

CDFA-FREP Final Report 2020

A. Project Information

1. **Project Title:** Demonstration of a combined new leaf sampling technique for nitrogen analysis and nitrogen applications approach in almonds
2. **Project's duration:** Year 3 of 3 (January 2018-December 2019)
3. **Grant number:** 16-0708-SA
4. **Project Leaders:**
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B. Objectives

1. Demonstrate the effectiveness of the new mid-April early leaf sampling and yield based nitrogen (N) application methodology in almonds (Saa et al. 2013, Muhammad et al. 2015).
2. Create a platform to promote the widespread adoption of best nitrogen management practices by almond growers throughout the Central Valley of California.

C. Abstract

Nitrogen in almond has historically been managed using the leaf sampling and critical value approach of nutrient management. In this approach leaf samples are collected in July and analyzed for nutrient concentration. The results are compared with established standards and annual fertilizer rates are increased if nutrients are deficient. Although this approach has value, it does not identify inefficient N use and does not provide information on the rate and time of nutrient demand. Further, tissue samples are generally collected late in the season when there is limited time to respond if deficiencies exist. To provide farmers with better tools, improved approaches that guide the time and rate of fertilizer application, offset irrigation water N contributions and provide methods for early season leaf collection and analysis that facilitates timely in-season monitoring of nitrogen status have been developed. Projects funded by the Almond Board of California and CDFA-FREP "Development of a Nutrient Budget Approach to Fertilizer Management in Almond" (project #07-0670) and "Development of leaf sampling and interpretation methods for Almond and Pistachio" (project number: 07-0671) and its extension in 2010 (project number: 10-0015-SA) have provided critical guidance for improved N management. Results of these projects have led to development of web-based tools of the Almond Board

(<https://www.sustainablealmondgrowing.org/>) CDFA-FREP [website and CropManage platform](https://cropmanage.ucanr.edu/Home/SplashPage?ReturnUrl=%2F) (<https://cropmanage.ucanr.edu/Home/SplashPage?ReturnUrl=%2F>).

While the development of new tools is essential if enhanced N use efficiency is to be realized, these tools will be of limited use if they are not widely adopted. The current project is designed to improve adoption of these tools by demonstrating the performance of the 'improved N management' protocols in contrast with 'traditional N management strategies' to farmers, managers and crop consultants. Field trials in 4 contrasting orchards were established in which 'standard' and 'improved' management strategies are contrasted (Figure 1). Extensive monitoring of nitrogen applications, yields, soil nitrogen and overall N budgets have been conducted. The adoption of 'improved N management practices' in which yield prediction, spring sampling and irrigation water offsets were implemented resulted in no difference in tissue N concentrations, equivalent or greater yields and a reduction in total N applied of 10-75 lbs acre year. Nitrogen use efficiency (NUE) was generally high in all fields ranging from 48% to 97%. On average, the improved N management practices resulted in an increase in N use efficiency (24% in year 1 and 7% in year 2) in contrast with traditional grower practices. NUE was improved in large part due to the inclusion of N present in irrigation water as a credit against N fertilizer requirements. The results also illustrate that N use efficiency is compromised by incorrect yield estimation and failure to conduct in season fertilization modifications as yield estimations are refined. Informal interviews with growers also indicate that uncertainty in yield estimations and uncertainties in nitrogen contribution from irrigation water are major limitations to improved nitrogen management.

To assist growers in their transition to improved N management practices we conducted 7 statewide N demonstration project days with a total of 725 attendees, presentations on N management strategies were made at FREP, Almond and Agronomy Society meetings. Two UC ANR publications were produced summarizing principles of N management and N management strategies in nut crops. Additional peer reviewed publications and extension events are planned for 2020.

D. Introduction

Excessive use of nitrogenous fertilizers in high value agriculture has resulted in the contamination of ground water with nitrate and in many parts of California, ground water nitrate levels exceed the EPA standard of drinking water quality of 45ppm nitrate. This is partly due to lack of best nutrient management protocols. Currently nutrient applications in almond are based largely on leaf sampling and application of critical value analysis. The critical value is the nutrient concentration in a standard leaf sample at which yield is 90% of the maximum yield. This approach provides an indication of adequacy or deficiency but little specific information on appropriate fertilizer rates or timing of applications. Although the critical value approach has been a valuable tool to identify deficiencies and toxicities this approach is not sensitive to over fertilization and is collected too late in the season to be used as a management tool. Leaf sampling has been found to be inadequate as a tool for N management in high value crops since it is inadequately sensitive to N fertilizer applications in the adequate through excessive range. The insensitivity of leaf critical value to over fertilization in perennial crops may have contributed to the over application of N fertilizers and excess N being lost to the environment with resulting accumulation in the ground water in California. A second constraint with traditional late summer leaf sampling is that the

results from this sampling are not available in time to influence the current year fertilizer decision making.

Over the past five years, improved fertilizer management strategies have been developed (see: <https://apps1.cdfa.ca.gov/FertilizerResearch/docs/Almonds.html>). Fertilizer rates are first calculated by estimating yield potential and applying fertilizer at a rate designed to replace N removed from the field in fruit and perennial growth. To achieve good nitrogen use efficiency (NUE) however requires the application of N in an amount and at a time to closely match plant demand. Annual nitrogen fertilization rates can be reduced in proportion to the N that is found in applied irrigation water and residual N in soil. Efficiency of N use can be further enhanced by avoiding N loss through leaching below the root zone. Early season leaf N monitoring can further ensure the grower that N levels are adequate to support optimal tree growth.

To address the limitations of traditional grower crop N management we have developed approaches that guide the time and demand of fertilizer and in-season monitoring of nitrogen. These projects were funded by FREP in 2008 (project #07-0670) title “Development of a Nutrient Budget Approach to Fertilizer Management in Almond” and (project number: 07-0671) “Development of leaf sampling and interpretation methods for Almond and Pistachio” and its extension in 2010 (project number: 10-0015-SA). This combination of new approaches to fertilizer management has the potential to improve the efficiency with which N is used in Californian almonds and hence to improve grower profitability and reduce N loss to groundwater. With any new approach, however, there must be a concerted outreach effort to educate growers through the use of outreach efforts including through the conduct of demonstration experiments in grower fields and presentation of results.

E. Work description

Task 1 (Objective 1) Demonstrate the effectiveness of the new mid-April early leaf sampling and yield based nitrogen (N) application methodology in almonds

1.1 Site selection:

(Completed Dec. 2016)

Four project demonstration orchards with treatment contrast between ‘Traditional Grower and ‘New’ nitrogen management strategies were established in 4 distinct 15-year-old Kern County Almond orchards averaging 80 acres with 50% Nonpareil, 50% Monterrey (only Nonpareil data was collected). Each of the four orchards were divided in half with one half receiving the ‘New’ N management protocols and the paired half receiving the ‘Traditional’ management practice. (Figure 1).

Two treatments (each half of a paired orchard block) were imposed:

Traditional Grower N Management:

- N rate was determined by experience, relative orchard vigor, and adjusted for tissue samples from prior year
- Application Timing- March, April, May, June - 30% -30% -30% -10%

‘New’ N Management Practice

- Nitrogen Rate determined by Bloom Yield Estimate and N demand of 68 lbs N/1000 lb. kernel yield, and assuming a 70% fertilizer use efficiency.
- Nitrogen rate was modified if needed following April leaf sampling
- N application rates were reduced by determination of N supplied in irrigation water (assuming 48" applied water)
- N Application rates were reduced by determining residual N in soil (48" rooting depth, 50% wetted volume, average soil Nitrate-N)
- Applications were made March 5th, April 20th, June 1, Aug 30 (20/30/30/20)

1.2 Yield Prediction and N management plan:

(February year 1; repeated February year 2)

In 'New' management practices treatments, yield predictions were made by an experienced extension specialist utilizing historical yield records, current bloom intensity and knowledge of winter and spring environmental conditions. Yield predictions were converted to nitrogen fertilization strategies using the Almond Board CASP nitrogen budgeting calculator decision support tool nitrogen management plans were generated for the orchard.

1.3 Soil and water analysis for NO₃-N:

(Initiate March Year 1 and ongoing)

Soil samples were collected in all demonstration sites at depths 0-18", 18-36" and 4-5 feet at the start of the project (winter 2016-17) to establish NO₃ baselines and then at the end of each succeeding season. The samples will be analyzed by Analytical Laboratory University of California Davis.

Water samples were collected from the irrigation water twice annually and analyzed for Nitrate concentration.

1.4 Nitrogen demand calculation and early-spring N application

(Initiate March year 1; repeated March year 2)

Based on predicted yield total N requirement of the crop calculated as kernel yield/1000 x 68 lbs and measurements of the amount of N from non-fertilizer sources including N per acre coming from soil and water, the final quantity of fertilizer will be calculated.

At 70% leaf out, 30% of annual N application was made.

1.5 Leaf tissue sampling:

(Initiate April Year 1; repeated April Year 2)

Composite leaf tissue samples will be collected in mid-April and July according to the guidelines of Saa et al, from all demonstration sites at full leaf expansion. The samples were analyzed at ANL UC Davis for nitrogen, potassium, phosphorous, iron, zinc, copper and manganese.

1.6 April yield estimation:

(Completed April year 1 & April year 2)

Crop yield was re-estimated at full leaf expansion to adjust fertilizer amount if estimated yield is different than predicted yield.

1.7 Fruit growth fertilizer application

(Completed April year 1 & April year 2)

Based on April yield estimate and April leaf tissue analyses, annual nitrogen demand was reevaluated. If estimated yield differed than predicted, N rate was revised. 30% of the annual N fertilizer demand will be applied.

1.8 Kernel fill fertilizer application

(Completed June Year 1 and June Year 2)

30% of annual nitrogen fertilizer demand as determined in task 1.7 was applied.

1.9 Yield determination:

(Completed September Year 1 and Sept Year 2)

Yield for each demonstration site will be determined using commercial harvest data from huller.

1.10 Early post-harvest fertilizer application:

(Completed Oct Year 1; Oct Year 2)

Postharvest N fertilizer was applied based on the actual yield. If actual yield equals the estimated yield, 10% of the annual N demand was applied at postharvest. If actual yield is lower than estimated yield and July leaf N is adequate then postharvest N was not applied.

1.11 Data analyses:

(Completed December Dec 2017 and Dec 2018)

Data was collected on yield, turnout percentage, and soil nitrate concentrations. Data for each demonstration site was compiled and analyzed for N off take, yield and changes in soil nitrate concentration.

1.12 Project site maintenance:

(2016 through 2018)

Project cooperators carried out all the necessary practices to maintain the trees in the project demonstration sites, such as irrigation, pest management, and orchard floor management.

Task 2 (Objective2). Create a platform promoting widespread adoption of best nitrogen management practices by almond growers throughout the Central Valley.

2.1 Project outreach:

(January-March 2018 and 19).

Working with FREP and UCCE facilitate grower field days were conducted at project demonstration sites in each region in the spring of 2018 and 2019. Guidelines for accessing and using the CASP online platform and nitrogen budgeting calculator decision support tool was developed using project funds and widely disseminated at project field days and CASP workshops, and online.

2.2 Reporting to FREP:

(Nov 2017, May 2018, Feb 2019)

Regular reports were sent to FREP on the project activities and progress

Subtask 2.2a: Interim report to FREP: Interim report was submitted in April each year

Subtask 2.2b. Annual report to FREP was submitted at the end of each season

Subtask 2.2c. Project data was analyzed and the results will be presented in the final report to FREP.

F. Results:

Objective 1:

Kern County: Demonstration trial sites were established at 4 UCCE cooperator orchards in year 1 according to task 1.1 through 1.12. (Figure 1)

Pre-season soil and water analysis: Pre-experiment soil samples were collected from within root zone (0-18, 18-36") and below Root Zone (4-5' and 6-8'). Samples were analyzed for nitrate at all depths and total available N in the soil profile was estimated assuming a 48" rooting depth and 50% field wetted volume. Figure 2 shows nitrate-N at the end of the season in year 2. Soil residual nitrate was generally low in the 0-5 ft rootzone with a trend to higher nitrate concentrations with traditional N application methods. Soil nitrate-N in the 5-9 ft rootzone was generally greater than in the 0-5 ft rootzone however no consistent difference between New and Traditional N management was recorded.

Irrigation water Nitrate N was generally low in all locations varying from 0-5 ppm Nitrate-N. Annual irrigation contribution to annual N budget was calculated assuming 48" irrigation volume and assuming 70% efficiency of N use.

Early and Mid-Season leaf tissue analyses were performed as described by Saa. et. al 2014 as recommended in the ABC-CASP program, all values were within acceptable range and hence no adjustments to fertilization plan was required. No significant differences in tissue N levels were observed between any field or treatment and all values were above established critical values. (Figure 3).

Nitrogen application rates and timings: (See Table 1)

- To establish fertilization rates for the New Nitrogen Management strategy the following steps were taken. (Refer to column titles (A-H) in Table 1): A) In February bloom yield estimate was performed visually by Blake Sanden, B) This value was multiplied by 68 lbs. per 100 lbs. estimated kernel yield, C) a 70% NUE value was assumed and used to estimate total

- fertilizer N requirement, D) The sum of irrigation water and soil nitrogen credit N was calculated and subtracted from calculated N demand (column C) to arrive at final fertilizer application rate (column E). Once final yield (column F) was determined in September the total N export in crop (column G) was then determined, from this the NUE (column G) and (Applied N over removed N - (column G)) was calculated. Applications were made March 5th, April 20th, June 1, Aug 30 (20/30/30/20) in the 'New N Management' treatment.
- In grower traditional management, N application rate (column E) was determined based upon historical experience with fertilization in these orchards and was applied in - March, April, May, June, in the proportions 30% -30% -30% -10%.
 - In both the New Nitrogen Management strategy and the Traditional nitrogen management strategy, there were no substantial fruit drop events and all tissue samples were within recommended levels, hence no in-season yield adjustment or fertilization rate adjustments were made.
 - In 6 of 8 sites across 2 years, NUE was improved when the 'New N Management' strategies were implemented (Table 1). In general, this improvement in NUE was the result of applying N credits for irrigation water N content. The subsequent reduction in N applied had no negative effect on yields or tissue N values. On the two instances where the 'Traditional N Management' out-performed the 'New N Management' this occurred as a result of early season overestimations of yield potential and failure to correct for apparent lower yield potential in May. Overall, results demonstrate that the 'New N Management' treatment results in improved NUE and demonstrates that accurate yield estimation is a primary driver of NUE.

Objective 2: Outreach and Education

- a. Working with FREP, the Almond Board of California and UCCE, four grower field days were conducted at project demonstration sites representing statewide almond production regions.

Outreach or educational materials published and/or printed can be accessed at the following sites:

- https://ucanr.edu/sites/scri/Crop_Nutrient_Status_and_Demand_Patrick_Brown/
- <http://www.ceresimaging.net/blog/nitrogen-needs-in-almonds-tips-from-ucs-patrick-brown>
- <http://www.ceresimaging.net/blog/nitrogen-refresher-patrick-brown-offers-tips-to-almond-growers-in-chowchilla>
- http://fruitsandnuts.ucdavis.edu/Weather_Services/Nitrogen_Prediction_Models_for_Almond_and_Pistachio/
- <https://ucanr.edu/sites/AlmondNH2Ofielddays/>
- Event Flyers Appended to this document.
- In collaboration with Michael Cahn, an Almond module was developed and integrated into the CropManage platform
(<https://cropmanage.ucanr.edu/Home/SplashPage?ReturnUrl=%2F>)

- The information from this and related projects was integrated into the CCA Nitrogen Certification Training Workshops held in March of 2016, 17, 18 and 19.
- Two UCANR publications on N management principles were produced (Principles of Nitrogen Management and Cycling <http://ciwr.ucanr.edu/files/283982.pdf>, Nitrogen Management in Nut Crops <https://ucanr.edu/sites/ciwr/files/318120.pdf>)
- The approaches identified and validated in this project have been incorporated in to the ongoing project, stakeholder meetings and surveys conducted under the Barriers to Adoption CDFA-FREP funded project.

2018 Field Days:

2018: 1. Field Day: Colusa

- Location: Nickels Soil Lab, Greenbay Rd., Arbuckle, CA
- Date: March 13, 2018 (8:30-1pm)
- Title: Spring Almond and Walnut Nutrient and Water Management Field Day
- Session Presentation Titles:
 1. ABC Overview and Almond Sustainability Program (large group talk) - Spencer Cooper, Jenny Nicolau, Rebecca Bailey
 2. Water and N management for integrated hull rot management (large group talk) - Franz Niederholzer
 3. Barriers to Adoption of Nitrogen Management Practices - Jessica Rudnick, Sat Darshan S. Khalsa, Stephanie Tatge
 4. Nitrogen management BMP's in walnut - Katherine Jarvis-Shean
 5. Managing boron in irrigation water – Patrick Brown
 6. Forward tissue sampling and overview of BMP trials to manage N and water - Miguel Guillen, Sebastian Saa
 7. Tools: Irrigation efficiency and timing - Allan Fulton
 8. CASP Module- Spencer Cooper/ABC
- Number of participants: 120
- Type of audience: growers, crop advisors
- Supporting documentation (e.g. flyers, program, etc.) – program flyers, grower press coverage, ABC coverage.
- CCA CEUs/Grower CEUs offered: Nitrogen Management = 2, Irrigation and Nitrogen Management = 1, other = 0.5

2018: 2. Field Day: Merced

- Location: Ash Slough Farms, Ave 21, Chowchilla, CA
- Date: Tuesday, March 20th 2018 (8:30-1pm)
- Title: Spring Almond Nutrient and Water Management Field Day
- Session Presentation Titles:
 1. Welcome! Grower/management conversation about goals and practices – Chris Morgner
 2. ABC Overview and Almond Sustainability Program (large group talk) - Spencer Cooper/ABC
 3. Nutrient Management Plans-Phoebe
 4. Soil and water testing for planning and feedback- Mae Culumber

- 5. Forward tissue sampling and overview of BMP trials to manage N and water –Patrick Brown and Miguel Guillen
- 6. Tools: Irrigation efficiency and timing –David
- 7. CASP Module- ABC
- Number of participants: 100
- Type of audience: growers, crop advisors
- Supporting documentation (e.g. flyers, program, etc.) – program flyers, grower press coverage, ABC coverage.
- CCA CEUs/Grower CEUs offered: Nitrogen Management = 2, Irrigation and Nitrogen Management = 1, other = 0.5

3. Field Day: Kern

- Location: Wonderful Ranch 3251, Brimhall Rd., Bakersfield, CA
- Date: March 21 (8:30-3pm)
- Title: Spring Almond Nutrient and Water Management Field Day
- Session Presentation Titles:
 1. Forward tissue sampling and overview of BMP trials to manage N and water –Patrick Brown and Miguel Guillen
 2. How does NMP reporting fit into the larger Irrigated Lands Regulatory Program? – Nicole Bell.
 3. ABC Sustainability Program: On-line tools for water and fertilizer management – Spencer Cooper/ABC
 4. Nutrient Management Plans- Nick Clark
 5. Soil/Plant/Water testing for planning and trouble-shooting NMP's – Keith Backman
 6. Tools for field assessment: Distribution uniformity, aerial/remote sensing – Blake Sanden
 7. ABC Overview and Almond Sustainability Program (large group talk)- ABC
 8. Barriers to Adoption of Nitrogen Management Practices – Sat Darshan Khalsa, Stephanie Tatge, Jessica Rudnick
 9. Control of navel orange worm via mating disruption / puffers etc. – Dave Haviland
 10. Spring diseases in Almonds- Mohammed Yagmour
- Number of participants: 150
- Type of audience: growers, crop advisors
- Supporting documentation (e.g. flyers, program, etc.) – program flyers, grower press coverage, ABC coverage.
- CCA CEUs/Grower CEUs offered: CURES – 3, CCA – 4, PCA – 1

2018: 4. Field Day: Tehama

- Location: California Almond Packers and Exporters (CAPEX), 21275 Simpson Road, Corning, CA.
- Date: Wednesday, March 27 2018 (8:30-12pm)
- Title: Spring Almond and Walnut Nutrient and Water Management Field Day
- Session Presentation Titles:
 1. Grower/Management conversation about goals of practices (large group talk)-Corning Grower Matt Esteve.
 2. ABC Overview and Almond Sustainability Program (large group talk)-Spencer Cooper/ABC
 3. Nitrogen management BMP's in walnut -Katherine Jarvis Sheen

4. Soil and water testing for planning and feedback – Luke Milliron
 5. Forward tissue sampling and overview of BMP trials to manage N and water –Patrick Brown and Miguel Guillen
 6. Tools: Irrigation efficiency and timing-Allan Fulton
 7. CASP Module- Spencer Cooper/ABC
- Number of participants: 129
 - Type of audience: growers, crop advisors
 - Supporting documentation (e.g. flyers, program, etc.) – program flyers, grower press coverage, ABC coverage.
 - CCA CEUs/Grower CEUs offered: Nitrogen Management = 2, Irrigation and Nitrogen Management = 1, other = 0.5

2019 Field Days:

Working with FREP and UCCE, three grower field days were conducted spring 2019 at project demonstration sites in three regions. For all grower field days:

- Title: Spring Almond and Walnut Nutrient and Water Management Field Day
- Type of audience: growers, crop advisors
- Supporting documentation (e.g. flyers, program, etc.) – program flyers, grower press coverage, ABC coverage, website.
- CCA CEUs/Grower CEUs offered: Nitrogen Management = 1.5, Irrigation and Nitrogen Management = 1, CM = 0.5. CURES credits = 3

2019: 1. Field Day: Del Rey – Fresno County – March 14, 2019 (8:30-12:30pm)

Location: Chandler Farms - West of McCall on Adams Avenue (Del Rey, CA) (36.63425, -119.613639)

- Number of participants: 66
- Session Presentation Titles:
 1. Welcome! Grower/management conversation about goals and practices (large group talk) – (Patrick Brown, Mae Culumber and Tom Chandler, farm owner).
 2. ABC Overview and Almond Sustainability Program (large group talk) (Spencer Cooper)
 3. Soil and water testing for planning and feedback (Mae Culumber)
 4. Forward tissue sampling and overview of BMP trials to manage N and water (Patrick Brown)
 5. Barriers to adoption of nitrogen management practices (Sat Darshan Khalsa)
 6. High frequency low nitrogen (HFLC) fertigation trials. (Hanna Ouaknin)
 7. Nitrogen management in first year recycled orchards. (Brent Holtz)

2019: 2. Field Day: Modesto – Stanislaus County – March 19th 2019 (8:30-12:30pm)

Location: Bowman Farms: California Ave, Modesto, CA 95358. (37.623653, -121.094636)

- Number of participants: 55
- Session Presentation Titles:
 1. Welcome! Grower/management conversation about goals and practices (large group talk) – (Patrick Brown, Mae Culumber and Tom Chandler, farm owner).

2. ABC Overview and Almond Sustainability Program (large group talk) (Spencer Cooper)
3. Nitrogen management in first year recycled orchards. (Brent Holtz)
4. Forward tissue sampling and overview of BMP trials to manage N and water (Patrick Brown)
5. Barriers to adoption of nitrogen management practices (Sat Darshan Khalsa)
6. High frequency low nitrogen (HFLC) fertigation trials. (Hanna Ouaknin)
7. CASP online tools for nitrogen and irrigation management. (Spencer Cooper)

2019: 3. Field Day: Chico – Butte County - March 26th, 2019 (8:30-12:30pm)

Location: Chico State University Farm, 311 Nicholas C, Shouten Ln, Chico, CA

- Number of participants: 116
- Session Presentation Titles:
 1. Welcome! Grower/management conversation about goals and practices (large group talk) – (Patrick Brown, Mae Culumber and Tom Chandler, farm owner).
 2. ABC Overview and Almond Sustainability Program (large group talk) (Spencer Cooper)
 3. Incorporating pressure chamber readings to refine irrigation management. (Luke Milliron)
 4. Forward tissue sampling and overview of BMP trials to manage N and water (Patrick Brown)
 5. Barriers to adoption of nitrogen management practices (Sat Darshan Khalsa)
 6. High frequency low nitrogen (HFLC) fertigation trials. (Hanna Ouaknin)
 7. Hull rots, their biology and management. (Franz Niederholzer)

G. Discussion and Conclusions

This project successfully demonstrated the effectiveness of the new mid-April early leaf sampling and yield based nitrogen (N) application methodology in almonds ('New N Management'). Spring sampling and irrigation water offsets were implemented and resulted in optimal tissue N concentrations, equivalent or greater yields and a reduction in total N applied of 10-75 lbs acre year. Nitrogen use efficiency (NUE) was generally high in all 'New N Management' treatments ranging from 48% to 97%. On average, the improved 'New N Management' practices resulted in an increase in N use efficiency (24% in year 1 and 7% in year 2) in contrast with traditional grower practices. NUE was improved in large part due to the inclusion of N present in irrigation water as a credit against N fertilizer requirements. The results also illustrate that N use efficiency is compromised by incorrect yield estimation and failure to conduct in season fertilization modifications as yield estimations are refined. Informal interviews with growers also indicate that uncertainty in yield estimations and uncertainties in nitrogen contribution from irrigation water are major limitations to improved nitrogen management.

In order to promote the widespread adoption of best nitrogen management practices, web-based tools were developed and outreach field days were held. Two web-based tools have been developed: 1) the Almond Board (<https://www.sustainablealmondgrowing.org/>) CDFA-FREP website and 2) CropManage platform (<https://cropmanage.ucanr.edu/Home/SplashPage?ReturnUrl=%2F>). In addition, seven statewide N demonstration project days were held with a total of 725 attendees. During these project days,

the web-based tools were demonstrated as well as 5-6 other projects related to fertilizer and water use management. The feedback from attendees was very positive.

H. Project Impacts

This project successfully demonstrated, under grower field conditions, that the adoption of an integrated N management systems including yield estimation, N offsets for irrigation water N, in-season sampling and adaptive in season N applications ('New N Management') resulted in crop yield and leaf tissue N levels that were equal or superior to more traditional N management strategies. Nutrient use efficiency was improved under 'New N Management' in 6 of 8 trials, with average improvement in NUE of 24% and 7% in year 1 and 2 respectively. The one instance in which traditional N management resulted in an NUE superior to 'New N Management' occurred as a result of poor yield estimation and failure to adjust N budgets in season. This illustrates the critical importance of accurate early season yield prediction to help prescribe in-season fertilization.

Multiple outreach events, incorporation of the results into publications and online tools and presentation at numerous industry events further reinforced the message that integrated and advanced N management can positively impact NUE with no negative effect on crop yield.

I. Outreach Activities

Outreach grower field days were held in the spring of year 2 and 3. Documentation of activities is outlined in the results section (F) and supporting documentation can be found in the appendix. The seven field days were popular among growers and included many CCA's and PCA's who serve as key informants for knowledge dissemination among growers (725 total attendees). The attendees were engaged, asked questions and gave positive feedback at the end of the day.

The data and findings from this work were presented in multiple grower and stakeholder meetings and published in numerous refereed journals, UCANR publications, incorporated into websites (CDFA-FREP and CropManage) and reported in grower targeted publications, newsletters and blogs. Details of outreach activities are linked to this report.

J. Factsheet/Database Template

Project Title: Demonstration of a combined new leaf sampling technique for nitrogen analysis and nitrogen applications approach in almonds

Grant number: 16-0707-SA

Project Leaders:

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Started January 2017 / Ended December 2019

Location: Various Locations

County: Kern

Highlights:

- 'New' N fertilizer practices (pre and in-season yield estimates, irrigation N offset, and early leaf sampling) were contrasted with traditional practices.
- Grower field trials demonstrated an increased NUE of N of 7-24% when all BMP's were utilized.
- Web-based management tools to help farmers implement refined practices were produced.
- Extensive outreach through field meetings, grower friendly publications and training programs have resulted in increased practice adoption.

Introduction:

Excessive use of nitrogenous fertilizers in high value agriculture has resulted in the contamination of ground water with nitrate. This is partly due to lack of adoption of the full suite of best nutrient management protocols. Several practices have been shown to improve the efficiency of N use in orchards. Accurate yield estimation is the most important determinant of N demand, estimation of N demand also requires the determination of N contribution from irrigation water and the offset of that N amount from fertilizer application. To optimize the utilization of N it is also essential that N applications be made in proportion to the current N demand in as many applications as is possible and that early season tissue N determination be conducted. Collectively the combination of all of these tools, along with in-season adjustment of fertilization quantities can result in improved NUE. To aid in grower acceptance of this suite of activities (New practices) it is essential that the efficacy of these methods be demonstrated through rigorously controlled and well replicated on-farm experimentation and effective outreach of demonstrated results. This project has successfully demonstrated the effectiveness of a refined 'New N Management' protocol without compromising almond yield or quality. The new protocol has been incorporated into web-based management tools and the concepts presented to growers and crop advisors via interactive field days.

Methods:

Four project demonstration orchards with treatment contrast between 'Traditional' Grower and 'New' nitrogen management strategies were established in 4 distinct 15-year-old Kern County Almond

orchards averaging 80 acres. Each of the four orchards were divided in half with one half receiving the 'New' N management protocols and the paired half receiving the 'Traditional' management practice. Two treatments (each half of a paired orchard block) were imposed: 1) 'Traditional Grower N Management' in which N application rate was determined by grower experience based upon relative orchard vigor. These N demands were then delivered in four application timings- March, April, May, June - 30% -30% -30% -10%. This 'traditional' practice was contrasted with 2) 'New N Management Practice' in which N Rate determined by Bloom Yield Estimate and N demand of 68 lbs N/1000 lb. kernel yield, and N application rate was modified based upon April leaf sampling. N application rates were also reduced by determination of N supplied in irrigation water (assuming 48" applied water) and residual N in soil (48" rooting depth, 50% wetted volume, average soil Nitrate-N). Applications were made in proportion to seasonal plant N demand in March 5th, April 20th, June 1, Aug 30 (20/30/30/20). yield predictions were made by an experienced extension specialist utilizing historical yield records, current bloom intensity and knowledge of winter and spring environmental conditions. Yield predictions were converted to nitrogen fertilization strategies using the Almond Board CASP nitrogen budgeting calculator decision support tool and nitrogen management plans were generated for the orchard. The final quantity of fertilizer was calculated based on predicted yield, total N requirement of the crop calculated as kernel yield/1000 x 68 lbs and measurements of the amount of N from non-fertilizer sources including N per acre coming from soil and water. N management strategies were demonstrated in four grower field trials and results extended through a large number of outreach, web and published outputs.

Findings:

This project successfully demonstrated the effectiveness of the full suite of N best management strategies including yield estimations, in season N determination, N offset from irrigation and balanced season long fertilizer application. In contrast to traditional practices this reduced N application rate resulted in equivalent or greater yields and a reduction in total N applied of 10-75 lbs. acre year. Nitrogen use efficiency (NUE) was high in all fields ranging from 48% to 97% and in the 'new' N management practices an increase in N use efficiency (24% in year 1 and 7% in year 2 was achieved in contrast with traditional grower practices. NUE was improved in large part due to the inclusion of N present in irrigation water as a credit against N fertilizer requirements. The results also illustrate that N use efficiency is compromised by incorrect yield estimation and failure to conduct in season fertilization modifications as yield estimations are refined.

In order to promote the widespread adoption of best nitrogen management practices, two web-based tools have been developed: 1) the Almond Board (<https://www.sustainablealmondgrowing.org/>) CDFA-FREP website and 2) CropManage platform (<https://cropmanage.ucanr.edu/Home/SplashPage?ReturnUrl=%2F>). In addition, a large number of outreach activities were performed.

Statewide N demonstration project days were held with a total of 725 attendees.



K. Copy of the Product/Result: A link to all publications will be available on Box.

<https://ucdavis.box.com/s/id0jy6d6ajqpvq7qpkdhvij9utm1svht>

- Baram, S., Dabach, S., Jerszurki, D., Stockert, C.M., Smart, D.R. (2018), Upscaling point measurements of N₂O emissions into the orchard scale under drip and microsprinkler irrigation. *Ag. Eco. Env.* 265, 103-111.
- Baram, S., Couvreur, V., Harter, T., Read, M., Brown, P. H., Hopmans, J. W., et al. (2016a). Assessment of orchard N losses to groundwater with a vadose zone monitoring network. *Agric. Water Manag.* 172. doi:10.1016/j.agwat.2016.04.012.
- Baram, S., Couvreur, V., Harter, T., Read, M., Brown, P. H., Kandelous, M., et al. (2016b). Estimating nitrate leaching to groundwater from orchards: Comparing crop Nitrogen excess, deep vadose zone data-driven estimates, and HYDRUS modeling. *Vadose Zo. J.* 15. doi:10.2136/vzj2016.07.0061.
- Khalsa, S. D. S., Rudnick, J. M., Lubell, M. N., and Brown, P. H. (2019b). Adoption of N Management Practices By Permanent Crop Growers in the San Joaquin Valley, California. in *ASA, CSSA and SSSA International Annual Meetings (2019) (ASA-CSSA-SSSA)*.
- Muhammad, S., Saa, S., Khalsa, S. D. S., Weinbaum, S., and Brown, P. (2017). 14 Almond Tree Nutrition. *Almonds Bot. Prod. Uses*, 291.
- Muhammad, S., Sanden, B. L., Saa, S., Lampinen, B. D., Smart, D. R., Shackel, K. A., et al. (2018b). Optimization of nitrogen and potassium nutrition to improve yield and yield parameters of irrigated almond (*Prunus dulcis* (Mill.) DA webb). *Sci. Hortic. (Amsterdam)*. 228, 204–212.
- Saa, S., Fernández, E., Muhammad, S., Río, A. O. Del, DeJong, T. M., Laca, E., et al. (2017). Increases in leaf nitrogen concentration and leaf area did not enhance spur survival and return bloom in almonds (*Prunus dulcis* [Mill.] DA Webb). *Acta Physiol. Plant.* 39. doi:10.1007/s11738-017-2401-1.
- Saa, S., Peach-Fine, E., Brown, P., Michailides, T., Castro, S., Bostock, R., et al. (2016). Nitrogen increases hull rot and interferes with the hull split phenology in almond (*Prunus dulcis*). *Sci. Hortic. (Amsterdam)*. 199. doi:10.1016/j.scienta.2015.12.027.
- Zhang, Z., Jin, Y., Chen, B., and Brown, P. (2019). California Almond Yield Prediction at the Orchard Level With a Machine Learning Approach. *Front. Plant Sci.* 10, 809.

L. Figures, Graphs and Appendix:

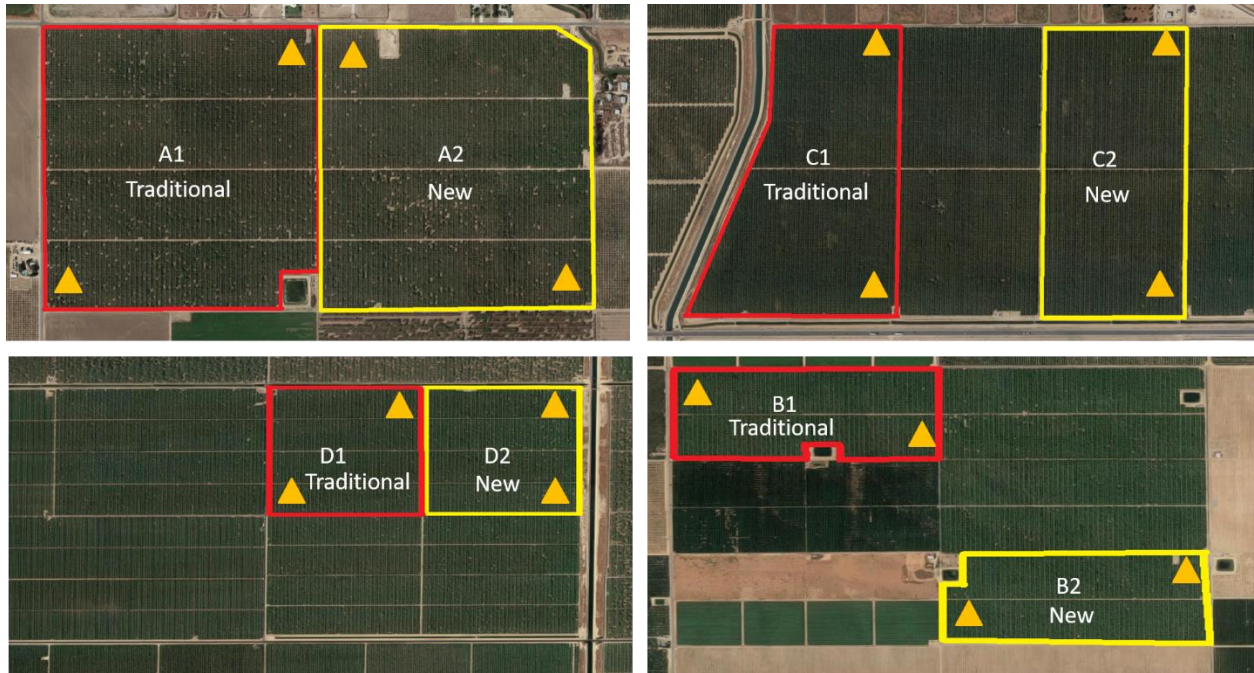


Figure 1: Four project demonstration orchards (A-D) with treatment contrast between 'Traditional Grower (1) and 'New' nitrogen management strategies (2) were established in 4 distinct 15 year-old Kern County Almond orchards averaging 80 acres with 50% Nonpareil, 50% Monterey (only Nonpareil data was collected).

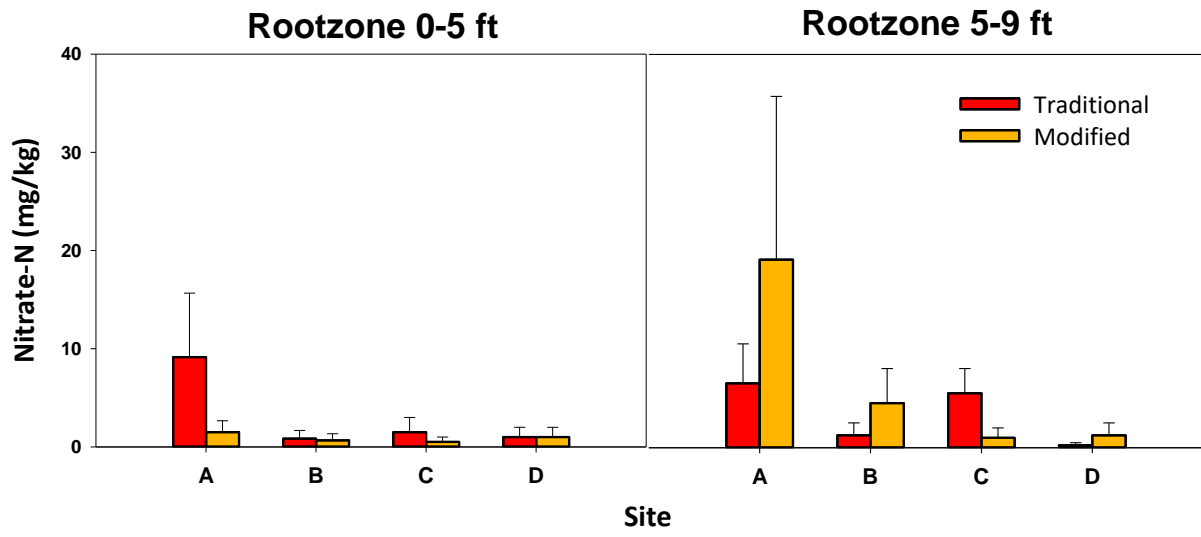


Figure 2: Soil nitrate in rootzone at the end of year 2.

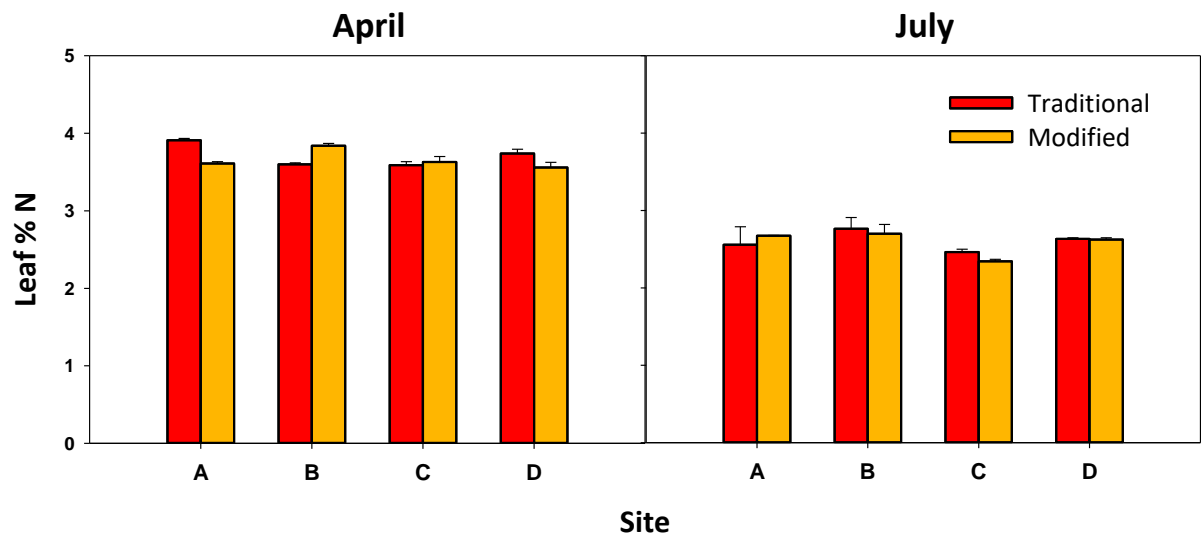


Figure 3: Leaf N (%) in April and July. BMP was equivalent to traditional method and both had more than adequate N.

Table 1: Nitrogen management demonstration trial year 2 contrasted with year 1. Paired fields within same orchard received either traditional grower management (A1,B1,C1,D1) or New Management Practices (A2,B2,C2,D2) utilizing yield estimation, early season sampling, 4 in-season fertilization in accordance with growth curve and N credits from soil and water.

RANCH - YEAR 2	1st Bloom Yield Estimate (lb/ac)	Spring Estimated N Demand @ 68 lb N/1000 lb	Required N @ 70% NUE	Total N Credit (lb/ac)	Total Applied N (lb/ac)	Final Nonpareil Yield (lb/ac)	Brown Fruit N export @68 lb N/1000 lb	Calculated NUE
Field A - Traditional	2650	180	257	20	249	2350	160	59%
Field A - New	2350	160	228	58	206	2526	172	65%
Difference in Applied N					-43			
Field B - Traditional	2550	173	248	21	245	2887	196	74%
Field B - New	2600	177	253	25	234	3629	247	95%
Difference in Applied N					-11			
Field C - Traditional	2650	180	257	15	210	3109	211	94%
Field C - New	2700	184	262	17	246	2579	175	67%
Difference in Applied N					-36			
Field D - Traditional	2200	150	214	34	249	2333	159	56%
Field D - New	2300	156	223	7	217	2172	148	66%
Difference in Applied N					-32			

RANCH - YEAR 1	1st Bloom Yield Estimate (lb/ac)	Spring Estimated N Demand @ 68 lb N/1000 lb	Required N @ 70% NUE	Total N Credit (lb/ac)	Total Applied N (lb/ac)	Final Nonpareil Yield (lb/ac)	Brown Fruit N export @68 lb N/1000 lb	Calculated NUE
Field A - Traditional	3400	231		69	235	3095	210	69%
Field A - New	2700	184	262	69	165	2910	198	85%
Difference in Applied N					-70			
Field B - Traditional	2900	197		15	245	2831	193	74%
Field B - New	3000	204	291	15	269	2661	181	64%
Difference in Applied N					24			
Field C - Traditional	3100	211		56	210	2745	187	70%
Field C - New	2200	150	214	56	134	2706	184	97%
Difference in Applied N					-76			
Field D - Traditional	2800	190		90	210	2097	143	48%
Field D - New	2800	190	272	90	144	2433	165	71%
Difference in Applied N					-66			

Appendix 1: Program flyers for field day outreach events.

Spring Almond and Walnut Nutrient and Water Management Field Day

Tuesday, March 13th, 2018, Arbuckle, CA

Please join us on Tuesday, March 13th from 8:30 am to 1:00 pm to participate in talks and rotating sessions on best water and nutrient management practices. This event is co-sponsored by UC Cooperative Extension, UC Davis, CDFA-FREP and the Almond Board of California.

Agenda

8:30-9:00-Registration and coffee

Group Talks:

9:00 am-9:30- ABC Overview and Almond Sustainability Program (ABC)

9:30-10:00 am- Water and N management for integrated hull rot management (Franz Niederholzer)

Rotating Stations (10:00-12:30pm)

- Barriers to Adoption of Nitrogen Management Practices (Jessica Rudnick, Sat Darshan S. Khalsa, Stephanie Tatge)
- Nitrogen management BMP's in walnut (Katherine Jarvis-Shean)
- Managing boron in irrigation water (Patrick Brown)
- Forward tissue sampling and overview of BMP trials to manage N and water (Sebastian Saa and Miguel Guillen)
- Tools: Irrigation efficiency and timing (Allan Fulton)
- CASP online tools (ABC)

Lunch to follow



Field day will highlight recent experimental results on BMP trials conducted in collaboration between UCCE and Dr. Brown's lab.

March 13th 8:30 am to 1:00 pm

Nickels Soil Lab

Greenbay Rd.
Arbuckle, CA

Directions: See map below

4 CCA Continuing Education Units
2 CURES Continuing Education Units

RSVP & Register at:

jpperry@ucanr.edu
or call 530-458-0570

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Spring Almond Nutrient and Water Management Field Day

Tuesday, March 20th, 2018, Chowchilla, CA

Please join us on Tuesday, March 20th from 8:30 am to 1:00 pm to participate in talks and rotating sessions on best water and nutrient management practices. This event is co-sponsored by UC Cooperative Extension, UC Davis, CDFA-FREP and the Almond Board of California.

Agenda

8:30-9:00-Registration and coffee

Group Talks:

9:00-9:30 am- Welcome! Grower/management conversation about goals and practices (Chris Morgner)

9:30 – 10:00 am- ABC Overview and Almond Sustainability Program (ABC)

Rotating Stations (10:00-12:30pm)

- Nutrient Management Plans (Phoebe Gordon)
- Soil and water testing for planning and feedback (Mae Culumber)
- Forward tissue sampling and overview of BMP trials to manage N and water (Patrick Brown and Miguel Guillen)
- Tools: Irrigation efficiency and timing (David Doll)
- CASP online tools (ABC)

Lunch to follow



Field day will highlight recent experimental results on BMP trials conducted in collaboration between UCCE and Dr. Brown's lab.

March 20th 8:30 am to 1:00 pm

Location:
Ash Slough Farms
Ave 21, Chowchilla, CA

Directions: Map below

Requesting 3.5 Continuing Education Units

RSVP & Register at:

<http://cemadera.ucanr.edu>
or call 559-675-7879

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KERN UCCE/Almond Board NMP FIELD DAY AGENDA – 3/21/2018

(Support & funding: Almond Board, CDFA Fertilizer Research Education Program)

8:30-9 Registration / Welcome, program introduction Coffee and donuts

9-9:30 (LARGE GROUP) Early season tissue sampling and overview of BMP trials to manage N and water – Patrick Brown – (Pomology/fertility, UC Davis) and Miguel Guillen

9:30-12 30 MINUTE ROTATIONAL TALKS/DISCUSSIONS
(Each speaker to repeat 4-5 times, as needed)

How does NMP reporting fit into the larger Irrigated Lands Regulatory Program? – Nicole Bell (Manager of Kern River Watershed Coalition Authority)

ABC Sustainability Program: On-line tools for water and fertilizer management - Almond Board of California

Nutrient Management Plans: the Bigger Picture – Nick Clark (Nutrient management & agronomy farm advisor, UCCE Kings-Tulare)

Soil/Plant/Water testing for planning and trouble-shooting NMP's – Keith Backman (senior agronomist for Dellavalle Lab and certified CURES instructor)

Tools for field assessment: Distribution uniformity, aerial/remote sensing – Blake Sanden (Irrigation & soils farm advisor, Kern UCCE)

12 – 1 BOX LUNCH

1-1:30 (LARGE GROUP) California Almond Sustainability Program (CASP – ABC)

1:30-3 30 MINUTE ROTATIONAL TALKS/DISCUSSIONS
(Each speaker to repeat 3 times, as needed)

Barriers to adoption of new practices- Mark Lubell and team (Environmental policy, UC Davis)

Control of navel orange worm via mating disruption / puffers etc. – Dave Haviland (Entomology/IPM, Kern UCCE)

Spring diseases in almonds – Mohammad Yaghmour (Deciduous crops advisor, Kern UCCE)

Spring Almond and Walnut Nutrient and Water Management Field Day

Tuesday, March 27th, 2018, Corning, CA

Please join us on Tuesday, March 27th from 8:30 am to 1:00 pm to participate in talks and rotating sessions on best water and nutrient management practices. This event is co-sponsored by UC Cooperative Extension, UC Davis, CDFA-FREP and the Almond Board of California.

Agenda

8:30-9:00-Registration and coffee

Group Talks:

9:00-9:30 am- Welcome! Grower/management conversation about goals and practices (Matt Esteve)

9:30 – 10:00 am- ABC Overview and Almond Sustainability Program (ABC)

Rotating Stations (10:00-12:30pm)

- Nitrogen management BMP's in walnut (Katherine Jarvis-Shean)
- Soil and water testing for planning and feedback (Luke Milliron)
- Forward tissue sampling and overview of BMP trials to manage N and water (Patrick Brown and Miguel Guillen)
- Tools: Irrigation efficiency and timing (Allan Fulton)
- CASP online tools (ABC)

Lunch to follow



Field day will highlight recent experimental results on BMP trials conducted in collaboration between UCCE and Dr. Brown's lab.

March 27th 8:30 am to 1:00 pm

California Almond Packers and Exporters (CAPEX)

Corning, CA

Directions: CAPEX plant address is 21275 Simpson Road, Corning, CA.

Field day site 1.2 miles west of plant on Simpson Road.

Requesting 3.5 Continuing Education Units

RSVP & Register at:

<http://cetehama.ucanr.edu>

or call 530-527-3101

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Spring Almond Nutrient and Water Management Field Day

Tuesday, March 26th, 2019 - Chico, CA

Please join us on Tuesday, March 26th from 8:30 am to 12:30 pm to participate in talks and rotating sessions on best water and nutrient management practices. This event is co-sponsored by UC Cooperative Extension, UC Davis, CDFA-FREP and the Almond Board of California.

Agenda

8:30-9:00-Registration and coffee/treats

Group Talks:

9:00-9:30 am- Welcome! Grower/management conversation about goals and practices.

9:30 – 10:00 am- ABC Overview and Almond Sustainability Program.

Rotating Stations (10:00-12:30pm)

- Forward tissue sampling and overview of BMP trials to manage N and water (Patrick Brown)
- Barriers to adoption of nitrogen management Practices. (Sat Darshan Khalsa)
- Incorporating pressure chamber readings to refine irrigation management. (Luke Milliron)
- Hull rots, their biologies and management. (Franz Niederholzer)
- High Frequency Low Nitrogen (HFNC) fertigation trials. (Teena Armstrong-Stockert)

Lunch to follow



Field day will highlight recent experimental results on BMP trials conducted in collaboration between UCCE and Dr. Brown's lab.

March 26th 8:30 am to 12:30 pm

Location: Chico State University Farm Pecan Orchard (see exact directions to site below)

Offering

3.5 CCA Continuing Education Units
2 CURES Continuing Education Units

RSVP to

<http://ucanr.edu/survey/survey.cfm?surveynumber=26918>

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Spring Almond Nutrient and Water Management Field Day

Thursday, March 14th, 2019, Del Rey, CA (Fresno County)

Please join us on Thursday, March 14th from 8:30 am to 12:30 pm to participate in talks and rotating sessions on best water and nutrient management practices. This event is co-sponsored by UC Cooperative Extension, UC Davis, CDFA-FREP and the Almond Board of California.

Agenda

8:30-9:00 - Registration and coffee/treats

Group Talks:

- 9:00-9:30am - Welcome!
Grower/management conversation about goals and practices.
- 9:30 – 10:00 am- ABC Overview and Almond Sustainability Program.

Rotating Stations (10:00-12:30pm)

- Soil and water testing for planning and feedback (Mae Culumber)
- Forward tissue sampling and overview of BMP trials to manage N and water (Patrick Brown)
- Barriers to adoption of nitrogen management practices (Sat Darshan Khalsa)
- High frequency low nitrogen (HFLLC) fertigation trials. (Hanna Ouaknin)
- Nitrogen management in first year recycled orchards. (Brent Holtz)

Lunch to follow



Field day will highlight recent experimental results on BMP trials conducted in collaboration between UCCE and Dr. Brown's lab.

March 14th 8:30 am to 12:30 pm

Location: Chandler Farms
West of McCall on Adams avenue (Del Rey) (36.63425, -119.613639)

Directions: Map below

Requesting

3.5 CCA Continuing Education Units
2 CURES Continuing Education Units

RSVP to

Mae Culumber

cmculumber@ucanr.edu

559-241-7526

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Spring Almond Nutrient and Water Management Field Day

Tuesday, March 19th, 2019, Modesto, CA

Please join us on Tuesday, March 19th from 8:30 am to 12:30 pm to participate in talks and rotating sessions on best water and nutrient management practices. This event is co-sponsored by UC Cooperative Extension, UC Davis, CDFA-FREP and the Almond Board of California.

Agenda

8:30-9:00-Registration and coffee

Group Talks:

- 9:00-9:30 am- Welcome! grower/management conversation about goals and practices.
- 9:30 – 10:00 am- ABC overview and almond sustainability program.

Rotating Stations (10:00-12:30pm)

- Forward tissue sampling and overview of BMP trials to manage N and water. (Patrick Brown)
- Barriers to adoption of nitrogen management practices. (Sat Darshan Khalsa)
- High frequency low nitrogen (HFLLC) fertigation trials. (Hanna Ouaknin)
- Nitrogen management in first year recycled orchards. (Brent Holtz)
- CASP online tools for nitrogen and irrigation management. (Spencer Cooper)

Lunch to follow



Field day will highlight recent experimental results on BMP trials conducted in collaboration between UCCE and Dr. Brown's lab.

March 19th 8:30 am to 12:30 pm

Location: Bowman Farms
5737 California Ave, Modesto, CA
95358. (37.623653, -121.094636)

Directions: Map below

Offering

3.5 CCA Continuing Education Units
2 CURES Continuing Education Units

RSVP to

<http://ucanr.edu/survey/survey.cfm?surveynumber=26880>

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2019 Field Day, Bowman Farms, Modesto. Session by Thomas Harter and Hanna Ouaknin



2019 Field Day Chico State Farm. Patrick H. Brown session on N management.



2019 Field Days, Fresno. Large group introduction.