Multi-Discipline Analysis of Long Term Nutrient Optimization Trial, Data Integration, Data Exploration, Web Delivery, and Application Development

Project No.: **13-PREC2-Brown**

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Objectives:

Originally proposed in grant 13-PREC2-Brown:

- In collaboration with SureHarvest develop web based and device based applications for growers and consultants to make N management decisions.
- To analyze data that has been collected during the *Nutrient Optimization* project and to use that data to derive new information, to model the determinants of yield, to create an understanding of whole orchard nutrient and water fluxes, and to examine relationships between the various parameters measured.

Additional goals established during the development of this project:

- Nitrogen workshop for the 2013 Almond Board Conference.
- Nitrogen management training for Certified Crop Advisers.
- Understanding spur survival in almond spurs.
- Kernel yield prediction from light interception and leaf nitrogen in individual trees.

Interpretive Summary:

This project was designed to further analyze results and data from the long-term nitrogen trial in almonds that was completed in 2013 and to produce several grower oriented products.

We have now completed in collaboration with SureHarvest an interactive web based program that growers can use to manage their nitrogen in almonds effectively. In addition, we have finalized a new approach and model that allows growers to sample leaves in April to predict leaf nutrient status in July. Both of these tools can be used to provide more accurate and sustainable N management strategies. This work is now available online through several sites listed below. Our goal is to extend these models and guidelines to all essential nutrient elements, this has been commenced and nutrient removal values for all elements are presented here.

A detailed accounting of N removal from orchards in harvested fruit has been completed. In well-managed orchards exhibiting good efficiency of N use and excellent productivity an average of 68 lbs N, 8.2 lbs P and 80 lbs K is exported from the orchard for each 1000 lb kernel yield. This value includes all of the nutrient removed in hull, shell and kernel.

In an effort to educate growers and advisors (CCA's) of the rationale and method for improved nitrogen management, we have collaborated with UCANR, CDFA, CAPCA to hold 5 two day workshops that have been attended by 650 CCA's and many growers. The workshops have been very well received. All materials including narrated videos will be prepared for public access and as part of ongoing training programs. Additional meetings are planned for 2015.

The effect of excess nitrogen on tree susceptibility to Hull Rot was carefully examined and it was demonstrated that high N can result in very significant increases in Hull Rot occurrence which may be the result of the role of N in delaying fruit maturity.

To better understand the factors that determine yield potential we have analyzed the manner in which almond spur survival and return bloom is affected by yield and have created several mathematical models to determine the relationship between tree size and tree N status on yield.

Materials and Methods:

A post-doctoral scientist (Sebastian Saa) under the direction of Dr. Brown was hired from September 2013 to March 2014 to perform the goals mentioned above utilizing data collected over the previous 5 years of nitrogen trials in almond. In collaboration with SureHarvest, we have developed a web based application and are working on smart phone applications for N management. To ensure good extension of N management practices we will conduct nitrogen workshops in the main regions of the almond growing regions of the Central Valley.

Results and Discussion:

Initial Target Activities/Outcomes:

1. Collaborate with SureHarvest on application development

a. Develop practical tool for growers

Task completed. The beta version of the web model (and optimized for smart phones or tablets) was presented during the 2013 Almond Board Conference. The official version was launched in 2014 and it is available at: https://www.sustainablealmondgrowing.org. The almond N module and the guidelines for leaf sampling are also available through the Fruit and Nut Center at http://fruitsandnuts.ucdavis.edu/Weather_Services/Nitrogen_Prediction_Models_for_Almond_and_Pistachio/. The model developed for early season sampling has been distributed to all major analytical labs and is in wide spread use. In addition, 70% of all Certified Crop Agronomists working in Almond have received training in model use during the UCANR/CAPCA Nitrogen Management Workshops held January – March 2014 http://ciwr.ucanr.edu/NitrogenManagement/

2. Complete nutrient budget analysis for all elements

a. Provide essential yield based nutrient demand data for all nutrients

Nutrient removal from the orchard expressed on a per 1000 kernel lb basis were calculated for all treatments from years 2009 through 2012 from a large experimental site in Kern County. Trees were 10 years old in 2009. As there was no significant effect of nitrogen source, potassium rate or potassium source on yield or nutrient removal, data for treatments E through L are not shown. Yield has a significant effect on N (**Table 2**) and a small effect on S removal but does not influence removal rates per 1000 lb kernel for any other nutrient (**Table 3**). Year has a significant effect on nutrient removal, however this is largely a consequence of year-to-year variation in yield.

On the basis of the recorded yield and calculated N export, calculation of nitrogen use efficiency and leaf tissue analysis the N treatments can be interpreted as follows.

> Years 2009 and 2010 (3500 lb average yield): Treatment A = Strong N deficit, Treatment B - adequate N, Treatment C – moderate excess N, treatment D – strongly excess N.
>
> Year 2011 (4400 lb average yield): Treatment A = Strong N deficit, Treatment B - moderate N deficit, Treatment C – slight excess N, treatment D – moderate excess N.
>
> Year 2012 (900 lb average yield): Treatment A = Moderate N deficit, Treatment B - moderate N excess, Treatment C – strongly excess N, treatment D – strongly excess N.

Task completed. Table 1, 2, and **3** below summarizes these results.

Table 1. Detail of fertilization treatments.

A	UAN32	125	60% SOP / 40% KTS	200
B	UAN32	200	60% SOP / 40% KTS	200
C	UAN32	275	60% SOP / 40% KTS	200
D	UAN32	350	60% SOP / 40% KTS	200

Table 2. Average nitrogen export in fruit (lb N/1000 lb kernel yield) in almond from 2009-2012 under fan jet irrigation. Letters in parenthesis indicate significant differences between treatments within the same year at the 0.05 level of significance. Refer to **Table 1** for description of treatments.

Treatment	2009	2010	2011	2012
A	53 (b)	55 (c)	54 (c)	54 (b)
B	56 (ab)	61 (b)	65 (b)	86 (a)
C	59 (a)	73 (a)	74 (a)	87 (a)
D	60 (a)	70 (a)	75 (a)	86 (a)

In summary, the overall average N export for well managed trees with good productivity and adequate but not excessive fertilizer N was determined to be 68 lbs N per 1000 lb kernel yield (based upon average offtake of treatments B and C in 2010 and 2011). This value includes all N present in the hull, shell and the kernel and resulted in maximal yield.

When trees are strongly N deficient, yield and kernel N is reduced to 54 lbs N per 1000 lb kernel yield but does not decline below this value suggesting that this is the minimum N content of a viable fruit. When N is applied in excess of requirement (treatment D, tissue N >2.6% and when yield is very low as in 2102) almond N export can increase to a maximum of 86 lbs N per 1000 lb kernel yield. This 86 lb per 1000 kernel lb value represents trees with very high leaf N (N>2.6%), and very low nitrogen use efficiency and, hence, resulted in substantial excess N present in soil at the completion of the growing season. There was no yield benefit to N application beyond that required to achieve 68 lbs N per 1000 lb kernel. High fruit N levels was a result of increased N accumulation in hulls and resulted in greater hull rot incidence.

Table 3. Average nutrient export in fruit (lb N/1000 lb kernel yield) in almond from 2009-2012 under fan jet irrigation. Each value represents the average of all four fertilization treatments.

Nutrient	2009	2010	2011	2012
P	7.2	8.4	8.6	12.3
K	72.5	82.8	76.5	91.5
S	2.2	2.3	2.8	3.0
Ca	7.2	7.2	6.1	5.7
Mg	4.4	4.5	4.5	5.1

Table 4. Micronutrient export (g) in fruit per 1000 lb kernel yield in almond from 2008-2012. Data shown for the 275 lb/ac N treatment.

Nutrients	2008	2009	2010	2011	2012
B	115	149	142	141	161
Zn	27	33	42	23	34
Mn	18	15	24	19	20
Fe	-	101	74	57	108
Cu	8	10	10	8	12

Across all years and treatments the export of Fe, Zn, Mn, Cu, Mg, Ca, K in fruit expressed on a per 1000 lb kernel yield basis remained quite consistent (**Table 4**). These values can be used as sound guidelines for nutrient replacement programs. In this experiment and other ongoing trials, however, considerable variation in removal rate of B (44- 250 g), N (54-86 kg), S (2-3 lb) has been observed as a result of N treatment rate or soil B supply levels. The average N removal rates per 1000 lb kernel of 68 lbs represent an average derived from high producing trees grown with excellent N management and is an ideal target value for N replacement scheduling.

3. Complete nutrient prediction analysis for all elements
    a. Validate April leaf sampling protocol for all nutrients

Partially completed. Further collaboration with the statistician Emilio Laca is underway to complete this task. A full and detailed peer review examination of the leaf nitrogen prediction model was performed in 2013 - 2014. This resulted in a peer review publication:

> *"Prediction of leaf nitrogen from early season samples and development of field sampling protocols for nitrogen management in Almond (Prunus dulcis [Mill.] DA Webb)". Plant and Soil, 380: 153-163 (2014).*

In summary, it was confirmed that summer leaf nitrogen concentration is well predicted by the use of the early season model ($r^2 = 0.9$). The elements that need to be collected in spring to perform this prediction are: N, B, K, Ca, and Mg. In addition, optimized sampling protocols for almond leaves in spring are explained in the above manuscript as well as in past ABC reports and at http://fruitsandnuts.ucdavis.edu/Weather_Services/Nitrogen_Prediction_Models_for_Almond_and_Pistachio/.

4. Use 3,600 individual tree yield data over 5 years to build yield prediction/explanation models
    a. Determine how yield, tree size and nutrient balance interact to determine yield potential and year-year yield variation

Partially completed. This task was divided in three subtasks. First subtask was to organize and merge all the water, weather, light, and nutrition data collected in the *Nutrient Optimization* project. Second subtask was to perform different statistical models following a pathway analysis that would define the main variables that affect almond yield. Third subtask was to select the best model and write a peer review publication identifying the parameters that best predict yield potential in almond. Subtask one was completed; subtask two is partially completed and has been submitted for publication, and subtask three has not started.

5. Development of whole orchard 'lifetime' nutrient balance analysis. This will integrate data on 5-year tree nutrient balance, tree size, perennial and annual nutrient status, soil N fluxes and pools.

   a. Refine the estimated NUE for Almond. Quantify soil N contribution; determine effect of soil N depletion on soil OM and soil N status.

This task is underway with long term N mineralization studies being conducted in collaboration with Dr. Will Horwath and refined measures N mineralization and leaching with Drs. Schellenberg, Smart, Hopmans and Sanden.

Nitrogen workshops task (Completed): Dr. Saa and Dr. Brown organized a nitrogen workshop, which was presented at the Almond Board Conference in December 2013. The workshop was an innovative "hands on" exercise in which the participants had the opportunity to practice the concepts needed to face the new nitrogen regulations.

In addition, Dr. Saa and Dr. Brown closely collaborated with the California Food and Agriculture Department to develop a nitrogen management-training course for certified crop advisers. Dr. Saa and Dr. Brown prepared and presented four workshops each with 220 minutes instruction. The main topics covered in those presentations were:

a) Stage of the Art in Nitrogen Cycle: Nitrogen Forms, Transformations, Functions, and Management in Agriculture.
b) Nitrogen Management in Permanent Crops that are Relevant for CA Agriculture Production.

All the material prepared by Dr. Saa and Dr. Brown as well as the lectures presented by other speakers are publically available for further training and educational purposes. http://ciwr.ucanr.edu/NitrogenManagement/

6. Utilize data on ET (CIMIS and Eddy CoVar), stem water potential, Cl leaching, soil moisture probes to cross validate and integrate

   a. Improved understanding of tree and orchard level water relations and irrigation dynamics.

Due to limitations imposed by water shortages in 2013 and 2014 which eliminated any leaching, prevented reliable soil moisture sampling and placed trees under water stress, this task was replaced by the following additional tasks:

a) Understanding spur survival in almond spurs (Completed):

Nitrogen competition between fruit and leaves at the spur level negatively affects assimilation as the season progresses as a consequence of biochemical and biophysical changes in Rubisco enzyme carboxylation capacity, maximum rate of RubP regeneration and stomata conductance. There was a high degree of spur autonomy in terms of fruit and leaf competition for nitrogen, which is in agreement with the existing carbon autonomy theory. We suggest that a high nitrogen demand in the presence of fruit, negatively affects the photosynthetic capacity of nearby leaves and this is correlated with spur death. **Figure 1** below shows the fruit effect on leaf nitrogen concentration under different types of almond spurs.

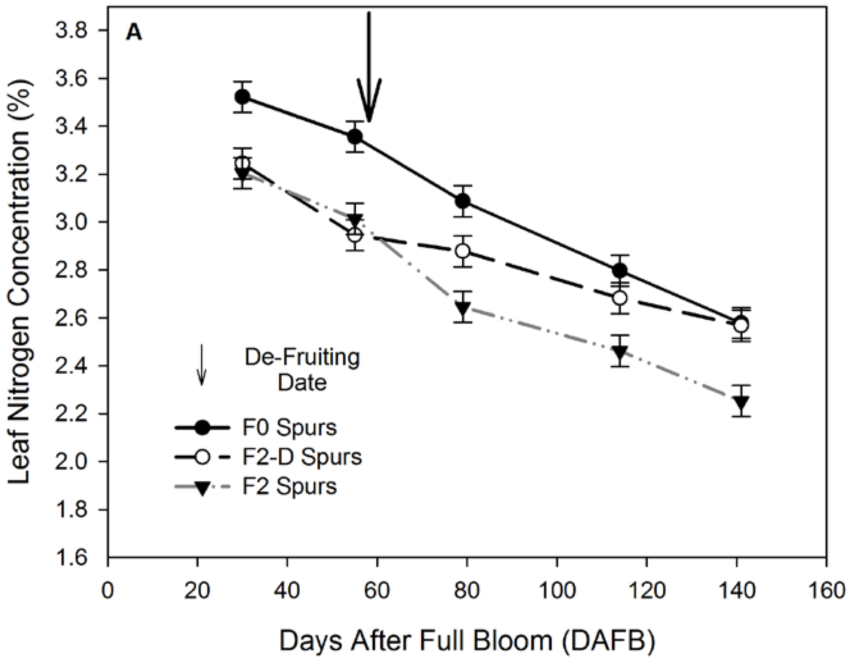

Figure 1. Effects of days after full bloom and spur type on leaf nitrogen concentration. Bars indicate one standard error from the mean (n = 135).

The results from this task resulted in a peer review publication: *"Fruit presence negatively affects photosynthesis by reducing leaf nitrogen in almond," Functional Plant Biology, online.*

b) Light interception, leaf nitrogen, and yield in almonds (Completed):

To develop this task Dr. Brown and Dr. Saa collaborated with Dr. Zarate-Valdez. The main results of this work indicate that light interception is a moderate predictor of almond kernel yield, while whole tree leaf nitrogen content (the combination of light interception and leaf N concentration) can explain up to 76% of almond yield variation over a period of two or three years (see **Figure 2**). In addition, it was found that fruit and leaf nitrogen contents are in close relationship at different stages of the growing season, which implies that leaf nitrogen content can be used as an early season predictor of yield and nitrogen use by the crop. More research on this topic is underway.

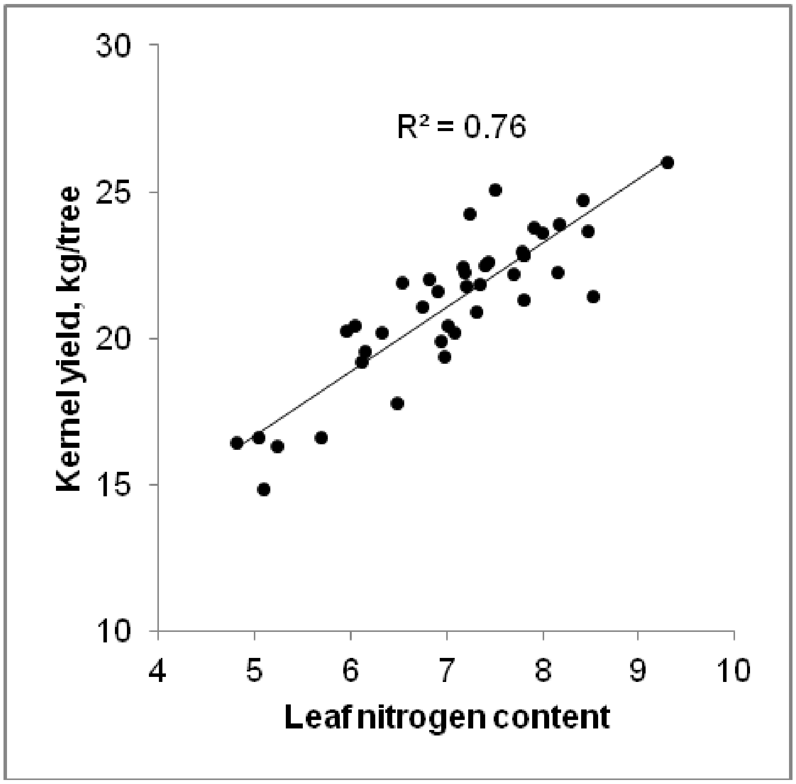

Figure 2. Effect of leaf nitrogen content (calculated as the product of the trees leaf area index and its leaf nitrogen content) in July on kernel yield of individual trees. Each point represents the average N content and yield during the years 2010 and 2011. Leaf N content was calculated as the product of the leaf area index times the leaf nitrogen concentration.

7. Examine relationship between nutrition, yield, canopy architecture, environment and the development of orchard diseases.

a. Improved understanding of extent and causes of nutrient disease interactions

Completed. For this task**,** Dr. Saa and Dr. Brown collaborated with Elana Peach-Fine (MSc student), Themis Michailides, Richard Bostock and Emilio Laca. The experiment involved selecting 80-100 spurs from 4 trees grown under two nitrogen rates and then following those same spurs through their developmental stages and to the development of hull rot symptoms. A significant effect of nitrogen on hull rot incidence was observed with only 8% of spurs developing hull rot in the low N treatment while 47 % developed hull rot in the high N treatment. High nitrogen affects hull rot by slowing hull development and increasing disease expression. (**Table 5**)

Table 5. Number and percent of tagged spurs in each stage in low N (125 lbs/acre) and high N (350 lbs/acre) treatments at different sampling dates during hull split development.

N rate (lbs/ac)	Phenological stage	17-Jul		25-Jul		1-Aug		8-Aug		14-Aug		22-Aug	
		n	%	n	%	n	%	n	%	n	%	n	%
125	stage a	81	84	65	68	29	30	3	3	1	1	0	0
125	stage b	12	13	20	21	42	44	42	44	7	7	3	3
125	stages c & d	3	3	10	10	20	21	27	28	23	24	0	0
125	stage e	0	0	1	1	5	5	24	25	57	59	83	86
125	hull rot	0	0	0	0	0	0	0	0	8	8	8	8
125	Total	96	100	96	100	96	100	96	100	96	100	96	100
350	stage a	92	96	80	84	58	62	13	14	4	4	1	1
350	stage b	4	4	13	14	29	31	54	58	21	23	11	12
350	stages c & d	0	0	2	2	5	5	17	18	32	34	1	1
350	stage e	0	0	0	0	2	2	5	5	6	6	31	34
350	hull rot	0	0	0	0	0	0	4	4	30	32	43	47
350	Total	96	100	95	100	94	100	93	100	93	100	92	100

Research Effort Recent Publications:

Accepted:

Sebastian Saa and Patrick H. Brown, "Fruit presence negatively affects photosynthesis by reducing leaf nitrogen in almond," Functional Plant Biology, - (2014).

Sebastian Saa, Patrick H. Brown, Saiful Muhammad, Andres Olivos-Del Rio, Blake L. Sanden, and Emilio A. Laca, "Prediction of leaf nitrogen from early season samples and development of field sampling protocols for nitrogen management in Almond (Prunus dulcis [Mill.] DA Webb)," Plant and Soil, 380: 153-163 (2014).

Submitted:

Jose L. Zarate-Valdez, Saiful Muhammad, Sebastian Saa, Bruce D. Lampinen and Patrick H. Brown, "Light interception, leaf nitrogen and yield in almonds: a case study". Under review in the European Journal of Agronomy.

In preparation:

“Nitrogen Increases Hull Rot and Interferes with the Hull Split Phenology in Almond (Prunus dulcis)” by Sebastian Saa, Elana Peach-Fine, Patrick Brown, Themis Michailides, Sebastian Castro, Richard Bostock, and Emilio Laca.