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

Project No.: **17-HORT13-Lampinen**

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Objectives:

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.
2) The second objective will be to complete calibration of the iPhone app for measuring midday canopy PAR interception, release it in the Apple store (done in fall of 2016)

and gather data on use from farm advisors and interested growers. Work is also ongoing on adapting it to a PC based platform for processing digital images.

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 2017 season was the ninth year that data was collected with the mobile platform. Data collected with the mobile platform suggests that there are several potential uses for this technology. The first is for providing a baseline for assessing how an orchard is performing relative performance 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 selections 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.

For the variety of uses this technology has been used, please see the references at the end of this report.

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 approved for inclusion in the Apple app store and is now available. We are currently working to create a PC based version of the image analysis tool to allow batch processing of files.

Materials and Methods:

<u>Objective 1-</u> Refine light interception/yield relationship in almond. Twenty-four almond orchard sites of varying ages and varieties from throughout the almond growing area of

California were selected for measurements in 2017 (**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 several federal grants. Other orchards were mapped from rootstock as well as pruning and

Site #	Location	Trial	Location
1		Almond precision irrigation Kerman early season	Fresno/Kerman
2		Almond precision irrigation Kerman mid-season	Fresno/Kerman
3		Almond Precision Irrigation Kerman preharvest	Fresno/Kerman
4		Almond Winter Recharge Glenn	Glenn/Orland
5		Almond Winter Recharge Tehama	Tehama
6		On Campus Almond Irrigation	Yolo/Davis
7		Browne Avenalis Almond	Fresno/Kearney
8		Browne Kearney Almond older	Fresno/Kearney
9		Browne Kearney Almond younger	Fresno/Kearney
10		Butte RAVT Chico	Butte/Chico
11		Madera RAVT Chowchilla	Madera/Chowchilla
12		Duncan Almond Pruning/Rootstock/Spacing Trial	Stanislau/Turlock
13		Kearney Holtz Almond	Fresno/Kearney
14		Kern Almond WPF east	Kern/Shafter
15		Kern Almond WPF west	Kern/Shafter
16		Littlejohn Almond New Trial	Merced/Winton
17		Littlejohn Almond Old Trial	Merced/Winton
18		Merced Almond WPF	Merced/Turlock
19		Nickels Almond Pruning	Colusa/Arbuckle
20		Nickels Organic Almond	Colusa/Arbuckle
21		Stanislaus RAVT Salida	Stanislaus/Salida
22		Scheuring Almond Rootstock	Yolo/Esparto
23		Shackel Kearney Almond Lysimeter	Fresno/Kearney
24		Tehema Almond Np and Mon WPF	Tehama/Corning

Table 1. Almond orchard sites mapped with Mule lightbar during 2017 season.

training trials. Using orchards from other studies allows us to utilize the data for multiple purposes.

<u>Objective 2-</u> Release final 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. Develop a PC based version of this to allow batch processing of files.

Results and Discussion:

<u>Objective 1</u> - Complete the collection of light interception and yield data for the orchards that have been followed for 5-6 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 2009-2016 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).

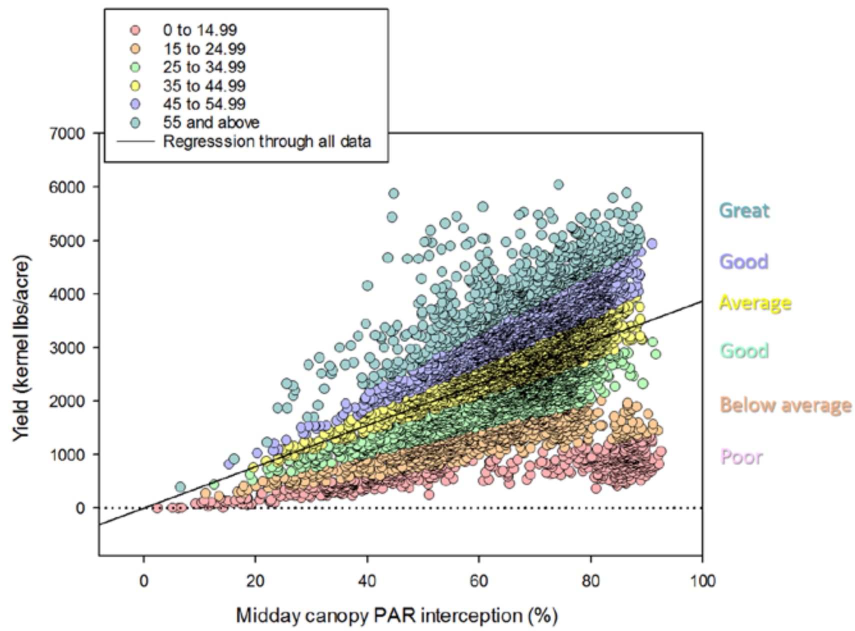


Figure 1. Midday canopy light interception versus yield relationship from mobile platform data for almond sites throughout state for 2009-2016 seasons. Solid line indicates average for all data. Categories are based on yield per unit light intercepted.

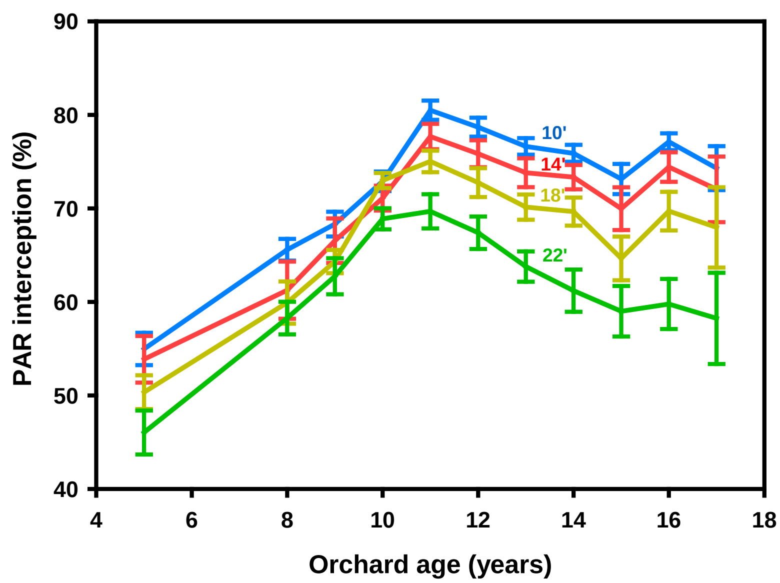


Figure 2. Midday canopy PAR interception from years 5 to 17 for different tree spacings in a variety and tree spacing trial in Stanislaus County conducted by Roger Duncan. Row spacing is 22’.

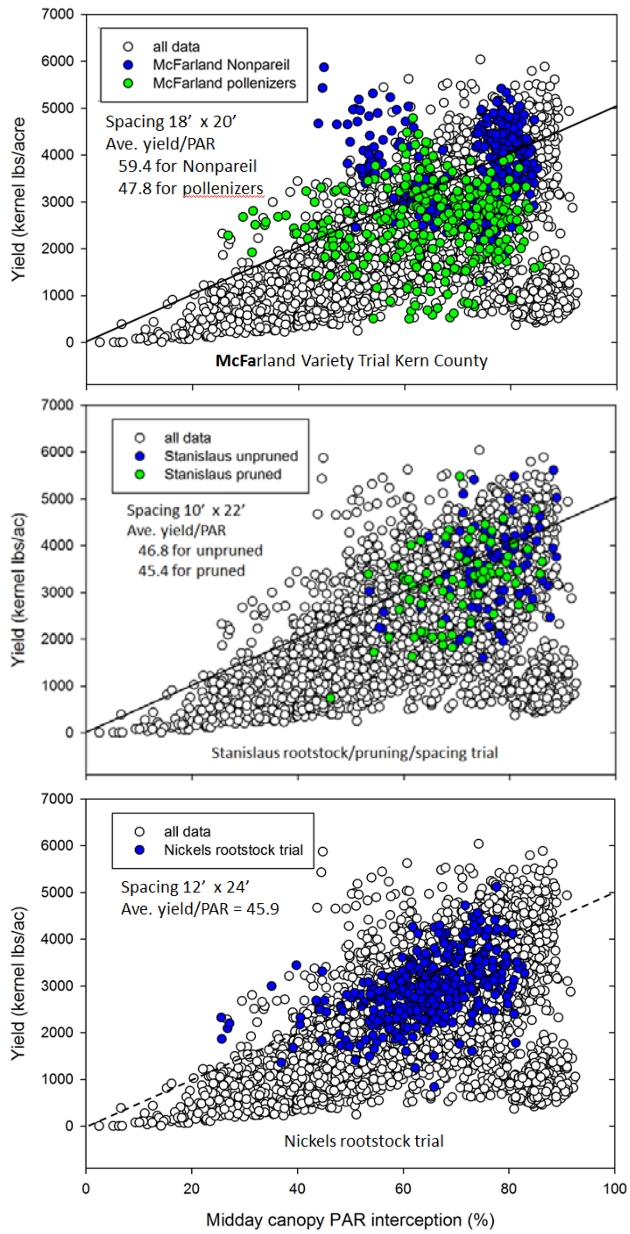


Figure 3. Midday canopy photosynthetically active radiation interception (PAR) versus yield for (top) the pollenizers and Nonpareil at the McFarland Variety Trial, (middle) Nonpareil from the pruned versus unpruned treatments at the Stanislaus rootstock/pruning/spacing trial, and (bottom) Nickels rootstock 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 (released as Kester) and Kahl had equivalent yield per unit light intercepted

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

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) 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 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 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, 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.

The relationship between midday canopy PAR interception in 2017 and cumulative 2016-2017 yield for the newest generation (2014) Regional Almond Variety Trials are shown in (**Figure 4)**. You can clearly see in this photo that there are strong site differences but also a wide spread in yields for a given level of PAR interception at any one site. This suggests that there

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

might be differences in yield efficiency among the cultivars and selections in this trial and this is supported by the data shown in (**Table 4)** showing significant differences in yield per unit PAR intercepted at all 3 sites.

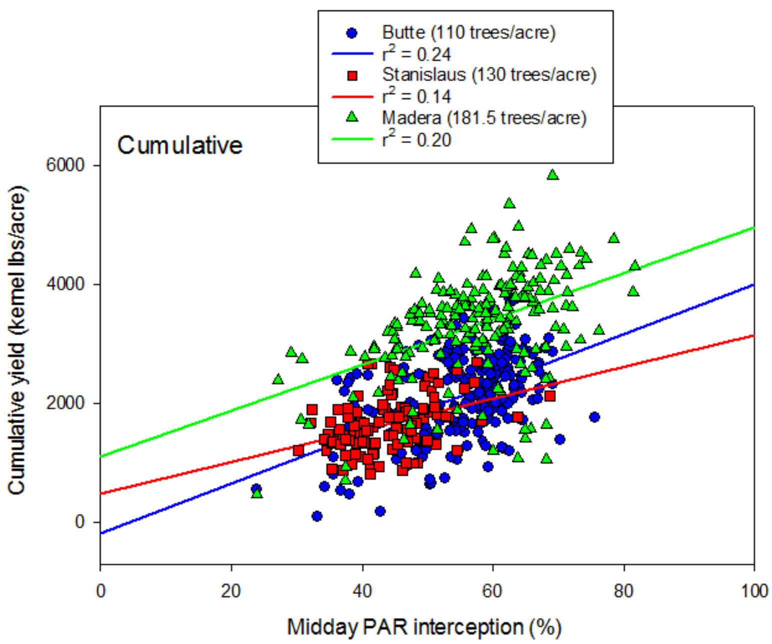


Figure 4. Relationship between midday photosynthetically active radiation (PAR) interception and yield variety or selection for 3 new Regional Almond Variety Trial sites for 2017 lightbar versus 2016-2017 cumulative yield.

Table 4. Yield per unit PAR intercepted from 2014 Regional Almond Variety Trials in 2017.

Butte

# reps	Variety or selection	Midday canopy PAR interception (%)	
4	Kester (2-19e) /Hansen	67.3	a
4	Capitola	66.1	a b
4	UCD18-20	62.4	a b c
4	Y117-91-03	60.5	a b c d
4	Kester (2-19e)	59.5	a b c d
124	**Nonpareil**	**59.1**	**a b c d e**
4	Booth	58.2	b c d e f
4	Self-fruitful P13.019	57.7	b c d e f
4	Sterling	55.6	c d e f g
4	Folsom	55.6	c d e f g
4	Winters	55.5	c d e f g
4	Supareil	55.1	c d e f g
4	Sweetheart	54.3	c d e f g h
4	Durango	54.2	c d e f g h
4	UCD3-40	51.7	d e f g h i
4	UCD1-16	50.6	e f g h i j
4	UCD7-159	50.5	e f g h i j
4	Y117-86-03	49.6	f g h i j
4	UCD8-201	49.5	f g h i j
4	UCD8-27	48.8	g h i j k
4	Eddie	48.3	g h i j k l
4	UCD1-232	47.4	g h i j k l
4	Aldrich	46.6	h i j k l
4	Jenette	44.5	i j k l m
4	Y116-161-99	42.6	j k l m n
2	Y121-42-99	41.0	k l m n o
4	Bennett	40.7	k l m n o
4	Wood Colony	40.2	l m n o
4	UCD8-160	37.7	m n o
4	UCD1-271	37.1	m n o
4	self-fruitful P16.013	35.3	n o

Madera

# reps	Variety or selection	Midday canopy PAR interception (%)	
4	Folsom	70.4	a
4	Capitola	70.2	a
4	UCD-1-271	66.0	a b
4	Sterling	65.9	a b
4	Booth	65.7	a b
4	Supareil	65.3	a b c
4	Sweetheart	64.4	a b c
4	UCD-3-40	62.6	a b c
4	Kester (2-19e)	61.5	a b c d
4	Eddie	60.5	a b c d
1	Y-121-42-99	59.1	a b c d
105	**Nonpareil**	**59.0**	**a b c d**
4	Y-117-91-03	58.7	a b c d
4	Y-116-161-99	58.5	a b c d
4	Aldrich	57.7	a b c d
4	UCD-8-27	56.0	a b c d e
4	Bennett	55.2	a b c d e
4	Self-fr-P16-013	54.7	a b c d e
4	Durango	52.9	b c d e
4	UCD-18-20	52.9	b c d e
4	Self-fr-P13-019	52.8	b c d e
4	UCD-7-159	52.5	b c d e
4	Y-117-86-03	52.3	b c d e
4	UCD-8-201	51.7	b c d e
4	Jenette	51.6	b c d e
4	Winters	51.0	b c d e
4	UCD-1-232	49.5	c d e
4	UCD-1-16	46.1	d e
4	UCD-8-160	46.0	d e
4	Wood Colony	41.2	e

Stanislaus

# reps	Variety or selection	Midday canopy PAR interception (%)	
4	Kester (2-19e) / Hansen	55.1	a
4	Y117-91-03	53.4	a b
4	Booth	50.1	a b c
4	Self-fruitful P13.019	49.8	a b c
4	Sweetheart	49.6	a b c d
4	Sterling	48.6	a b c d e
4	Folsom	48.2	a b c d e f
4	Capitola	46.4	a b c d e f g
4	UCD18-20	46.0	b c d e f g
4	Y121-42-99	45.9	b c d e f g
4	UCD3-40	45.9	b c d e f g
4	Supareil	45.9	b c d e f g
4	Eddie	45.6	b c d e f g
4	UCD1-16	45.2	b c d e f g
4	Winters	44.7	b c d e f g
4	Kester (2-19e)	43.2	c d e f g
4	UCD1-271	42.5	c d e f g
4	UCD1-232	41.9	c d e f g
4	Y116-161-99	41.3	c d e f g
4	Bennett	41.1	c d e f g
4	Jenette	40.9	c d e f g
4	Y117-86-03	40.4	d e f g
4	UCD7-159	40.0	e f g
4	Aldrich	39.9	e f g
4	UCD8-27	39.8	e f g
124	**Nonpareil**	**39.5**	**e f g**
4	UCD8-201	39.1	f g
4	Durango	38.9	f g
4	self-fruitful P16-013	38.1	g
4	UCD8-160	37.7	g

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 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 5**). 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).

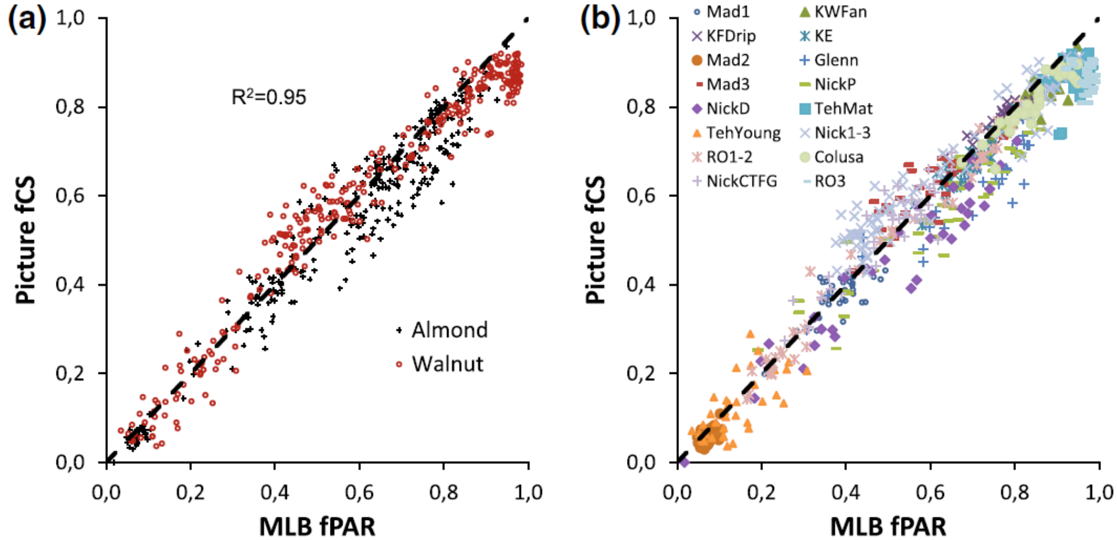


Figure 5. Canopy light interception in almond and walnut as measured by the Mule light bar (MLB) and digital photography techniques in 20 different orchards in California. The regression equation for the trend line of all data in (a) is fCS = 0.9064 x fPAR + 0.0339; R^2 = 0.95. The dashed line corresponds to the 1:1 line.

Objective 2- An iPhone application to estimate canopy light interception and PAR interception in walnut and almond has been developed and has been in the Apple App Store for several years.

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 6**). 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 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 7**). Of course, these numbers must 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.

The application has been calibrated for almonds and the results are promising as it is shown in (**Figure 8)**. (**Figure 8a)** shows the comparison between the Mule light bar data and images of orchard floor shadows processed manually using ImageJ. **(Figure 8b)** 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. Overall, the iPAR app performed very well.

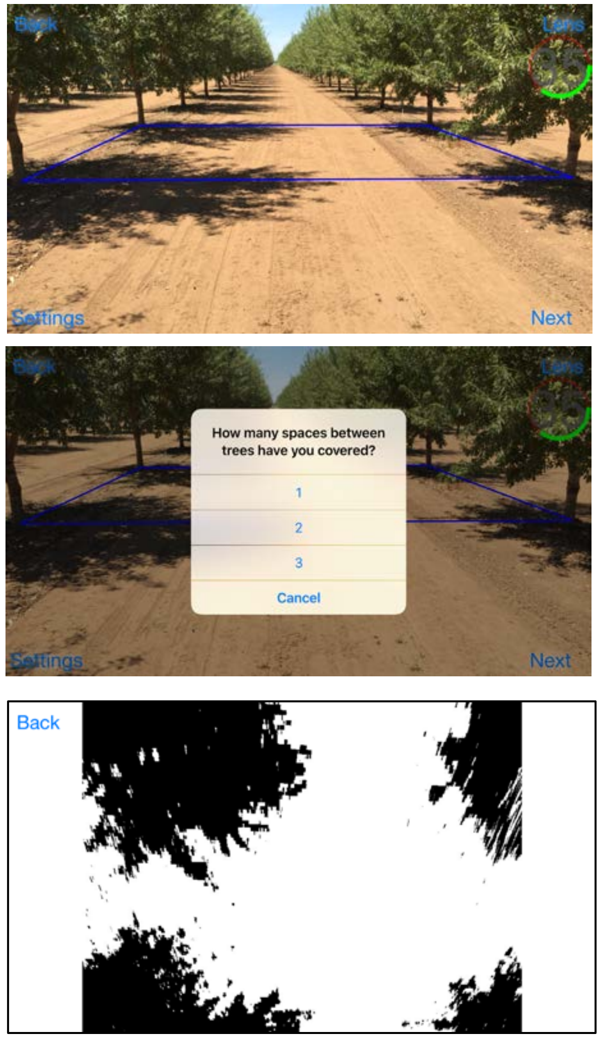


Figure 6. Screenshots from the iPhone app showing (top) image of orchard floor with trapezoid to denote area between 4 tree trunks, (middle) prompt asking if 1,2 or 3 tree spaces were covered, and (bottom) image that has been orthocorrected and converted to a black and white image for pixel counting.

Field name: Joe Martinez Call Menz

Date: Sep 8, 2016 Start Time: 3:29 PM

Crop: Almond

Number of Measurements: 9

Average PAR: 53 %

Water requirements: 37.9 inches

Estimated Nitrogen: 131 - 182 lbs/acre

Yield potential: 1923 - 2671 kernel lbs/acre

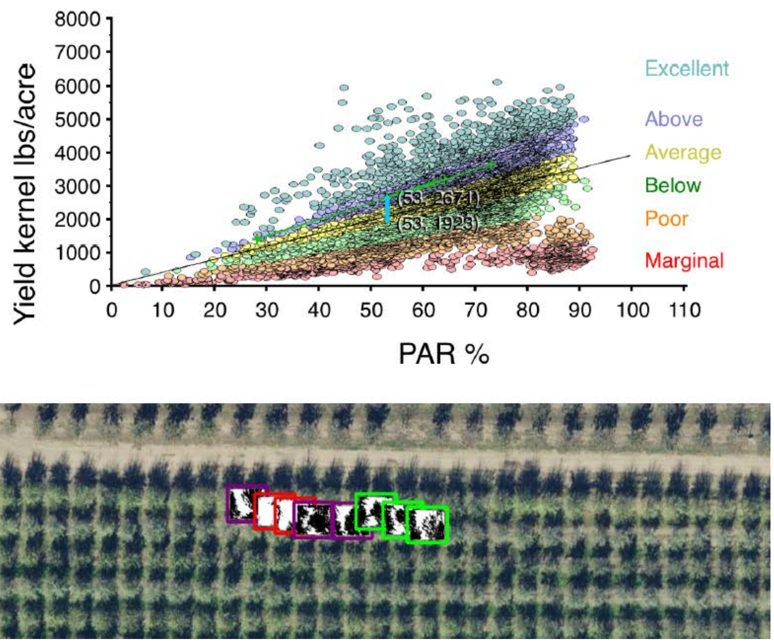


Figure 7. Report generated by the app. The report can also be sent to recipient by email from iPAR app. A more detailed report showing data for each individual photo can also be sent in an Excel file format if desired.

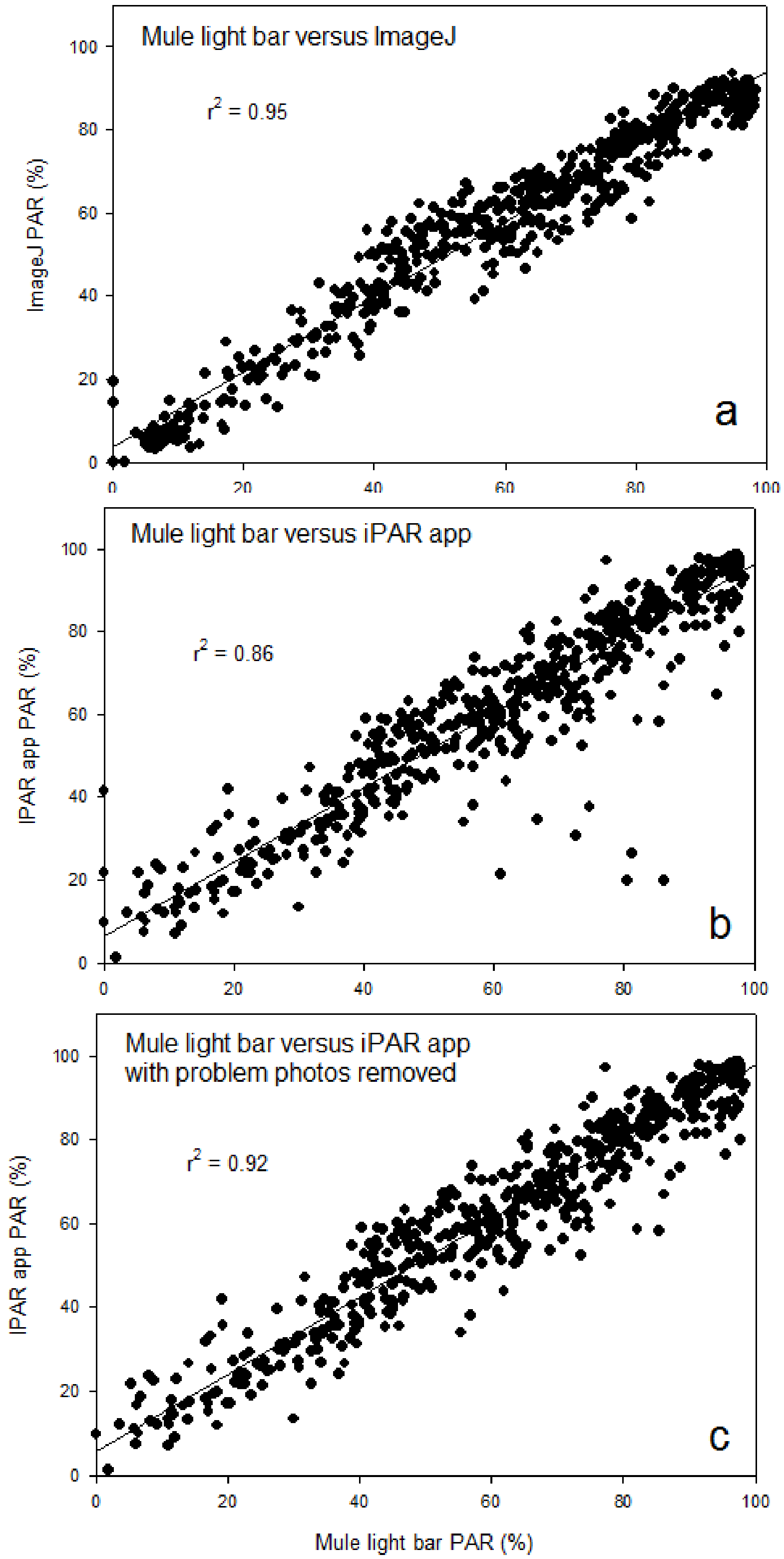


Figure 8. Photosynthetically active radiation (PAR) interception versus PAR estimated from ground shadows using ImageJ (a), and the iPAR app (b). Points in **Figure 14b** on lower right were all from orchards with a wet area around the drip tubing and this caused problems with the photos such that only the wet area was interpreted as shadows. **Figure 14c** has these points removed. The recommendation based on this is to not do iPAR photos for several days after irrigation.

We have also used the iPAR app to estimate interception over the course of a day (**Figure 9**). PAR interception was relatively flat through the day in the medium density McFarland Variety Trial orchard while there was a substantial decrease in the high density Agromillora orchard (**Figure 9**). Part of this difference was made up by a somewhat higher integrated interception in the high-density orchard resulting in about 76% of the daily integrated interception for the high versus medium density orchards. However, much of the canopy in the high-density orchard has problems with cankers due to damage from mechanical hedging and the over the row harvester. In addition, the hedging results in lots of non-productive vegetative growth most likely leading to lower productivity per unit PAR intercepted (we were not able to measure yield in these orchards this year).

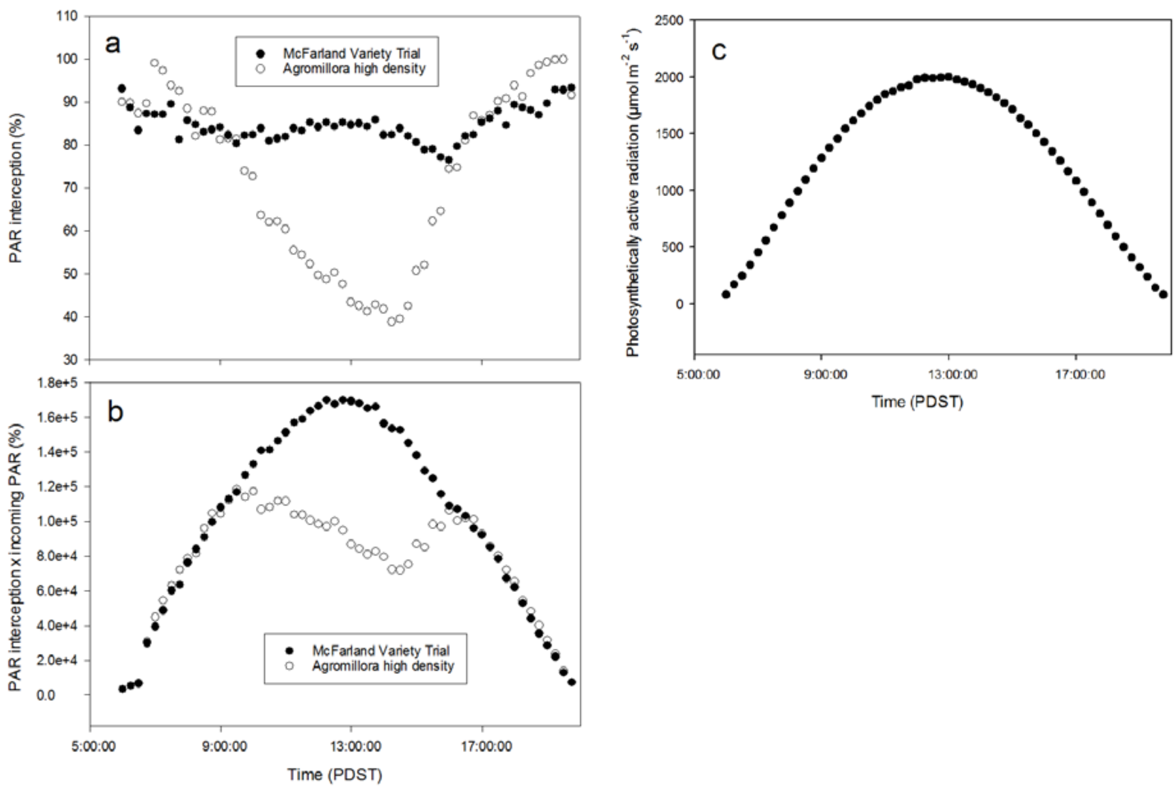


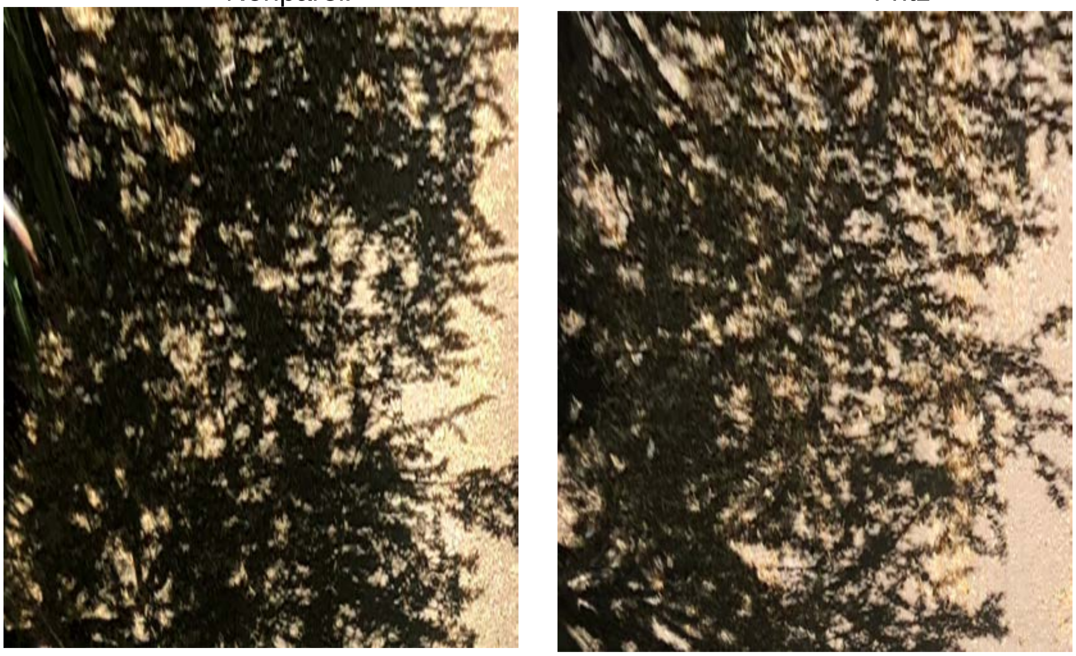
Figure 9. Data on June 12, 2017 from a high density and medium density orchard in Kern County showing (a) PAR interception over the day measured using a time lapse camera and importing photos to iPAR for processing, (b) PAR interception times incoming PAR, and (c) PAR from a local weather station. The McFarland medium density orchard was planted at 20’ x 18’ (121 trees per acre) and the Agromillora high density orchard is planted at 11’ x 5’ (792 trees per acre).

We are currently working to create a PC based version of the image analysis tool to allow batch processing of files. This will allow more rapid processing of large numbers of photos in a timelier fashion.

On a farm call earlier this summer, we observed pollinizer varieties in an orchard were tending to show signs of overwatering while the Nonpareil did not. By using our iPhone camera and processing the images using GIMP (GNU IMAGE Manipulation Program- http://gimp.org) we were able to determine that the water needs were probably about 9% less for Fritz versus Nonpareil due to the increased amount of light that was falling through the canopy (less dense shade- see (**Figure 10)**.

Geometrically corrected iPhone images of orchard shadows

Nonpareil | Fritz



Images converted to black and white using GIMP

Nonpareil average 76.1% | Fritz average 69.6%

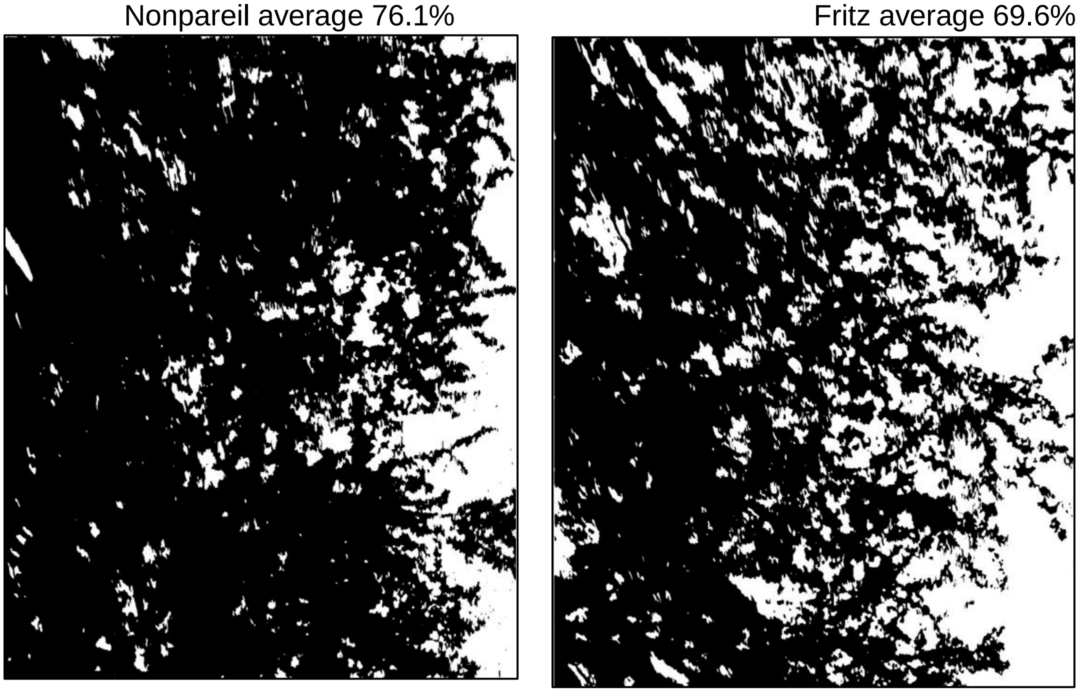


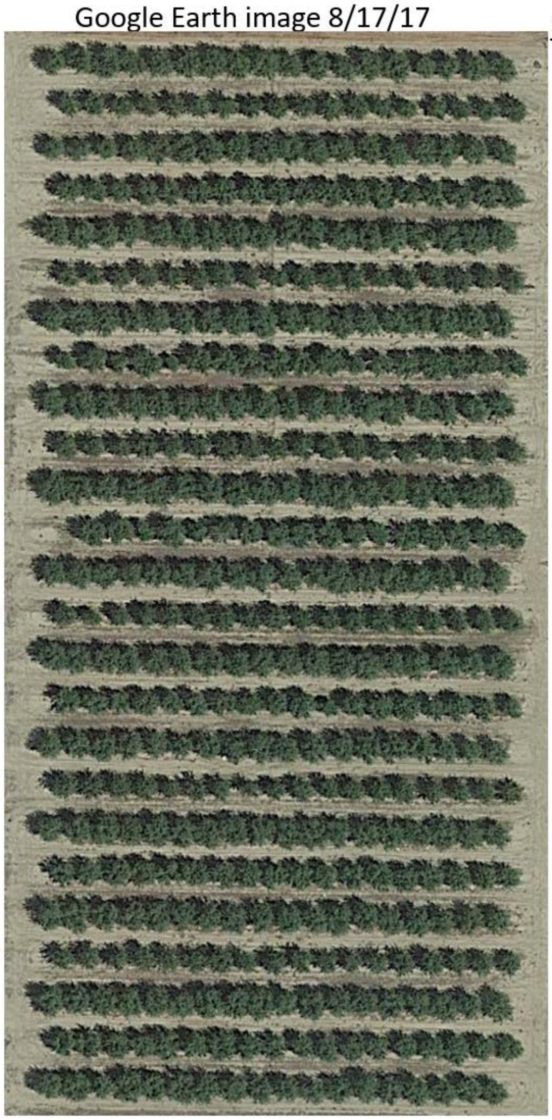
Figure 10. Black and white image for orchard floor shadows calculated using GIMP. Images were taken at midday and separated into left and right halves to separate out light interception from Nonpareil versus each of two pollenizers.

This would be useful for scheduling differential irrigation if the orchard had separate systems

We have also been working with Ali Pourreza in Bio and Ag Engineering on comparing our light bar data with his drone imagery. We are still in the process of analyzing these data but so far results look promising. We have run the light bar and flown the drone in our Stanislaus RAVT with Roger Duncan, the Kearney almond lysimeter trial with Ken Shackel and Mae Culumber and the almond precision irrigation trial with Mae Culumber and Khaled Bali. These comparisons will be presented at the Almond Conference and in the annual report next year.

In the Kearney almond lysimeter trial (**Figure 11**), average interception by Nonpareil, Monterey and Wood Colony respectively was 46.9, 39.5, and 30.9 (**Figure 12**). This means that Nonpareil was intercepting 16% more PAR compared to Wood Colony. This is significant and would likely lead to problems with the Wood Colony being excessively wet after irrigation if the needs for Nonpareil are being fully met.

Google Earth image 8/17/17



Row	PAR int. by row (%)	
1 Nonpareil	47.1	
2 Wood Colony	29.2	
3 Nonpareil	42.0	
4 Monterey	41.6	
5 Nonpareil	49.3	
6 Wood Colony	30.8	
7 Nonpareil	49.3	Light bar was run on 7/27/17
8 Monterey	39.6	
9 Nonpareil	49.7	
10 Wood Colony	32.1	
11 Nonpareil	51.7	
12 Monterey	36.3	
13 Nonpareil	47.9	
14 Wood Colony	31.0	
15 Nonpareil	45.5	
16 Monterey	37.9	
17 Nonpareil	41.7	Lysimeter row
18 Wood Colony	30.7	
19 Nonpareil	47.8	
20 Monterey	41.4	
21 Nonpareil	46.8	
22 Wood Colony	31.9	
23 Nonpareil	47.5	
24 Monterey	40.4	
25 Nonpareil	50.6	

Figure 11. Google Earth image and PAR interception for each row calculated using the mobile platform light bar data.

We are currently working with Ali Pourreza (Assistant Specialist in Cooperative Extension in Bio and Ag Engineering at UC Davis) to compare and calibrate data from their drone flight imagery with the PAR data from the Mule light bar. (**Figure 12)** shows the data from the Kearney almond lysimeter trial orchard comparing the PAR interception from the mule light bar with the canopy cover calculated with the drone imagery.

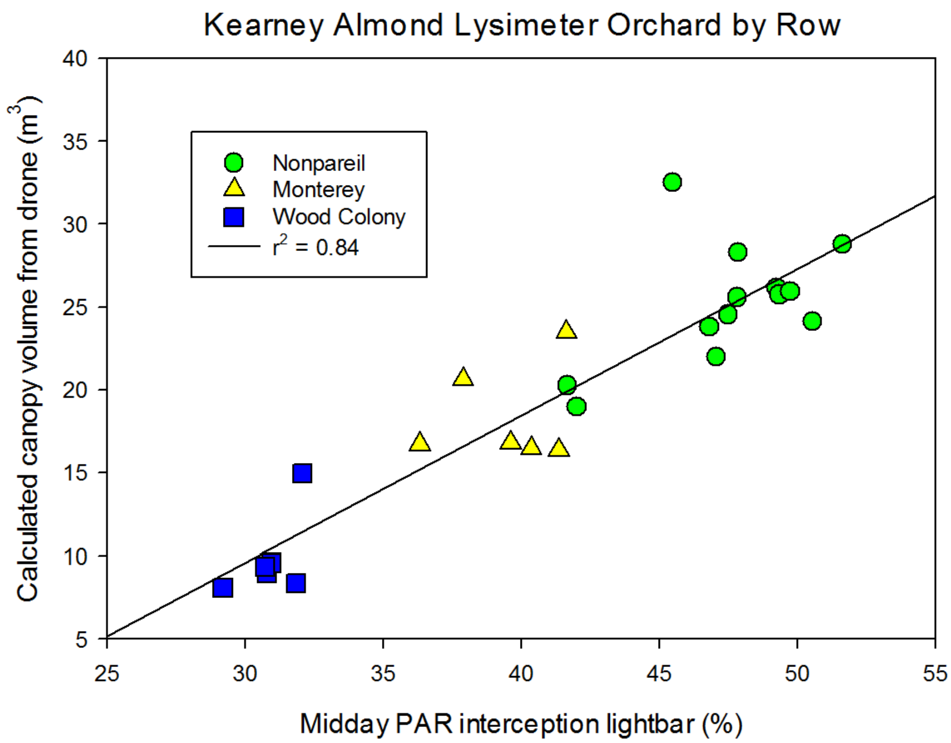


Figure 12. Midday PAR as measured with the mule lightbar compared to canopy volume calculated from the drone imagery from Ali Pourreza.

These data suggest that whether you calculate PAR interception with the mule light bar or canopy volume with the drone imagery, there are large enough differences in light interception or canopy volume that it would be beneficial to irrigate each variety independently to ensure that the smaller varieties are not over-irrigated. This would also likely have the benefit of shifting more of the yield to the more valuable Nonpareil.

The final thing we have been working on is redoing the iPAR app for estimated PAR interception from images of the shadows on the orchard floor. The first stage in this process has been working with Venkatesh Akella in Computer Science and Engineering at UC Davis to create an online program on PCs to process images of orchard floor shadows. We have a preliminary version of this working and should have it online in the next few months. It will likely be hosted on an ANR server and linked from the Fruit and Nut Research and Information Center. The eventual plan is still to integrate this work with Brian Bailey's modelling work. We are currently working with the Plant Sciences Department as well as ANR (both employ programmers with expertise in these areas) to develop a long-term plan for maintaining apps and online resources.

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 varieties or selections. 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. In addition, for the past three years we have been looking at the impacts of using almond orchards for winter recharge of groundwater on PAR interception. 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. Publications describing the mobile platform light bar and its applications are listed at the end of the report.

The iPhone app for estimating light interception was field tested and refined during the 2015-2017 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) is available in Apple App Store. We are currently working on ua PC based version of the image analysis tool to allow batch processing of images in a more automated fashion. This online software should be available in the next few months.

Current and future directions:

- Investigate light interception/yield relationship (ongoing)
- Adjust treatments for relative canopy area in any type of study such as pruning trials (ongoing)
- Evaluate performance of new cultivars- separate out effect of faster tree growth versus higher productivity per unit canopy light interception (ongoing)
- Work to compare drone imagery from Ali Pourreza with Mule light bar PAR data
- Integrate the iPAR app with Brian Bailey's modelling work
- Evaluate impacts of different pruning and training treatments on light interception and productivity (ongoing)
- Aid in assessing value of orchards

Research Effort Recent Publications:

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