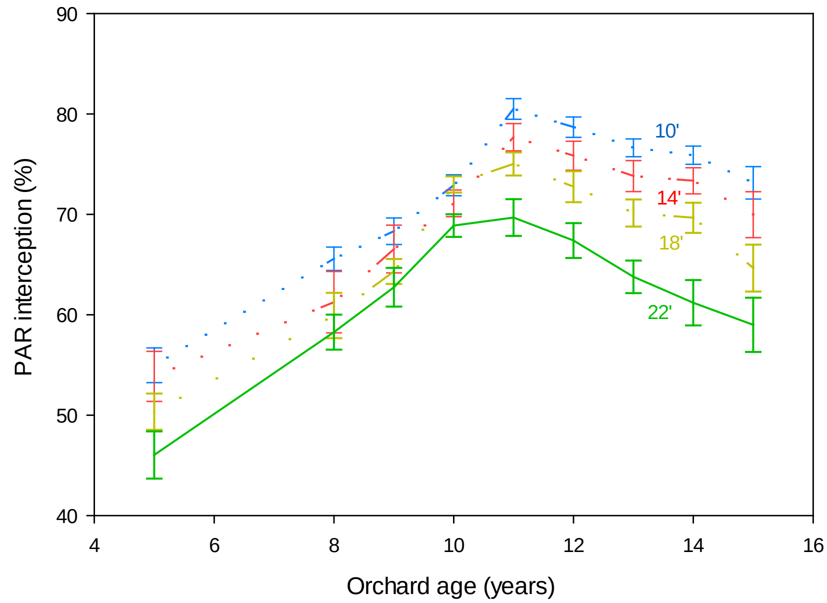

Figure 2. Midday canopy PAR interception from years 5 to 15 for different tree spacings in a variety and tree spacing trial in Stanislaus County conducted by Roger Duncan.

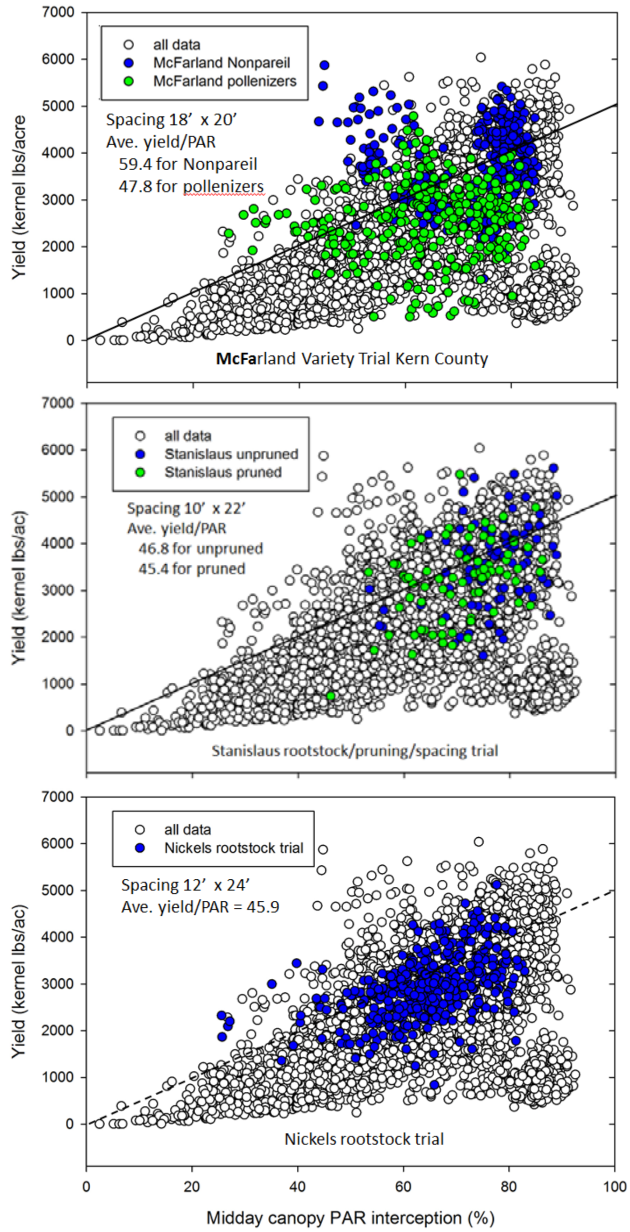

Figure 3. Midday canopy photosynthetically active radiation interception (PAR) versus yield for (top) the pollenizers and Nonpareil at the McFarland Variety Trial, (middle) Nonpareil from the pruned versus unpruned treatments at the Stanislaus rootstock/pruning/spacing trial, and (bottom) Nickels rootstock trial Nonpareil compared to all other orchard sites in the light bar study.

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 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.

Table 2. Yield per unit light intercepted by Nonpareil source and variety for McFarland Variety trial 2009-2014.

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

Figure 3 shows the data for three sites that are performing at fairly high levels. The top figure is data from a replicated variety trial in McFarland California. At this site the Nonpareil have averaged 59.4 and the pollenizers 47.8 kernel pounds per 1% PAR intercepted. This is one of the most productive orchards in our study. The middle graph in **Figure 3** shows data from the Stanislaus rootstock/pruning/spacing trial (the same site as shown in **Figure 2**). This site has averaged 46.8 and 45.4 kernel pounds per 1% PAR intercepted for the unpruned and pruned treatments respectively. The bottom graph shows data from a rootstock trial at Nickels Soil Lab in Arbuckle. The Nonpareil in this trial have averaged 45.9 kernel pounds per 1% PAR intercepted. All three of these sites have very high yields relative to statewide averages.

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 yields per unit PAR intercepted for 4 years that data has been collected from this trial. The variety with the highest PAR interception (Sonora) did not have the highest overall yield since it’s 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.

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

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) at 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

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 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 colour 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).

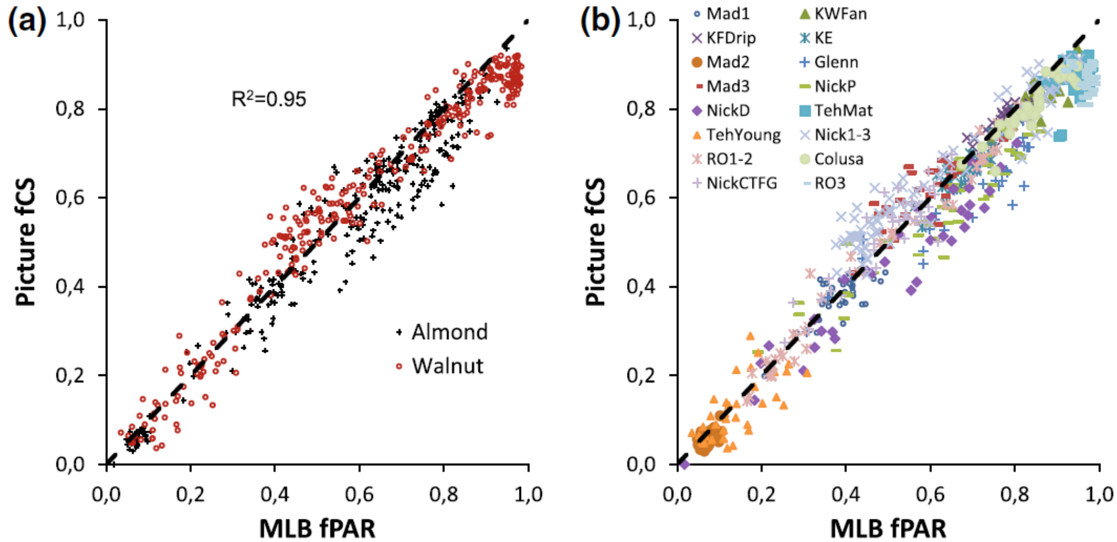

Figure 4. Canopy light interception in almond and walnut as measured by the Mule light bar (MLB) and digital photography techniques in 20 different orchards in California. The regression equation for the trend line of all data in (a) is fCS = 0.9064 x fPAR + 0.0339; R^2 = 0.95. The dashed line corresponds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

<u>Objective 2</u>

An iPhone application to estimate canopy light interception and PAR interception in walnut and almond has been developed and has recently been submitted to the Apple App Store for approval.

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). Screenshots from the app are shown in **Figure 5**. The iPhone app

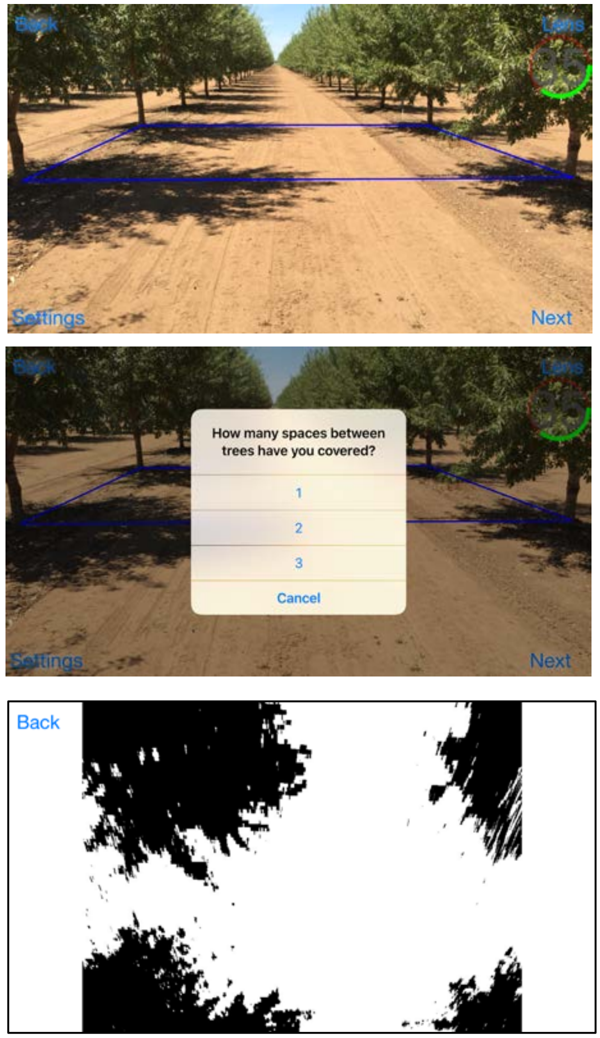

Figure 5. Screenshots from the iPhone app showing (top) image of orchard floor with trapezoid to denote area between 4 tree trunks, (middle) prompt asking if 1,2 or 3 tree spaces were covered, and (bottom) image that has been orthocorrected and converted to a black and white image for pixel counting.

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 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. The iPhone app generates both an expected yield for this level of PAR interception as well as the expected nitrogen needs for a crop of the average and best yields for a canopy of this size (**Figure 6**). Of course these numbers have to be taken in context of the fact that even in an optimally managed orchard, large fluctuations in year-to-year yield and nitrogen needs can occur due to weather events such as poor bloom time weather, etc.

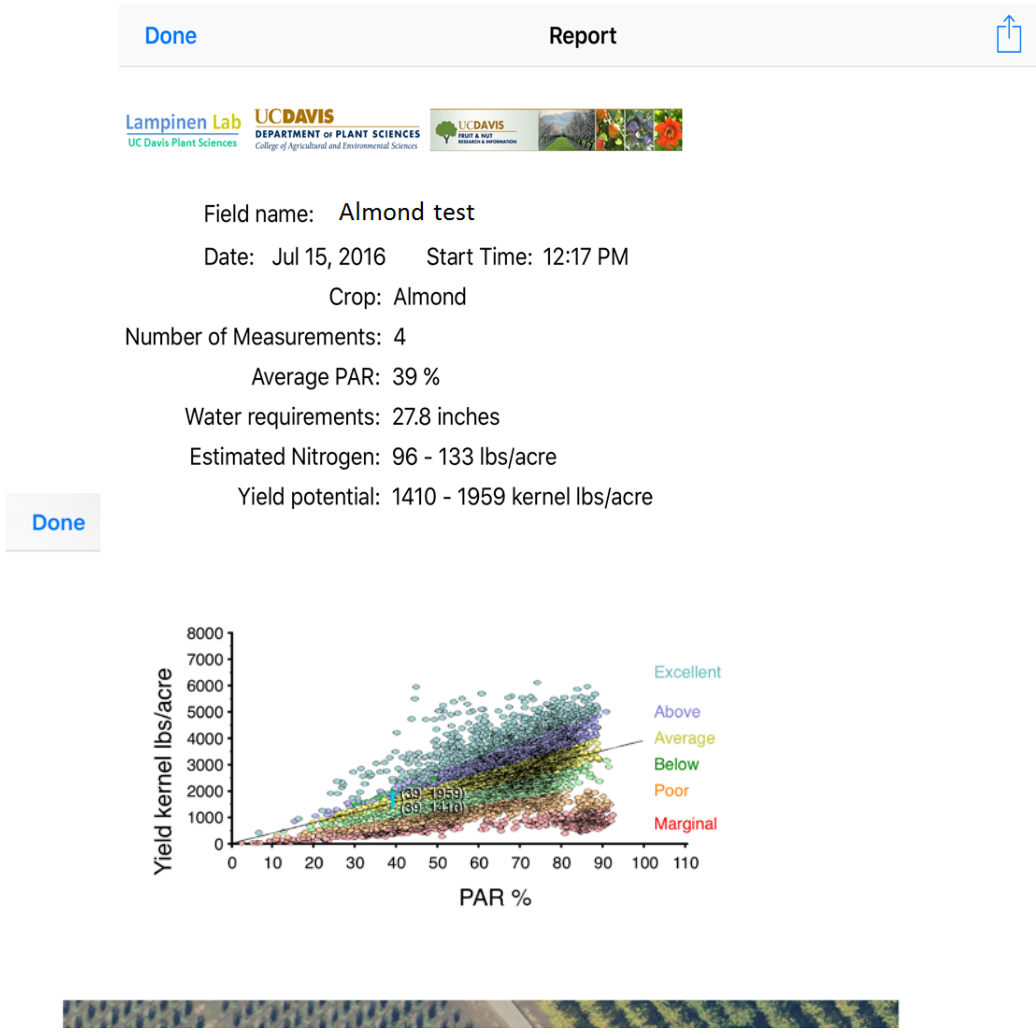

Figure 6. Report generated by the app. The report can also be sent to recipient by email from iPAR app. A more detailed report showing data for each individual photo can also be sent in an Excel file format if desired.

The application has been calibrated for almonds and the results are promising as it is shown in **Figure 7**. **Figure 7a** shows the comparison between the Mule light bar data and images of orchard floor shadows processed manually using ImageJ. **Figure 7b** shows the comparison between the Mule light bar and the iPAR app with all images included. The points on the lower right were all found to be from one orchard which was very recently irrigated and hence had very dark soil near the drip line. This caused problems for the iPAR app so based on this, it is not recommended to use the app until several days after irrigation. **Figure 7c** shows the data with the points with the wet drip pattern removed. Overall, the iPAR app performed very well.

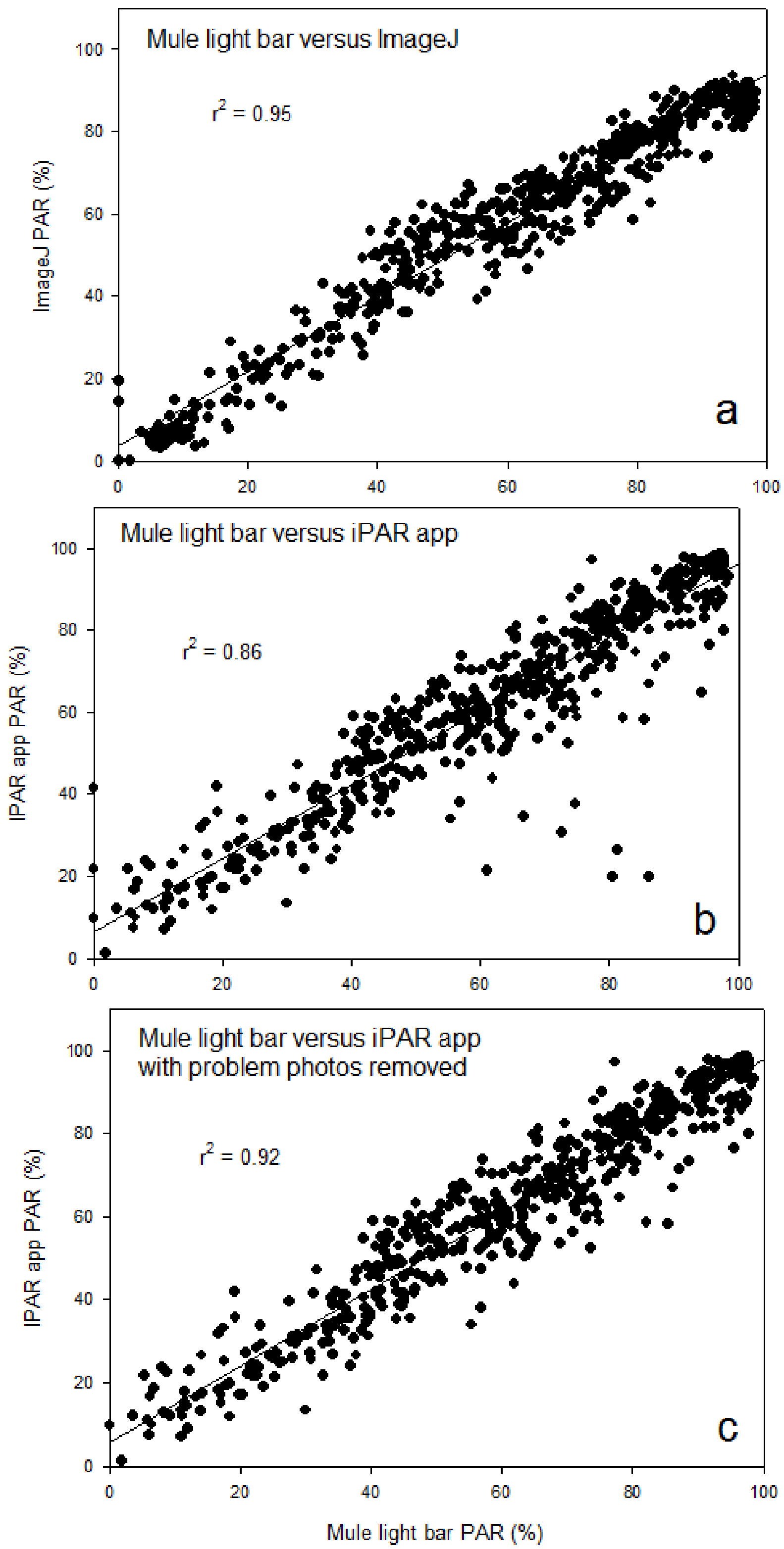

Figure 7. Photosynthetically active radiation (PAR) interception versus PAR estimated from ground shadows using ImageJ (a), and the iPAR app (b). Points in **Figure 7b** on lower right were all from orchards with a wet area around the drip tubing and this caused problems with the photos such that only the wet area was interpreted as shadows. **Figure 7c** has these points removed. The recommendation based on this is to not do iPAR photos for several days after irrigation.

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. This data is 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.

The iPhone app for estimating light interception was field tested and refined during the 2015 and 2016 seasons. The output was also compared extensively to estimates of PAR interception from the Mule light bar as well as to images processed manually by ImageJ. It performed well and the app (named iPAR) was submitted to the Apple App Store in September 2016 and will be available for use in the 2017 field season.

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Research Effort Recent Publications:

<u>Journal</u>

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Abstracts

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