ALMOND BOARD OF CALIFORNIA

RESEARCH UPDATE 2019

Advancing the California Almond Industry through Research

Launched in 1973, the Almond Board of California (ABC) has invested in independent scientific research, in the U.S. and internationally, to support continued innovation and improvement in how almonds are grown and consumed. In the initial years, research focused on almond production but has since expanded to four distinct research areas:

- Production: including horticulture, pest and disease management, irrigation, soil health, tree nutrient management, harvesting, biomass utilization and pollination and bee health.
- Environment: from water quality and sustainable supply management, to air quality, carbon footprint, and soil health.
- Human nutrition: research on heart health, diabetes, weight management and skin health.
- Quality & Food Safety: optimization of almond quality while addressing prevalence and management of food pathogen risks.

This report summaries the current portfolio of ongoing research in these major areas.

To ensure research targets industry priorities and delivers practical and relevant information to growers, handlers, food companies and consumers, the ABC engages over 100 stakeholders from across the industry to serve on several committees and working groups. These groups help set strategic direction and provide oversight of the research programs. This includes the Strategic Agricultural Innovation Committee (SAIC), which oversees production, biomass, and environmental research; the Almond Quality and Food Safety Committee (AQFS) which oversees quality and food safety research; and the Nutrition Research Committee (NR).

The ABC encourages publication of sponsored research to ensure independence and peer review. Growers can learn about new innovations through the ABC's communication and outreach publications, events, our partnerships with USDA with California's outstanding network of cooperative extension and farm advisors, and efforts by other industry members.

To learn more detail about current and past research projects, the ABC's research data base contains forty years of research project reports that can be searched on line at http://www.almonds.com/growers/resources/research-database.

The ABC's research helps California almond farmers and processors provide a safe, wholesome and sustainable product.

The ABC sends warm wishes for a prosperous 2020 and would like to express gratitude to our research committees', industry volunteers, and researchers.

For the Almond Board of California,

Richard Waycott
President and CEO
rwaycott@almondboard.com

Karen Lapsley
Chief Scientific Officer
(Nutrition Research Committee; Biomass Working Group)
klapsley@almondboard.com

Josette Lewis
Director, Agricultural Affairs
(Strategic Ag Innovation Committee; Pollination Bee Health Working Group)
jlewis@almondboard.com

Swati Kalgaonkar
Associate Director, Nutrition Research
(Nutrition Research Committee)
skalgaonkar@almondboard.com

Gabriele Ludwig
Director, Sustainability & Environmental Affairs
(Sustainability Working Group)
gludwig@almondboard.com

Tim Birmingham
Director, Quality Assurance and Industry Services
(Almond Quality & Food Safety Committee)
tbirmingham@almondboard.com

Sebastian Saa
Senior Manager, Agricultural Research
(Orchard, Tree, Rootstock; Irrigation, Nutrients, Soil Health; Harvest; Working Groups)
ssaa@almondboard.com

Guangwei Huang
Associate Director, Food Research & Technology
(Biomass; Harvest Working Groups)
ghuang@almondboard.cm

Jesse Roseman
Principle Analyst, Regulatory, Environmental Affairs
(Pest Management Working Group)
jroseman@almondboard.com

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Efficacy of AF36 Prevail after Commercial Application, Search for the Best Timing of Application, and Susceptibility of Almond Cultivars to Aflatoxigenic *Aspergillus* Species

Project Leader: Themis J. Michailides
University of California Davis/ Kearney Agricultural Research and Extension Center (KARE), 9240 South Riverbend Ave., Parlier, CA 93648; (559) 646-6546 tjmichailides@ucanr.edu

PROJECT SUMMARY

Objectives

The overall goal of this project is to optimize the use of atoxigenic strain technology to reduce aflatoxin contamination in California almonds. This includes improving the sporulation efficiency of the AF36 Prevail®, implementing an area-wide, long-term management program to change the population structure of the aflatoxin producing fungi, *Aspergillus* Section *Flavi,* to reduce the overall aflatoxin-producing potential of the population, and at the same time, to reduce the risk of damaging the environment and the beneficial microflora in almond orchards
The current specific objectives are:

- To develop a qPCR protocol to evaluate the ratio AF36 / *A. flavus* & *A. parasiticus.*
- To study the risk of infection during the period that the almond fruit are drying on the ground.
- To determine the optimal period of application and improved sporulation of AF36 Prevail in almond.
- To determine the effect of almond cultivars on aflatoxin accumulation.
- To monitor the atoxigenic A. flavus AF36 in commercial almond where AF36 is applied and evaluate its effect on area-wide long-term reduction of aflatoxin in almonds.

Background

Aflatoxins are carcinogenic contaminants produced by the fungi *Aspergillus flavus and A. parasiticus.* The almond industry has taken extensive measures and supports pre- and post-harvest research to control aflatoxin and to assure compliance with aflatoxin regulations. Area-wide management programs might be the best option to reduce the risks of aflatoxin contamination in tree nuts, including almonds.

Discussion

Determining the effect of atoxigenic biocontrol as part of an area-wide program will require increasing the number of fields and samples to analyze. Specific primers differentiating *A. flavus* AF36 from other *A. flavus*/*A. parasiticus* were developed and used in a Real Time PCR (SNP-qPCR) program to quantify the proportions of both AF36 and *A. flavus/A. parasiticus* contained in the samples. This method can expedite the analysis of samples, reducing its costs and increasing the certainty of the study.

In the 2018 timing of application experiment, the first application was made before hull split (26 June). Sporulation at all times of application was around 50%, with the highest percentages observed in July after hull split started. Aflatoxin was not detected in any of the almond samples. Displacement, measured as % of AF36, in the kernels at all times of application ranged from 47% to 55% and it was significantly higher than the control (5% sporulation), except for the latest application in August (22% sporulation). This experiment is being repeated in 2019 and currently samples are being processed and analyzed for both displacement and aflatoxin.

The influence of soil moisture and temperatures on the sporulation of AF36 Prevail and a second product, Afla-Guard®, was also evaluated. Optimal sporulation occurred at soil moisture between 15 and 18%. Temperatures below 15ºC significantly delayed the sporulation of AF36 Prevail, regardless of soil moisture. These temperatures are common in the Central Valley until mid-June.

In an area where tree nuts at risk of aflatoxin contamination (pistachio and almond) are grown together the effect of AF36 applications on area-wide management is being evaluated. In one part both pistachio and almond were treated, while in another only pistachio was treated. The change of the population structure of *A. flavus* between the almond treated and not treated areas will be evaluated.

Project Cooperators and Personnel: R. Jaime, T. Garcia, J. Moral, R. Puckett, V. Gabri, and L. Boeckler, UC Kearney Ag Center; Parlier, CA.

Altered Lipid Metabolism-Bifenthrin-Resistant Navel Orangeworm (NOW) Potential Cross-Resistance to Pesticides

Project Leader: May Berenbaum Researchers: Esther Ngumbi, Daniel Bush, Mark Demkovich
Dept. of Entomology, University of Illinois, 505 S. Goodwin Ave., Urbana, IL 61801 (217)333-7784 maybe@illinois.edu

PROJECT SUMMARY

Objectives:

- **1:** Determine and compare cuticular hydrocarbon profiles between insecticide-resistant and susceptible strains of navel orangeworm (NOW)
- **2:** Determine LC_{50} contact toxicity of chlorantraniliprole and methoxyfenozide to larval NOW from a range of populations, with bifenthrin as a positive control
- **3:** Determine whether kaolin clay can prevent egg hatch and/or cause neonate mortality

Background, Results, and Discussion:

Objective 1: The insect wax layer comprises cuticular hydrocarbons (CHCs) that both prevent desiccation and provide intraspecific communication signals. CHCs can also contribute to insecticide resistance via reduced penetrance. We assessed the role of CHCs in NOW insecticide resistance. We found differences in cuticular hydrocarbon profiles between adults of pyrethroid-resistant (R347) and susceptible strains. Hydrocarbon profiles consisted of 47 compounds of lengths ranging from C_{17} to C_{43}. Generally, R347 adults had greater total CHC quantities, but relative quantities of individual components were similar. We also found that CHC quantities increased with age. Our results indicate that CHCs vary by strain and age and could potentially be useful biomarkers to differentiate between insecticide-resistant and susceptible strains. A manuscript from this work is in review at *Journal of Chemical Ecology*.

Objective 2: We developed a bioassay to assess insecticide toxicity through direct exposure to eggs and contact exposure across a treated surface. Bifenthrin concentrations of 5, 10, 20, and 40 ppm were sprayed on eggs resting on filter paper placed on the surface of artificial diet in Petri dishes. Neonates thus experienced contact exposure to treated filter paper before reaching their food underneath the treated surface. The resistant strain experienced significantly lower egg mortality relative to the susceptible strain. More larvae survived the contact exposure in the resistant strain up to three weeks after the sprays. With this method using bifenthrin as a positive control, we will bioassay contact toxicity of chlorantraniliprole and methoxyfenozide.

Objective 3: Kaolin clay hampers feeding and survival in some insect pests via an unknown mechanism; one suggested mechanism is abrasion or disruption of CHCs. We treated almond kernels with kaolin, chlorantraniliprole, or both together. In two sets of trials, we used kaolin concentrations based on field applications of both ~40 lb per 100 gallons and ~15 lb. In both versions of the experiment, kaolin and chlorantraniliprole reduced penetration of NOW larvae into the almonds and the percentage of kernels infested after one week. In addition, kaolin and chlorantraniliprole interacted synergistically, although at a reduced level in the 15 lb treatment. R347 was more resistant to all treatments (including chlorantraniliprole, which was unexpected) but was still significantly affected. These results indicate that kaolin can improve insecticide efficacy, possibly by disrupting CHCs. Dr. Joel Siegel is currently conducting field trials at ~15 lb per 100 gallons, and we are repeating the laboratory experiments using bifenthrin.

Project Cooperators and Personnel: Joel Siegel, USDA/ARS, Parlier, CA

Comparison of Navel Orangeworm Attractants

Project Leader: Charles Burks
USDA/ARS, 9611 S. Riverbend Ave., Parlier, CA 93648 (559) 596-2757, charles.burks@usda.gov

PROJECT SUMMARY

Objectives for current year:

- Examine the effect of trap characteristics on the ability of a new attractant to detect navel orangeworm, either alone or in with an added pheromone lure

Background:

Within the last decade, a newly introduced pheromone lure for navel orangeworm has greatly improved reliability of detection of potentially damaging populations of navel orangeworm. During the same period, pheromone mating disruption grew from a rarely used practice to a pest management tool used in around 500,000 acres of tree nuts. Mating disruption has become an important part of the pest management arsenal for some but has reversed gains in detection since mating disruption very effectively suppresses pheromone traps over a long distance.

Previous research funded by The Almond Board has shown that traps baited with phenyl propionate effectively capture navel orangeworm adults in the presence of mating disruption. Moreover, addition of a pheromone lure significantly synergized detection compared to traps baited with phenyl propionate alone. More recent tests, however, suggested that this synergy is almost completely reversed when the phenyl propionate and pheromone traps are combined in delta traps (generally preferred by pest managers) rather than wing traps (preferred by researchers).

Research in 2019 systematically compared the effect of trap design on detection of navel orangeworm in mating disruption by traps baited with phenyl propionate alone, or both phenyl propionate and pheromone lures.

Other research also compared, within the same test, detection with phenyl propionate vs. detection based on females captured in traps baited with oviposition baits (for example, Peterson traps) or eggs on egg traps.

Discussion:

Stock delta traps baited only with PPO captured significantly more adults than wing traps baited with a pheromone lure, and all versions of the delta trap baited with PPO captured nominally or significantly fewer adults than a wing trap baited with PPO alone, and significantly fewer adults than a wing trap baited with both PPO and a pheromone lure. Among delta trap variations, addition of a pheromone lure significantly increased the number of adults captured, and the open-sided modification had the same effect. Adding a pheromone lure to PPO presented in the open-sided modified version of a delta trap brought captures to within the same range in the multiple range test as the wing trap with PPO alone. Wing traps with PPO captured significantly more adults than stock delta traps baited with PPO, whether or not accompanied by a pheromone lure

In a mating disruption orchard, fluctuation in weekly counts in a stock delta trap baited only with a pheromone lure was consistent with seasonal abundance patterns typically observed with pheromone traps in the absence of mating disruption. With 8 replicates within 20 acres, both eggs on egg traps and females on ovipositional traps were detected during peaks corresponding to the beginning of second and third flights, but not at other times.

Project Cooperators and Personnel: Brad Higbee, Adair OK and John Beck, Gainesville FL

Arthropod Pest Management in the Lower San Joaquin Valley

Project Leader: David Haviland
University of California Cooperative Extension, Kern County, 1031 S. Mount Vernon, Bakersfield, CA 93307
(661) 868-6215, dhaviland@ucdavis.edu

PROJECT SUMMARY

Current Objectives:

- Evaluate novel methods for pheromone dissemination in mating disruption programs for navel orangeworm
- Validate trap-based monitoring programs for sixspotted thrips that aide in treatment decisions for spider mites
- Evaluate seasonal sixspotted thrips abundance and activity patterns in almond
- Evaluate the effectiveness of miticides for Pacific spider mite
- Manage a University-based research and demonstration orchard for almond pest management research

Background and Discussion:

Mating disruption for NOW- During 2017 we conducted research showing that mating disruption on 40-acre plots reduced male captures by >90% in pheromone traps and reduced damage by approximately 50%. Six demonstration sites during 2017 and 2018 on 60-100 acre scale showed trap capture reductions of >95% with an average of 50-70% reductions in damage. These trials used aerosol-based mating disruption systems made by Pacific Biocontrol, Suterra, Semios and Trécé. Economic analysis across all sites during both years showed that adding mating disruption to an existing management program pays for itself.

During 2019 we evaluated four different methods for delivery of pheromone. This included two aerosol-based emitters, a meso-dispenser, two microencapsulated pheromone products sprayed four or two times at monthly intervals, and a foam-based product applied to the tops of the trees using a drone. All plots were 40 acres in size with each treatment replicated in four different Kern County almond orchards. Plots were evaluated using egg traps, pheromone traps, and pheromone traps that included phenyl proprionate (PPO) lures. Data are currently being processed for dissemination at the Almond Industry Conference and other educational meetings this winter.

Sixspotted thrips– We continue to evaluate the role of sixspotted thrips as the primary predator of spider mites in the San Joaquin Valley. Yellow strip traps (3"x5", Great Lakes IPM), continue to be the best method for thrips monitoring. Previous work determined that finding thrips on cards in April and May indicates that biocontrol is adequate to control early-season mites. At hull split and beyond, mite populations quickly crash if there are more than three thrips per card per week. The same patterns held true during all field trials during 2019. We are currently in the process of further refining these thresholds based on post-hull split data from three orchards in 2019 and season-long data from twelve almond orchards across the San Joaquin Valley over the past two years.

Miticide efficacy- Each year we conduct a field trial to evaluate registered and experimental miticides for use in almonds. In our most recent study cumulative mite densities were significantly reduced by eleven different miticides, including three that are approved for use in organic orchards. This, and previous trials, have helped almond growers make educated decisions when making miticide applications.

Research orchard maintenance – We continue to maintain a 7-acre almond orchard in Shafter, CA with partial support from the Almond Board of California. Between the years of 2010 and 2019 this orchard has been used for 73 different trials by multiple investigators.

Project Cooperators: Stephanie Rill, UCCE - Kern County;

Another Look at Pheromonal or Related Attractants for Leaffooted Bugs Infesting California Nut Crops

Project Leaders: Jocelyn Millar[1], Houston Wilson[1], and Kent Daane[2]

[1]Dept. of Entomology, UC Riverside, Riverside CA 92521 (951) 827-5821, millar@ucr.edu; (559) 646-6519, Houston.wilson@ucr.edu

[2]Dept. of Environmental Science, Policy, and Management, UC Berkeley, 212 Wellman Hall, Berkeley CA 94720 (559) 646-6522, kdaane@ucanr.edu

PROJECT SUMMARY

Objectives for current year:

- Identify, synthesize, and bioassay final pheromone candidates from male *Leptoglossus zonatus* and *L. clypealis.*
- Bioassay summer- and winterform bugs to assess whether cuticular lipids are involved in overwintering aggregations.
- Optimize trap characteristics, with and without attractant lures.
- Test attraction of bugs to infrared radiation

Background:

Leaffooted bugs are a major problem in California nut crops, and there are currently no cost-effective methods of monitoring them, especially early in the season. The problem is compounded by the tendency for large numbers of bugs to move into a crop rapidly, so that infestations can go from negligible to substantial within a few days. Previous research has shown that these bugs use pheromones in different contexts, from alarm to aggregation and mating. We are looking at the pheromone chemistry of two species, *Leptoglossus zonatus* and *L. clypealis*, under both summer and overwintering conditions, to see whether we can identify chemical or other signals that control the rapid crop infestations in season, and the formation of overwintering aggregations in fall.

In parallel with work on possible chemical attractants, we are optimizing trapping/ monitoring methods, using traps with and without chemical attractants. In addition, Takacs et al. (2009) showed that *Leptoglossus occidentalis,* a pest of conifers, used infrared (IR) cues to locate cones, which are warmer than the rest of the tree due to the high metabolic activity in the cones. We are testing *L. zonatus* to determine whether they also may be responsive to IR cues associated with developing nuts.

Discussion:

Chemistry work has focused on identification and synthesis of the final component in extracts from males and developing a better synthesis of the major compound *cis*-α-bergamotene. Based on a partial identification of the final component, we synthesized our best guess, which proved to be incorrect. Thus, we collected more extracts all year from males. We hope to have the final compound purified from these combined extracts by the annual meeting, in quantities large enough for an unequivocal identification. The compound will then be synthesized for bioassays next year.

We had previously determined that hanging cross-vane traps coated with fluon could effectively trap LFB, and that yellow or blue traps were best. In 2019, we evaluated seasonal effects of these traps as LFB sequentially colonized almonds, pistachios, and pomegranates. Thus, multiply replicated series of black, white, red, yellow, green, and blue traps were deployed in almonds March-May, then moved to pistachios from end of May-August, and finally moved to pomegranates at the end of September. The data are still being collected and will be reported at the annual meeting.

We determined that *L. zonatus* has the same type of IR receptors as *L. occidentalis*, and a laboratory experiment is in progress to evaluate *L. zonatus* responses to infrared cues. Preliminary data will be reported at the meeting.

Project Cooperators and Personnel: Dr. Sean Halloran, Dr. Steve McElfresh, graduate students Tessa Shates and Robert Straser.

Arthropod Integrated Pest Management in the Sacramento Valley

Project Leaders: Emily J. Symmes
University of California Cooperative Extension and Statewide IPM Program (530) 538-7201, ejsymmes@ucanr.edu

PROJECT SUMMARY

Objectives for current year:

- (1) Evaluate alternatives to conventional insecticides for reducing navel orangeworm (NOW) damage in Sacramento Valley orchards (various mating disruption modalities and programs, including passive emitters and sprayable formulations).
- (2) Evaluate monitoring and decision-support (i.e., treatment timing, thresholds) methods for NOW in conventional and mating disruption orchards in the Sacramento Valley.
- (3) Evaluate the abundance, seasonality, and impacts of sixspotted thrips for spider mite biological control in the Sacramento Valley.

Background and Discussion:

The overall objectives of this ongoing research are to continue to evaluate integrated pest management (IPM) practices for the key arthropod pests of almonds and demonstrate their efficacy and economic viability in the Sacramento Valley in order to increase adoption of IPM practices in alignment with the Almond Board 2025 goals.

Navel orangeworm (Objective 1): NOW mating disruption experiments were established in three commercial almond orchards in the Sacramento Valley (Colusa and Glenn Counties). Treatments included (1) medium-density passive disruption system (Cidetrak® NOW MESO, Trécé Inc., 20/acre); (2) sprayable pheromone (experimental formulation, four applications by ground); (3) sprayable pheromone (experimental formulation, four applications by drone); (4) sprayable pheromone (experimental formulation, two applications by ground); (5) sprayable pheromone (experimental formulation, two applications by drone); and (6) no mating disruption.

Efficacy measures included season-long trap numbers (three trap stations per treatment plot, each consisting of 1 pheromone, 1 PPO, 1 Peterson, and 1 egg trap), and harvest damage (4,000 Nonpareil/treatment plot; 2,000 Monterey/treatment plot).

Navel orangeworm (Objective 2): Trapping data from seven commercial almond orchards (Butte, Colusa, Glenn, Tehama Counties) were collected season-long. Trap sets at each location included pheromone traps, Peterson traps, egg traps, and PPO traps. Nonpareil harvest samples were collected from each site (min. 2,000 Nonpareil) and evaluated for NOW infestation and damage. Correlation(s) among trapping data and harvest damage will be evaluated to continue developing robust data sets from which treatment threshold guidelines can be developed.

Spider mites (Objective 3): Sixspotted thrips were monitored in commercial almond orchards using yellow sticky strip traps to determine seasonal abundance, effect of trap size, and relationship between predators and spider mite populations in the Sacramento Valley.

At press time, data from the 2019 season are still being collected and analyzed.

Project Cooperators and Personnel:
Mike Alvarez, UCCE Butte County; almond growers; PCAs.

Influence of Different Cover Crop Systems on Navel Orangeworm (NOW) and Its Natural Enemies

Project Leaders: Houston Wilson[1], Kent Daane[2], Amelie Gaudin[3]

[1]Dept. Entomology, UC Riverside, Kearney Ag. Center, 9240 S. Riverbend Ave., Parlier, CA 93648, (559) 646-6519, houston.wilson@ucr.edu; [2]Dept. Environmental Science, Policy and Management, UC Berkeley, 212 Wellman Hall, Berkeley, CA 94720, kdaane@ucanr.edu; [3]Dept. of Plant Sciences, UC Davis, One Shields Ave., Davis, CA 95616, (530) 752-1212, agaudin@ucdavis.edu

PROJECT SUMMARY

Objectives for current year:

- Quantify the influence of ground covers on sanitation efficacy
- Determine the influence of ground covers on mummy mortality

Background:

A team of UC researchers (A. Gaudin, J. Mitchell, N. Williams, B. Hanson, A. Westphal, H. Wilson, K. Daane) are currently investigating the potential of cover crops to help almond growers improve the overall health of their orchards. Specifically, the group is evaluating the use of (treatment #1) a winter pollinator mix and (treatment #2) a winter-summer soil mix, the performance of which will be compared to plots with (treatment #3) bare-soil plots with no ground covers.

Traditionally the use of cover crops in IPM has focused on their ability to either (a) increase biological control by supporting natural enemies or (b) reduce pest densities by acting as a trap crop or by inducing changes in host-plant quality that make it less suitable for pest development. Unfortunately, none of these processes are likely to be enhanced enough by the addition of a cover crop to increase regulation of navel orangeworm (NOW) populations below the extremely low damage thresholds (<2%) required for this commodity. These low thresholds are primarily due to the association between NOW and aflatoxin, which is heavily regulated in key export markets.

Alternately, it may be that the addition of winter ground covers influences NOW populations via impacts on sanitation and NOW mortality in mummy nuts. Sanitation of mummy nuts is the foundation of NOW management, and here the hypothesis is that the addition of ground covers could potentially have both positive and negative effects on this. The potential negative effect is that ground covers could harbor mummy nuts and generally interfere with sanitation efforts (i.e. reduce sanitation efficacy). The potential positive effect is that ground covers are thought to create an inhospitable environment for overwintering NOW that ultimately increases mortality. Our goal is to better characterize these effects and quantify whether ground cover effects on mummies is a net positive or negative.

Broadly speaking, this cover crop project is unique in that it will evaluate the influence of cover crops on multiple ecosystem services such as pollination, water use, and soil quality – as well as control of pests. Here, we propose to determine the impact of these treatments on mummy sanitation and the mortality of overwintering NOW within those mummy nuts.

Discussion:

This is a winter project, so the various cover crops were sown this fall in replicated experimental plots at the UC Westside Research and Extension Center (Five Points, CA) and on commercial almond acreage near Arvin, CA. Evaluations of sanitation efficacy and mummy mortality are currently underway and will continue through May 2020.

Project Cooperators and Personnel:
Mohammed Yaghmour, UC Cooperative Extension, Kern County; David Haviland, UC Cooperative Extension, Kern County.

Development of Sterile Insect Technique (SIT) for Navel Orangeworm (NOW)

Project Leaders: Houston Wilson[1], Charles Burks[2]

[1]Dept. Entomology, UC Riverside, Kearney Ag. Center, 9240 S. Riverbend Ave., Parlier, CA 93648, (559) 646-6519, houston.wilson@ucr.edu; [2]USDA/ARS, Crop Protection & Quality Research Unit, 9611 S. Riverbend Ave., Parlier, CA 93648, (559) 596-2757, charles.burks@usda.gov

PROJECT SUMMARY

Objectives for current year:

- Determine the influence of moth strain, irradiation, shipping/handling and release mechanism on field and laboratory performance of NOW

Background:

Mass rearing and irradiation of navel orangeworm (*Amyelois transitella*) (NOW) provides a unique opportunity to explore the use of sterile insect technique (SIT) as part of an area-wide integrated pest management (IPM) program for almond, pistachio and other tree crops affected by NOW. This endeavor also may provide large quantities of NOW that can safely be released into commercial fields in large-scale mark-release-recapture experiments to improve monitoring techniques and mating disruption. In its current form, moths for this NOW-SIT project are produced and irradiated at a USDA-APHIS facility near Phoenix, AZ, and then shipped to California for release. In order to fully capture the opportunities offered by a NOW-SIT program, it is necessary to first verify the viability and performance of irradiated/shipped moths relative to wild moths. As such, this project evaluates the effects of both irradiation as well as the shipping process on NOW flight, dispersal and mating competitiveness under both laboratory and field conditions.

In 2018, data from aerial and ground releases of irradiated/sterile NOW in the absence of mating disruption provided little if any evidence that released males were able to fly to and/or locate pheromone sources. In contrast, irradiated/sterile NOW females were generally reproductively competitive (i.e. they effectively called and mated with wild males).

Objectives at the start of the 2019 season were to parse the relative importance of radiation dose, insect strain, and shipping/handling effects (cold and darkness) inherent in the release procedures used to date.

Discussion:

Mark-release-recapture experiments were carried out in almond and pistachio plots at the UC Kearney and Westside Research and Extension Centers. While recovery of male NOW was initially very weak, even when releasing non-irradiated males (recovery <1%), small changes to the release mechanism led to significant increases in recovery of males, including irradiated males (recovery ~2-6%). Data from previous mark-release-recapture studies with non-irradiated, locally produced NOW led to recovery rates between 10-20%. In 2019, we similarly made multiple releases of non-irradiated, locally produced NOW into the Kearney and Westside experimental plots and found that under these conditions' recovery was widely variable and ranged from 1-10%. Recovery of these locally produced moths was also highly variable in a pomegranate orchard, with up to 20% recovery during flowering and <5% afterwards. Under these conditions of low recovery, there was a small but statistically significant difference in recovery between moths never shipped and moths shipped from ourselves to ourselves.

A wind-tunnel study found that locally-produced males from the strain of NOW used in the Phoenix mass-rearing facility (i.e. "P-strain") effectively responded to a female pheromone source, albeit slightly less vigorously in some aspects than a locally-produced control strain of NOW collected from Mendota in 2010 (i.e. "M-strain").

Flight-mill studies are currently underway, and preliminary data indicate that locally produced P-strain moths fly as vigorously as M-strain, but that the P-strain moths shipped out from the Phoenix facility flew significantly less, regardless of irradiation.

The data to date suggests that, compared to effects of moth strain or radiation dose, the influence of shipping/handling and release mechanism appear to have a strong influence on the field performance of these sterile/irradiated NOW (particularly males).

Herbicide Performance and Crop Safety Evaluations in the Conventional Almond Production System: Field Research and Extension Support

Project Leader: Bradley D. Hanson
Department of Plant Sciences, University of California, Davis, Robbins Hall, Davis, CA 95616
(530) 752-8115, bhanson@ucdavis.edu

PROJECT SUMMARY

Objectives for current year:

- Evaluation and comparison of registered preemergence and postemergence herbicides in commercial almond orchards
- Evaluate effective sequential herbicide programs for control of glyphosate-resistant summer annual grasses.
- Determine emergence timing and biology of threespike goosegrass, a growing challenge in several almond production regions, to inform better management practices.

Background:

The overarching goal of our research and extension program (http://hanson.ucdavis.edu/) is to contribute to the economic and environmental sustainability of perennial cropping systems through effective weed management. Real world weed management and herbicide performance data form the backbone of an extension effort aimed at providing information to growers, Pest Control Advisors, Farm Advisors, the crop protection industry, and the regulatory community. This type of research is ongoing and is relevant to the greater than 99% of almond growers that utilize herbicides for weed management.

Discussion:

The first objective focuses on the control of winter annual weeds with preemergence and postemergence herbicides in research station and commercial almond orchard locations in the Central Valley. Similarly, postemergence herbicides commonly used throughout the almond growing season will be tested for the control of a suite of weedy species.

The second objective addresses the need for season-long weed management in almond production systems. With the widespread presence of herbicide-resistant summer weed biotypes in California almond orchards, postemergence herbicide efficacy is reduced. Experiments will address the underlying hypothesis is that either a single application of Prowl H2O in early winter or an additional sequential treatment in early spring will enhance control levels of tough/glyphosate-resistant summer grass weeds through the end of the growing cycle.

The third objective addresses the need for up-to-date information on the biology and control of tough summer weed species, particularly threespike goosegrass, which is suspected to be resistant to glyphosate and is a rapidly expanding problem in tree nuts in California. As this species is a relatively new problem in California orchards and is not common elsewhere in the US, basic information on the biology of this species and effective control strategies are needed

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Project Cooperators and Personnel: Seth Watkins, Katie Martin, Steven Haring, Drew Wolter, Matt Fatino, and Gale Perez, UC Davis; Mariano Galla, UCCE – Glenn/Butte/Tehama, and Lynn Sosnoskie, UCCE Merced/Madera

Non-Fumigant Approaches and Diagnostics for Orchard Replacement and Soilborne Disease Management

Project Leader: Greg Browne
USDA-ARS Crops Pathology and Genetics Research Unit, Department of Plant Pathology, UC Davis, One Shields Ave., Davis, CA 95616; (530) 754-9351, gtbrowne@ucdavis.edu

PROJECT SUMMARY

Objectives for current year:

- Optimize preplant soil remediation strategies based on almond byproducts and anaerobic soil disinfestation (ASD) for almond replant problems.
- Relate benefits of ASD and soil fumigation to underlying impacts on soil microbial and other soil properties.
- Determine causal species and manageable factors associated with incidence of *Phytophthora* in young almond orchards.
- Improve diagnostics for prescriptive management of almond replant problems.

Background:

Efficient development of crop production potential in young, replanted almond orchards can be seriously compromised by several soilborne diseases. Among the most common of these are: Prunus replant disease (PRD) (a young tree growth suppression mediated by the soil microbial community in successive plantings of almond or other *Prunus* species); plant parasitic nematodes (root damage caused by several species), and Phytophthora (crown and root rots caused by >10 species of *Phytophthora*). Preplant soil fumigation has been widely used to manage the former two diseases, whereas integrated cultural, chemical, and genetic approaches are most effective for control of Phytophthora. Because regulatory restrictions on fumigation are expected to intensify with time, we are working to optimize ASD and its components (soil amendment, solarization, etc.) as alternatives to fumigation. Our work with Phytophthora is designed to closely monitor the causal populations so that representative species are selected for testing rootstocks, oomycete fungicides, and soil management practices (prevalence of different *Phytophthora* species has shifted markedly over the last decade). Our work with replant diagnostics is designed to improve decision-making about whether or not an orchard being replaced would benefit from preplant soil fumigation or other remediation strategies. Conventional methods are available for assessing the need for fumigation as called for by nematodes, but much less is known about how to predict the need for fumigation based on potential for PRD.

Progress and Discussion:

ASD and its optimization. At a commercial replant trial established in 2019 near Chowchilla, we are monitoring performance of almond trees following ASD treatments based on (1) ground almond hull and shell substrate and (2) rice bran. Each substrate was applied in separate treatments, with and without a tarp cover, and with and without extra postplant nitrogen applications. The trial also includes multiple macro and micronutrient fertilizer treatments to determine the degree to which tree growth can be improved through fertilization. In this trial, all treatments followed whole orchard recycling. Tree growth and nutrition data from this and additional, older trials will be presented.

Phytophthora diseases. Our statewide surveys indicate that *Phytophthora niederhauserii* and a variant of *P. cinnamomi* are the most prevalent, and problematic species of *Phytophthora* on almond in California. We periodically supply collections of our isolates to collaborator J. Adaskaveg for testing sensitivity to fungicides. We have detected new species of *Phytophthora* affecting almond, including *P. chlamydospora* and *P. rosacearum*. Our greenhouse experiments to date have not detected a strong effect of whole orchard recycling on incidence or severity of disease caused by *P. niederhauserii*.

Diagnostics for replant decisions. To date, as a basis for diagnostics development, we sampled soils from six almond orchards (one near Arbuckle, two near Modesto, one near Chowchilla, three near Parlier). Additional sites are being located. Each orchard will be replanted within a year of sampling and will include fumigated and non-fumigated areas. Microbial, physical, and chemical properties are being analyzed for each of the soils and, ultimately, will be related to replanted orchard growth.

Project Cooperators and Personnel: N. Ott, A. Khan, A. Poret-Peterson, H. Forbes, K. Sanchez, M. Gillis, A. Hodson, M. Yaghmour, B. Holtz, P. Gordon, F. Niederholzer, G. Brar, M. Culumber, and F. Trouillas

Biology and Management of Almond Scab and Alternaria Leaf Spot

Project Leader: J. E. Adaskaveg
Department of Microbiology and Plant Pathology, University of California, Riverside, CA 92521
(951) 827-7577 jim.adaskaveg@ucr.edu

PROJECT SUMMARY

Objectives:

- Determine population composition of the scab pathogen *Fusicladium carpophilum* and occurrence of sexual reproduction.
- Evaluate new and registered fungicides for their efficacy against scab and Alternaria.
- For scab management, evaluate the effect of dormant and in-season applications.
- Establish baseline sensitivities, monitor for fungicide sensitivity shifts in the pathogens, and characterize mechanisms for resistance against SDHI and DMI fungicides.

Background and Discussion:

Scab caused by *Fusicladium carpophilum* and Alternaria leaf spot caused by *Alternaria alternata* and *A. arborescens* are economically important summer diseases of almond, especially in locations with high humidity and poor air circulation. Severity of both diseases was lower in 2019 following a general trend over the last few years. This is likely because of reduced irrigation due to the drought and subsequent less favorable disease conditions.

We continued to evaluate populations of the scab pathogen from different areas in the state. Molecular population methods indicated no evidence for sexual recombination. Thus, *Fusicladium* and *Alternaria* spp. appear to only reproduce asexually by conidia in California. Based on molecular analyses, however, two species of *Fusicladium* may exist sympatrically and occupy the same niche on almond tissues and may even be present in the same lesions.

On almond, the FRAC (FC) 7 boscalid, fluopyram, fluxapyroxad, isofetamid, and penthiopyrad are registered, and pydiflumetofen and pyraziflumid are in development. Randomly generated resistant mutants may accumulate in pathogen populations after repeated selective pressure (i.e., application of one FC). Genetic mutations have been identified in *Alternaria* spp. in SDH subunits B, C, and D that correspond with resistance to selected SDHI fungicides (FC 7). The highest incidence of resistance occurs against boscalid, fluxapyroxad, penthiopyrad, and pyraziflumid. Currently, only moderate resistance (EC_{50} <0.5 ppm) has been detected to fluopyram and in one isolate to the new pydiflumetofen. We identified cross resistance patterns among SDHI fungicides that correlated with mutations SDHB-H277Y, SDHB-277L, or SDHC-H134R. Most isolates carried the SDHC-H134R mutation. Resistance to newer SDHI sub-groups is detected before commercial introduction. Thus, either less-sensitive variants pre-exist, or resistance is an ongoing selection process related to fitness or non-detrimental changes in the pathogen.

The new FC 3 Cevya was highly active against *Alternaria* isolates and against isolates molecularly identified as *F. carpophilum*. Chlorothalonil-oil dormant treatments delay scab inoculum production on overwintering twig lesions and are an anti-resistance strategy (a smaller population is exposed to selection processes) that align in-season, springtime treatments for scab, Alternaria leaf spot, and rust. In-season fungicide timings for scab are initiated at twig lesion sporulation, whereas the Disease Severity (DSV) model (with positioning of sensors 10-16 ft in the outer canopy) optimizes timing for Alternaria management. Calendar-based timing starting in late spring with warm temperatures and dew formation can also be used for Alternaria leaf spot with 1-3 applications in 3-week intervals.

In our two trials on Alternaria leaf spot in 2019 with moderate levels of disease, the experimentals V-10424 and pre-mixtures Miravis Top, Miravis Prime, and UC-2 were similarly very effective as several registered fungicides (e.g., Cevya, Fervent, Fontelis + Teb, Luna Experience, Ph-D, and Quadris Top).

In our two trials on the management of scab, in-season treatments with Cevya, Luna Experience, Quadris Top, a mixture of Ph-D and Tebucon, as well as the experimentals pyraziflumid, V-10424, and pre-mixtures UC-2, Miravis Top, and Miravis Prime resulted in the lowest disease incidence and severity. Based on previous trials, under high-disease conditions, a three-spray program should include dormant applications with chlorothalonil-oil (or the less effective copper-oil) and two petal-fall applications. Under lower disease pressure, a dormant treatment or in-season treatments alone should be considered.

Project Cooperators and Personnel: H. Förster, D. Thompson, Y. Luo, D. Cary, UC Riverside; L. Milliron (UCCE Butte Co.; F. Niederholzer, UCCE - Colusa Co.; and L. Wade, UPI

Biology and Management of Almond Brown Rot, Jacket Rot, Shot Hole, Rust, and Hull Rot

Project Leader: J. E. Adaskaveg
Department of Microbiology and Plant Pathology, University of California, Riverside, CA 92521
(951) 827-7577 jim.adaskaveg@ucr.edu

PROJECT SUMMARY

Objectives:

- Evaluate new conventional and organic compounds for their spectrum of activity, systemic action, and persistence in managing brown rot, jacket rot, shot hole, gray mold, rust, and hull rot.
- Establish baseline sensitivities of fungal pathogens against new fungicides and determine shifts in fungicide sensitivity.
- Evaluate almond genotype susceptibility to foliar diseases that develop naturally in an almond variety trial at UC Davis.

Background and Discussion:

In 2018-19, we evaluated new treatments against major foliar and fruit diseases of almond in California in the field and laboratory. We tested the newly registered Cevya (FRAC Code - FC 3) and Fervent (FC 3/7), as well as the experimental pyraziflumid (FC 7), Sercadis (FC 7), Miravis Prime (FC 7/12), and Miravis Top (FC 3/7). Numbered products with FCs partially or not disclosed included UC-2 (FC 3/?), F4406-3 (FC 7/?), EXP-19A, V-10424, and V-10484. Among biologicals, we tested Dart, Cr-7, Serenade ASO, Cinetis, and Ecoswing. These were compared to registered single-active-ingredient and pre-mixture compounds belonging to the DMIs (FC 3), SDHIs (FC 7), anilinopyrimidines (FC 9), and QoIs (FC 11). Under California conditions, the availability and use of fungicides with different modes of action in rotation or mixture programs will prevent the selection and build-up of resistant pathogen populations. Furthermore, the use of pre-mixtures and tank mixtures expands the spectrum of activity allowing management of several diseases with a single treatment.

Incidence of brown rot, shot hole, and Botrytis gray mold was often high in the spring of 2019. For brown rot management on cvs. Drake and Wood Colony, all conventional fungicides were highly effective, reducing the incidence to 5.5% or less as compared to 35.8% and 19.8% in the untreated controls of each cultivar, respectively. For shot hole on cv. Drake, most fungicides performed extremely well, whereas Rhyme and Luna Sensation (FRAC 7/11) were somewhat less effective. The biologicals Dart, Ecoswing, and Cr-7 were also very effective on cv. Wood Colony.

In a second-year survey of orchards in Butte, Colusa, Sutter, San Joaquin, and Stanislaus Co., *R. stolonifer* was found to be the predominant cause of hull rot; whereas *A. niger* was much less common.

Studies on the management of hull rot were conducted in orchards with *Rhizopus stolonifer* as the main pathogen. Fungicides containing FC 3, 7, 11, or 19, as well as Cinetis and the alkalizing foliar fertilizer dipotassium-phosphate (di-KPO_4) reduced the incidence of hull rot over the last three years. Di-KPO_4 was applied to possibly neutralize fumaric acid that is produced by hull rot pathogens and is responsible in part for dieback symptoms of branches. The desiccant $AlSO_4$ was least effective. Phytotoxicity was not observed in any treatment.

Hull rot management should always include cultural methods including proper nitrogen fertilization and irrigation practices. A two-spray program is suggested for hull rot at pre-hull split in early/mid-June (targeting *Monilinia* pathogens) and at early hull split (targeting the *Rhizopus* pathogen). Quadris Top or Serenade ASO applied to the soil significantly reduced hull rot in one trial but not the other. Efficacy studies need to be done with *A. niger*. In our studies, 60 to 75% control was consistently obtained with a two-application program regardless of cultivar.

In baseline sensitivity studies, isolates of *M. laxa* were highly sensitive to the new SDHIs pyraziflumid, pydiflumetofen, and isofetamid. A much wider range in sensitivities was determined for *B. cinerea,* and sensitivity characteristics of isolates were similar for pydiflumetofen and pyraziflumid. This indicates that cross resistance is present among SDHI sub-groups and that SDHI fungicides should always be rotated with different FRAC codes.

In evaluation of natural host resistance to diseases in our variety block, data were obtained for brown rot, shot hole, and rust for 23 varieties or genotypes in 2019 (data presented in the poster at the annual meeting).

Project Cooperators and Personnel: D. Thompson, H. Förster, S. Haack, D. Cary, UC Riverside; R. Duncan, UCCE - Stanislaus Co.; B. Holtz, UCCE - San Joaquin Co.; M. Yaghmour, UCCE Kern Co.; and L. Wade, UPI.

Biology and Management of Bacterial Spot of Almond in California

Project Leader: J. E. Adaskaveg
Depart of Microbiology and Plant Pathology, University of California, Riverside, CA 92521
(951) 827-7577 jim.adaskaveg@ucr.edu

PROJECT SUMMARY

Objectives:

- Determine distribution of bacterial spot in California almond orchards and genetic variability of pathogen populations
  - Collection of strains of *Xanthomonas arboricola* pv. *pruni* (*Xap*) from several almond growing areas
  - Determination of the genetic variability by molecular methods
- Identify overwintering sites and time of infection
- Determine in vitro sensitivity of *Xap* against copper, mancozeb, antibiotics, and selected biologicals
- Develop field management programs
  - Dormant applications in winter
  - Spring-time applications

Background and Discussion:

Bacterial spot caused by *Xanthomonas arboricola* pv. *pruni* (*Xap*) continues to be a problem and has spread throughout the Central Valley of California (Butte, Colusa, Kern, San Joaquin, Merced, Madera, and Stanislaus, Co.). Wet springs are highly favorable for the disease, but it can develop throughout the growing season in orchards where foliage is frequently wet from dew, rain, or high-angle sprinklers. It is most serious on cv. Fritz, but can also be found on Nonpareil, Aldrich, Butte, Carmel, NePlus Ultra, and Price. Outbreaks occurred in the spring of 2019 with high rainfall in May. No copper resistance in the pathogen populations was detected during surveys in 2015 to 2019. Molecular comparisons of strains using REP, BOX, and ERIC PCR primers showed little genetic diversity, and a homogeneous population suggests a recent introduction of the *Xap*.

In the spring, the pathogen was again isolated from overwintering symptomatic fruit mummies, but also from healthy flower buds, as well as emerging leaves and spurs close to infected mummies in the tree. This confirmed that mummies are the major primary inoculum source. Spur isolations represent the first recovery of *Xap* from a woody tissue in California, suggesting that infected spurs may be an inoculum source after diseased mummies fall. Cankers are also suspected but have not been observed to date. Field-inoculations of flowers, young fruitlets, and immature fruit of cv. Fritz were successful, indicating a long susceptibility of almond tissues. Flower inoculations may not directly result in an infection but may allow survival of the pathogen.

In-season treatments at full bloom (FB), petal fall (PF), or after petal fall on cv. Fritz significantly reduced the disease. Two treatments at FB and PF were most effective; whereas later applications were less effective. FB and PF applications applied in combination with a dormant application of copper had significantly lower disease than in-season treatments alone. The most effective and consistent treatments included copper (e.g., Badge X2, Champ, ChampION^{++}, Kocide 3000) alone or mixed with mancozeb; kasugamycin mixed with mancozeb or copper; oxytetracycline, and selected experimentals. Copper phytotoxicity was not observed on leaves in 2019 probably because of high rainfall that removed copper residues.

Among organic products, Blossom Protect/buffer performed similar to Champ when applied at FB and PF, and Serenade ASO also significantly reduced the disease from the control. These represent options for organic growers. The experimentals nisin and Ɛ-poly-L-lysine were also effective and potentially represent a new strategy for managing bacterial diseases.

Based on our results from several years of field studies, in wet winter/spring seasons, a delayed dormant bactericide application to reduce inoculum should be followed by bloom and petal fall treatments around rainfall events and rising temperatures to prevent new infections. Bloom applications with copper cause minimal phytotoxicity. In drier spring seasons, only a dormant treatment or bloom/petal fall applications may be necessary for effective disease management. Kasugamycin is pending registration on almond. Integration of different compounds should reduce the potential of resistance to any one mode of action and overuse of copper that may cause phytotoxicity.

Project Cooperators and Personnel: S. Haack, and H. Förster; R. Duncan, UCCE - Stanislaus Co.; B. Holtz, UCCE - San Joaquin Co.; L. Wade, UPI.

Control and Management of the Newly Introduced Destructive Wood Decay Pathogen, *Ganoderma adspersum*.

Project Leaders: Dave Rizzo[1] and Bob Johnson[2]
[1]Dept. of Plant Pathology, UC Davis, One Shields Ave., Davis, CA 95616 dmrizzo@ucdavis.edu
[2]Dept. of Plant Pathology, UC Davis, One Shields Ave., Davis, CA 95616 bobjohnson@ucdavis.edu

PROJECT SUMMARY

Objectives for current year:

- Confirm infection pathway and process
- Access rootstocks for susceptibility to infection and decay
- Increase capacity of private diagnostic labs to identify *G. adspersum*
- Provide outreach and extension

Background:

Between fall 2015 through fall 2018, we investigated reported incidents of root and butt rot related tree failure in 57 orchard blocks in 11 counties. *Ganoderma* species were the cause of 95% of tree failures that we investigated; 94% of those failures were caused by the previously unreported species, *Ganoderma adspersum*.

G. adspersum is native to Eurasia and more aggressive than other *Ganoderma* species. The pathogen can overcome the reaction zone of the tree that generally limits the impact of wood decay fungi (Schwarze and Ferner, 2003). Not only was *G. adspersum* the most prevalent species among reported tree failures, but the extent of tree loss and relatively young age of affected orchards is in direct contradiction to established understanding of the effects of wood decay fungi in California almonds. We have recorded substantial tree loss in orchards as young as 4 years, as well as complete removal of numerous orchard blocks 14 years of age and younger. *G. adspersum* has only been confirmed in the five counties of the southern almond growing region, however recent reports suggest it may be present as far north as Merced County.

Discussion:

We are in the primary stages of developing spore inoculation methods so as to be able to accurately replicate natural infections. We have adapted mushroom culture techniques to grow *G. adspersum* fruiting bodies in the lab and have successfully produced spores. Spore inoculations of almond rootstocks will commence in this winter. A trial examining possible differences in rootstock susceptibility to decay was ended in October 2019, and analysis is underway. Selective media to allow for more rapid identification of problematic *Ganoderma* species are being developed and early results show clear growth differences when gallic acid is added to the media.

Project Cooperators and Personnel: Neil McRoberts and Tom Gradziel, UC Davis; Franz Niederholzer, UCCE-Yuba/Sutter/Colusa Counties; Roger Duncan, UCCE- Stanislaus County;

Management of Trunk and Scaffold Canker Diseases of Almond

Project Leaders: Florent P. Trouillas[1, 2] and Leslie A. Holland[1,2]
[1]Dept. of Plant Pathology, UC Davis, One Shields Ave., Davis, CA 95616 (559) 646-6566, flotrouillas@ucanr.edu
[2]UC Kearney Agricultural REC, 9240 S. Riverbend Ave, Parlier, CA 93648 (559) 646-6570, lholland@ucdavis.edu

PROJECT SUMMARY

Objective for current year:

- Provide effective control strategies for the management of almond canker diseases

Background:

Trunk and scaffold canker diseases (TSCD) constitute the major cause of tree death in almond orchards in California. The broad cultivation of almond combined with intensive production practices including mechanical harvest and repeated pruning have contributed to a recent increase in canker disease occurrence. Sampling of orchards from 2015-2018 revealed five major canker diseases of almond. The main diseases are band cankers and other Botryosphaeriaceae cankers as well as Ceratocystis canker. Three newly identified almond canker diseases include Cytospora-, Eutypa- and Collophora cankers. Pruning wounds serve as the main entry sites for infection by canker pathogens, and protection of pruning wounds following primary and secondary scaffold selections is recommended to prevent early infection and ensure almond tree longevity. Pruning wound protection and susceptibility trials were established to determine the best fungicidal products as well as best pruning timing to lower risks of infection. From 2016-2018, eight independent field trials were conducted to test the efficacy of 26 fungicidal products including fungicides, paint, and biocontrols to protect pruning wounds from infection by canker pathogens. During two consecutive dormant seasons (2017/18 and 2018/19), four independent field trials were conducted to investigate the seasonal susceptibility of pruning wounds to infection, as well as the duration of pruning wound susceptibility in order to determine pruning periods with reduced risk of infection.

Discussion:

Results of the pruning wound protection trials revealed that several products provided great efficacy to protect pruning wounds. Topsin M (FRAC 1) and Vintec, a *Trichoderma* biocontrol product provided the best protection (70 to 100% disease control) against all canker pathogens tested. The premixture fungicide, Merivon (FRAC 7/11) also provided high efficacy against the range of canker pathogens. Paint applied for pruning wound protection provided limited efficacy. Pruning wound susceptibility field trials were conducted in the field to determine the month (Sept, Oct, Nov, Dec, Jan) and duration (0, 1, 2, 3, 5, 8 weeks) when pruning wounds are most susceptible to infection by canker pathogens. Both the 2017/18 and 2018/19 trials indicated that fresh pruning wounds (inoculated immediately after pruning) in September through January were the most susceptible to pathogen infection in comparison to wounds inoculated after 1 to 8 weeks after pruning. Overall pruning wound susceptibility declined substantially after 2 weeks following pruning and continue to decrease overtime. September had the highest infection rate across all wound ages in all trials. January had the lowest infection rate overall and the shortest duration of wound susceptibility. Fall and early winter (Sept through Dec) pruning appeared more conducive to infection by canker pathogens than the month of January. This work suggests that one application of a pruning wound protectant such as Topsin M or Vintec following pruning in January should significantly reduce risks of infection of pruning wounds by canker pathogens.

Project Cooperators and Personnel: Mohamed Nouri, and Brent Holtz UCCE – San Joaquin County; Franz Niederholzer, UCCE – Sutter-Yuba Counties; David Haviland and Mohammad Yaghmour – UCCE – Kern County.

Epidemiology and Management of Phytophthora Root and Crown Rot of Almond in California

Project Leaders: James E. Adaskaveg[1] and Greg Browne[2]
[1]Dept. of Microbiology and Plant Pathology, UC Riverside, Riverside, CA 92521 (951) 827-7577, jim.adaskaveg@ucr.edu
[2] USDA, UC Davis, 347 Hutchison Hall, Davis, CA 95616 (530) 754-9351, gtbrowne@ucdavis.edu

PROJECT SUMMARY

Objectives:

- Evaluate the in vitro toxicity of new fungicides against *Phytophthora* species from almond
- Evaluate new fungicides for the management of root rot and crown rot of almond and compare to the registered fungicides.
- Evaluate for phytotoxicity and tree growth

Background and Discussion:

Phytophthora root rot and crown rot of almond can be caused by several species of *Phytophthora* including *P. cactorum, P. cambivora, P. cryptogea*, *P. megasperma*, and *P. niederhauseri*. Phytophthora diseases are widely distributed and may cause high losses in newly planted orchards. Disease development depends in part on the rootstock and the species of *Phytophthora* involved, but the disease is most severe in soils with poor drainage that are waterlogged. The pathogens survive as oospores, chlamydospores, and/or hyphae in plant debris in the soil, depending on the species. Under favorable conditions, hyphae start growing or chlamydospores and oospores germinate to produce sporangia that contain zoospores - the main infective propagules. Zoospores are motile in water, are attracted by plant exudates, and infect feeder roots and the crown.

Management of Phytophthora diseases is by use of tolerant rootstocks, proper irrigation, and use of mefenoxam or phosphonate (e.g., potassium phosphite, fosetyl-Al) fungicides. New fungicides including mandipropamid (Revus), fluopicolide (Presidio), ethaboxam (Intego), and oxathiapiprolin (Orondis) with high activity against *Phytophthora* species have become available for evaluation. They have different modes of action (belong to different FRAC Codes) and will possibly allow for better disease control and fungicide resistance management in almond. Registrants support their registration on almond. We are evaluating the effectiveness of these fungicides on almond in two comparative field studies.

The in vitro activity of the new fungicides against 11 *Phytophthora* species was generally higher than for mefenoxam and potassium phosphite. Oxathiapiprolin had the highest activity with EC_{50} values for mycelial growth inhibition of <0.001 µg/ml. A rather narrow range of EC_{50} values (0.001 to 0.01 µg/ml) was also found for mandipropamid, but for ethaboxam and fluopicolide higher rates were generally needed and the range was wider.

In our first orchard trial at UC Davis with Nonpareil scions on Hansen or Nemaguard rootstocks planted in 2016 and inoculated with *Phytophthora* spp., a final evaluation was done in Sept. 2019, two years after the second of two soil applications. Thirty percent of control trees showed gumming cankers on the lower trunk, and many trees were dead. *P. cactorum* was isolated from the cankers. Trees treated with Orondis 200OD at 2.4 or 9.6 fl oz/A were all healthy, and a single tree that was treated with the 4.8-fl oz rate showed symptoms (5% incidence). Disease incidence of the Presidio-Intego mixture was 15%, and that of all other treatments (i.e., ProPhyt, Ridomil Gold, Revus, Presidio, Intego) was statistically similar to the control. Thus, Orondis showed long-lasting, high efficacy; the other treatments may have to be applied more frequently.

In the second orchard that was planted and inoculated in 2017 and treated three times, 34.4% of control trees had gumming cankers, and no disease was observed for Orondis (4.8- and 9.6-fl oz rates), Revus, and ProPhyt/Ridomil Gold. Disease incidence was 6.3% for Presidio and Presidio-Intego. Incidence for Intego and Ridomil Gold by themselves was not significantly different from the control. No phytotoxicity was observed.

Thus, we are identifying new effective fungicides for managing Phytophthora diseases of almond. This is important because phosphonate and mefenoxam resistance in *Phytophthora* species has been found in other crops. Furthermore, phosphite residues remain a problem because maximum residue limits (MRLs) need to be established in other countries. The new fungicides will have international MRLs established, and Orondis and Presidio are now commercially available on other tree crops.

Project Cooperators and Personnel: H. Förster, D. Thompson, and W. Hao, Department of Microbiology and Plant Pathology, University of California, Riverside.

Detection of Band Canker Pathogens in Young Almond Trees in Nurseries and Orchards and Disease Management

Project Leaders: Themis J. Michailides
University of California Kearney Agricultural Research and Extension Center, 9240 South Riverbend Ave., Parlier, CA 93648
(559) 646-6546, tjmichailides@ucanr.edu

PROJECT SUMMARY

Objectives for current year:

1. Determine whether latent infections by *Botryosphaeria* initiate in nursery trees (2018 & 2019).
2. Initiate fungicide treatments to protect nursery stock plants from such infection before planting and/or in the early age (1, 2, and 3 years) of trees after planting in the field.

Background and Discussion:

Band canker of almond became more severe recently, significantly affecting almond production in California. The disease is caused by eight different fungi in the family of Botryosphaeriaceae. Our previous studies demonstrated that some of these pathogens existed in shoots as latent infection at various levels that cannot be easily detected and isolated with traditional culturing method. We developed *q*PCR approach to sensitively and accurately detect and quantify six canker-causing pathogen groups. With this method, we found the clue of accumulation of infections from old to young shoots. We also found that the latent infection levels of different pathogen groups as predominant populations varied among almond orchards, and *Lasiodiplodia* spp.*, Neofusicoccum* spp. and *Cytospora* spp. are the three major groups among most orchards. Importantly, we found various latent infection levels of these pathogens in shoots of young trees (1st to 2nd leaf). This implied the possibility of young trees carrying the pathogens from nurseries to new-planted orchards that could serve as important source of initiation of the disease development. Continuously, we investigated latent infections of potted young almond trees from different nurseries using our *q*PCR method, and we found some pathogens in these ported trees with various latent infection level, including *Lasiodiplodia* spp.*, Neofusicoccum* spp. and *Cytospora* spp. To answer the question about where the pathogens initially come from, we focused on determination of possibility of existence of the pathogens in mother trees from which the buds were used in grafting in nurseries. In 2019, we collected shoots of mother trees from two major nurseries in central valley, and we finished the data analysis for one nursery using the method described above. The DNA of *Cytospora* was detected from shoots of various varieties with different latent infection levels, while infection levels of *Neofusicoccum* spp. was comparatively low. None of the other 4 pathogen groups were detected from these shoot samples, and none of these pathogens were detected from buds of these shoots. Comparison in latent infections among almond cultivars in these shoot samples is in progress. We are still working on shoot samples from another nursery now.

In this project, we also focused on fungicide trials to determine the possible disease control strategies. The treatments we used included Topsin™, Topsin™ + Rally® sprayed on the trunks and untreated control. In 2018, two almond orchards (2nd leaf) were used with three replicates for each treatment, each with 50 or 75 trees. In 2019, two other almond orchards (1st and 2nd leaf) were used with the same treatments and replicates, each with 50 trees. No significant difference among treatments were found in the 2018 trial. In the 2019 trial, the 1st leaf orchard did not show any symptoms of band canker among treatments, while in the 2nd leaf orchard, the two fungicide treatments showed significant reduction of incidence of trees showing gumming and canker symptoms, compared with those of untreated control (50 - 58%). The incidence of diseased trees treated with Topsin™ + Rally® (12 - 14%) was not significantly different from that treated with Topsin™ only (14- 22%). The results indicated that the fungicide treatment of trunks of young trees could effectively reduce the development of band canker disease. More research is needed to test our conclusion, and the development of canker disease in these treated trees will be continuously investigated over few more seasons.

Project Cooperators and Personnel:
Yong Luo and Dan Felts, UC Kearney Agric. Res. & Ext. Center; Franz Niederholzer, UCCE Yuba/Sutter/Colusa; Dani Lightle, UCCE Glenn/Butte; and Chris Taylor, almond grower and PCA in Glenn Co.

Investigation of *Aspergillus niger* Causing Hull Rot and Conditions Conductive to Disease Development in Kern County

Project Leaders: Mohammad Yaghmour[1] and Themis J. Michailides[2]
[1]UCCE – Kern County, 1031 S Mt. Vernon Ave., Bakersfield, CA 93312; (661) 868-6211, mayaghmour@ucanr.edu
[2]University of California Davis/Kearney Agricultural Research and Extension Center (KARE), 9240 S. Riverbend Ave, Parlier, CA 93648; (559) 646-6546, tjmichailides@ucanr.edu

PROJECT SUMMARY

Objectives for current year:

- To complete *Aspergillus niger* pathogenicity tests and study almond fruit susceptibility.
- To assess disease incidence and monitor inoculum dispersal in the orchard.
- Effect of tree water and nitrogen status on disease development.
- Establish cultural and chemical control strategies of hull rot caused by *A. niger*.

Background and Discussion:

Hull rot is primarily caused by *Rhizopus stolonifer* and *Monilinia fructicola* causing the leaves, spurs, and parts of the shoot near the infected fruits to die. In Kern County, and the Southern San Joaquin Valley, *R. stolonifer* is more prevalent, and this fungus produces an acid which acts like a toxin which moves from the infected fruit into the surrounding tissues killing the vascular tissues. Hull rot affects future yields by killing fruiting spurs and wood. In the past years, orchards affected with hull rot in Kern County and other Counties in the central valley showed presence of *A. niger* in symptomatic branched affected by hull rot. Many samples processed by Dr. Michailides showed that hull rot samples from the San Joaquin and Sacramento Valleys were infected with *A. niger* alone and/or *R. stolonifer*.

During the 2019 season, field inoculations and pathogenicity studies were performed on Nonpareil variety by inoculating the fruit with spore suspension. While inoculated fruits reproduced the typical symptoms of hull rot where leaves shriveled and caused necrosis of the fruit peduncle. Many fruits in the control developed hull rot due to natural infection by *R. stolonifer* and some of the inoculated spurs had mixed infections. We also repeated the experiments looking at the most susceptible developmental stage by inoculating fruit at the three developmental stages (unsplit, deep V, and split less than 1 cm). Inoculated fruits that are split less than 1 cm had the highest percentage of spurs developing hull rot symptoms. Also, population of *A. niger* on fruit were assessed again, and results shows that the highest population of *A. niger* was observed later in July and through early August and corresponded with fruit that already split with less than 1 cm.

July nitrogen leaf analysis were not significantly different between the two experimental sites, showing differences in hull rot incidence for the second year in a row, and it was within the normal range, suggesting that leaf nitrogen concentration did not play a role in disease development in this orchard.

Preliminary work looking at sensitivity of *A. niger* to different groups of fungicides was tested *in vitro* and in the field. *In vitro* tests showed that *A. niger* was sensitive to fungicides in the FRAC groups 3, 7+11, and 7. An experiment with three fungicides belonging to FRAC groups 3, 7+11, and 11 was conducted in a commercial orchard and showed that all fungicides tested reduced the number of symptomatic spurs by approximately 39 to 54% compared to control.

Project Cooperators and Personnel: Brent Holtz, UCCE-San Joaquin County; Mae Culumber, UCCE-Fresno County; Florent Trouillas, UC Davis-KARE

Continued Assessment of Almond Orchard Performance and Soil Health Following Biosolarization Using Almond Residue Amendments

Project Leaders: Christopher Simmons[1] and Amanda Hodson[2]
[1]Dept. of Food Science and Technology, UC Davis, One Shields Ave., Davis, CA 95616 (530) 752-2109, cwsimmons@ucdavis.edu
[2]Dept. of Entomology and Nematology, UC Davis, One Shields Ave., Davis, CA 95616 (530) 752-2592, akhodson@ucdavis.edu

PROJECT SUMMARY

Objectives for current year:

- Measure nematode community composition, including phytoparasitic species, in biosolarized and control soils.
- Measure soil phytonutrient content (total and mineral nitrogen, extractable phosphorus and potassium) in biosolarized and control soils.
- Measure soil physical and chemical properties (organic matter content, water holding capacity, cation exchange capacity) in biosolarized and control soils.
- Measure trunk diameter, normalized difference vegetation index (NDVI) and normalized difference red edge index (NDRE) in trees grown in biosolarized and control soils.

Background:

Biosolarization is an integrated soil pest management technique that uses passive solar heating and organic matter amendments to create soil conditions that are antagonistic to pests and beneficial to overall soil health. In the summer of 2017, a biosolarization field trial was conducted at a commercial orchard in Chico, CA. Biosolarization was implemented using almond hulls and shells from different varieties as soil amendments to help drive pesticidal conditions in the soil. The treatment occurred during the preplant period and the orchard was subsequently established in January of 2018. Soil properties, including nutrient and nematode profiles, were monitored since the onset of biosolarization. Tree growth measurements were incorporated after orchard planting. The current project continues to monitor these metrics in the second year following orchard planting.

Discussion:

Current data show that there have been persistent benefits to soil nutrient content. Specifically, total nitrogen and potassium have remained elevated in biosolarized plots compared to untreated control plots at 24 months post-treatment. Over the same period, soil carbon and organic matter content remained elevated in biosolarized soils, which is a promising indicator of persistent benefits to soil organic matter content, soil water holding capacity and soil carbon sequestration. The initial suppression of root lesion nematodes in the biosolarized soil persisted, with nearly non-detectable levels measured at 20 months post-treatment. Early measurements of trunk diameter for trees grown in biosolarized and untreated soils indicated trees required adaptation to the biosolarized soil, as indicated by slower growth. However, by 24 months post-planting, the growth rate uniquely accelerated for trees in biosolarized soils, indicating successful adaptation.

Project Cooperators and Personnel:
Emily A. Shea, PhD candidate, Agricultural and Environmental Chemistry Graduate Group, University of California, Davis, CA

Rory P. Crowley, Director of Business and Research Development & Assistant Operations Manager, Nicolaus Nut Company, Chico, CA

Development of Spray Backstop: a low-maintenance system to reduce spray drift without limiting the spray and air delivery

Project Leaders: Alireza Pourreza[1]
[1]Dept. of Biological and Agricultural Engineering, UC Davis, One Shields Ave., Davis, CA 95616
(530) 752-9290, apourreza@ucdavis.edu

PROJECT SUMMARY

Objectives for current year

The main goal of this project is to develop a spray attachment system that improves the performance of air-assist sprayers in Almond, primarily by reducing spray drift. The goal for the first year of this project was to craft a spray backstop prototype for young, small trees (2nd leaf) where the scale of the sprayer can be kept small. The specific objectives for the second year of this proposal are:

- Evaluate spray drift reduction and coverage improvement using the Spray Backstop system
- Design and fabrication of the second version of the Spray Backstop mechanism which is light and foldable.
- Evaluate the performance of the new foldable system in almond orchards.

Background

Almond acreage in California has increased by one third to over 1,000,000 acres in the last ten years, with the farm-gate value approaching $6 billion. Each bearing acre receives at least 4-6 pesticide applications per year to protect the crop and/or trees from insect, mite and/or disease damage. Vigorous, unpruned canopies have become more common, challenging uniform spray delivery and pest control, while the pesticide tools available to growers have also changed. There has been a shift away from the broad spectrum, contact materials to formulations targeting eggs and juvenile life stages of target pests that require excellent coverage to deliver effective control.

To have a good coverage, especially in the treetops, it is a regular practice to use a diverging air jet, generated by an axial or centrifugal fan operating at ground level, that carries entrained pesticide upwards into the canopy. However, the excessive air flow that is required to deliver spray to the treetops, increases the potential for off-site movement of pesticides as drift.

Discussion

In the second year of this project, a foldable spray backstop system is being designed and fabricated based on the pattern of spray cloud movement obtained by analysis of the images/videos captured by an unmanned aerial vehicle. The second prototype of the spray backstop includes a mast and a foldable screen structure that covers the trees and blocks the spray droplets escaping from trees' tops or sides. In October 2019, we tested the developed system in a young almond orchard. In these tests, we evaluated the off-site movement of spray droplets with continuous loop sampling method. In addition, we divided the experimental trees into three sections based on height and collected leaf samples from each section (with and without the backstop system). The samples were tested in the laboratory to examine the effectiveness of the system in controlling drift and improving coverage. By the end of the second year, we will craft a light and foldable spray backstop system based on the results obtained this year.

Implementing the spray backstop in almond pest/disease management practices will improve the environmental aspect of almond production by decreasing spray drift. In addition, better spray coverage decreases the chance of yield loss that directly affects the economic aspect of almond production.

Project Cooperators and Personnel:
Ali Moghimi (postdoc), Ken Giles (Professor), UC-Davis; Farzaneh Khorsandi , UCCE, Davis; Franz Niederholzer, UCCE, Colusa County.

Biology, Monitoring, and Management of Brown Marmorated Stink Bug (BMSB) in Almond Orchards

Project Leader: Jhalendra Rijal
University of California Cooperative Extension, Stanislaus County, 3800 Cornucopia Way, Ste. A, Modesto, CA 95358
(209) 525-6800, jrijal@ucdavis.edu

PROJECT SUMMARY

Objectives for current year:

- Conduct BMSB detection and seasonal monitoring in almond orchards
- Characterize the temporal effect of BMSB feeding on developing almonds using cage studies
- Assess the BMSB damage in commercial orchards by collecting and evaluating the fruit samples at different times of the year

Background and Discussion:

Brown marmorated stink bug (BMSB) is an invasive stink bug species from Asia and has been spread to over 43 U.S. states causing a significant economic burden to growers. In California, since the finds of a big BSMB population in mid-town Sacramento in 2013, BMSB has become established in urban areas of 16 counties. In crop, we reported the first finds of BMSB population in orchards – peach in 2016, and almond in 2017. Since then, the reproducing populations of BMSB have been in several almond orchards in Stanislaus and Merced counties with substantial crop damage from early spring to mid-summer. These observations have been alarming as we found increased spread and damage by this pest in crops in the northern San Joaquin Valley. BMSB adults overwinter in warm places (houses/barns/structures/dead trees, etc.) and migrate to crops for an extended period during the spring (March-June), can reproduce, and remain active in the orchard throughout the season; this likely pose a greater challenge in controlling this insect.

Tested and recommended monitoring tools

Based on the studies conducted in past two years in 14 orchards, we were able to recommend the use of sticky panel trap baited with BMSB lures to 1) detect BMSB adults when moving into the orchard from the overwintering places, 2) perform seasonal monitoring of the population and tracking BMSB life stages and generations. BMSB traps are effective for both nymphs and adults. In addition, we recommended to use visual and beat tray sampling methods to confirm the BMSB infestation in the orchard. Using traps, we concluded that BMSB activity can begin as early as mid-March and continued throughout the season in almond orchard.

Feeding damage characterized

We conducted a controlled study in which BMSB was provided opportunity to attack various stages of the nut development (fruit set to maturity). We found that feeding on early-season nuts (mid-March – early May) led to substantial nut drop upto 100% in first two weeks, and this trend has decreased as fruit becomes bigger and gains its full size. The feeding after that point showed gumming on the fruit externally, and that resulted in gummy, dimpled, have dark feeding spots on the kernels. These kernels are categorized as 'bug damage' in the processor's grading sheet.

Damage and potential risk factors identified

We observed variation in the BMSB population and damage among orchards. Orchards with BMSB overwintering shelters and host plants (e.g., *Ailanthus* tree, also called tree of heaven) in the vicinity had a large BMSB pressure, more damage. Also, we found that damage intensity in edges was significantly higher than the interior. We compared ten almond varieties for BMSB damage and found no variety immune to BMSB. Preliminary results showed that Monterey, Fritz, Aldrich are more susceptible than others.

Project Cooperators and Personnel:
Frank Zalom, UC Davis

Sustainable Microbial Biocontrol of Brown Rot Blossom Blight in Almond

Project Leader: Rachel Vannette
[1]Dept. of Entomology and Nematology, UC Davis, 43 Briggs Hall, Davis, CA 95616 (530) 752-3379, rlvannette@ucdavis.edu

PROJECT SUMMARY

Objectives for current year:

- Identify candidate BCAs for BRBB-Our first step was to isolate potential BCAs naturally present on almond flowers collected in several conventional and organic almond orchards throughout CA. Once isolated, they were tested for their efficacy in suppressing *M. laxa* growth in culture.

Background:

Almonds face pressure from an array of damaging bloom diseases such as brown rot blossom blight (BRBB; caused by *Monilinia laxa*), and currently growers primarily rely on the use of fungicides for their control. Flower inhabiting microbes provide a natural, sustainable form of biocontrol for brown blossom blight while potentially minimizing costly non-target effects on almond pollinators and the services they provide and potentially increasing flower attractiveness to pollinators.

Discussion:

In order to identify candidate microorganisms for biological control of brown rot blossom blight, almond flowers were collected from both conventional and organic almond orchards in different counties in California. Additional candidate microorganisms were collected from natural flower populations in Yolo and Solano counties in California. Purified isolates were identified by the amplification of a conserved DNA or RNA region by Polymerase chain reaction. Amplicons were sequenced and compared to sequences already available in Gen Bank. Isolation work from almond flowers resulted in a collection of approximately 250 microorganism isolates. Fourteen *Epicoccum nigrium*, 12 *Aureobasidium* sp., 10 *Bacillus* sp. and 2 *Penicillium* sp. isolates were selected from these almond isolates to be tested for antagonistic activity against *M. laxa* isolate KARE1135. Nine bacterial isolates from the genera *Acinetobacter*, *Micrococcus*, *Neokomagataea* and *Pseudomonas* and 15 fungal isolates from the genera *Metschnikowia*, *Cryptococcus*, *Hanseniaspora*, *Candida*, *Lachancea*, *Mayerozyma*, *Starmerella*, *Zygosaccharomyces* and *Pencillium* were selected from the microorganisms isolated from natural flower populations. These isolates include species associated with bee hosts suggesting they will be safe for use with honeybees as well as species associated with flower stigmas, the location of initial *Monilinia* colonization.

Antagonist activity was tested using the dual culture technique in Petri dishes filled with potato dextrose agar (PDA) medium. Mycelial plugs (5 mm diameter) of the pathogen and putative fungal antagonists were placed on the same Petri dish 3 cm from each other. Paired cultures were incubated at 25^{o} C for up to 14 days. Plates inoculated with only the pathogen served as controls. The inhibition halo was measured, and the percent of relative growth inhibition calculated. Results of the dual culture method assay showed that out of the 62 isolates tested, 26 produced inhibition zones. K661, K781 and Ba95 produced the largest inhibition zones which averaged 1cm. Several isolates (A33, A17, EC_084, K768, K769 and MAV_P_B1) did not produce inhibition halos; however, they showed significant growth inhibition on *M. laxa* which suggests that these isolates may act as substrate competitors of *M. laxa* in the absence of antimicrobials production. Our current work addresses our remaining objectives:

- Determine the safety of BCAs on HB brood and adults.
- Evaluate effects of BCAs on floral attractiveness and HB pollination.

If any of the chosen potential BCAs are found to induce mortality or jeopardize health in HB brood or adults, they will be excluded from further testing. Additional experiments are underway to address remaining objectives.

Project Cooperators and Personnel:
Florent P. Trouillas, UC Davis-KARE; Elina L. Niño, UC Davis; Robert N. Schaeffer, Utah State University; Amber Crowley-Gall, UC Davis

Can Venturi Nozzles Deliver Drift and Pest Control?

Project Leader: Franz Niederholzer
UCCE Colusa, 100 Sunrise Blvd, Suite E, Colusa, CA 95932 (530) 218-2359, fjniederholzer@ucanr.edu

PROJECT SUMMARY

Objectives for current year:

- Establish field trial in mature almonds in summer, 2019, testing venturi and/or standard hollow cone nozzles for NOW control at 100 or 200 gallons per acre spray volume.
- Conduct spray drift trial comparing AI vs standard hollow cone nozzles.

Background:

The almond industry is caught in a Catch 22 between the need for effective pest control – especially for navel orangeworm (NOW) – under challenging conditions (dense canopies of unpruned, vigorous trees using a limited arsenal of pesticides) and the need to limit pesticide drift from orchards. Surface water contamination by drifting pesticides (for example, chlorpyrifos) may result in regulatory cancelation of one or more of the few remaining, effective NOW pesticides, making pest control (and resistance management) harder to achieve.

More drift control practices/tools that effectively control pests are needed. Recent research documenting drift reduction by spraying in from outside rows or using sprayer fans operating outside the orchard to keep spray within the orchard are beneficial when tree rows parallel roads and other sensitive areas off the farm. However, these practices are more challenging to use effectively when the tree rows are perpendicular to sensitive areas. Venturi nozzles (AKA “Air Induction” or “AI” nozzles) generate coarse to extra coarse (C/XC) diameter droplets. Given the acceptance of venturi nozzles in herbicide spraying in the US and in herbicide and orchard spraying in Europe, drift and NOW control from these nozzles should be compared to the performance of conventional spray nozzles in almond orchards.

Research from Europe shows mixed results for pest control using venturi nozzles with airblast sprayers, although these nozzles are widely available and researched for over a decade. In limited studies in tree crops in California, UC and private researchers have seen little to no difference in pest control (or % spray coverage) using large vs small to medium diameter droplets. However, these studies were not done on large, unpruned almonds. More data, both for pest AND drift control, is needed comparing venturi to conventional hollow cone nozzles in mature almond orchards.

Discussion:

A 20-acre, replicated field trial in a conventional Nonpareil+pollinizers block was established in July, 2019. Intrepid® (methoxyfenozide) at 16 oz/acre targeting the 2nd generation of NOW was sprayed twice, two weeks apart, in July and bifenthrin, equivalent to 1 lb Brigade/acre, was sprayed once, targeting the third NOW generation, in early August. A PTO sprayer with 38” fan applied all treatments at 2 MPH between 3-9 AM to minimize evaporative loss of spray. Treatments were 1) 100 gpa with hollow cone nozzles delivering fine/moderate droplets, 2) 200 gpa using nozzles of the same design as 100 gpa treatment, 3) 100 gpa using hollow cone venturi nozzles delivering coarse droplets and 4) 200 gpa using more of venturi nozzles used with 100 gpa. A 3-row section of the orchard was not sprayed. Molybdenum (Mo) tracer was included in every tank applied in the second spray. Three different measurements of spray coverage/efficacy were made and are under analysis:

1) **Lab bioassay**: Sprayed Nonpareil (NP) nuts from low (5-7’) or high (17-20’) in the canopy were taken to Dr. Siegel’s lab, exposed to NOW eggs by placing the eggs in the nut suture. Nut damage and surviving NOW are counted after 6 weeks.

2) **Field Damage:** Yield sample analysis (1000 NP nuts/rep after pickup)

3) **Tracer analysis** (PPM Mo/NP nut from lower and upper canopy)

Results will be ready by the conference to present and discuss.

Drift field studies along with droplet size analysis from conventional and venturi hollow cone nozzles will be completed this fall and the results presented at the conference.

Project Cooperators and Personnel:
Joel Siegel, USDA-ARS, Parlier; Ken Giles, UC Davis Bio and Ag Engineering Department (retired), Emily Symmes, UC IPM Area Advisor, Sacramento Valley, and Stan Cutter, Nickels Soil Lab, Arbuckle, CA

Almond Variety Development

Project Leader: Tom Gradziel
Dept. of Plant Sciences, UC Davis, One Shields Ave., Davis, CA 95616 (530) 1575, TMGradziel@ucdavis.edu

PROJECT SUMMARY

Objectives for current year

The goal of the variety development program is to develop and test a series of new California adapted varieties solving current and emerging needs. These include self-fruitfulness, improved water use efficiency, improved disease and pest resistance and adaptation to a changing climate.

Background

The California almond industry is in a period of transformation driven by increasing market and environmental demands, reductions in water and other natural resources, loss of pollinators, and changing climates. While almond represents a diverse and highly adaptable species, commercial production is dependent almost entirely on the variety Nonpareil and its pollenizers, most of which have Nonpareil and Mission as direct parents. Consequently, the UCD Almond Variety Development program is pursuing the incorporation of promising new and diverse germplasm to provide new genetic solutions to current and emerging production challenges.

Discussion:

In 2019, over 11,000 seeds were obtained from controlled crosses targeting priority traits with an emphasis on self-fruitful pollenizers for the critical early Nonpareil bloom. The previously UCD released Winters variety provides consistent year-to-year coverage of this early bloom but is self-incompatible, requiring cross-pollination. The more recently released Sweetheart variety covers this production critical bloom time but is only partially self-fruitful. Advanced UCD selections 1-271, 1-232 and 8-260 show good early bloom coverage and are fully self-fruitful. They are currently being tested in Regional Variety Trials. Additional selections showing promise, including UCD10-2-107, 119 and 147, which are now being propagated for regional grower testing. These self-fruitful varieties could be planted as pollinizers for Nonpareil or in solid or mixed plantings. Long-term regional testing of the recently UCD released variety Kester has demonstrated good bloom overlap with the later Nonpareil bloom with high productivity and freedom from Noninfectious Bud-Failure which has often been a problem with untested new varieties. Kester is also being planted as an alternative to Padre in Butte/Padre orchards. Kester is not self-fruitful as it is intended to be planted with Nonpareil or Butte, both of which require honeybee pollinators.

The breeding program is also pursuing the development of a self-fruitful Nonpareil-type variety. Consistent, high levels of self-fruitfulness has been achieved by combining genes of from peach (Independence source) and almond species (source for European and Australian self-fruitful varieties). This newly incorporated breeding germplasm also allows the development of improved disease and pest resistance, water use efficiency, and kernel quality. Other examples include very long-term storage potential in RVT selections UCD1-16 and the web-trait that confers high shell-seal (NOW resistance), hull-rot resistance and high kernel-to-nut crack-out ratios. This diverse, new germplasm is also providing promising options for emerging orchard practices including high-density orchards and orchard systems using catch-frame harvest.

Project Cooperators and Personnel: S. Marchand, B. Lampinen, UCCE-Davis; J. Adaskaveg, UCR; S. Metcalf, UCD; F. Niederholzer, UCCE-Colusa; R. Duncan, UCCE-Stanislaus; P. Gordon, L.K. Milliron, UCCE-Butte and G. Brar, CSU-Fresno.

Field Evaluation of Almond Varieties

Project Leader: Bruce Lampinen
Department of Plant Sciences, University of California, Davis, One Shields Ave., Davis, CA 95616
(530) 752-2588, bdlampinen@ucdavis.edu

PROJECT SUMMARY

Objectives:

To evaluate the characteristics of the most promising almond varieties developed in the almond breeding programs at UC Davis, the USDA Agricultural Research Service as well as commercial introductions in an orchard setting.

- Continue collecting data on bloom, hullsplit, light interception, yield and quality in 2014 Regional Variety Trials (planted in the winter of 2014).

Background and Discussion:

Regional almond variety trials provide both almond growers and researchers with a valuable information resource.

2018 was the third year for complete data collection at the next generation almond variety trials that were planted in the spring of 2014 in Butte, Stanislaus and Madera Counties. The Butte, Stanislaus and Madera trials were planted on Krymsk86, Nemaguard and Hansen 536 rootstocks, respectively. In the current generation trials, there are four replications of each of 30 pollinizers – an experimental improvement initiated with the completed McFarland trial. Nonpareil is planted in every other row in all three trials. Trees are planted at a density of 110, 130 and 173 trees per acre in the Butte, Stanislaus and Madera trials respectively. Fourteen of the pollinizer test varieties in the trials from the University of California, USDA Agricultural Research Service, and commercial nurseries are self-compatible. In 2015, missing trees were replanted.

In 2018, bloom and hullsplit data were collected at all 3 replicated trials. Light interception data was collected at the trials as well using the mobile platform lightbar. In addition, the trials were harvested for the third time in 2018. Yields at the Butte trial averaged from 570 to 3265 kernel pounds per acre in the fourth leaf. At the Stanislaus trial yield ranged from 1130 to 2613 kernel pounds per acre in the fourth leaf. The yields at the Madera trial ranged from 236 to 3483 kernel pounds per acre.

Studies are also relating yield and production efficiency by using data from the mobile platform lightbar that measures light intercepted by tree canopies. We are also working with Ali Pourreza in Bio and Ag Engineering and Brian Bailey in Plant Sciences at UC Davis to further refine these relationships.

Project Cooperators and Personnel: Phoebe Gordon, UCCE- Madera County, Dani Lightle and Luke Milliron, UCCE-Butte/Glenn/Tehama Counties; Roger Duncan, UCCE - Stanislaus County; Joseph H. Connell, UCCE - Butte County, Tom Gradziel, Sam Metcalf, Ali Pourreza and Brian Bailey, UC Davis; Craig Ledbetter, USDA/ARS, SJVASC, Parlier

Almond Culture and Orchard Management (Farm Advisor Projects)

Overall Project Leader: Katherine Jarvis-Shean
University of California Cooperative Extension, 70 Cottonwood Street, Woodland, CA 95695
(530) 377-9528, kjarvisshean@ucanr.edu

PROJECT SUMMARY

The Almond Board provides funding for UC Farm Advisors to conduct research projects, including the following seven almond-related efforts.

Can additional nutrition in first leaf trees alleviate symptoms of Prunus Replant Disease?

Project Leader: Phoebe Gordon, UCCE Madera and Merced Counties

Fertilizer applications started in April, 2019. Of the six treatments, the slow-release and micronutrient treatments were applied in full. The slow release was calibrated to apply six ounces of actual nitrogen per tree. The nitrogen only, 15-15-15, and phosphorus treatments were split into six applications, applied approximately once a month between April and September. Leaf tissues were sampled in July and September and analyzed.

Evaluation of Latex Trunk Paint as Herbicide Injury Protectant

Project Leader: Dani Lightle, UCCE Glenn County

Latex paint is commonly applied to 2nd leaf trees following carton removal, and extension literature around the country touts trunk paint as a method to reduce herbicide drift injury. Glyphosate, glufosinate and glyphosate+ glufosinate treatments at label and 3x rates were applied directly to the trunks of 2nd leaf almonds protected with cartons, fresh paint, aged paint or no paint. Trees were rated for trunk damage (gumming) and canopy stress for ten weeks post-application. Trees treated with 3x rate of glyphosate, 3x rate of glufosinate, or the label and 3x rate of glyphosate + glufosinate sustained higher levels of damage when they were painted than if no paint was applied. Trees with cartons sustained little to no damage from trunk applications and provide the most reliable form of protection of young trees from herbicide damage.

Evaluation of mating disruption products and monitoring tools for Navel Orangeworm control in almonds

Project Leader: Jhalendra Rijal, UCCE Northern San Joaquin Valley

The use of mating disruption for Navel Orangeworm (NOW) management in almonds has been increased significantly in the past couple of years. Since mating disruption interferes with male moth's ability to follow female pheromone, pheromone lures are not effective in those orchards. Recent studies showed that Phenyl Propionate (PPO), an attractant to Navel Orangeworm can be used to monitor navel orangeworm activity. Also, the use of ground pistachio bait (i.e., Peterson bait) to attract females in almond orchards has become more common. In this project, we evaluated commercial NOW attractants (Trece PPO, Alphascents PPO, Peterson bait, and pheromone) in three orchards with plots with or without the use of mating disruption. We are still gathering data, and the conclusion will be reported at a later date.

Tree growth and soil health response to wood mulch incorporation in a newly established orchard

Project Leader: Mae Culumber, UCCE Fresno County

The project objective is to determine if a 50-60 ton/ac wood chip (WC) amendment rate has a detrimental impact on establishment of young

almond trees and to monitor soil biological and chemical shifts to identify mechanisms of tree nutrition and growth trends. Wood Chip plot tree growth and leaf % nitrogen (N) was no different (~2%) than all other treatments including the control in 2018. Similar to prior years, significantly higher ammonium (NH_4+-N), greater organic carbon (C), and total N were observed in WC soils in 2018. Evaluation of soil phospholipid fatty acid (PFLA) resulted in significantly higher overall fungal and bacterial biomass, arbuscular mycorrhizae, saprophytes, actinomycetes, rhizobia, and protozoan populations. Continued tree growth and soil nutrient monitoring will take place from establishment to the nut bearing growth period of the orchard.

Documenting the Effects of Annually Applied Green Waste and Manure Composts on Almond Tree Performance
Project Leader: Roger Duncan, UCCE Stanislaus County

Many studies have shown that soil applications of composted green waste or manure can increase water holding capacity, diversity and activity of soil microorganisms, soil nutrients such as potassium and nitrogen, humic acid, organic matter and carbon sequestration. Despite these published reports on improvements in “soil health”, it is difficult to find data that prove improvements in orchard performance and yield. Despite the lack of data, many government agencies are advocating that growers should apply organic matter such as composted green waste to their orchard soils. Current costs for purchase, delivery and application of composted green waste in the Modesto area is approximately $27 per ton. Common application rates range between five & ten tons of compost per acre, representing a significant investment to the grower. It is important to determine if almond growers can improve tree performance and/or yield enough to recover such a substantial input cost.

Can blossom thinning at full bloom improve shoot growth and future yield in heavily cropped almonds?
Project Leader: Franz Niederholzer, UCCE Colusa and Sutter/Yuba Counties

Crop removal is an untested option for increasing tree size when tree spacing selected exceeds tree growth potential. Potassium thiosulfate (1.5% v/v at spray volume of 150 GPA) was sprayed at full bloom on 10th leaf ‘Independence’ almonds planted 20’ x 16’. Fruit set was significantly reduced by the caustic KTS, but no increase in shoot growth was observed in treated compared to unsprayed trees. Yield was not affected by KTS, but nut size was significantly increased.

Using high resolution computed tomography (HRCT) to image almond spurs
Project Leader: Elizabeth Fichtner, UCCE Tulare County

Dormant spurs were collected from commercial almond orchards in Tulare and Kings Counties for three-dimensional imaging using the high resolution computed tomography system housed at CSU Bakersfield. Spur tissues were scanned and files were re-constructed to produce 3D images and short video clips of spurs. Video footages allow for a “virtual reality” travel into spur tissues, and video clips have been incorporated into educational presentations utilized at UC extension meetings. In combination with graphic illustrations rendered by botanical illustrator, H. Hartzog, a new suite of visual aids has been generated for print, electronic, and oral presentations

Field Evaluation of Almond Rootstocks

Project Leader: Roger Duncan
University of California Cooperative Extension, Stanislaus County, 3800 Cornucopia Way #A, Modesto, CA 95358 (209) 525-6800, raduncan@ucdavis.edu

PROJECT SUMMARY

Objectives:

This project encompasses several long-term trials located in Butte, Yolo, Stanislaus and Fresno Counties. Each field trial separately evaluates the field performance of numerous rootstocks compared to long-time local standards. Each trial location presents different production challenges and includes the following objectives:

- Evaluation of alternative rootstocks irrigated with low quality (saline) irrigation water in alkaline, heavy soil (Stanislaus County).
- Evaluation of alternative rootstocks under very high boron conditions (Yolo County).
- Evaluation of rootstocks in unfumigated replant locations in sandy (Stanislaus) and heavy (Butte) soil.
- Performance comparison of conventional rootstocks with peach x almond hybrid rootstocks and dwarfing rootstocks in different EC zones (CSU Fresno).

Background and Discussion:

Selecting the appropriate rootstock for specific soil conditions is critically important for the long-term success of an almond orchard. Rootstocks influence the vigor of a tree, anchorage, and date of crop maturity. More importantly, rootstocks can guard against soil-borne pathogens like nematodes, crown gall, Phytophthora, Verticillium wilt and oak root fungus. They can also affect above ground pathogen susceptibility in the case of hull rot or band canker. Tolerant rootstocks enable plantings into areas with chemical soil challenges such as high pH, sodium, chloride or boron.

Nemaguard and Lovell, long-time industry standard rootstocks, have some significant flaws. Both often perform poorly in heavy, alkaline soils and are susceptible to Phytophthora, oak root fungus, crown gall, and other diseases. Nemaguard is also susceptible to ring nematode and bacterial canker while Lovell is highly susceptible to rootknot nematode and crown gall. This project involves several separate field trials evaluating over 25 different rootstocks from various breeding programs around the globe.

Some of the highlights documented in these field trials include:

- High chloride tolerance of most peach x almond hybrids, Rootpac R and Viking.
- Rootstocks least tolerant to chloride include Lovell, Krymsk 86, and Nemaguard.
- Most peach x almond hybrids and Viking accumulate significantly less hull boron than other rootstocks. However, no tested rootstock appears to be highly tolerant of excessive boron.
- Lovell, Krymsk 86, Atlas, Cadaman, and HBOK 50 accumulate the most hull B.
- Krymsk 86, PAC9908-02, Hansen, and Viking have exhibited very good anchorage while Hansen x Monegro (HM2) has unacceptably poor anchorage. Empyrean 1 is questionable.
- Atlas appears to be tolerant to Verticillium wilt disease while Lovell and Hansen appear highly susceptible.
- Hansen, Krymsk 86, & Brights 5 can host high levels of ring nematodes while Krymsk 86 can also host substantial numbers of root knot and root lesion nematodes. Viking, Lovell, Guardian and Empyrean 1 support fewer ring nematodes than Nemaguard.
- Krymsk 86 and Rootpac-R showed the highest potassium leaf levels in Butte County but not in other trials.

Project Cooperators and Personnel: Joseph Connell, UCCE – Butte County (Emeritus); Katherine Jarvis-Shean, UCCE – Yolo & Solano Counties; Gurreet Brar, CSU Fresno

Integration of Tree Spacing, Pruning, and Rootstock Selection for Efficient Almond Production

Project Leader: Roger Duncan
University of California Cooperative Extension, Stanislaus County, 3800 Cornucopia Way (#A), Modesto, CA 95358 (209) 525-6800, raduncan@ucdavis.edu

PROJECT SUMMARY

Objectives:
Evaluate the long-term effects of three key management factors: tree spacing (planting density), rootstock, and training/pruning techniques on orchard production and longevity.

Background and Discussion:
This project, initiated in 2000, has examined the long-term, integrated yield effects of various minimal training and pruning strategies with different tree spacings over a 20-year period. The Nonpareil and Carmel varieties are planted 22, 18, 14 or 10 feet apart down the row while the rows are 22 feet apart.

Summary of Short & Long Term Results:
Effects of Pruning (or not)

- The pruning portion of this trial has been concluded. After twenty years, this trial has confirmed that pruning does not improve almond yield in the short term or long term. In many years, yields were slightly lower in annually pruned trees compared to trees that have been essentially unpruned for the duration of the experiment. This was true across all tree densities and rootstocks.
- Cumulatively, annually pruned Nonpareil trees yielded 508 – 1481 lb per acre less than unpruned trees during the duration of the pruning experiment, depending on rootstock.
- Pruning the Carmel variety reduced yields more than the Nonpareil variety. Depending on rootstock, annually pruned Carmel trees have cumulative yields 977 – 6075 lb per acre less than unpruned Carmel trees.
- Annually pruned trees have historically captured less photosynthetically active radiation (PAR) than unpruned trees. This indicates that pruned trees have a lower yield potential than unpruned trees.
- Based on the results of this experiment, annual pruning would have reduced cumulative gross revenue by over $13,000 per acre over a nineteen-year period, including yield reduction and the cost of pruning and brush disposal.

Effect of Tree Spacing

- Yield effects (positive and negative) have varied depending on the vigor and ultimate size of the trees. In general, the smaller Carmel variety on the moderate vigor Nemaguard rootstock has shown significant yield benefits to closer spacing. Through the 19th leaf, the closest spacing (10 feet between trees) accumulated 7564 lb per acre greater than the widest spacing (22 feet).

Cumulative Yield of Carmel on Nemaguard

- 10’ x 22’: 48,593 lb per acre
- 14’ x 22’: 45,595 lb per acre
- 18’ x 22’: 43,805 lb per acre
- 22’ x 22’: 41,029 lb per acre

- Conversely, very vigorous trees have had highest yields at more moderate spacings. Through the 20th leaf (including 2019 yield), Nonpareil trees on the very vigorous Hansen rootstock have the highest cumulative yields when planted 18 feet apart.

Cumulative Yield of Nonpareil on Hansen

- 10’ x 22’: 45,146 lb per acre
- 14’ x 22’: 46,029 lb per acre
- 18’ x 22’: 48,687 lb per acre
- 22’ x 22’: 44,776 lb per acre

Project Cooperators and Personnel: Bruce Lampinen, University of California, Davis

Nickels Soil Lab Projects

Project Leader: Franz Niederholzer
UCCE Colusa, 100 Sunrise Blvd, Suite E, Colusa, CA 95932 (530) 218-2359, fjniederholzer@ucanr.edu

PROJECT SUMMARY

Objectives for current year:

In support of two ongoing series of projects on almond production at Nickels Soil Laboratory:

- Continue to evaluate the economics of organic almond production methods suitable for California conditions and in compliance with U.S. Department of Agriculture and CCOF (California Certified Organic Farmers) certification requirements and compare the results with those for standard production methods.
- Planting density down trial, evaluating 4 different tree spacings down the tree row: (12', 14', 16', or 18') planted in 2017.

Background:

Like other food producers, more almond growers are shifting to organic production methods, thanks to a growing market.

Making such a transition, though, poses challenges for the growers. Among them would be how to deal effectively with such critical issues as disease control, insect control, weed control, and providing adequate nutrition, especially nitrogen.

Furthermore, although anecdotal information abounds on organic almond growing practices, there remains a lack of science-based information relevant to organic almond production.

To objectively explore what's involved in organic production, the Nickels Soil Lab is being used as the site of a research / demonstration orchard.

Since it was planted in 2006, this orchard has been being used to monitor and evaluate all aspects of producing organic almonds, including costs. The outcome will likely be a well-documented process—and possibly the basis for a viable commercial operation.

Another current and key topic of interest to almond growers is planting density- balancing cost with returns. A planting density x rootstock x pruning trial has been conducted in the northern San Joaquin Valley for more than a decade, but we are not aware of a similar trial in the Sacramento Valley. A spacing trial, without replicated rootstock or pruning treatments in 2017. Across the row spacing was held at 21', while down the row spacings of 12', 14', 16', or 18' were planted. Titan (peach/almond hybrid) and Rootpac-R (almond/plum) hybrid rootstocks were used with Nonpareil (50%), Aldrich (25%) and Kester (25%) scions, but not in a pattern to statistically compare the two rootstocks.

Discussion:

Nonpareil yield in the conventional and organic blocks were considerably lower in 2019 than the high levels of 2018, perhaps due to poor bloom weather in February 2019.

Maintaining adequate nitrogen in the organic block remains the biggest challenge at this time. Cost of liquid organic fertilizer and incorporating dry, less expensive organic N sources have been some of the issues faced in 2019 crop year.

Third leaf Nonpareil yield data from the spacing trial is being analyzed and will be presented at the conference.

Project Cooperators and Personnel:

John Edstrom, UCCE-Colusa County (retired); Bill Krueger, UCCE-Glenn County (retired); Bruce Lampinen, UC Davis; Stan Cutter, Nickels Soil Lab, Arbuckle, CA

Rootstock Breeding

Project Leader: Tom Gradziel
Dept. of Plant Sciences, UC Davis in (530) 1575, TMGradziel@ucdavis.edu

PROJECT SUMMARY

Objectives for current year

Develop a series of multifunctional rootstocks combining all required traits for continued production in the main California growing regions as well as expanded production into newer regions.

Background

Changes in field management practices have led to the need for a new generation of almond rootstocks. Germplasms derived from interspecies hybrids are being used to achieve the largest possible array of vigor and desirable horticultural and resistance traits. UCD breeding lineages have been developed combining almond, peach and plum as well as wild Prunus species including P. argentea, P. bucharica, P. davidiana, P. fenzliana, P. domestica, P. mira, P. orthosepala, P. scoparia, P. tangutica and P. webbii.

Discussion

Because most successful rootstocks are interspecies hybrids, our goal is to identify species sources and combinations conferring required resistance (nematodes, salinity, diseases, etc.) and then identify individuals within those species that when used as crossing parents will also confer regionally required traits (anchorage, tolerance to waterlogged soil, boron, etc.). We are developing strategies to generate large numbers of complex interspecies hybrids, identify the most promising selections and then propagate multiple copies for large-scale resistance and productivity testing.

Over 500 inter-species UCD selections are currently in field-testing. Hybrids between almond and peach species show good promise as sources of nematode resistance, salinity tolerance and vigor. P. davidiana shows promise for root knot and ring nematode resistance. An additional 100 progeny from this source were propagated in 2018/19 for large-scale testing. Over 1,000 new almonds by P. davidiana progeny were also bred in 2019 using parents having possible lesion nematode resistance as well. Field plots have been developed for screening for resistance to oak root fungus, crown gall and water-logging soils. Molecular markers to identify species origins and possible resistance genes are being analyzed for over 400 of our most promising parents and selections. Molecular markers for root knot and oak root fungus resistance are being pursued with collaborators in Spain and Clemson Univ. In 2019, we generated over 50 progeny from a difficult oak root fungus resistant P. cerasifera to nematode resistant peach cross that are currently being evaluated at Clemson. Univ. of Florida collaborators have identified potential sources of resistance to heartwood-rot among several hundred UCD accessions. In 2019, an additional 210 F2 seed were generated at UCD for further disease and molecular analysis at UF. Over 240 segregating F2 progeny from a peach by P. tangutica cross have are now being propagated for crown-gall testing by the Kluepfel lab. Over 100 progeny were sent to the Dandekar lab where genotypes amenable to transformation & regeneration were identified, thus opening the door to the use of genetic engineering options to complement future rootstock deficiencies.

Project Cooperators and Personnel: K. Gasic**,** J. Preece, M. Aradhya, G. Browne, D. Kluepfel, T. Michailides, A. Westphal, R. Duncan, J. Chaparro, G. Drakaki, A. Dandekar, P. Brown and C. Fleck.

Development and Testing of a Mobile Platform for Measuring Canopy Light Interception

Project Leader: Bruce Lampinen
Department of Plant Sciences, University of California, Davis, One Shields Ave., Davis, CA 95616
(530) 752-2588, bdlampinen@ucdavis.edu

PROJECT SUMMARY

Objectives:

- Utilize the mobile platform light bar to complete collection of light interception and yield data for long term studied orchards with the goal of determining what happens to this relationship as orchards age.
- Further refine the iPhone application to calculate canopy light interception and create a PC based version of image processing software to allow batch processing of images.

Background and Discussion:

Data collected on tree canopy light interception has shown that it is a valuable indicator of an almond orchard's potential productivity. Results suggest that 50 kernel pounds of almond can be produced for each 1% of total incoming midday canopy photosynthetically active radiation (PAR) that is intercepted. These data are also valuable in evaluating new cultivars to assess whether higher yields can be attributed to higher efficiency or whether they simply grow faster.

Traditionally, obtaining the PAR data has been a slow and labor-intensive process based on use of a hand-held lightbar. Consequently, data gathering has often consisted of only limited and small-scale sampling and of collecting PAR data from only a portion of the row where yield data was collected.

Starting about 9 years ago, a mobile platform lightbar was developed on a Kawasaki Mule. It can span an entire row (up to 32 feet), and includes an advanced data logger and accurate GPS. With this setup, it is possible to gather data at a high rate of speed.

In 2018, research concentrated on collecting Light interception data on the orchards that had the longest term data sets with the goal of understanding what factors lead to yield declines as orchards age. Light bar data was collected in a total of 20 almond trials in 2018 including rootstock trials, variety trials, irrigation trials, pruning trials, cover cropping trials, etc. We are also working with Ali Pourreza in Bio and Ag Engineering at UC Davis to use drone imagery as another means of assessing canopy size and with Brian Bailey in Plant Sciences at UC Davis to integrate our iPAR app with his modeling work.

A working version of the iPhone app for estimated midday canopy PAR interception was released in the Apple store under the iPAR name in the fall of 2016. This app gives growers a tool to estimate yield potential and estimated nitrogen needs of a given orchards based on canopy size.

Overall, this project has the potential to significantly improve orchard design and management by providing a basis for better managing water, as well as providing quantitative estimates of production potential and crop nitrogen needs.

Project Cooperators and Personnel: Shrini Upadhyaya, Ken Shackel, Ali Pourreza, Brian Bailey, and Sam Metcalf UC Davis; Greg Browne, USDA-ARS, Davis; Mae Culumber, UCCE – Fresno County, Roger Duncan, UCCE - Stanislaus County; Elizabeth Fichtner, UCCE- Tulare County; Allan Fulton, UCCE - Tehama County; Phoebe Gordon, UCCE- Madera County, Brent Holtz, UCCE - San Joaquin County; Dani Lightle and Luke Milliron, UCCE - Butte/Glenn/Tehama Counties; Franz Niederholzer, UCCE – Colusa/Sutter/Yuba Counties; Blake Sanden, UCCE – Kern County

Integrated Conventional and Genomic Approaches to Almond Rootstock Development

Project Leaders: M. Aradhya[1], C. Ledbetter[2], D. Kluepfel[3], G. Browne[3], and A. Westphal[4]

[1]USDA/ARS, National Clonal Germplasm Repository, UC Davis, CA 95616 (530) 752-9392, mkaradhya@ucdavis.edu;
[2]Crops Diseases, Pests, and Genetics, USDA/ARS, Parlier, CA 93648; (559) 596-2817, craig.ledbetter@ars.usda.gov;
[3]USDA/ARS, Davis, UC Davis, CA 95616, dakluepfel@ucdavis.edu and gtbrowne@ucdavis.edu;
[4]UC Riverside & Kearney Ag. Center, S. Riverbend Ave., Parlier, CA 93648, andreas.westphal@ucr.edu

PROJECT SUMMARY

Objectives

1. Produce interspecific hybrids with species that are potential donors of disease resistance.
2. Perform disease resistance screening of rootstock hybrids produced in objective 1 to identify promising hybrids.
3. Bud/graft scion cultivars on to hybrid rootstocks identified in obj. 2 to establish field trials.

Background

The goal of our project is to develop rootstocks with durable resistance to soil borne diseases such as phytophthora crown and root rots, crown gall, and root-knot, lesion, and ring nematodes. Emphasis was on the production and disease resistance evaluation of a wide array of interspecific hybrids representing the taxonomic and genetic diversity in the *Prunus* gene pools. Generation of this diverse genetic background is key to our search for effective disease resistance. However, over the next year we will change our focus to the evaluation of existing hybrids produced in the project.

Discussion

Two hundred forty-six clonal plants representing 51 genotypes were root-inoculated with Agrobacterium tumefaciens, the causal agent of crown gall. After emerging from dormancy, plant roots were examined for crown gall. Plants from six promising genotypes PM49, PM37, PV11, DK1, PM40 and DV1-13 were identified with little to no disease symptoms in 2019 evaluations.

In 2019 Phytophthora greenhouse screening (*P. cinnamomi* and *P. niederhauserii)*, six out of 35 hybrids tested showed moderate levels of resistance. Further field screens are planned for 2020.

In nematode screening, eleven genotypes that were favorable in prior year-root lesion and root-knot nematode evaluations were planted in sandy soil and inoculated with ring nematode in 2018. These will be evaluated in the upcoming dormant season.

A set of 42 new hybrids produced during 2018 and 2019 will be evaluated during 2020. No more hybrids will be produced beyond 2020. Two field trials will be established in 2020 at UCD Armstrong and Kearney Ag. Center to examine 20 elite hybrids previously shown to exhibit resistance to one or more of the pathogens being examined in this project.

Promising hybrids previously examined for disease resistance are listed here:

Rootstock	Parentage	RK	RL	CG	PHY
197-113	*P. persica x P. tangutica*		*	*	*
97-190	*P. persica x P. dulcis*		*		
197-199	*P. persica x P. davidiana*	*		*	*
197-200	*P. persica x P. davidiana*	*			
197-206	*P. persica x P. kensuensis*	*	*		
197-209	*P. persica x P. kuramica*		*		
197-214	*P. persica x P. bucharica*		*	*	
197-217	*P. persica x P. kuramica*			*	
197-6	*P. persica x P aregentea*	*			*
197-95	*P. persica x P. tangutica*	*		*	*
198-18	*Nemaguard x P. kensuensis*	*			
L1-2	*P. cerasifera*				*
P2-1	*Nemared x P. argentea*		*	*	
P2-2	*Nemared x P. argentea*	*			
P2-4	*Nemared x P. argentea*	*		*	
P4-1	*Nemared x P. fenzliana*			*	*
P4-10	*Nemared x P. fenzliana*	*	*	*	
P4-25	*Nemared x P. fenzliana*	*	*	*	*

RK = root knot; RL = root lesion; CG = crown gall; PHY = Phytophthora

Project Cooperators and Personnel: J. Preece, C. DeBuse, and J. Moersfelder, USDA/ARS; D. Velasco, E. Johnson, G. Drakakaki, T.Gradziel, and F. Lewis, UC Davis; and R. Robinson & C. Fleck of Sierra Gold Nurseries.

Tree Architecture and Development of New Growing Systems

Project Leader: Grant Thorp
Plant & Food Research Australia Pty Ltd, 7 Bevan St, Albert Park, Melbourne, Victoria 3206, Australia.
+61 4 2261 0748 grant.thorp@plantandfood.com.au

PROJECT SUMMARY

Objectives for current year:

- Optimize pruning systems for current and future almond varieties and rootstocks planted at high density
- Accelerate identification, breeding and commercialization of almond varieties with tree architectures suitable for high density orchards

Background and progress:

Almond orchards of the future will need to be more efficient, using new varieties and rootstocks and more cost-effective and sustainable growing and harvesting systems. This program of collaborative research between Australian and Californian science groups is helping to address this challenge.

As physiologists, our target is to assist almond breeders and growers to select/identify new varieties that have architectural features associated with high productivity and that have a natural tendency to be easily grown as central leader trees suitable for planting at high density.

Projects, including pruning responses and architectural studies, were planted in 2018 and 2019 in collaboration with John Slaughter and Kaylan Roberts at Burchell Nursery in Fowler, C. These trials now include 13 advanced genotypes from the UC), Davis breeding program, in collaboration with Dr Tom Gradziel, four from the Burchell Nursery breeding program, and five commercial varieties — ‘Nonpareil’, ‘Monterey’, ‘Wood Colony’, ‘Winters’ and Shasta®. All trees were planted at high density (15 x 7.5 ft). A similar mix of varieties and advanced genotypes were planted at UCD Wolfskill, in collaboration with Dr Bruce Lampinen.

In these projects, we are characterizing desirable architectural traits in current and potential new almond varieties starting with “unpruned” trees in their first leaf budded onto clonal rootstocks. All trees are trained in the nursery to develop central leader trees and then left to develop in the field for 2 years with no pruning, so that the true natural growth habit of each genotype, including flowering and fruiting patterns, can be recorded.

In related projects, with fewer genotypes, we are comparing a range of tree training and minimal-pruning treatments, designed to facilitate the establishment of trees, with a central leader or a narrow slender pyramid tree shape.

Architectural data from pruned and unpruned trees were collected from all genotypes during 2019. Key attributes recorded were the relative dominance of the trunk; the number, length, diameter and orientation of scaffold branches; the number, length and diameter of mainly sylleptic dard shoots and proleptic subterminal shoots; and the size of buds and internode lengths. These descriptions are sufficient to cover both dard and spur type genotypes and also compact genotypes with short internodes.

From these data we have developed a phenotyping tool for breeders to rapidly characterize breeding populations for architectural traits of interest.

The first yield data will be collected in 2020.

Project Cooperators and Personnel: Gurreet Brar, CSU Fresno; Bruce Lampinen, Tom Gradziel, UC Davis; John Slaughter, Kaylan Roberts, Burchell Almond Genetics; Ann Smith, Michael Coates, PFR Australia.

New Germplasm and Training Systems for High Density Catch Frame Almond Systems

Project Leader: Bruce Lampinen
Department of Plant Sciences, University of California, Davis, One Shields Ave., Davis, CA 95616
(530) 752-2588, bdlampinen@ucdavis.edu

PROJECT SUMMARY

Objectives:

- Evaluate new germplasm from the UC Davis almond breeding program, USDA almond breeding program for tree structure conducive to central leader architecture for catch frame systems

Background and Discussion:

The California almond industry is under pressure from numerous fronts including issues related to water use (crop per drop), dust, food safety, etc. This project is designed to investigate new germplasm and training systems for high density catch frame almond production systems to aid in Almond Board efforts to transition to catch frame harvest systems due to dust and food safety related concerns.

This project is designed to develop compact central leader trees that are compatible with high density plantings and catch frame harvesting. This includes 8 advanced selections from the UC Davis Almond Breeding Program that show promising architecture for central leader tree architecture as well as 3 items from the commercial breeding program and commercial varieties ‘Nonpareil’, ‘Monterey’, ‘Wood Colony’, ‘Winters’ and ‘Shasta’.

The research question to be investigated is whether or not we can generate central leader almonds that are compact and compatible with catch frame harvesting.

This study complements the trial at Fresno State University (Thorpe and Brar) which has different within row spacings by adding in new germplasm from the almond breeding program from UC Davis. The plan is to maintain a central leader architecture with as little manipulation as possible.

Tree were planted in April 2018 at a spacing of 7’ x 17’ in a randomized block design with 3 replicates and 4 trees in each replicate. All trees were left un-headed from the nursery. Initial measurements taken included height and circumference at planting. The plan was to rate the architecture as to tendency towards forming a central leader.

After the first year, about half of the items looked promising in terms of a tendency towards forming a central leader. However, in the second year many side shoots grew up competing with the central leader. it would have taken a lot of pruning to maintain a central leader. After 2 years of following these items, we do not think that it is possible to reliably generate central leader almond trees without a great deal of manipulation of the canopy. This trial is planned for removal after the 2019 field season measurements are completed.

Project Cooperators and Personnel: Tom Gradziel, Sam Metcalf, Loreto Contador and Tran Nguyen, UC Davis, Grant Thorp, Plant and Food Research Australia, Gurreet Brar, CSU Fresno

Gene Prediction and Genome Functional Annotation of 'Nonpareil'

Project Leader: Jonathan Fresnedo-Ramirez
Dept. of Horticulture and Crop Science, The Ohio State University, 1680 Madison Ave., Wooster, OH 44691
(330) 263-3822, fresnedoramirez.1@osu.edu

PROJECT SUMMARY

Objectives for current year

- Develop a gene prediction model for the genome assembly of 'Nonpareil'.
- Develop a transcriptome with full length transcripts of genes in 'Nonpareil' using single-cell RNA sequencing technology.
- Develop a functional gene annotation of the 'Nonpareil' genome.
- Integrate optical mapping data to refine the 'Nonpareil' genome.

Background

Despite its relevance, genomic resources specific to almond are lacking, particularly for high-value cultivars. The lack of these basic resources hinders a deeper study of important mechanisms and crop traits, limiting the ability to develop tools and strategies to address the needs and challenges of future almond production.
To provide genomic resources for almond, an interdisciplinary team including researchers from The Ohio State University (OSU) and UC Davis have initiated an effort to develop the first completely assembled and annotated genome sequence for 'Nonpareil' almond cultivar.

Discussion

The collaborative effort has resulted in a high-quality draft assembly for almond. Using a combination of Illumina technology and high-throughput chromosome conformation capture (Hi-C), a high-quality high-continuity draft assembly of the gene space was produced.

Next, a gene prediction and functional annotation pipeline that employs a combination of *ab initio* (intrinsic) and evidence-based (extrinsic) gene finding approaches was successfully implemented at the Ohio Supercomputer Center. First, repeats and low complexity regions were identified and subsequently masked in the 'Nonpareil' assembly. As a result, 27% of the genome was soft-masked for repeat elements, a majority of which comprised of interspersed repeats (25%), suggestive of transposition or retro-transposition events.

Second, a preliminary gene prediction analysis resulted in identification of 28,637 gene models, with an average gene length of 2.82 kilobase pairs. This translates to ~ 48% of the assembled 'Nonpareil' genome covered by the total length of gene models. For comparison, about 27,000 gene models (~ 40% of the genome) were reported in the almond 'Texas' (a.k.a. Mission), and 26,873 gene models in peach (~ 38% of the genome). These numbers suggest that the 'Nonpareil' gene content is within the expected gene content in the *Prunus* genus. The predicted gene models were supported by expression or transcript data generated from 'Nonpareil' tissues, protein sequences for related cultivars, and/or presence of protein domains identified by a protein family database search.

Third, a functional annotation of the protein sequences associated with the predicted models found ~68% were associated with at least one biological function while the rest are of unknown function.

Finally, a high proportion of 'Nonpareil' gene content supports the ongoing effort of improving the genome assembly using optical mapping technology to uncover additional gene regions.

Project Cooperators and Personnel: Wilbur Z. Ouma & Tea Meulia, MCIC – Ohio State University; Thomas Gradziel, UC Davis

Managing for Soil Health: Targets and Potential in Almond Orchards

Project Leaders: Amélie Gaudin[1]

[1]Deptartment of Plant Sciences; UC Davis; One Shields Ave., Davis, CA 95616; (530) 752-1212; agaudin@ucdavis.edu

PROJECT SUMMARY

Objectives for current year:

- Sample various orchards across a management gradient and complete analyses of soil health parameters
- Explore the relationships between soil health and functions of interests to growers and soil biological communities, specifically soil microbes and nematodes.
- Create soil health outreach materials for almond growers

Background:

Soil health building practices are gaining popularity across California agroecosystems as a means to improve the overall sustainability and resilience of crop productions whilst maintaining system productivity. In addition, many relevant orchard management challenges such as salinity, water and nutrient use efficiency, and soil-borne pest and disease pressures are influenced by the regulatory and supportive functions provided by a healthy, living soil. Despite our growing understanding of the importance of soil health in supporting ecosystem services, much of the research on how soil management impacts ecosystem service potential remains focused in annual cropping systems. This – combined with management that tends to emphasize the tree over other system components – has resulted in a knowledge gap about the functional importance of soil health in Almond systems and untapped potential to improve the ecosystem services that drive sustainability, resilience, and productivity. This project aims at quantifying the potential benefits of soil health to almond growers. We will also work with our collaborators to explore how soil organisms, namely soil microbes and nematodes, relate to ecosystem service potential and soil health. This knowledge will be used to create regional benchmarks for soil health in almond productions that reflect both production and sustainability goals.

Discussion:

During winter of 2019 thirteen orchards located in Yolo County were selected from a larger pool of potential orchards to represent a variety of soil management practices and investment and soil health (e.g., conventional bare soils, cover crops, organic amendments…). Restricting the geographic region of our study will minimize the climatic and edaphic factors that influence the potential to build soil health. We developed a framework to evaluate the benefits and potential tradeoffs by combining soil and tree properties with management history. Specifically, we defined that healthy soil in an almond orchard should build and store carbon, regulate nitrogen cycling, conserve water, efficiently use inputs, maintain soil structure, and support diverse and active soil communities.

Soil samples were taken from each orchard in May 2019 and used to analyze a suite of physical, chemical, and biological indicators of soil health and function. We will continue to analyze the remaining soil properties and work with our collaborators to explore how soil health relates to the taxonomic composition and functional potential of soil microbial and nematode communities. Additional ecosystem services – including disease suppression, resilience to environmental stressors, and increased nutrient retention – will be explored through the analysis of the soil food web. We will couple our soil analysis with tree metrics and orchard management history to explore the relationships between soil, tree, and ecosystem health and management systems. Finally, we will use the knowledge gained from this project to create benchmarks of soil health for almond growers from our study region that optimize production and sustainability goals. We hope that the framework created for and knowledge gained from this project will serve as a stepping-stone for the development of soil health building practices for orchard systems as well as contribute to further explorations of the relationships between orchard soil management and sustainability.

Project Cooperators and Personnel: Jorge Rodriguez, Amanda Hodson (UC-Davis), Tim Bowles (UC-Berkeley), Katherine Pope (UCCE-Yolo, Solano Cos), Krista Marshall (PhD student)

Three-Dimensional Modeling of Water Use and Photosynthesis in Almond Orchards

Project Leader: Brian Bailey[1]
[1]Dept. of Plant Sciences, UC Davis, One Shields Ave., Davis, CA 95616 (530) 752-7478, bnbailey@ucdavis.edu

PROJECT SUMMARY

Objectives for current year:

- Collect additional canopy geometry, leaf gas exchange, and meteorological data for model parameterization
- Perform sub-leaf model validation against lysimeter data
- Simulate seasonal water use for virtual orchards with different designs and analyze trade-offs in water-use efficiency

Background:

Field experimentation, along with intuition, has been the traditional approach used by agronomists and growers to better understand crops, and ultimately improve efficiency in production. Making robust conclusions that lead to the adoption of new practices is typically slow, as very large data sets are required in order to separate physiological effects from the high natural variability in the system of interest. Inability to rapidly vary environmental, geographical, and architectural conditions also limits the utility of field experimentation.

This project seeks to develop a robust modeling system that can be used to evaluate proposed management strategies in a virtual environment prior to field experimentation. This will accelerate the speed of innovation and add an additional layer of information to supplement data collected in the field.

Crop models have been utilized for many decades as a tool to better understand cropping systems. While models have been relatively successful in representing field/annual crops, modeling perennial cropping systems presents many considerable difficulties such as storage of carbohydrates over winter, and their complex and seasonally-varying architectures.

Our approach is to represent the full three-dimensional geometry of the canopy and associated physical processes at the leaf scale. The model outputs will be absorbed sunlight, evapotranspiration fluxes, and photosynthetic rates for every leaf and surface in the canopy, which can be easily aggregated to give whole-plant and whole-field values.

Our overall goal is to determine optimal management practices that minimize plant water requirements without sacrificing yields. We have been working to develop the modeling system, and to rigorously validate it against detailed field measurements.

Results & Discussion:

One key finding of the past year's work is the importance of performing simulations at the sub-leaf scale rather than at the leaf scale. There can be considerable variability in light interception across an individual leaf and taking this into account rather than averaging over each leaf can decrease modeled canopy water fluxes considerably, with largest differences occurring for more dense canopies. Another lesson learned was the importance of using the appropriate within-canopy environmental conditions as input for simulations. Air temperature, humidity, and especially wind speed measurements collected within the canopy were significantly different from above-canopy conditions and conditions at the nearest CIMIS station. Initial validation of the model has been performed, and further validation is ongoing. Once the model has been validated (end of year 2), we will use the model in year 3 to construct virtual orchards of different densities and analyze trade-offs in water-use efficiency, and how particular orchard designs impact production versus water use.

Project Cooperators and Personnel:
Eric Kent, Ken Shackel, Bruce Lampinen, Ted DeJong, Matthew Gilbert, UC Davis

Development of Tree Carbohydrate Budget of Almonds Under Changing Central Valley Climatic Conditions

Project Leaders: Maciej Zwieniecki and Anna Davidson
Dept. of Plant Sciences, UC Davis, One Shields Ave., Davis, CA 95616 (530) 752-1843, mzwienie@ucdavis.edu

PROJECT SUMMARY

Objectives for current year:

(1) Continue developing and implementing a state-wide database on almond carbohydrate dynamics available to growers that provides specific information on healthy tree Non-Structural Carbohydrates (NSC) content in respect to region, variety, age, and season as a guidance for management practices.
(2) Determine links and trade-offs between growth, storage and yield. Determine cumulative impacts of environmental stresses on carbohydrate management including the combined effects of thermal and water stress.
(3) Evaluate current management practices of winter chill substitutes and winter irrigation on carbohydrate status of the tree (a continuing effort).
(4) Establish experimental tools for studying shoot physiology under variable environmental conditions in the lab and in the field including detailed analyses of starch and soluble sugar concentration dynamics, enzyme activity, and expression pattern of genes encoding enzymes from carbohydrate metabolism pathways (a continuing effort).

Background:
California's Central Valley is affected by a slow climatic shift that is reducing the Valley's fog cover. The net result is an increased incidence of variable thermal conditions during winter including higher average temperatures, more severe frost nights, and hot sunny days that can affect tree phenology.

These factors combined with the increasing use of saline ground water supplies have produced an unprecedented set of new abiotic stresses that affect horticultural production. Vegetative life of any perennial plant can be described as a continuous struggle to acquire, transfer, and store energy that is necessary to grow, reproduce, and protect from abiotic and biotic stresses and allow survival of dormancy.

Carbohydrates (sugars) are responsible for the majority of long-distance energy transfers and long-term storage of energy in plants.
They are the ultimate currency that the plant uses to interact with the environment. The understanding of carbohydrate physiology as plants respond to environmental stress while accomplishing their reproductive functions is of key importance for predicting yields, analysis of stress, and a plant's ability to mediate salinity, drought, or winter survival. Understanding of carbohydrate management is especially important in long-lived perennial crops like almond that must balance short-term (seasonal) vs multi-year benefits with effects being carried out over multiple years.

Discussion:
We are in the third year of a *citizen research* project that allows for analysis of carbohydrates in almond orchards across California (Objective 1). High seasonal variation of NSC and starch reserves was found pointing at mid-summer as the most important period for reversal in the NSC trend from supply to accumulation of storage. This suggests that management practices during and post-harvest might influence the future performance of an orchard.
Specifically, the amount of NSC in October was positively correlated with the following year's yield suggesting that management aiming at increasing storage of NSC in October is beneficial. This might require irrigation that stops tree increment growth in August and September exploring tradeoffs between growth and storage (Objective 2).
Development of canopy rain exclusion and heat supplement to study physiology of dormancy (Objective 3 and 4).

Project Cooperators and Personnel: Anna M. Davidson, UC Davis

Management and Benefits of Cover Crops in Almond Orchards

Project Leaders: Amélie Gaudin[1], Jeffrey Mitchell[2], Andreas Westphal[3]
[1]Department of Plant Sciences; UC Davis; One Shields Ave., Davis, CA 95616; (530) 752-1212; agaudin@ucdavis.edu;
[2]KARE; 9240 S. Riverbend Ave., Parlier, CA 93648; (559) 646-6564; jpmitchell@ucdavis.edu;
[3]Department of Nematology; University of California Riverside at KARE; (559) 646-6555; andreas.westphal@ucr.edu

PROJECT SUMMARY
Objectives for current year:

- Compile knowledge on the use, management, and barriers for adoption of cover crops in irrigated almond orchards.
- Quantify the benefits and tradeoffs of winter cover crops and resident vegetation compared to fallow on productivity and soil health, water balance and weed pressure in three different geographical regions differing in average annual rainfall
- Determine the host status of various cover crops species and mixes to key plant-parasitic nematodes.

Background:
Planted or natural vegetation cover crop during the fall/winter impact various aspects of soil quality regulating N, water, and C dynamics which may be of benefit to the sustainability and resilience of almond industry. Previous projects and farmers experience show that this practice is compatible with large scale almond production and California growers recognize the theoretical benefits that might come from implementing cover cropping. However, we lack concrete information to guide cost-benefit analyses of implementing cover crop and address concerns about potential increase in water usage. We are now entering our third field season. We will continue to determine benefits and trade-offs associated with two different winter cover crop mixes in terms of soil health and pest suppression and pollination across different rainfall zones in both bearing and non–bearing orchards. In addition, we will monitor the impacts of cover crop termination dates on these services to provide strong basis for further optimization of winter cover crop systems for almond orchards.

Discussion:
We have conducted a grower survey and reached to ~2500 almond farmers and advisors to better understand barriers to adoption of cover crops and data needs. Preliminary results indicate that growers expect that cover cropping will provide multiple joint-benefits, in addition to improvements in tree nutrition. The value of cover crop benefits is already recognized by most growers, with soil health and pollinator habitat being of highest importance. We also are in the process of setting up the third year of our three replicated trials across the Sacramento and San Joaquin Valley with either (T1, T2) two winter planted cover crops (pollinator mix and soil mix), (T3) winter resident vegetation, and (T4) bare ground across four rainfall regions. The collection of data regarding water use and storage has been completed and the analysis will be shared soon. We will continue our monitoring of soil health outcomes and weed suppression while the significance of cover crops for supporting pollination and improve sanitation efficiency are tackled in affiliated projects. Our preliminary results indicate that cover crops likely do not reduce Almond yields and can rapidly improve aggregate stability compared to bare soils. The brassica dominated mix has a large weed suppression potential. Finally, we will continue our field studies building on greenhouse studies performed in previous year to evaluate parasitic nematode host status of Croalatia sp. along with the species and mixtures from the pollinator and soil mixes tested. This will include ability to suppress root-knot, ring and/or lesion nematodes.

We have put together a large team of very talented farm advisors and UC researchers. Their experience combined with the system approach implemented here will help better understand the relationship between benefits and tradeoffs of winter soil cover across rainfall zones. This will help guide the design of locally-adapted and practical floor management strategies that do not interfere with imperatives of intensive almond production while maximizing benefits obtained from cover crops. This project will also assist the development of integrated pest and water/fertility management strategies necessary to meet the future needs of the California almond industry.

Project Cooperators and Personnel: UCCE: D. Doll, D. Lightle, M.Culumber, M.Yaghmour; Project APIS: B.Synk; UCD: A.Hodson, B.Hanson, and their respective personnel. PhD students: C.Creze (Gaudin), S.Haring (Hanson); Growers: Wegis Ranch (Backersfield), Valley Pride (Fresno), Castle farm (Merced), Bosque Verde (Corning)

Development of Disease Resistant Hybrid Rootstocks through Cell Culture

Project Leaders: Abhaya M. Dandekar
Dept. of Plant Sciences, UC Davis, One Shields Ave., Davis, CA 95616 (530) 752-7784, amdandekar@ucdavis.edu

PROJECT SUMMARY

Objectives for current year

- Develop embryogenic cultures from immature hybrid seed at early stages of development
- Develop propagation systems from hybrid tissues

Background

Almonds (*Prunus dulcis*) are California's #3 agricultural commodity, grown on a million acres with an annual production of over two billion pounds valued at $5.6 billion (farm gate value). In many production areas, soil borne disease, pests and environmental problems besiege almond productivity and reduce grower profitability. Many diseases, pests and environmental problems can be addressed by grafting almond scion varieties to resistant rootstocks. Currently, growers use a *Prunus* hybrid rootstocks that has significantly improved almond productivity, but which also increases susceptibility to certain diseases, pests and environmental stressors. Creating new hybrid rootstock varieties resistant to these ailments is a path forward and the focus of this investigation. *Prunus* hybrid seed will be created using parental materials that contain resistance traits of interest. A key objective of our study is to isolate and culture plant stem cells from these hybrid tissues and to develop cell and tissue culture systems to propagate individual hybrid seed sources, leading to the development of novel hybrid rootstocks for almond orchards in California.

Discussion

The goal of this study is to culture plant stem cells from *Prunus*-almond hybrid seed tissues and to develop cell- and tissue-based propagation systems leading to the development of novel hybrid rootstocks for almond orchards in California. Multiple crosses were made using a peach selection with root knot nematode and possible ring nematode resistance in early springs of 2018 and 2019, to create hybrid seed for this study. Mission was used as the almond seed parent. Embryos were rescued from hybrid seed at early stages of development to propagate embryonic stem cells. Multiple experimental conditions were evaluated, including age of embryo, culture media, growth factors and incubation conditions, to induce the embryos to proliferate in culture and/or to develop embryogenic callus that can be induced to generate somatic embryos. In 2018 out of 50 immature nuts 10 embryogenic cultures were initiated and 4 independent hybrid somatic embryo lines were initiated. All these cultures were validated for producing somatic embryos which continued to proliferate when exposed to embryo proliferation media. Desired embryo lines were desiccated to initiate germination and shoots were obtained. Propagated plantlets look healthy and similar to most of almond peach hybrids. More crosses were made in 2019 because the cooler weather prolonged bloom. In 2019 out of 50 immature nuts 20 cultures were initiated and 14 independent somatic embryo lines were obtained. Germination systems were developed for the somatic embryos to enable the further testing of their genetic attributes in the laboratory and greenhouse.

Project Cooperators and Personnel:
Thomas Gradziel, Charles Leslie, David Tricoli, Greg Browne, Paulo Zaini and Sriema Walawage.

Almond High-Density Trial at CSU Fresno: Developing New Orchard Systems with Modified Row and Tree Spacing

Project Leader: Gurreet Brar
Dept. of Plant Science, California state University, Fresno, CA 93740 (559) 278-4119, gurreetbrar@csufresno.edu

PROJECT SUMMARY

Objectives for current year:

- To establish the trees in the trial block and to compare tree growth in terms of height and girth.

Background:

The high-density almond trial was planted in February 2018 with two cultivars Nonpareil and Shasta on Nemaguard rootstock. The experiment is situated in the University Agricultural Laboratory of the California State University, Fresno. The trees were planted at 6 different Tree X Row spacing:

i) 16 x 21 ft (130 trees per acre); ii) 10 x 21 ft (207 trees per acre); iii) 10 x 18 ft (242 trees per acre); iv) 7 x 18 ft (346 trees per acre); v) 10 x 15 ft (290 trees per acre); vi) 7 x 15 ft (415 trees per acre).

There are 6 replicated blocks for each of the six spacing treatments, randomized within each block of row spacing. There are 5 replicate data trees in each treatment block of a cultivar-spacing combination. The trees planted at 16 x 21 ft spacing were planted as control trees that had been headed back in the nursery and all side shoots trimmed. All remaining trees were planted as “unpruned” central leader trees taken direct from the nursery to be grown with minimal pruning to produce mature, full height trees up to 16 or 20 ft tall depending on row width. Trees planted 10 ft apart along the rows were trained as narrow palmette style trees in summer by removing any large structural branches growing out into the center of the rows. Trees planted 7 ft apart along the rows will be pruned in both directions to produce a slender pyramid tree shape. During 2019 growing season, trees were summer pruned mechanically.

Discussion:

During the 2019 season, some central leader trees were selectively pruned at the top to select a dominant central leader shoot wherever the top shoots were forking or where the terminal bud stopped growing due to weather conditions or mechanical damage. The trees that died during 2018 season were marked by the end of the year and were transplanted with healthy trees in February 2019. During June-July 2019, the trees in 7- and 10-foot tree spacing across all row spacings (practically all unheaded central leader trees, leaving only 21 x16 conventional training) were trimmed along the rows to stimulate growth and to achieve a desired pyramidal shape. Further, the trees in 7-foot spacing treatment were trimmed on all sides. All trimming was done with a mechanical hedger. Measurements on tree height and trunk diameter were taken in March 2019. In tree height, all central leader trees within each cultivar did not have statistically significant differences between spacing treatments. However, Shasta trees were significantly taller than Nonpareil trees. In terms of trunk girth all trees were similar in trunk girth and no significant differences were found among spacing treatments or cultivars. The headed trees in 21X16 treatment were significantly shorter that their unheaded/central leader counterparts, because they were headed back in the nursery.

Project Cooperators and Personnel: Grant Thorp, Plant & Food Australia, grant.thorp@plantandfood.com.au

Development of an Unmanned Aerial Vehicle (UAV)-Based Canopy Profile Mapping Technique to Replace the Mobile Platform Lightbar

Project Leaders: Alireza Pourreza[1]
[1]Dept. of Biological and Agricultural Engineering, UC Davis, One Shields Ave., Davis, CA 95616
(530) 752-9290, apourreza@ucdavis.edu

PROJECT SUMMARY

Objectives for current year:

The main goal of this project is to reduce cost and improve adoption of canopy cover measurements for precise orchard management. The specific objectives for the current year are:

- Calculate individual tree canopy cover percentage values for both aerial LiDAR point cloud and aerial photogrammetry images for three research orchards and one commercial orchard
- Evaluate similarity of canopy cover percentage values between LiDAR-extracted values with photogrammetry-extracted and lightbar-measured values
- Develop a precise prediction model based on canopy geometry and spectral characteristics

Background:

Canopy cover percentage (CCP) of an almond tree has been shown to correlate with its harvest yield. The reliable method currently, measures CCP with a mobile platform lightbar—a time-intensive, specialized tool, challenging wide-spread adoption of this metric. To increase adoption, this project looks at an aerial sensing application to reduce cost, time, and training required for CCP data collection.

Photogrammetry is a technique that uses a collection of RGB images taken at multiple angles and distances to create a 3D reconstruction of an object. In this research project, photogrammetry can provide a high-resolution canopy profile map, allowing users to isolate an individual tree's canopy and calculate CCP.

Small UAV platforms can be used to capture the RGB images needed for photogrammetry. These platforms are quickly becoming cheaper and easier to use, with recent releases offering a built-in, high-resolution, maneuverable camera. Additionally, we assess the use of canopy spectral reflectance in addition to canopy geometry for improving yield prediction accuracy. LiDAR in this project is used to reveal the internal structure of trees and serves as a more precise, but expensive reference for photogrammetry analysis.

Discussion:

In the current year of this project, aerial LiDAR, photogrammetry, multispectral, and lightbar data was collected for three research orchards (~1400 trees) and one commercial orchard between April and September 2019. A program has been written to segment individual tree canopies from photogrammetry data automatically while LiDAR and lightbar data are currently being examined and tabulated.

Individual tree yield (wet weights) were collected for the research orchards. Subsamples of harvested almonds were dried and weighed to determine a dry yield to wet weight correlation factor for estimating dry yield of an individual tree. The dry yield will be correlated with CCP and other geometry/spectral features such as canopy cover, volume, height, and vegetation indices to improve yield prediction.

In the dormant season, while the trees are defoliated, aerial LiDAR and images will be collected to created tree structure, better segment the vegetation, and improve the CCP calculation with photogrammetry.

Project Cooperators and Personnel:
Kyle Cheung (graduate students) and Ali Moghimi (Postdoc, Dept. of Biological and Agricultural Engineering), Bruce Lampinen (CE Specialist) and Ken Shackel (Professor, Dept. of Plant Science), UC Davis

Technical Transfer Teams Serving Commercial Beekeepers in Almonds

Project Leaders: Dennis vanEngelsdorp[1] and Karen Rennich[1]
[1]Bee Informed Partnership, 4112 Plant Sciences Bdg, College Park, MD 20742 (301) 404-3799, krennich@umd.edu

PROJECT SUMMARY

Objectives for current year

The Almond Board has supported Tech Transfer Teams (TTTs) since 2011 and is currently providing partial support for 6 Technical Transfer professionals. Objectives of this project are:

- Help sustain, in part, all regional TTTs whose participants migrate to pollinate almonds in California. The goals of these teams include improving the health of colonies prior, during and after this critical pollination event.
- Provide on ground, rapid response to bee incidents during or connected to almond pollination in order to help make fact-based risk assessments.

Background

To respond to the pressing needs of increased pollination, a consortium of bee researchers from our nation's leading research labs and universities created the Bee Informed Partnership, Inc. (BIP), a nonprofit organization dedicated to improving the health and sustainability of honey bees. We take a fourfold approach to achieving this aim:
1) BIP conducts an annual survey of US beekeepers to monitor the country's colony health, mortality rates and what management practices beekeepers employ to help to minimize colony losses;
2) BIP facilitates outreach and research programs by making our colony health and survey data publicly available through our interactive online platform;
3) BIP engages citizen beekeepers to increase awareness of major threats facing honey bees and to encourage them to monitor and manage the health of their colonies; and
4) BIP provides field and laboratory honey bee health support services to commercial beekeepers who manage the vast majority of the country's honey bee colonies.

Discussion

BIP's Technical Transfer Teams are currently partnered with 110 commercial beekeepers across the country who collectively manage 21% of US colonies across 17 states. Our high throughput lab analyzes over 10,000 samples annually and the efficiency with which we report our findings enables beekeepers to make swift management decisions. Our novel, science-based honey bee health surveillance program has led to promising success for BIP's effort; beekeepers participating in our program lose 32% fewer colonies than those who do not. BIP's colony health database is now the largest repository of bee health metrics in the US, serving as an invaluable tool for researchers and educators (https://bip2.beeinformed.org/). Given BIP's national scope, the number of commercial beekeepers we work with, and the caliber of our honey bee researchers, *BIP is on the forefront of capturing disease outbreaks and are able to note issues and respond quickly, often before they become a problem for the beekeeper*. In these instances, the ability to rapidly respond to these reports is important for maximizing the chance of successfully identifying the cause of the problem and minimizing colony losses or spread to other colonies among geographic regions. Reducing losses means that a larger number of healthier colonies are available for almond pollination. BIP strives to lead data visualization and are working to improve our contextual reports. We have completed our Commercial Field guide and have updated and revised our Disease Manual (in English and Spanish) to help commercial operations train and educate their team. Our skilled technical transfer personnel have indicated that the single largest contributor to a successful operation is an engaged and educated crew.

Project Cooperators and Personnel: Bee Informed Partnership, Inc.

Evaluating Cover Crop Benefits to Pollinators and Pollination in Almond Orchards

Project Leaders: Neal M. Williams[1]
[1]Dept. of Entomology, UC Davis, One Shields Ave., Davis, CA 95616 (530) 752-9358; nmwilliams@ucdavis.edu

PROJECT SUMMARY

Objectives for current year

- Quantify the flowering phenology of alternative cover crops as they relate to orchard bloom
- Quantify potential competition by cover crop on pollinator visits almond orchard through monitoring visitation rates of bees to blooming almond orchards and different cover crop mixes.

Background

Almond pollination relies on healthy bees. Although almond pollen and nectar are important resources, alternative pollen and nectar sources immediately preceding and following almond bloom would benefit bee health through increased nutritional diversity.

Cover crop plantings in orchards are being trialed to boost forage for honeybees at critical times, and also for their potential benefits to soil health. An ongoing grower concern associated with such plantings is that they do not compete for pollinator services with the blooming orchard in a way that would negatively impact yield.

Discussion

In 2018, with industry and UC research collaborators, we completed a first year assessing the performance of cover crop plantings and their impact on visitation and pollination at study orchards in three growing regions.

Cover crop plantings targeting soil health and pollinators established in all three regions and provided resources to bees during and after almond bloom.

Cover plantings did not decrease visitation to orchards when compared to neighboring unenhanced rows, or to nearby unenhanced orchards illustrating they did not compete with orchards for pollinators. Forage plantings did not significantly increase almond nut set.

The lack of effect on nutset may be due to delayed bloom of cover crop plantings. Consistent earlier sowing of the cover mix will be required. In drier regions and years fall irrigation will likely be needed

In the continuing project we explore at two study sites developed by Amelie Gaudin and collaborators (Corning and Merced). Sites are planted with alternative cover crop mixes. The project would assess phenology and visitation associated with replicated cover plantings at each study site over the almond season.

Flowering Phenology activities: At each site we will sample bloom of orchards and cover crop mixes, once approximately one week prior to orchard bloom, three times during bloom and once post orchard bloom. These allow us to characterize the flowering phenology of the cover crop mixes as they relate to almond bloom.

Pollinator visitation: We will assess bee visitation to almond and cover crop mixes in morning and afternoon on each of the three sample dates during orchard. These visits coincide with the phenology visits and are proposed to occur the same day or the day immediately preceding or following phenology assessment.

Data entry and coordination: We will coordinate with members of the Gaudin lab. Williams lab will assist in coordination during bloom, then complete data entry shortly after almond bloom and work with Gaudin and Wilson lab members to provide coordinated data to the larger project.

Project Cooperators and Personnel:
Amelie Gaudin, UC-Davis; Houston Wilson, UC-Riverside;

Effect of Almond Insecticides, Fungicides, and Phytochemicals on Honey Bees

Project Leaders: Reed Johnson[1] and Chia-Hua Lin[2]
[1]Dept. of Entomology, Ohio State Univ., 1680 Madison Ave., Wooster, OH 44691 (330) 202-3523, johnson.5005@osu.edu
[2]Dept. of Entomology, Ohio State Univ., 2021 Coffey Road, Columbus, OH 43210 (614) 292-4624, lin.724@osu.edu

PROJECT SUMMARY

Objectives for current year

- Test the potential for three insecticides, six fungicides and a spray adjuvant, alone and in combinations, to affect:
    - Adult worker honey bee survival when sprayed with simulated tank-mixes
    - Larval worker survival when combined in field-relevant ratios
- Using a queen rearing test, determine whether a limited subset of insecticides, fungicides, adjuvants or their combinations can affect:
    - Queen honey bee development and survival
    - Translocation of active ingredients from pollen to nurse bees and in royal jelly

Background

Beekeepers providing honey bees for almond pollination continue to experience unacceptable colony losses that they attribute to the exposure to insecticides, fungicides and spray adjuvants applied during bloom. Some beekeepers observe death of adult bees, larvae, or pupae while others report having trouble rearing queens or experience lingering problems in colonies weeks following almond pollination. Data from the California Department of Pesticide Regulation shows that in 2017 insecticides were applied to approximately 55,000 acres of almonds during the blooming period (Feb. 15 – Mar. 15) when bees are present. Nearly all insecticides applied during this period are in a tank-mix with fungicides and spray adjuvants. Research is needed to identify the particular insecticides, fungicides or combinations that are capable of producing the effects beekeepers have observed. Findings will allow for more focused recommendations regarding pesticide application to protect bees and pollination.

Discussion

Previous work identified the combination of the insecticide Altacor (chlorantraniliprole) and the fungicide Tilt (propiconazole) as potentially toxic to adult and larval honey bee workers. We found that the addition of the organosilicone-containing spray adjuvant Dyne-Amic to this combination, applied in a spray to bees at the maximum label rate, caused substantial mortality in adult bees.

A similar effect was observed in honey bee queens developing in queen-rearing boxes provisioned with pollen contaminated with this combination of pesticides. Queen larvae exposed the Altacor-Tilt-Dyne-Amic mixture showed reduced survival to capping and adult emergence relative to treatments not receiving the spray adjuvant. Worker larvae that were artificially reared with diet contaminated with the active ingredients in these pesticides also showed reduced survival.

Diflubenzuron, the active ingredient in Dimilin, has demonstrated toxicity to honey bee larvae alone and in combination with fungicides. Further increased toxicity was observed when the spray adjuvant was added to diflubenzuron, alone or in combinations, in larval diet.

Spray adjuvants have the potential to further increase the toxicity of insecticides and combinations that are already toxic to honey bees.

Project Cooperators and Personnel:
Colin Kurkul, Will Passifiume, Adrianna Pollee, Nicole Sammons, Michael Chapman, Sreelakshmi Suresh, and Dylan Ricke, Ohio State University; Emily Walker and Wyatt Foss, College of Wooster; Jessica Lyons, Kent State University

Mitigating Adverse Effects of Pesticides on Honey Bees Through Dietary Phytochemicals

Project Leaders: May R. Berenbaum
Dept. of Entomology, University of Illinois at Urbana-Champaign, Urbana, IL (217) 333-7784, maybe@illinois.edu

PROJECT SUMMARY

Objectives:

- **Determine effects of pesticide/adjuvant/phytochemical interactions on queen quality**
  - 1a. Effects of consuming pesticide-contaminated pollen on worker longevity, nursing behavior, olfactory responsiveness, and hypopharyngeal gland (HPG) morphology in nurse bees.
  - 1b. Which of these adverse effects can be reversed by consuming phytochemicals.
  - 1c. Impacts of developing in a pesticide-contaminated environment on virgin queen flight capacity.
- **Evaluate impacts of almond phytochemicals**
  - 2a. Characterize antioxidant and phytochemical composition of almond honey and pollen.
  - 2b. Evaluate effects of almond-characteristic phytochemicals on worker longevity.

Background

Pesticides are generally ingested by bees along with dietary phytochemicals in nectar and pollen, as well as with adjuvants; these chemicals can all interact to influence bee health. We have shown that consuming p-coumaric acid and quercetin increases worker longevity ingested in concentrations naturally occurring in honey. Moreover, chronic exposure to the fungicide propiconazole reduces worker longevity at field concentrations (0.9 ppm). Propiconazole (Tilt) interacts with the insecticide chlorantraniliprole (Altacor) when ingested, consistent with the results from our Ohio State collaborators.

Discussion

Our preliminary data also show that nurses consuming pesticide-contaminated pollen provide sub-optimal care of queen larvae. Nurses ingesting propiconazole and chlorantraniliprole with an adjuvant tended queen larvae less assiduously than those consuming uncontaminated pollen. These behavioral responses were not observed in bees provided with quercetin-supplemented sugar water.

Additionally, via electroantennography, we found pesticide-induced alterations in olfactory responsiveness to brood pheromones, a larval signal pheromone (ocimene), and the alarm pheromone 2-heptanone. Our preliminary data, from one hive, show that, in the presence of the adjuvant Dyne-Amic, nurse bees ingesting Altacor and Tilt together exhibit reduced sensitivity to olfactory stimuli. However, response patterns varied with hive identity; additional replicates of these trials may reduce this variation. Also important in nurse behavior is secretion of royal jelly by the hypopharyngeal glands (HPG); certain pesticides can alter gland morphology and possibly royal jelly secretion. Our preliminary data, however, did not show effects of Altacor/Tilt/Dimilin on HPG acini size ($F = 1.769$, $P = 0.134$).

By collaborating with Ohio State investigators, we completed assays evaluating effects of Altacor/Tilt/Dimilin on virgin queen flight; data are being analyzed to ascertain whether pesticides alter queen flight capacity.

To characterize phytochemicals of almond honey/pollen, we collected first batch almond honey/pollen from a field and market this Spring. Via HPLC-MS, we identified as abundant constituents in almond honey abscisic acid and the flavanone galangin. Surprisingly, amygdalin, assumed to occur in almond honey, was not detected. Other constituents are currently being identified.

Almond honey was also evaluated for its antioxidant capacity relative to other monofloral honeys. Almond honey exhibited the second-highest antioxidant capacity of all tested monofloral honeys, exceeded only by buckwheat honey. We completed a longevity assay of adult bees evaluating the effect of propiconazole-chlorantraniliprole ingestion along with the almond honey and are analyzing the results.

Project Cooperators and Personnel:
Ling-Hsiu Liao, Wen-Yen Wu, Daniel J Pearlstein, Lucas Brodie Dunn, Vicente T Aldunate, Jihoo Kim, UIUC; Reed Johnson, Chia-Hua Lin, OSU; Charley Nye, UC Davis.

Using Cold Storage to Stabilize the Supply of Honey Bees for Pollination

Project Leaders: Brandon Hopkins[1]
[1]Dept. of Entomology, Washington State University, 100 Dairy Rd., Pullman, WA 99164 (509) 335-0881, bhopkins@wsu.edu

PROJECT SUMMARY

Objectives for current year

- Establishment of controlled atmosphere research chambers.
- Initiate first winter CO2 varroa mortality experiments.

Background

The goal is to develop a method utilizing indoor storage of honey bee colonies that will significantly improve the management and reliability of commercial pollination in Almonds. We are proposing to accomplish this through four specific objectives:

1) Establish 3 controlled atmosphere (CA) research chambers capable of holding commercially-relevant numbers of honey bee colonies. (**accomplished this year)** .

2) Use CO_2 to kill Varroa mites in CA storage (**2019-2020 winter**). This approach will reduce honey bee miticide exposure that has been shown to cause a suite of health problems in colonies and is a major contributor to the unsustainable annual losses.

3) Utilize CA storage to force a mid-season break in brood cycle (**spring and summer 2020**).

Most of the colony losses caused by Varroa are caused by the mites' exponential growth during the summer months while bees are making honey. However, most miticides can't be applied during this time and no miticides effectively control mites during their reproductive phase in the capped brood (pupae). Forcing beekeepers to either wait too long before applying miticides or requires multiple (3-4) applications to cover a full brood cycle (24 days). This is expensive considering the cost of materials, labor, and fuel to treat thousands of colonies, and ultimately, is largely ineffective.

Discussion

Alternatively, we will demonstrate that commercial beekeepers can move thousands of colonies into cold storage mid-season to create a break in brood and achieve greater mite control with only a single application. 4) Demonstrate the benefits of CA storage/cold storage and disseminate the information from this work to commercial beekeepers and develop best management practices that result in greater reliability in the supply of honey bees for almond pollination

The work on this project has been focused on securing additional funding and planning with WSU facilities to prepare for arrival of the new equipment (controlled atmosphere chambers). We utilized the funding provided by the WTRC ($100,000) in addition to the funds provided by the Almond Board of California ($97,000) to secure the purchase of three chambers and get on the university facilities workflow for installation of the chambers (October 2019). This is a slight delay from proposed work as the university received funding for a new honey bee research laboratory in Othello, WA where the research chambers for this project will be located. The new site will expand pollinator research capacity, but the change in location for the chambers has delayed establishment of the chambers by a couple months. The delay wont effect future objectives or timeline.

Project Cooperators and Personnel: Walter S. Sheppard

Evaluating Cover Crop Benefits to Honey Bees within Almond Orchards

Project Leader: Elina L. Niño[1]
[1]Dept. of Entomology and Nem., UC Davis, One Shields Ave., Davis, CA 95616 (530) 500-2747, elnino@ucdavis.edu

PROJECT SUMMARY

Objectives for current year:

- Quantify almond and cover crop use by honey bees, as well as honey bee foraging activity at the hive entrance: Do bees use floral resources from the cover crop present before, during and after almond bloom and does their presence affect the level of flight activity in colonies? This will be a direct collaboration with the Williams lab group to correlate pollen use with impacts of colony health.
- Evaluate potential benefits of cover crops in almond orchards for improved colony health and survival: Does the cover crop foraged on by honey bees improve immediate and long-term colony health status and survival?

Background:

Honey bees remain the most important managed pollinator used for almonds. Almond pollination is reliant on healthy and plentiful honey bee supply. However, in the past years beekeepers have been experiencing annual colony losses of up to 45% (Kulhanek et al. 2017, beeinformed.org). Complex interactions of multiple stressors play a major role in driving these losses and include parasites such as varroa mites, various pathogens including viruses, pesticide exposure, and poor nutrition. Interestingly, research thus far demonstrates that honey bees benefit from having access to plentiful and diverse pollen sources leading to improved immunity and pesticide detoxification ability (Alaux et al. 2010; Schmehl et al. 2014; Niño et al., in prep), and could potentially reverse negative effects of migratory stress during pollination season (Simone-Finstrom et al. 2016). While almond pollen and nectar are valuable resources for bees, having almost two thirds of the Nation's colonies in California almond orchards early in the year presents a perfect prospect to provide colonies with additional forage with a goal of improving their long-term health and survivorship. Efforts to provide supplemental forage to colonies prior, during and after almond bloom are underway; however, there is a great need for recording how these efforts translate into long-term colony health, productivity, and survival. Prior research clearly demonstrated potential benefits of orchard border plantings of mustards and wildflowers in supporting both honey bees and wild bees (Niño, Williams, McFrederick), the question remains how cover crops might be implemented in this context. *We, therefore proposed within the larger collaborative project, to determine potential long-term benefits of cover crops in almond orchards for honey bee colony health and survivorship.*

Discussion:

Due to the lack of sufficient replicative sites the project will be completed during the 2020 almond season. We are currently in the process of identifying optimal orchard locations. *Ultimately, this work will complement our prior research on evaluating border forage strips for bee health, with a goal of further refining supplemental forage planting recommendations*.

Project Cooperators and Personnel:
Neal Williams, UC Davis
Danielle Downey and Billy Synk, PAm

Influence of Whole Orchard Recycling on GHG Emissions and Soil Health in a Newly Established Almond Orchard

Project Leaders: Mae Culumber[1] and Suduan Gao[2]
[1]UCCE-Fresno County, 550 E Shaw Ave. Suite 210-B, Fresno, CA 93710 (559) 241-7526, cmculumber@ucdavis.edu
[2]USDA-ARS 9611 S. Riverbend Ave. Parlier, CA 93648 (559) 596-2870, suduan.gao@ars.usda.gov

PROJECT SUMMARY

Objectives for current year:

- Monitor field level variability of nitrous oxide (N_2O) and carbon dioxide (CO_2) emissions, after a one-time WOR mulching rate of 45 T/ac dry wt at a commercial almond farm in Parlier, Ca.
- Describe the effect of WOR on soil carbon and nitrogen cycling and identify the biological mechanisms
- Quantify wood chip decomposition rates

Background:

Loss of co-generation facilities disposal methods have coincided with an increase in the volume of orchard waste across the Central Valley. Some growers have reverted to burning, which emits regulated air quality pollutants. Whole orchard recycling (WOR) incorporates orchard waste on-site, without burning or moving the debris to another location, preventing the release of air pollutants into the atmosphere. When mulched into the soil, high carbon (C) containing amendments like wood chips increase soil organic matter (SOM). Agricultural systems with high SOM that receive frequent applications of water and various rates and types of fertilizer, have shown both decreases and increases in carbon dioxide (CO_2) and nitrous oxide (N_2O) greenhouse gas (GHG) emissions. A study was initiated in April 2018 to find what impact a high rate (45 T/ac dry wt) of recycled wood chips will have on N_2O and CO_2 emissions, soil edaphic factors, and tree establishment for three years after planting. Gas flux chambers were installed in both wood chip mulched and control plots to measure differences in GHG flux and soil N pools in the tree rootzone and the inter-tree spaces where applied nutrients are not taken up. Flux sampling is conducted weekly at a minimum, and more frequently during management events like fertigation, irrigation, and tillage.

Net changes in soil N and labile dissolved organic C pools from 0-15 cm are measured monthly one day following fertigation.

Discussion:

Wood chip treatments had higher N_2O and CO_2 emissions compared to conventional in the fertigated drip line during the first and second year after orchard recycling in a replanted orchard. Similar to the control, woodchip treatment N_2O fluxes were consistently low except for the one to four-day period after fertigation. N_2O and CO_2 fluxes appeared to decline after mid-to-late summer in 2018 and 2019. The wood chip N_2O emission factor (EF) near 1.1% was greater than the control in 2018, but consistent with the average reported for many crops. Data collection and analysis of the impacts of WOR and orchard management on cumulative GHG emissions is ongoing. Preliminary soil analyses suggest consistently higher ammonium levels in wood chip soil prior to fertigation events. Wood biomass in the alleyway remained largely the same from December 2017 to October 2018, suggesting potential for long term C storage in the unirrigated, unfertilized portions of the orchard. Rapid degradation of wood chips in the fertigated berm, and improved nutrition and growth in wood chip trees in 2019 indicate growers may lower fertilization to standard rates by the second growing season. Initial low vigor and insufficient leaf N early on points to the need for early spring fertilization to mitigate stunting problems. Further research is needed to pinpoint the optimal timing and necessary season long fertility rates in the first two growing season after recycling.

Project Cooperators and Personnel: Brent Holtz UCCE-San Joaquin County; Greg Browne, USDA-ARS, Davis; Amelie Gaudin, UC-Davis; Elias Marvinney UC-Davis, Amisha Poret-Petersen USDA-ARS Davis, Emad Jahanzad UC-Davis; Cameron Zuber UCCE-Merced; Luis Toledo UCCE-Fresno; Dan Rivers UCCE-San Joaquin

Almond Orchard Recycling

Project Leader: Brent A. Holtz
University of California Cooperative Extension in San Joaquin County, 2101 East Earhart Ave, Suite 200, Stockton, CA 95206 (209) 953-6124 baholtz@ucdavis.edu

PROJECT SUMMARY

Objectives for current year:

- The overall goal of this project is to comprehensively assess the implications of whole orchard recycling (WOR) with the standard practices of orchard removal, either burning for energy co-generation or open field.
- Quantify the effect of WOR on physical, chemical, and biological soil properties.
- Assess the impact of WOR on replanted tree growth, nutrition, yield, and water and nitrogen efficiency.

Background:

WOR, as an alternative to co-generation or open field burning, could reduce net orchard greenhouse gas emissions by sequestering carbon from orchard biomass. The wood residue generated by WOR, estimated to be 45-70 tons per acre, appears to increase soil carbon, organic matter, fertility, water infiltration rates and water retention. The first orchard grinding trial at Kearney, established in 2008, compared WOR of stone fruit trees with the Iron Wolf rock crusher, estimated at 30 tons per acre, to burning and incorporating the ash. The orchard was replanted to almond and greater yields, significantly more soil nutrients, organic matter, and organic carbon were observed in the grind treatment when compared to the burn. Leaf petiole analysis also revealed higher nutrients levels in trees growing in the grind treatment. A deficit irrigation trial documented increased water use efficiency and stomatal conductance with WOR. In trials established since 2015 we have observed increased soil organic carbon, total nitrogen, and gravimetric water content with WOR, while observing decreased soil compaction and bulk densities. We observed that large soil macro-aggregates accumulated more carbon in the WOR soils, demonstrating that woodchips have the potential to store and physically protect carbon from microbial breakdown. Significantly more microbial biomass carbon was observed with WOR while microbial biomass nitrogen was decreased.

Discussion:

Preliminary data from the 2015 trials suggest that our nitrogen (N) recommendation for first year almond trees may need to double, from 4 to 8 oz N per tree, after WOR in order to prevent reduced growth. Early applications of N, even at planting, appear more important than N applied later in the season. In three trials the effects of WOR and preplant fumigation are being tested. Preplant soil fumigation significantly stimulated tree growth, with or without WOR, indicating that WOR did not interfere with fumigation. We have observed no impact of WOR on the incidence of crown rot, root rot, or canker disease. Greenhouse experiments of WOR on plant-parasitic nematodes were conducted. Several WOR sites appear to have some suppressiveness against root lesion nematode, but not towards ring. Nematode-trapping fungi were isolated from WOR sites. These micro-fungi can capture nematodes and use them as a nutrient source. We hope to investigate their ecological importance in more detail. A new experimental orchard was established at Kearney to examine both nitrogen and irrigation efficiency after WOR. We hypothesize that increased nitrogen and irrigation efficiency will be observed as wood chips bind and hold both applied N and moisture, ultimately releasing both in the rootzone. We estimate almond growers have implemented WOR on over 20,000 acres since 2015.

Project Cooperators and Personnel
Mae Culumber, UCCE - Fresno, Greg Browne, Suduan Gao, Amisha Poret-Peterson, USDA-ARS, Andreas Westphal, UC Riverside, Cameron Zuber and David Doll, UCCE - Merced, Amélie CM Gaudin, Emad Jahanzad, UC Davis, Mohammad Yaghmour, UCCE - Kern, Franz Niederholzer, UCCE - Colusa, Sutter, Yuba, Phoebe Gordon, UCCE - Madera

Geophysical Imaging of Sediment Texture

Project Leader: Rosemary Knight
Dept. of Geophysics, Stanford University, Mitchell Bldg., 397 Panama Mall, Stanford CA 94305
(650) 736-1487, rknight@stanford.edu

PROJECT SUMMARY

Objectives for current year:

- Compare results from tow-TEM and drone-TEM to evaluate the utility of these geophysical methods for characterizing recharge site sediment texture.
- Complete cone penetrometer testing (CPT) and borehole nuclear magnetic resonance (NMR) logging to support the interpretation of previously acquired tow-TEM and drone-TEM data in an almond grove in the Tulare Irrigation District.
- Integrate all TEM, CPT, and NMR data to develop a 3D model of sediment texture.

Background and Discussion:

A key objective when selecting sites for on-farm recharge is to identify sites where both the quantity and quality of water reaching the groundwater system can be maximized. A good understanding of subsurface sediment texture can play a critical role in meeting this objective. To map the sediment texture, we have employed novel geophysical imaging technologies capable of imaging to a depth of ~60 m with lateral resolution of tens of meters and vertical resolution on the order of meters.

We have selected an almond grove in the Tulare Irrigation District as our test site. In 2017 we acquired an outstanding dataset using the tow-TEM system, which tows a geophysical instrument behind an all-terrain vehicle (ATV). The result was a spatially dense map of the subsurface electrical resistivity underlying the entire almond grove. In fall of 2019, we acquired an additional dataset using drone-TEM, which utilizes a ground transmitter and a drone-carried receiver to collect data to also map subsurface resistivity. We were able to acquire high quality data that are currently being interpreted. This system has a coarser resolution than the tow-TEM system but has the advantage that it could be used during a flooding event when collecting tow-TEM data would not be possible due to the impact of the ATV on wet soils.

In order to interpret the subsurface resistivity models from both of these datasets to understand sediment texture, a resistivity-to-sediment-texture transformation is required. Sands and gravels tend to be the high resistivity units, and the clays tend to be the low resistivity units, but variable water content complicates our ability to transform the image of resistivity to sediment texture. To establish the resistivity-to-sediment-texture transform, we acquired cone penetrometer testing (CPT) data at five locations where we had tow-TEM data; these provided 1D profiles of the sediment texture and electrical resistivity down to ~30 meters. These data allow us to begin interpretation of the subsurface resistivity models in terms of sediment texture.

While our existing resistivity-transform can yield significant insight into the subsurface sediment texture, there is uncertainty in this transform as a result of the unknown degree of saturation of these sediments. This uncertainty motivates the next step in this research. We will install five CPT holes and log them with a borehole nuclear magnetic resonance (NMR) system from Vista Clara. The NMR data will give estimates of the water content, needed to reduce the uncertainty in our resistivity transform. We will use these data to improve our resistivity transform, and integrate all of the datasets at our test site to develop a 3D model of sediment texture.

Project Cooperators and Personnel:

Meredith Goebel and Gordon Osterman, Stanford University; Hiro Shima, OYO Corporation; Akira Jomori, Neo Sciences; Aaron Fukuda, Tulare Irrigation District

Using Agricultural Floodplains to Help Recover Native California Fish Populations

Project Leaders: Andrew L. Rypel[1],[2]

[1]Center for Watershed Sciences & [2]Department of Wildlife, Fish & Conservation Biology University of California Davis, One Shields Ave., Davis, CA 95616, (530) 752-9567, rypel@ucdavis.edu

PROJECT SUMMARY

Objectives for current year:

- Receive, grow, and implant 450 juvenile Chinook salmon with JSATS tags in a rice field. Subsequently track outmigration routes and survival (2019 and 2020).
- Bench test methods for growing, marking, and volitionally releasing salmon in rice fields (2019-2021).
- Develop partnerships and technical advisory groups with fish managements agencies, agricultural interests, NGOs, and other resource management groups (2019-2021).
- Train and graduate a master's student from UC Davis on this work (2018-2021).

Background:

Water availability continues to be a challenge for fishes and farms throughout California. The number of fish species listed under the US Endangered Species Act is increasing and more stringent water policies are connected to the decline of fishes. Diminishing salmon populations are emblematic of these issues because of complex life cycles requiring water availability at critical times, and their nexus with cultural, commercial, and recreational fisheries.

There is growing understanding that availability of flooded habitats during critical periods might be key for salmon, especially as juveniles. The Central Valley was in fact once a vast floodplain wetland teeming with diverse fishes and wildlife. Salmon born in upstream gravel beds were transported to fertile floodplain habitats where juveniles reared. After growth and acquisition of large energy reserves, fish returned to the river healthy and prepared for out-migration.

Discussion:

We developed a study utilizing acoustic telemetry transmitters to test whether rearing of juvenile salmon on winter-flooded agricultural (rice) fields in the Central Valley resulted in increased survivorship to the ocean. 12,000 juvenile fall-run Chinook salmon were obtained from the Feather River Fish Hatchery during winter 2018-2019. Despite challenging river conditions, 600 fish were split between experimental cages and reared in each of two winter-flooded rice fields in the Yolo Bypass at Conaway Ranch. An additional 300 fish were reared under laboratory conditions. We collaborated with growers to prepare and flood fields in the fall to receive fish. Upon reaching taggable size in mid-late April, surgeries were performed on all 900 fish to implant acoustic transmitters into individual fish. Tagged individuals were then released into the system at strategic floodplain and river channel locations. Final tracking results from this year's work are still pending.

In winter 2019-2020, we will replicate our study while also making several modifications. Importantly, we will work on dry-side-levee fields (River Garden Farms) to encourage more stable rearing conditions for study and faster salmon growth. This will likely enable earlier tagging and fish release schedules that will better align with crop planting and fish outmigration phenologies.

This project is being conducted in close collaboration with the California Rice Commission as part of a grant from USDA NRCS. Our project will be used to develop a practice standard for growers to help raise salmon in agricultural fields in the Central Valley. Growers are directly involved in our project, specifically to test and refine field management and provide salmon the ability to exit fields naturally.

Project Cooperators and Personnel: Paul Buttner - California Rice Commission; Jacob Katz, Jacob Montgomery & Jayme Ohlhaver - California Trout; Rachelle Tallman, Dennis Cocherell, Francine De Castro, Leah Mellinger, Wilson Xiong, Gabriel P. Singer - UC Davis.

Assessing Orchard Management Factors and Practices for Tradeoffs in Life Cycle Environmental Impacts and Resource Use of California Almond

Project Leader: Alissa Kendall[1]
[1]Dept. of Civil and Environmental Engineering, UC Davis, One Shields Ave., Davis, CA 95616
530-400-3151, amkendall@ucdavis.edu

PROJECT SUMMARY

Objectives for current year:

- Enhance almond life cycle assessment (LCA) model to:
  - report results at finer geospatial scale
  - report a full range of environmental impact categories
  - account for interactions between orchard inputs, biomass productivity, and yield
- Produce scenario and sensitivity results to explore uncertainty in the environmental performance of CA almond production
- Produce regional results accounting for differences in orchard inputs and productivity throughout the Central Valley

Background:

Commercial orchards in California's Central Valley demand significant energy, chemical, and material inputs throughout their lifespan. Life cycle analysis (LCA) of the almond production system can quantify the specific environmental impacts associated with individual orchard management practices and growing conditions, providing a baseline for improved environmental performance and data for carbon trading and product labeling.

We have developed a comprehensive, process based LCA model capable of characterizing almonds produced in various sub-regions of California's Central Valley, accounting for regional differences in common management practices, nutrient and pest management inputs, typical yields and regional conditions. This model also incorporates biomass and yield productivity response curves for water application and tree spacing, allowing quantification of potential environmental tradeoffs that may occur with variable management practices and input quantities.

Discussion:

Newly available data from other ongoing and recently completed ABC-supported projects, including orchard age maps, soil carbon storage under alternate end-of-life practices like whole orchard recycling (WOR), almond sustainability survey results, and the effects of wood decay on standing biomass and orchard productive lifespan have contributed to the increased capability of this almond LCA model, as well as raising new questions and modeling opportunities.

Business-as-usual (BaU) scenario results have been produced for 'typical' almond acreage in the Sacramento Valley, San Joaquin Valley, and Tulare Lake regions, including GHG emission, criteria air pollutants, human health impacts, and resource consumption on a per acre and per kg kernel basis. Sensitivity analysis has quantified the effects of a wide range of biomass and irrigation-related parameters on model outputs, while scenario analysis has revealed the potential benefits and tradeoffs between various impact categories for a number of irrigation and end-of-life management strategies.

The differences between current results and those previously published (Kendall et al 2015, Marvinney et al 2015) have been quantified, and the contribution of various factors including biomass power plant closure, electricity grid de-carbonization, groundwater depletion, updated data sources and modeling improvements to the observed changes in model output have been assessed.

We have found that the carbon and energy footprint of almond production has increased since 2015, due mainly to increases in irrigation energy demand derived from increased groundwater depth as well as increased open burning of EoL biomass and reduced GHG offset value of biomass electricity due to grid de-carbonization. We have also found that practices such as solar irrigation pumping and WOR can improve environmental performance in multiple impact categories, helping to offset the reduction of credits for avoided emissions derived from use of biomass as an energy feedstock.

Project Cooperators and Personnel:

Elias Marvinney (post-doc), UC-Davis

Physiology and Management of Salinity Stress and Nitrate Leaching in Almond: Influence of Rootstock, Scion and Supplemental Nutrition

Project Leader: Patrick Brown[1]
[1]Dept. of Plant Sciences, UC Davis, One Shields Ave., Davis, CA 95616 (530) 752-0929, phbrown@ucdavis.edu

PROJECT SUMMARY

Objectives for current year:

- Improve our understanding of plant response to spatial/temporal variation in ion distribution in the root zone
- To determine which specific mineral element is dominant for root response under heterogeneous saline conditions with focus on N-P-K.
- Quantify the effect of saline conditions on nitrate uptake kinetics of almond.
- Understand how non-uniform salinity affects water, nutrient, and salt uptake to devise improved salt management strategies

Background and Discussion:

Heterogeneous ion distribution is a characteristic of micro-irrigation systems and yet our understanding of the biology and management of these systems is inadequate. Last year we demonstrated that root responses are quickly reversible, and proportional to salt concentration. This critical information gave us some insight of plant response to heterogeneous salinity and nitrate distributions. New hypotheses were tested during this year using split-root hydroponic system, where roots of a single plant were divided in two equal parts. This approach was used to determine temporal variation of nutrient, water and salt under non-uniform root environments. Saline environmental conditions were switched between sub-zones during the experiment to test root responsiveness. This experiment showed time frame of root responses under saline environments and is relevant to the pattern changes that would be expected between irrigation events.

These results are relevant because they suggest possible irrigation frequency treatments that should be tested under field conditions. Results also contribute to our understanding of irrigation management under saline conditions. This experiment (and others previously performed) strongly suggest that minimizing the time in which root sub-zones are exposed to saline stress, while ensuring portions of roots are always maintained under favorable nutrient conditions, could minimize the uptake of salt under micro-irrigation.

In a collaborative work with CDFA-FREP funding 6 large single tree lysimeters started data collection testing different irrigation treatments. Biological parameters obtained from ABC funded research will be integrated with soil nutrient dynamics measured in the CDFA project to improve our overall understanding of the root zone. Irrigation and fertigation strategies will be designed based upon soil modelling and environ-mental monitoring and direct root-zone instrumentation being conducted under the collaborative CDFA-FREP funded program.

Take home message of this year results:
- Location of nutrients in the root soil volume, determines the location where almond roots will be active. Controlling the distribution of nutrients in the sub-zones of the whole root system may be a useful tool to minimize root activity in saline root zones. Distribution of nutrients and saline ions can be modulated by increasing irrigation-fertigation frequency to avoid depletion of nitrogen in the active root zone.

Project Cooperators and Personnel:
Francisco Valenzuela-Acevedo and Daniela Reineke, UC Davis

Lysimeter – Whole Tree ET Response to Mild and Moderate Water Stress

Project Leader: Ken Shackel
Department of Plant Sciences, University of California, Davis, One Shields Ave., Davis, CA 95616-8683
(530) 752-0928 kashackel@ucdavis.edu

PROJECT SUMMARY

Objectives:

- Continue orchard establishment (year 5), and maintain SWP and growth/yield uniformity between the lysimeter tree and the rest of the orchard.
- Continue to monitor ETc of the lysimeter tree and compare it to current estimates based on canopy shaded area.
- Test candidate methods for automated measurement of SWP and/or water stress.
- Test for a relation between irrigation and shaker injury, as well as candidate methods to prevent ceratocystis infection when damage occurs.

Background:

Indirectly measured ET (soil water balance) from high yielding orchards has indicated that almond crop coefficients (Kc) may be higher than previously thought, but it is not clear whether and to what extent Kc decreases when almond trees experience water stress. Based on SWP readings with the pressure chamber, many commercial almond orchards exhibit periodic (intended or unintended) moderate stress during the growing season. There are documented benefits of managed (with SWP) deficit irrigation with moderate levels of water stress at hull split in almond, so a more accurate description of the relation between Kc and SWP in almond would allow more accurate estimates of the water savings associated with this practice.

Discussion:

Average Nonpareil yields in 2019 for this 5th leaf orchard were 2070 kernel pounds per acre. Midseason average Kc values were about 1.2, although daily values exhibited substantial variation, ranging from 1.0 to 1.3. During deficit irrigation periods (hull split and harvest), values dropped to as low as 0.3, but also recovered when irrigation was resumed. This indicates that physiological (stomatal) control of transpiration is very effective in almonds, and that almonds can substantially reduce consumptive water use when under stress. Prototype commercial (FloraPulse) micro-tensiometers (MT's) were installed on the lysimeter tree and an adjacent tree on June 20 and showed good agreement with pressure chamber measured SWP. Both measurements indicated that trees quickly recovered to baseline SWP following irrigation but began to fall below baseline within 4 days of irrigation, and reached a much higher level of water stress (-20 bars) over the next 2 days. A similar relative pattern of stress was indicated by commercial (Phytech) dendrometer measurements. Hence, at least on this soil type (Hanford Fine Sandy Loam) almonds may exhibit 'feast and famine' behavior, with very little time between a condition of full irrigation (baseline SWP) and substantial stress. Both MT and dendrometer technology are showing promise as automated devices to monitor water stress. Half of one Nonpareil row was deficit irrigated approaching shaker harvest, and the other half fully irrigated to within a few days of harvest. All of the trees in this row were harvested with excessive shaking. In the deficit treatment, 6 out of 9 trees showed no damage, whereas in the irrigated treatment only 1 out of 9 trees showed no damage. Monitoring the rate of trunk growth with dendrometers may provide an effective guide to deficit irrigation before harvest to reduce shaker injury. Additional research is being conducted at the lysimeter plot, but will be reported independently by cooperators.

Project Cooperators and Personnel: Bruce Lampinen, UC Davis; Mae Culumber, UCCE - Fresno and Madera Counties; Andrew McElrone, USDA/ARS, UC Davis; Alireza Pourreza, UCCE; Reza Ehsani, UC Merced; Florent Trouillas, UCCE.

Evaluating the Effectiveness of Surface Renewal and Other Technologies to Determine Almond Tree Water Use and Water Stress

Project Leaders: Andrew McElrone[1] and Nicolas Bambach[2]

[1] USDA-ARS, Dept. of Viticulture, UC Davis, One Shields Ave., Davis, CA 95616 (530) 754-9763, ajmcelrone@ucdavis.edu
[2] LAWR Department, UC Davis, One Shields Ave., Davis, CA 95616 (530) 302-5358, nbambach@ucdavis.edu

PROJECT SUMMARY

Objectives for current year:

- Validate previous results on the accuracy of the stand-alone surface renewal method to estimate evapotranspiration.
- Develop and assess an alternative method to estimate evapotranspiration based on semi-high frequency infrared temperature.
- Advance the understanding of physical-based methods to detect plant physiological stress and inform irrigation management.

Background:

Evapotranspiration (ET) from an almond orchard results from the tree canopy-atmosphere exchange, and represents the primary driver of agricultural water demands. Reliable, real time ET data is needed by growers to precisely match crop water demands. The development and refinement of practical and inexpensive techniques to measure ET is needed. The surface renewal method has emerged as a viable method to measure plant canopy- atmosphere heat exchange and estimate ET. Stand-alone surface renewal stations (SR) are being used to quantify site-specific ET in a variety of crops (grapes, strawberries, alfalfa, pistachio, almonds). This stand-alone approach was validated in vineyards but requires additional testing for use in almonds even though growers are relying on this approach to determine their irrigation practices.

Discussion:

We are confident that SR effectively quantifies almond orchard ET, however, the sensitivity of the method to seasonal canopy changes and crop physiological stress needs more attention. Therefore, we have continued our efforts to optimize SR as a cost-effective irrigation management tool that provides almond growers with information about both the amount and timing of irrigation events. We have combined SR, plant water status, gas exchange, and infrared thermometry (IRT) to address our objectives. In 2018 and 2019, we collected eddy covariance, surface renewal, and ancillary data from our station at the weighing lysimeter. Cooperating labs are synthesizing results across efforts.

ET measurements from SR were strongly correlated with those from two eddy covariance methods and with tree water use measured with a weighing lysimeter in the experimental almond orchard at the Kearney Ag Center. These relationships have been found to be consistent across growing seasons. We advanced developing a new method based on canopy infrared temperature to estimate ET. High frequency canopy infrared radiometers were used to derive sensible heat flux density (H) combining eddy diffusivity and surface renewal approaches. We found that plant canopy temperature traces show ramp-like features such as those observed from air temperature measured above canopies. This could enable the use of IRT sensors for determining site specific (or even individual plant) water demands and the timing for application based on plant stress as these sensors have been used for decades to track crop water stress indices (e.g. CWSI and SCR). We are further developing approaches to understand how these indices scale to well-understood leaf level measurements of crop water stress (i.e. water potentials and gas exchange).

Project Cooperators and Personnel: Dr. Ken Shackel, Wes Collatz, Marshall Pierce, UC Davis

Assessment of Almond Water Status Using Inexpensive Thermographic Imagery

Project Leader: Brian Bailey
Dept. of Plant Sciences, UC Davis, One Shields Ave., Davis, CA 95616 (530) 752-7478, bnbailey@ucdavis.edu

PROJECT SUMMARY

Objectives for current year:

- Quantify the sensitivity of various crop water stress indices (CWSIs) to environmental conditions and stomatal conductance
- Conduct field experiment to monitor the onset of stress during dry-down events based on measurements of temperature (leaf, canopy, trunk), stomatal conductance, photosynthesis, and leaf/stem water potential
- Evaluate the performance a number of methods based on thermal imaging in measuring the onset of water stress, and ultimately in their ability to inform irrigation decisions

Background:

In order for almond growers to meet the future demands for reduced water consumption, the efficiency of irrigation practices must be improved to minimize waste. The traditional means for accomplishing this goal is to use some indication of tree water demand to guide irrigation scheduling. While various sensing techniques do indeed give improved indications of plant water demand than traditional crop coefficients, adoption of such technologies is often slow because of expense, both in terms of money and time. Sensing networks are expensive to maintain and rapidly become dilapidated if significant maintenance resources are not allocated.

Smartphone-based sensing platforms present a feasible yet challenging means for measuring plant water status. Utilizing the computational power of smartphones can reduce the cost to purchase and maintain sensing systems but have the drawback that they only provide measurements at a single point (or limited number of points) in time and space. Our goal is to develop a thermal sensing-based smartphone application that can effectively determine almond irrigation needs with the use of Crop Water Stress Indices (CWSIs) to estimate the water status of the trees.

Results & Discussion:

To make application of the thermal sensing technique easier in the field, we showed that it is possible to use a single dry reference surface (green paper) and a mathematical model, which avoids having to use petroleum jelly or spraying a leaf with water to obtain the dry and wet reference temperatures needed to calculate CWSIs.

Results suggested several recommendations for infrared measurement of leaf temperature and the use of CWSIs to estimate plant water status. According to the results of the sensitivity analysis, it is not recommended measure the CWSI in shaded conditions, but rather to perform measurements in full sun (*i.e.*, PAR>700 µmol m^{-2} s^{-1}). Even the “best” and most commonly used CWSI failed to separate the effect of wind speed from water stress (Poirier-Pocovi and Bailey, 2020).

In year 2, we tracked a dry-down period following irrigation with conventional methods (stem water potential and leaf gas exchange), and simultaneously collected thermal images of the leaf, canopy and other organs (stem, trunk). The ultimate aim of this study is to determine whether thermal imaging can accurately detect the onset of water stress over the time. Initial results indicated that CWSIs are noisy and can only accurately detect stress when trees are very stressed. Initial analyses suggest that trunk surface temperature may be more reliable for formulating CWSIs.

Project Cooperators and Personnel:
Magalie Poirier-Pocovi, Bruce Lampinen, Astrid Volder (UC Davis)

Variable Rate Irrigation Practices on Almond

Project Leaders: Khaled Bali[1] and Catherine Culumber[2]

[1] UCANR Kearney Agricultural Research & Extension Center, 9240 S. Riverbend Ave., Parlier, CA 93648. (559) 646.6541, kmbali@ucanr.edu

[2] UCCE - Fresno County, 550 E. Shaw Ave. Ste 210-B, Fresno, CA 93710, (559) 241-7515, cmculumber@ucanr.edu

PROJECT SUMMARY

Objectives for current year:

- Retrofit the irrigation system in a way that allows the grower to manage irrigation zones as small as one acre.
- Develop irrigation decision support system to determine irrigation requirements based on site specific conditions related to climatic conditions, soil type, growth stage, soil salinity, water quality, and other site-specific factors to improve water use efficiency.
- Evaluate the impact of variable rate irrigation on crop yield, water use efficiency, fertilizer use efficiency, reduction in energy use and reductions in greenhouse gas emissions and document the economic benefits of variable rate irrigation on almond.

Background:

Almond growers in California are under continuous pressure to grow orchards with limited water supplies. Sustainable almond production in California requires careful management of limited water supplies and smart irrigation practices to stretch the available water and minimize the environmental issues associated with over-irrigation. New technologies related to variable irrigation and water status technologies such as Tule, in addition to other soil and plant-based methods could be used to conserve water and improve efficiency. A primary goal of this program is to determine an orchard's irrigation needs more precisely and then have irrigation schedules to meet crop water requirements, thereby reducing water and nitrogen losses, and energy use.

Discussion:

A 70 acre, 9-year old commercial almond orchard near Hanford was selected and 36 one-acre variable irrigation (VRI) zones were implemented on approximately 50% of the field and the other 50% were used as control. Netafim installed the variable rate irrigation system in 2018 and the 2018 growing season was used as a baseline for yield and other variables. The VRI practices were implemented with the start of the 2019 growing season using a VRI schedule on each of the 36 zones. The schedule was based on canopy coverage and NDVI index. The weekly irrigation schedule was based on current reference evapotranspiration, crop coefficient, and field measurements such as actual evapotranspiration from Tule stations, soil moisture sensors, and stem water potential from selected management zones. We implemented six different irrigation management strategies (A, B, C, D, E, and F) and each of the 36 zones received the required irrigation amount based on one of the management strategies. We determined soil moisture content, canopy light interception as midday canopy photosynthetically active radiation (PAR), NDVI, applied water, soil moisture content, and yield for each zone during the growing season. In addition, we had several virtual orchard measurements and drone flights to determine tree size, height, and percent shaded area, and NDVI. Yield was determined from selected rows in all VRI plots and control in August 2018 and 2019.

Project Cooperators and Personnel:
Ashley Correia (Almond Board of California), Todd Rinkenberger (Netafim), James Nichols (Nichols Farms), Daniele Zaccaria and Bruce Lampinen (UCD), Alireza Pourreza (KARE), Dan Munk (UCCE-Fresno County), Blake Sanden (UCCE-Kern County), David Doll (UCCE- Merced County), Allan Fulton (UCCE-Tehama County)

Data-Driven Physiological Modeling of Canopy Photosynthesis for Precision Irrigation Management

Project Leader: Tom Buckley[1]

[1]Dept. of Plant Sciences, UC Davis, One Shields Ave., Davis, CA 95616 (530) 752-0320, tnbuckley@ucdavis.edu

PROJECT SUMMARY

Objectives for current year:

- (1) Parameterize a canopy photosynthesis model in Nonpareil and Aldrich and drive it with continuous measurements of canopy conductance from sap flow.
- (2) To help scale the model from leaf to orchard level, quantify variation in PAR within tree crowns, and in intrinsic water use efficiency (iWUE, the ratio of photosynthesis to stomatal conductance) among trees.
- (3) Determine how changes in irrigation affect modeled canopy photosynthesis and measured SWP as environmental conditions vary across a growing season.
- (4) To allow canopy photosynthesis to be modeled without sap flow data, parameterize and test a physiological model for canopy conductance in Nonpareil and Aldrich.
- (5) To determine guidelines for more effective irrigation scheduling, use the model to simulate the impact of a range of potential irrigation strategies.

Background:

Irrigation scheduling in almond is usually based on target ET estimated from meteorological data (ETo) or midday stem water potential (SWP). Though practical and straightforward, these measures are distantly related to the purpose of irrigation, which is to enable trees to keep their stomata open to allow photosynthesis -- which provides all the energy and carbon that underpins yield. This project aims to understand how irrigation and climate (especially ETo and temperature) affect canopy photosynthesis, and to use that understanding to compare alternative irrigation strategies and identify optimal strategies, using physiological modeling.

We are using sap flow to obtain a continuous estimate of canopy conductance (stomatal opening) and using that to drive a physiological model of canopy photosynthesis and to parameterize a physiological model of canopy conductance. We will use the combined model to simulate alternative irrigation strategies, with the ultimate objective of identifying a strategy that makes the best possible use of limited water while also being practical for growers to apply.

In 2017-2018, we developed a new sap flow method and tested it at an orchard near Arbuckle. In 2019, we experimentally withheld irrigation for two 7-day periods in half of our instrumented trees, and measured leaf stomatal conductance, photosynthetic parameters and pre-dawn and mid-day leaf and stem water potentials, before and after each artificial drought. We are now (early October) processing these data to apply them to our canopy photosynthesis model.

Discussion:

Our results thus far indicate that the biochemical parameters of photosynthesis are unaffected by short-term drought and are similar between Nonpareil and Aldrich, but stomata are severely affected. Moreover, it appears that most trees are unable to fully recover, either in canopy conductance or photosynthesis, after a drought of even 7 days in mid-summer, with large effects on yield. We expect to have complete results and simulations by the Almond Conference in December (after a period of fall rain, which is needed to zero our sap flow probes).

Project Cooperators and Personnel:
The project is being carried out by the Buckley Lab (Tom Buckley & PhD students Heather Vice and Marshall Pierce).

Advanced Irrigation Management for Young and Mature Almond Orchards

Project Leader: Isaya Kisekka[12]

Dept. of Land, Air, & Water Resources[1], UC Davis, One Shields Ave., Davis, CA 95616 530-379-9549 ikisekka@ucdavis.edu
Dept. of Biological and Agricultural Engineering[2], UC Davis, One Shields Ave., Davis, CA 95616

PROJECT SUMMARY

Objectives:

1. Establish an automated precision irrigation system capable of remotely irrigating almond trees by variety.
2. Evaluate regulated deficit irrigation in Nonpareil, Butte, and Aldrich in the period from hull-split initiation to harvest and quantify effects on total yield, nut quality, water applied, and water productivity.
3. Quantify crop water use (ET) of young almond orchards and determine corresponding crop coefficients (Kc) for 1st, 2nd, 3rd, and 4th leaf) almond trees.

Background:

Almond orchards typically have two or three different varieties within the same orchard to establish effective cross-pollination. Each almond tree variety experiences critical growth stages (i.e. hull-split, maturity) at different times in the year. As a result, each variety within an orchard may have different water needs at the same time. Without an irrigation system that allows a farmer to independently irrigate the varieties, a farmer would likely gear the irrigation scheduling toward whichever variety profits the most. This project is investigating how to independently irrigate different varieties in the same orchard while minimizing interferences due to harvest activities and offset growth stages of the different varieties through the adoption of a remote irrigation valve control system.

The second part of this project focuses on quantifying crop water use in young almond trees. An increase in new almond orchard plantings has motivated us to refine estimates of crop water use and crop coefficients in different ages of young almond orchards using a variety of ET modeling and measurement methods.

Discussion:

This project addresses the following research questions:

1. Does irrigating almond trees by variety within the same orchard improve production (i.e., yield, quality, water use efficiency, and profitability)?
2. How do different almond varieties respond to regulated deficit irrigation (RDI) during hull-split and what are the implications of this on irrigation management and Almond Board of California's goal of reducing the amount of water to produce a pound of almonds?
3. How can irrigation by variety be practically implemented on a commercial orchard and how much would a retrofit cost on a per acre basis?
4. How much water do young almond orchards use and what are the crop coefficients (Kc) growers should be using for different ages of young almond orchards (e.g., 1st, 2nd, 3rd, and 4th leaf)?

We retrofitted a drip irrigation system with remote valve control in a 4-acre mature almond orchard in Arbuckle, CA to compare the effects of irrigating by variety versus not irrigating by variety in two regulated deficit irrigation treatments. We implemented 50% ET and 75% ET treatments from hull-split initiation to harvest in all varieties in two different ways, (1) irrigating all varieties according to Nonpareil hull-split initiation and harvest dates to simulate an orchard in which irrigation management decisions are driven by Nonpareil growth stages, and (2) irrigating according to variety specific hull-split initiation and harvest dates to simulate an orchard with the ability to irrigate by variety.

The second part of this project will quantify the water consumption of young almond orchards in 1st, 2nd, 3rd, and 4th leaf almond orchards in Corning, CA. Crop water use will be determined through surface renewal ET stations and remote sensing algorithms. Crop coefficients will be obtained for each age of almond trees.

Project Cooperators and Personnel: Kelley Drechsler, Franz Niederholzer, UCCE – Colusa County; Allan Fulton, UCCE – Tehama County; Andre Daccache, UC Davis

The Effect of Early Post-Harvest Irrigation on Tree Health

Project Leader: Tom Buckley[1]
[1]Dept. of Plant Sciences, UC Davis, One Shields Ave., Davis, CA 95616 (530) 752-0320, tnbuckley@ucdavis.edu

PROJECT SUMMARY

This project aims to understand how tree health is affected by harvest-time irrigation enabled by off-ground harvesting. Our approach is to quantify the carbon budget and physiological status during the post-harvest period, for two varieties with different harvest dates (Nonpareil and Monterey), under conditions similar to off-ground harvesting (irrigation return within 3 days of harvest) vs traditional harvesting (irrigation return delayed after harvest). We are measuring canopy conductance from sap flow, modeling canopy photosynthesis and measuring stem carbohydrates.

Objectives for current year:

- Monitor canopy conductance, photosynthesis and water status during harvest and post-harvest period of 2019 season.
- Monitor stem carbohydrate stores during harvest and post-harvest period of 2019 season.
- Analyze effect of harvest stress and post-harvest irrigation on tree carbon balance.

Background:

Withholding irrigation before and after harvest (to minimize bark damage and allow nuts to dry on the ground) causes water stress. Because flower bud initiation and differentiation occur around harvest time, harvest stress may directly impact subsequent-year flowering and fruit production. Stomatal closure under water stress suppresses photosynthesis, reducing energy stores needed for shoot growth and flowering in subsequent years and possibly leading to early leaf drop.

Off-ground harvesting makes it possible to irrigate immediately after harvest, but questions remain about the potential benefits of off-ground harvesting for tree health and yield. Because harvest time can differ by up to six weeks between varieties, the intensity of harvest stress likely differs between varieties. The relative impact of harvest stress, and thus the value of preventing it, also likely depends on the status of carbohydrate stores at harvest.

Discussion:

The project is being carried out at a commercial farm that utilizes micro sprinklers, so nuts can be kept dry despite irrigation almost immediately after harvest by sweeping them into the center of each row. Thus, the degree of harvest water stress is much smaller than typical for an orchard requiring a long dry period after harvest. As a result, our preliminary data indicate that the stressed and irrigated trees did not differ significantly in any measurable parameters. We hope to repeat the experiment in the future in a location where much greater differences in irrigation amount and timing can be imposed, to better replicate the degree of harvest stress commonly experienced across California.

Project Cooperators and Personnel:
The project is being carried out by the Buckley Lab (Tom Buckley & PhD students Heather Vice and Marshall Pierce), with input from co-PI Patrick H. Brown and access to instruments and protocols for carbohydrate measurement provided by Maciej Zwieniecki and his lab group.

Using SWP to Delay the Start of Irrigation in the Spring

Project Leaders: Ken Shackel[1], Allan Fulton[2], Roger Duncan[3] and Bruce Lampinen[4]

[1]Dept. of Plant Sciences, UC Davis, One Shields Ave., Davis, CA 95616-8683 (530) 752-0928, kashackel@ucdavis.edu
[2]UC Coop. Ext., Tehama County, 1754 Walnut Street, Red Bluff, CA 96080 (530) 527-3101, aefulton@ucdavis.edu
[3]UC Coop. Ext., 3800 Cornucopia Way, Ste. A, Modesto, CA 95358 (209) 525-6800, raduncan@ucdavis.edu
[4]Dept. of Plant Sciences, UC Davis, One Shields Ave., Davis, CA 95616-8683 (530) 752-2588, bdlampinen@ucdavis.edu

PROJECT SUMMARY

Objectives:

- (2019) collect pre-treatment data on grower irrigation management, SWP, PAR, and yield at north (Fulton) and mid-south (Duncan) commercial almond sites.

Background:

Recent results in walnut (highly sensitive to water stress) have demonstrated that delaying the start of irrigation in the spring, based on SWP, can substantially reduce overall seasonal water application (10 – 20 inches, depending on the year), with no long term effect on crop yield and a general improvement in tree appearance. These delays, which varied from 1 to 2 months after the grower normally started irrigation, were also associated with small (5-10%) but measurable increases in crop load and nut quality (edible yield). Soil measurements indicated that these trees used stored soil moisture to compensate for the irrigation deficit. However, counter to expectations, this use of soil moisture did not result in water stress at harvest, and in fact, trees in the delayed treatments were less stressed at harvest compared to control trees. In almond, Prichard (1990 – 1993 study) reported that a plant-based deficit irrigation regime gave higher yields (93% of control yield with 66% applied water) than an ET-based deficit irrigation applying the same water (77% yield with 66% water), and it has become widely recognized that SWP is valuable for deficit irrigation approaches. However, this recent data in walnut may also be the first example of standard ET-based irrigation scheduling resulting in over-irrigation.

The driving question for this project is whether starting irrigation too soon in the spring can have long term negative consequences for root and tree health and/or yield. The other side of this same question, however, is whether mild or moderate stress in the spring may actually have a long-term benefit to almond productivity in mature orchards, by reducing unnecessary vegetative growth and/or promoting branching and flower bud development. It is universally assumed that the goal of irrigation is to match ET, and the wisdom of matching ET through the entire growing season has apparently never been questioned.

Discussion:

Experimental plots were established in commercial almond orchards in Tehama Co. (2 sites), and in Stanislaus Co. (1 site). Initial measurements indicate that each site is relatively uniform in terms of tree water status (SWP), but there are clear SWP differences between sites as a result of soil types and irrigation practices. The contrasting sites in Tehama Co. are of particular interest. Both are 50% Nonpareil, but one site (field #28) is on a class 1 Columbia silt-loam soil, and the other (field #11) is on a class 2/3 loam/gravely loam soil. In field #28 trees are high vigor and it is clear that soil water is readily available because the trees show minimal water stress (SWP), despite being irrigated at about 50% ET. On the other hand, field #11 trees are less vigorous and show mild to moderate water stress, even though they are irrigated at 100% ET. Interestingly, 2019 yields were lower in field #28 (1760 lbs/ac) than field #11 (2840 lbs/ac), possibly suggesting that the vigor in field #28 may be 'excessive.' These are initial results, prior to the application of any irrigation differential, but it may be possible to reduce irrigation in field #28 in order to control vigor and improve cropping.

Project Cooperators and Personnel: Patrick Brown, Jan Hopmans, David Smart, Mike Whiting, University of California, Davis

Effect of Partial Fertilizer Substitution with Organic Matter Amendments on Nutrient Cycling

Project Leaders: Sat Darshan S. Khalsa[1] and Patrick Brown[2]
Department of Plant Sciences, University of California, Davis, One Shields Ave., Davis, CA 95616
(707) 205-7007, [1]sdskhalsa@ucdavis.edu [2]phbrown@ucdavis.edu

PROJECT SUMMARY

Objectives:

- To verify the efficacy of composted manure and green waste compost as a partial substitute to fertilizer
- To determine of how increases in soil organic carbon (SOC) and total nitrogen (TN) impact nitrogen (N) availability
- To contrast OMA *supplementation* (OMA plus standard N fertilizer) and *substitution* (OMA plus reduced N fertilizer)
- To test the impact of composted manure on soil moisture at different depths

Discussion:

Organic matter amendments (OMA) offer a viable option to supplement or partially substitute synthetic fertilizers. We examined the effects of OMA source and supplementation versus substitution treatments. We applied composted manure and green waste compost in fall, and measured their effects on leaf nutrient status, N availability, soil moisture and 2019 yield (*data not shown*). Leaf N, P and K were not significantly different between OMA sources and the control in 2016 and 2017. However, during 2018, leaf N concentrations were significantly greater than the control. This result shows an increase in N uptake from OMA during from 2017 to 2018.

In 2018, soil organic carbon (SOC) was greater for both the OMA sources compared to the control. The same trend was apparent for total nitrogen (TN). Overall, SOC and TN from OMA sources and the control decreased in 2017 suggesting that soil organic matter built up during 2016 rereleased in 2017. This result is consistent with the greater 2017 leaf nutrient concentrations. There was a subsequent build up in SOC and TN in 2018. There were no significant differences in soil inorganic N between OMA sources and the control however, inorganic N increased relative to the control in 2017 and 2018. that N availability from OMA sources increased from 2016 to 2017.

Soil Olsen-P was nearly significantly different in 2016 due to greater concentrations from OMA sources compared to the control. In 2017 and 2018, Olsen-P from composted manure was greater than both green waste compost and the control. OMA sources were greater in soil exchangeable K compared to the control in 2016, 2017 and 2018. Nitrogen availability was greater from OMA sources compared to the control in 2016 and 2017 although not significantly different until 2017. In 2018, N availability from OMA applied continued to increase as evidenced by higher leaf N concentrations. These results demonstrate N from OMA sources requires more than one year to be plant available.

Soil moisture measured by VWC averaged by month and treatment was 7.0% to 20% higher in the composted manure (CM) compared to the control. The CM fall treatment had the highest mean VWC in the majority of months. We measured the largest significant difference between treatments in July 2016. Results from 2017 show similar trends, but treatment differences were no longer significant and could be related to greater irrigation water application driving OMA mineralization. Tree SWP averaged by month and treatment was 0.03 to 1.50 MPa less negative in the CM treatments than the control in 2016 and 2017, but the differences were not significant. Almond fruit from all OMA treatments contained no human pathogens. These results support application of *composted* OMA sources with exclusion periods of greater than 120 days are a food safe practice. Visit our poster for more information on 2019 effects on almond yield.

Project Cooperators and Personnel: Hannah Lepsch UC Davis; Roger Duncan UCCE - Stanislaus; Daniel Rivers and Brent Holtz, UCCE - San Joaquin; Jeffery A. McGarvey, USDA

Boron Management and Remediation in Almond

Project Leader: Patrick H. Brown
[1]Dept. of Plant Sciences, UC Davis, One Shields Ave., Davis, CA 95616 (530) 304-1390, phbrown@ucdavis.edu

PROJECT SUMMARY

Objectives for current year:

- To determine how irrigation water boron (B) concentration, time of exposure and life-stage of the orchard interact to cause B toxicity, productivity loss and orchard decline.
- Measure soil B leaching by different soil types and remediation strategies, so new B leaching guidelines are established.

Background and Discussion:

A review of the boron toxicity in irrigation waters (n=2,650) demonstrates that 12% of current Almond production by volume exceeds 0.7 ppm, a level that will compromise almond productivity. In some counties, this % is even greater (Yolo 72%, Stanislaus 31%, Fresno 28%, San Joaquin 24%). 15% of all almond hull samples (n=2,558) exceeded 200 ppm B. High irrigation water B is a major constraint to Almond expansion into new regions (Western – Yolo: Kern: Fresno: San Joaquin: and Stanislaus counties). Furthermore, there was a widely reported increase in B toxicity during the drought of 2007-2014 as growers increasingly utilized contaminated ground water. Therefore, the most promising approach to growing almonds with high B irrigation water is to develop strategies to remove B from the irrigation source.

Current B almond guidelines are not specific to crop growth stages, nor do they establish if a reduction in irrigation water B throughout the whole of a crop lifetime is superior to a reduction in B during discrete periods. Information is needed to guide growers on the adoption of B mitigation strategies, including strategies for high residual B leaching in soils.

During 2019 season, experimental plots were established in a randomized complete block design (RCBD). The RCBD has five blocks for three B treatment levels (0.5 ppm, 1.0 ppm, and 3.0 ppm) that are maintained at constant B. In addition, 5 replicate blocks were established, each irrigated with 2 ppm B for discrete phenological periods Early Season (March- mid-June), mid-season (mid-June-August), and late season (August-December). This design will provide information on B distribution within the plant, B losses in senesced leaves and fruit and a determination of the relative sensitivity of different plant organs at phenological stages, once leaves, non-fruiting and fruiting spurs, nuts, and hulls were recently harvested and analyzed.

In addition, a soil column leaching experiment (n=45) was built at UC Davis. Established reclamation procedures for elevated B concentration soil suggest about three times as much water demand as reclamation of saline soils. In order to update such B leaching guidelines, soil samples (Corning, Rincon, San Ysidro, Tranquility and Yolo series) from high B almond orchard sites, under different management strategies, were sampled and characterized. To ensure representativeness and to be able to interpolate to different environmental conditions, soil columns were built with samples from different soil composition (wide soil textural range) and properties (pH levels).

Preliminary data from newly established trials have suggested that B adsorption varies with pH levels, demonstrating the importance of soil specific management strategies.

Project Cooperators and Personnel: Lori Salcido and Kirk Pumphrey, Boron Solutions and Westwind Farms. Katherine Jarvis-Shean, Farm Adviser Sacramento-Solano-Yolo County. Christine M. Stockert, Staff research Associate, UC Davis Plant Sciences. Pedro Lima, Postdoctoral Research Associate, UC Davis Plant Sciences.

Almond Water Production Function

Project Leaders: Ken Shackel[1], Blake Sanden[2], Allan Fulton[3], David Doll[4] and Bruce Lampinen[5]
[1]Dept. of Plant Sciences, UC Davis, One Shields Ave., Davis, CA 95616-8683 (530) 752-0928, kashackel@ucdavis.edu
[2]UC Coop. Ext., Kern County, 1031 S. Mt. Vernon Ave., Bakersfield, CA 93307 (661) 868-6218, blsanden@ucdavis.edu
[3]UC Coop. Ext., Tehama County, 1754 Walnut Street, Red Bluff, CA 96080 (530) 527-3101, aefulton@ucdavis.edu
[4]UC Coop. Ext., 2145 Wardrobe Avenue, Merced, CA 95341-6445 (209) 385-7403, dadoll@ucdavis.edu
[5] Dept. of Plant Sciences, UC Davis, One Shields Ave., Davis, CA 95616-8683 (530) 752-2588, bdlampinen@ucdavis.edu

PROJECT SUMMARY

Objectives:

- Develop a water production function (WPF) for almonds grown in California that will relate potential yield to water applied, accounting for the site-specific effects of orchard cover, soils, varieties, and physiological level of stress experienced by the tree

Background:

In the 1980's, seasonal almond crop water use (evapotranspiration or "ET") was estimated to be about 42 inches and yields of 2,500 lb/ac were rare. More recent studies in Kern County have reported water use of 56 inches and yields of over 4,800 lb/ac. ABC funded research has shown that these high productivity levels require a high level of canopy cover (80-90% light interception), and it is clear that for young trees a high-water availability is key to early canopy establishment. However, for a mature canopy it is not yet clear whether a high-water availability and maximum water use are necessary for high yields, or desirable for sustainable orchard management. For instance, many high production orchards also see increased disease problems (e.g., hull rot and loss of lower canopy spurs and limbs).

Discussion:

From 2013 to 2017, replicated plots of almonds in commercial orchards located in Tehama, Kern, and Merced counties have been subject to a range of irrigation levels. Depending on the year and site, the 5-year average estimated seasonal water use has ranged from 41-60 inches (74% - 116% ET), but for a given site and year the yield responses to water has been variable. Statistical differences in yield among the different irrigation treatments have only occurred consistently at the Kern site, although for the 5 year averages, both the Kern and the Merced sites (but not the Tehama site) have shown a trend for higher yields with greater amounts of water. For Kern and Madera we estimate that one inch of water would correspond to an additional 28-30 kernel pounds per acre of production. This is somewhat lower than the estimate of 42 pounds recently obtained by Goldhamer and Fereres (G&F, 2017). Differences in yield responses among sites were associated with unique differences in the two main components of yield at each site: nut load and kernel weight. At all sites, as well as in the G&F study, kernel weight always showed a clear increase with increased irrigation, and in the G&F study, increased kernel weight was the only factor that increased yield. For the current study, increased yield was largely due to increased kernel weight at Merced, equally due to increased kernel weight and nut load at Kern, and the lack of a yield response at Tehama was the net effect of an increased kernel weight and an equal decrease in nut load. These results, and those presented in previous reports for this project, indicate that kernel size responds in a straightforward manner to increasing water availability, particularly during midsummer (June/July), but whether or not this translates to an increase in orchard yield will depend on how water availability during this period, and other periods of the year, affect nut load. Further research into this question will be needed in order to maximize 'crop per drop' in almonds.

Project Cooperators and Personnel: Patrick Brown, Jan Hopmans, David Smart, Mike Whiting, University of California, Davis

Genomic and Transcriptomic Approaches to Understand Noninfectious Budfailure Syndrome in Almonds

Project Leaders: Mysore R. Sudarshana
USDA-ARS, Department of Plant Pathology, UC Davis, One Shields Ave., Davis, CA 95616
(530) 752-3621 mysore.sudarshana@usda.gov

PROJECT SUMMARY

Objectives for current year

- Conduct bisulfite sequencing on DNA from Bud Failure (BF) and normal trees.
- Sequence small RNA (sRNA) from almond shoots exhibiting BF and control trees.
- Conduct bioinformatics analysis of methylated DNA and small RNA profile to identify differentially expressed genes and silenced genes in BF trees compared to normal trees.

Background:

Almond bud failure (BF) is a genetic disorder that affects several major almond cultivars (cvs.) including the most popular cv. Nonpareil. In affected trees, the vegetative buds fail to develop, leading to reduced productivity. Trees with severe BF may suffer up to 50% yield loss. With rapid expansion of almond acreage in California and gradual climate change over years, almond production regions are getting exposed to warmer temperatures in the summer and thus increasing the risk of BF in the following seasons. Genetic disorders in crop plants are poorly understood and there are no models in plants to understand this disorder. This project proposes to expand on the recent studies By Drs. Ramirez and Gradziel at UC Davis, which shed light on DNA-(de)methylation patterns in almond trees exhibiting BF. Our long-term goal is to identify genes that are associated with BF expression and identify genetic markers that can help identify trees prone to develop BF in the next two to three years. The approach taken will be exploratory and we intend to conduct methyl omics on the genomic DNA in BF trees and normal trees to obtain clues on the loss or gain of gene functions due to methylation, including analysis of mRNA and small RNA profiles to determine differences in gene expression patterns. The outcome will enable the design of diagnostics for BF potential.

Discussion:

We identified an orchard in Yolo county that has Carmel trees of the same age showing trees with severe BF and those with little to none. Bud, leaf, and branch tissue was collected in Spring of 2019. High throughput sequencing of mRNA and small RNA fraction was performed on a selection of the samples. From this, we were able to obtain ~73.4million raw RNA-seq reads and ~244.4million raw small RNA seq reads. These were then processed, and de-novo assembled and differentially expressed genes found (ones hopefully associated with BF). However, these results are only the start to giving strong candidate genes and a complete RNA profile. Therefore, sampling was performed again in Fall of 2019 after a second round of buds appeared on the same trees. Sequencing of these samples is underway. This additional information should help build a better picture of the issue.

Since the last update, additional genomic resources for almond have been produced by research groups in the USA and Spain. While these can be helpful, cultivar specific information expected from a collaboration with Dr. Ramirez will be most useful. Additionally, we have assembled the complete chloroplast genome of Nonpareil.

Provided that good quality sequencing is returned, and associations exist, we plan to have candidates for BF associated markers, based on sequencing data by the next update.

Project Cooperators and Personnel: Kurtis Dluge, Thomas Gradziel, and S.P. Dinesh-Kumar, UC Davis; J. F. Ramirez, Ohio State University, Wooster, OH.

Manipulating Irrigation Patterns to Evaluate Fine Root Traits, Root Production Rates, and Fine Root Physiology in Almond Trees

Project Leader: Astrid Volder, Bruce Lampinen, Brian Bailey
Department of Plant Sciences, University of California, Davis, One Shields Ave., Davis, CA 95616
(530) 752.8527; avolder@ucdavis.edu

PROJECT SUMMARY

Objectives:

- Measure impact of irrigation strategies, transplant source (potted vs bare root), and pruning on root production, root traits & physiology on 2nd leaf almond trees at UC Davis

Background and Discussion:

Root, shoot, and vascular traits are tightly linked to expected survival and growth rate under drought conditions. The supply of water to and within plants is determined by soil water availability (water content and soil type), plant architectural traits (e.g., root:shoot ratio, root depth, root surface area, leaf area, tissue density), as well as axial and radial hydraulic conductance of the root system. Generally, there are tradeoffs between characteristics that confer stress resistance and those that allow a high physiological activity. We aim to study variation in root morphological, anatomical and physiological traits in response to multiple irrigation scenarios.

In 2015 a dedicated field trial (1.1 acre) was installed at UC Davis to study both temporal and spatial patterns of root production, morphology, and physiology in response to short- and long-term drought. Both bare-root and pot grown trees (Nonpareil, Wood Colony, and Monterey on Krymsk 86 rootstock) were planted in February 2015 with a 15 ft (between row) x 9 ft (within row) spacing. At planting, bare-root trees and potted trees had similar total root surface area, but potted trees had a much greater proportion of surface area in the fine root fraction. The trees were not staked or fertilized, and were initially pruned, but not headed in the main experiment. The main experiment tested the impact of pruning, irrigation, and nursery treatment, while the edge trees were used to separately test the impact of heading and pruning at planting.

Newly planted trees exhibited a very even root production rate to 1 m depth, however, trees that were headed and pruned had strongly reduced initial root production below 1 m depth compared to unheaded and unpruned trees, 5 months after planting. In the first season after planting, new root growth primarily occurred in the 0-80 cm deep soil layer during the summer, while root growth production shifted to deeper soil layers (80-130 cm) in the Fall (Sep – Nov).

Reduced irrigation treatments were implemented in June 2016, and trees receiving 70% irrigation exhibited more negative water potentials. Although bare root trees were significantly larger at planting, pot grown trees exhibited greater relative growth rates, and initial size differences between trees were greatly reduced by March 2018. There was no difference in growth rates between trees planted from root pruning pots versus Ellepots.

There was a strong negative impact of pruning on tree diameter growth rate which was proportionally greater than the impact of reducing irrigation event size by 30%. To date we have not observed a consistent impact of pruning on root production patterns whereas reduced irrigation reduced new root production in June as our first irrigation generally started mid-May. We found very little new root production after June and root death was greater than root production during summer, fall and winter. 36 trees and their root systems have been excavated and their root allocation and traits are currently being assessed. Initial visual observation suggests that there was no impact of growth method (bare root versus pot) on development of the coarse root system.

The overall goal is to combine information derived from this project with information from associated projects (water and N uptake rates, water and N movement in soils, carbohydrate allocation) to improve the design of irrigation and fertigation systems as well as recommend optimal irrigation strategies.

Project Cooperators and Personnel: Paul Martinez, Xinyu Yao, Courtney Nichols, Hana You and Maciej Zwieniecki, UC Davis

Subcellular and Molecular Characterization of Salinity Tolerance in Almonds with Novel Tools

Project Leader: Georgia Drakakaki
Department of Plant Sciences; University of California, Davis; One Shields Ave.; Davis, CA 95616
(530) 752-1664; gdrakakaki@ucdavis.edu

PROJECT SUMMARY
This project aims at the establishment of methodologies for the characterization of root physiology contributing to environmental adaptability with emphasis on salinity stress. This will aid in the identification of traits that can accelerate breeding programs towards best sustainable rootstocks.

Objectives for Current Year

- Develop assays of examining root structure and root development.
- Characterize commercially available rootstocks in response to salinity.

Background

California is experiencing increasing soil salinization, which is projected to accelerate due to the increased use of saline ground water. Almond plants, one of the most economically important crops in California, are strongly sensitive to salt stress. Selection of elite rootstocks with improved salinity tolerance affords a way to ensure high yield production in this long-term trend. The plant roots are the first contact for nutrients and microorganisms and are important for robust and sustainable growth. Thus, the plant root provides an efficient boundary against external stresses in order to maintain plant fitness. So far, most of the rootstock characterization is based on aerial parts (leaf and shoot phenotypic symptoms) while little is known about the uptake and translocation of nutrients and salts throughout the root system under environmental stresses. Thus, it remains challenging to select for superior rootstocks. The development of methodologies towards identifying sodium uptake, ion sequestration and its effect on cellular morphology and viability for various rootstocks and rootstock/scion combinations is a hitherto unexplored approach.

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Discussion

So far, we have developed the methodologies for the characterization of cellular barriers in roots, as well as the localization the implicated ions in salinity stress. In our experiments, distinct, genotype specific, subcellular accumulation patterns of sodium were observed in rootstocks, suggesting differences in transport mechanisms and sequestration between Empyrean-1, Krymsk 86 and the Controller -5. We hypothesize that control of ion uptake in combination with redistribution and inhibition of transport contributes to salinity tolerance. Our data on characterization of root barrier differentiation showed differences in root maturation among the different genotypes under salinity stress. Preliminary data indicate an important role of cellular barriers in allowing sodium transport within root tissue. We continue the structural analysis of root vasculature to determine the relative root cell barrier differentiation in different rootstocks and the role of specific cell barriers in salinity tolerance.

This methodology will provide the flexibility for future extensions beyond salinity stress to assess cellular structural modifications in response to biotic and abiotic stresses, including that of various pathogens. We expect that dissemination of the developed methodology will spur rapid adaptation and follow up studies, in tandem with a proliferation of the use of advanced microscopy tools in almond research on the cellular level. Employing cell biology, and biochemistry of the cell wall, our studies will aid in the dissection of cell barrier differentiation and cell wall deposition in the abiotic and biotic stress response with application of our insights providing tools toward the development of sustainable rootstocks.

Project Cooperators and Personnel: Hongguang Pang, Yuhang Shao, Shuxiao Zhang, Oliver Betz, Shahab Madahhosseini, John Preece, Bruce Lampinen, Patrick Brown, Tom Gradziel, Astrid Volder, Roger Duncan, Chuck Fleck, John Labavitch, Judy Jernstedt, Thomas Wilkop

Linking Performance of Almond Rootstocks to Underlying Physiological and Genetic Determinants of Salinity Tolerance

Project Leader: Devinder Sandhu
USDA-ARS US Salinity Lab, 450 W Big Springs Rd., Riverside, CA 92507
(951) 369-4832, devinder.sandhu@ars.usda.gov

PROJECT SUMMARY

Objectives for current year

- Objective 1. Evaluation of selected almond rootstocks for their effects on scion performance under salinity stress and identification of underlying genetic components.
- Objective 2. Using priming as an alternate approach to mitigate salinity stress in almond rootstocks.
- Objective 3. Functional validation of almond genes involved in salt tolerance using model plants.

Background and Discussion

Our initial screen of 16 almond rootstocks under 5 different treatments of irrigations waters of mixed ion compositions revealed that mostly Na, and to a lesser extent, Cl concentration in irrigation water are the most critical ion toxicities for almond rootstocks. Of the physiological parameters, photosynthetic rate displayed highest correlation with survival rates and trunk diameter. This year we characterized different rootstocks under different salt concentrations and the ability to store Na and Cl in their leaf tissues. Top performing rootstocks under salinity include Rootpac40, Empyrean 1, Cornerstone and BB 106. These rootstocks also had least amount of tissue accumulation of Na and Cl, suggesting that ion exclusion may be the main component trait of the salt tolerance mechanism in almond.

Expression analysis of 24 genes known to play important roles in salt tolerance revealed that the *HKT1* and *AKT1* genes displayed the highest upregulation (expression) in salinity treatments in roots and *NHX1*, *SOS3* and *AKT1* were highly upregulated in salinity treatments in leaves. Of the genes involved in Cl transport, SLAH1 and SLAH3 were significantly downregulated in almond leaves and CLC_C and SLAH3 were highly upregulated in roots under salinity stress.

RNA-seq analysis resulted in identification of several genes involved in different pathways that are induced on salt treatment and also differentially expressed between the sensitive and resistant rootstocks. Some important differentially expressed genes include – SOS2, NHX2, SOS3. In addition, genes coding for transmembrane receptors, ion transporters, organic solutes, hormones were also differentially expressed. These genes are potential candidates that can be further characterized to understand their specific role in the salt tolerance mechanism in almond.

In the previous years, we have studied ungrafted rootstocks for their salt tolerance. This year, we are evaluating 7 selected rootstocks, grafted with Nonpareil and Monterey under three irrigation waters to determine if genetic control is similar in grafted and ungrafted plants. This analysis will increase our understanding about possible interactions between rootstocks and scions under salinity stress.

We are using alternate technologies such as “priming” to mitigate effects of salinity in short term. This year we are conducting a trial where we are using two rootstocks, 2 scions, 2 salt levels and 5 treatments (4 primers + 1 zinc). Four primers include salicylic acid, H_2S, melatonin and control. Effect of different primers on plant growth will be evaluated in May 2020 (after 9 months of continuous treatment).

We complemented the Arabidopsis *athkt1* knockout mutant with *HKT1* ortholog (*PpHKT1)* from the almond rootstock ‘Nemaguard’. Two Arabidopsis transgenic lines survived salt concentrations up to 120 mM NaCl, however, the mutant *athkt1* died after 18 days. Both transgenic lines showed significantly higher biomass, longer lateral roots, lower electrolyte leakage and higher relative water content compared to the *athkt1* mutant at 80 mM NaCl treatment. The expression analyses showed that *PpHKT1* was induced in transgenic lines under salt treatment, which confirmed that the expression of *PpHKT1* in the Arabidopsis mutant can complement salt tolerance function. We have also shown that complementation of the *atsos2* mutant with *PpSOS2* resulted in enhanced salt tolerance as compared to the mutant lines suggesting conservation of SOS2 function in Arabidopsis and almond.

Understanding of genetic networks regulating salt tolerance will help in developing new rootstocks for saline conditions.

Project Cooperators and Personnel:

Jorge Ferreira and Donald Suarez, USDA-ARS US Salinity Lab, Riverside, CA

Evaluating HFLC Nitrogen Management Strategies to Minimize Reactive Nitrogen Mobilization from California Almond Orchards

Project Leaders: Thomas Harter[1], David R. Smart[2], Patrick Brown[3]
[1]Dept of Land, Air & Water Resources, UC Davis. One Shields Ave., Davis, CA 95616, thharter@ucdavis.edu
[2]Dept.of Viticulture and Enology, UC Davis. One Shields Ave., Davis, CA 95616, drsmart@ucdavis.edu
[3]Dept.of Plant Sciences, UC Davis. One Shields Ave., Davis, CA 95616, phbrown@ucdavis.edu

PROJECT SUMMARY

Objectives for current year:

- Demonstrate the efficacy of HFLC under real world conditions as both an economically and environmentally promising practice. Using an adaptive management approach, fine-tune the HFLC approach and demonstrate, in a commercial scale almond orchard, that HFLC fertigation practices increase water and nutrient use efficiency while successfully producing high yields and reducing groundwater quality impacts
- Comparing and contrasting three monitoring approaches for regulatory compliance in a scientifically rigorous systems approach: 1. Water and nitrogen mass balance (WUE, NUE). 2. High resolution water and nitrogen flux monitoring within and immediately below the root zone. 3. High resolution on-site groundwater monitoring

Background:

Offsite transport of reactive nitrogen (N) in the forms of NH_4^+, NO_3^-, NH_3, NO_x and N_2O from agriculture is facing increased regulatory scrutiny due to air quality, climate, and drinking water quality impacts. One of those is the Irrigated Lands Regulatory Program (ILRP), developed maintain ground and surface water quality in California, which includes regulating nitrate leaching from irrigated crops. To comply, growers must implement N management plans, improve N use efficiency, and reduce N leaching to groundwater. HFLC is an innovative management practice which applies N at each irrigation event (about 15 events compared to 3-6 events) yielding higher WUE and NUE, while potentially reducing nitrate leaching to groundwater in a variety of specialty crops. However, commercial orchard scale implementation with direct measurements of resulting groundwater quality improvements immediately underneath the orchard is lacking.

Discussion:

Comparing the yield from the past five years prior to HFLC management showed that HFLC management during 2018 did not affect the yield. Mass balance approach show greater NUE for HFLC compared to BMP in previous years (0.85 vs. 0.7) and lower excess of nitrate (18 vs. 50 lb/acre respectively). Monthly water mass balance show that the irrigation amount is lower than the actual ET. Leaching occurs with infiltration from winter rains. Root zone monitoring show high variability of water and nitrate fluxes. On average, root zone fluxes are consistent with the mass balance, and with observed leaching during the winter rains (average of 9 in of water was leached with root zone monitoring, and 7.9 in with mass balance) Groundwater nitrate concentrations show high spatial variability but very little temporal variability. Historic water mass balance of the past five years show a consistent low to negligible recharge rate for 2013 - 2016, which may drive the low temporal variability.

Project Cooperators and Personnel: Hanna Ouaknin, Teena Stockert, Patrick Nickols , UC Davis.

Developing Plant-Based Recommendations for Water Management in a Dry Winter

Project Leader: Ken Shackel
Department of Plant Sciences, University of California, Davis, One Shields Ave., Davis, CA 95616-8683
(530) 752-0928 kashackel@ucdavis.edu

PROJECT SUMMARY

Objectives:

- Automate the existing pot study site by instrumenting each pot with a soil sensor
- Repeat winter drought study with additional treatments designed to bracket specific windows of time
- Conduct a pilot field study for the effects of delaying or omitting winter irrigation on bloom time and subsequent effects on in-season water stress levels
- (Additional objective made possible through USDA cooperation): pilot test High Resolution CT scanning for describing/staging dormant bud development.

Background:

In winters with low rainfall, it is common for growers to ask the question “do I need to winter irrigate?” This research project has determined that significant water stress (SWP in the -15 to -30 bar range) during dormancy (December/January), can delay flower bud development, and that bloom can be delayed up to 20 days, compared to fully irrigated controls (SWP around -2 bars). The amount of delay depended on the level and duration (but not on the timing) of stress. However, stress had no apparent effect on vegetative buds, with leaf-out in stressed trees occurring at the same time as controls. Hence, in stressed trees, bloom can occur substantially after leaf-out, but fruit set and development is normal. Flower structures develop in the late summer, and water stress during that time in peach can cause fruit abnormalities (e.g., doubles). Only one 1952 paper reported that withholding irrigation in December/January in field apricot caused a slight delay in flower development, but after irrigation was applied, flower development recovered. It is widely assumed that very little development occurs during dormancy, particularly prior to chill accumulation (typically mid-December in almonds). Our results however, suggest that bud growth both before and after chilling can be slowed by water stress, and that the delaying effect will translate to a delay in bloom. Delaying bloom could reduce the probability of spring frost damage to flowers, but the net effect of modifying bloom/leaf-out overlap is not known.

Discussion:

This year we specifically targeted the imposition of water stress prior to full chill accumulation (i.e., by mid-December). For the same overall stress, we obtained the same delay as observed in the previous two years. In cooperation with USDA colleagues, also we tested the ability of high-resolution CT scanning (HRCT) to detect and measure 3D flower structures in the intact bud. The 3D reconstructions clearly showed the stages of early flower size and development in great detail (pistil, ovary, stamens, etc.). Bud dry weight was also measured periodically, and both lines of evidence were consistent: the early stages of flower development, including development prior to chilling (so called ‘endo-dormancy’), are sensitive to water stress, and delays in this development translate into delays in bloom. In a Shafter, CA field trial, omitting the last irrigation in October caused early defoliation and mild stress (-15 bars) by mid-November, compared to controls (-4 bars). A rainfall of only 0.64” in late November however was sufficient to increase SWP to the control level, resulting in only a small (3days) but detectible delay in bloom.

Project Cooperators and Personnel: Bruce Lampinen, UC Davis; Andrew McElrone, USDA/ARS, UC Davis; Mohammad Yaghmour, UCCE, Kern Co.

Drying Fresh Harvested Almonds

Project Leaders: Michael Coates[1] and Irwin Donis-Gonzalez[2]

[1]Plant & Food Res. Australia, Waite Campus, Urrbrae, SA 5064 + 61 4 3171 0647, michael.coates@plantandfood.com.au
[2]Dept. of Bio and Ag. Eng., UC Davis, One Shields Ave., Davis, CA 95616 +1 530 752-8986, irdonisgon@ucdavis.edu

PROJECT SUMMARY July 2019

Objectives for the current year

- Construction and validation of stockpile tunnel dryer
- Construction and validation of mobile batch drying station
- Test effectiveness of dryer on in-hull fruit, maintaining relative humidity (RH) below saturation. Optimise airflow and depth of product
- Compare stockpile, and batch mechanical drying to control
- Test on multiple cultivars
- Evaluate for concealed damage, cavities, shell staining and pest damage

Background

Visible dust is a growing concern as both production increases and traditional growing regions are becoming more and more urbanized. What was once a seasonal disturbance is becoming a greater problem, with orchard dust moving into towns and across main traffic thoroughfares. Most the dust is created after the fruit have been shaken from the tree. It's the act of sweeping the fruit into windrows that creates the problem by agitating and blowing the soil along with the fruit. The soil billows up in dust clouds, reducing visibility. This ultimately creates a windrow equally filled with fruit and soil and is further compounded by picking up the combination of fruit and soil (within the windrow) and billowing a second round of dense dust into the surrounding air.

Solutions to the dust problem focus on removing the sweepers and potentially the 'pick-ups'. These range from modifying current equipment to completely changing the harvest model to an off-ground process that catches the fruit before they hit the ground.

Off-ground harvesting requires additional mechanical drying to prevent the fruit from spoiling by maintaining temperature and RH low enough to prevent the growth of molds and bacteria.

This project looks to establish the protocols surrounding the airflow delivery requirements to maintain that quality within a closed environment (batch) and within an open air, centrally aerated stockpile.

Discussion

This project is making use of both the Californian and Australian almond harvests to accelerate the research process. The Australian season established large variability from the start of the shaking cycle to the end of the shaking cycle for each cultivar tested ('Nonpareil', 'Carmel' and 'Monterey'). Kernel moisture below 12% may not require forced air to be dried in an aerated stockpile. Above 12% may need additional air (and heat).

The Californian season demonstrated successful attempts to dry fruit both in batches and as a smaller experimental stockpile. Analysis is still under way, but additional modeling will be required to establish how to obtain better control over the distribution of forced air within the stockpile.

Project Cooperators and Personnel

Montgomery orchards (Mark Montgomery), Ismael Mayanja (MSc. Student), Nichols soil lab orchards (Dr. Franz Neidermier)

Developing Effective Drying Methods for Minimizing Quality Defects for Off-Ground Harvest Almonds

Project Leader: Zhongli Pan
Department of Biological and Agricultural Engineering, UC Davis, One Shields Ave., Davis, CA 95616, Tel: (530) 7400-3400, zlpan@ucdavis.edu

PROJECT SUMMARY

Objectives for current year:

- Investigate the initial moisture content (IMC) distribution of off-ground harvested almonds and their components (hull, shell and kernel).
- Determine the drying characteristics of almonds with different IMC under different drying conditions in the hot air temperature range of 45-60°C, and air velocities of 1 and 2 m/s.
- Evaluate the quality of dried almonds, including, insect damage, concealed damage, cavity, color, and oil quality.
- Determine the physical and pneumatic characteristics of almonds and their components for separation.
- Develop mathematical models and provide suggestions to almond industry about the optimum drying conditions of almonds with different varieties and IMC.

Background:

This research project is to develop a drying method for different varieties of almonds from the off-ground harvest to produce high quality almonds by minimizing the quality defects.

Discussion:

The tests were conducted using a pilot scale dryer and a bench top dryer at UCD. Drying air temperatures of 45, 50, 55 and 60ºC and air velocities of 1 and 2 m/s were used. Three almond varieties of Nonpareil (soft shell), Fritz (hard shell) and Monterey (semi-hard shell) were used. The statues of the tests and timeline to complete the analysis are shown in the following table:

The status of data analysis and available results are reported as follow:

Almond variety	Status of tests	Status of analysis	Timeline of completion
Nonpareil	Completed except oil quality	Completed	Completed
Monterey	Completed except oil quality	In progress	By Nov. 5th
Fritz	Completed except oil quality	In progress	By Nov. 15th

- For off-ground harvested Nonpareil, the IMC of in-shell and in-hull almonds ranged from 4.2 to 24.5%, while the IMC of kernels ranged from 4.1 to 11.8%. The overall IMC was 20.9%.
- The drying characteristics of Nonpareil showed that the drying time decreased significantly with the increase of temperature and speed of the drying air. At the temperature of 60 °C and air speed of 2 m/s, it took 150 min to dry the almonds from their IMC to 6% of kernel MC. It was also found that approximately 60% of the energy consumption were used for moisture removal from hulls.
- The available data indicated that there were no quality defects under the tested conditions.
- The insect damage percentage of conventional harvested almonds was about three times higher than that of off-ground harvest almonds.
- The available results related to the physical and aerodynamic properties of almonds revealed the possibility of separation of off-ground harvested almonds into in-hull almonds, in-shell almonds, and hulls using size and pneumatic sorting before drying.
- Development of models is still in progress.

Project Cooperators and Personnel:
Dr. Franz Niederholzer: Farm Advisor
UC Cooperative Extension Colusa County

Handling Fresh Harvested Almonds

Project Leaders: Michael Coates[1] and Reza Ehsani[2]
[1]Plant & Food Res. Australia, Waite Campus, Urrbrae, SA 5064 +61 4 3171 0647 michael.coates@plantandfood.com.au
[2]Dept. of Mech. and Aero. Eng., UC Merced, 5200 N Lake Rd, Merced, CA 95343 +1 863 396 9585, rehsani@ucmerced.edu

PROJECT SUMMARY

Objectives for the current year:

- Develop a deflection shield that moves and expands with the extension of the boom arm on a traditional side arm shaker.
- Using an inverted blower, direct fruit coming down the trunk out into the row.
- Evaluate the distribution of fruit.
- Using current UC Merced research continue the development of a finger wheel pick-up and slow-arm sweeper.
- Visually compare levels of dust creation to traditional sweep and pick-up.

Background:

Visible dust is a growing concern within the industry as both production increases and traditional growing regions are becoming more and more urbanized. What was once a seasonal disturbance is becoming a more significant problem. Most of the dust is created after the fruit has been shaken from the tree. It's the act of sweeping the fruit into windrows that creates the problem by simultaneously agitating and blowing the soil along with the fruit. The soil billows up in clouds of dust, creating reduced visibility. This ultimately creates a windrow that is equally filled with fruit and soil and is further exacerbated by picking up the combination of fruit and soil (within the windrow) and billowing a second round of dust into the surrounding air.

Solutions to the dust problem focus on removing the sweepers and potentially the 'pick-ups'. This ranges from modifying current equipment to completely changing the harvest model to an off-ground process that catches the fruit before it hits the ground.
This project looks at keeping fruit off the tree line by deflecting the fruit during the shaking process and then adapting a 'finger wheel' harvester with a low-velocity sweeping arm to collect the fruit from the orchard floor without the need to windrow.

Discussion:

This project is making use of both the Californian and Australian almond harvest to accelerate the research process. The project started late in the season in Australia. This limited us to testing a blower to remove windfalls and debris along the tree line by blowing air at a lower velocity and parallel to the ground.
The California season saw the construction of a rig to test the finger wheel rollers on almond fruit.
The initial prototype test was conducted on Independence® fruit with a first pass accuracy of 32%. Modifications to the rig brought the second test first pass accuracy up to 77%. Trials have not been finished yet for this season, but we hope to introduce a larger finger wheel and side sweeper to improve first pass accuracy. The wheel has potential as a primary fruit collection method, but also as a secondary collection method for orchard floor sanitation.

Project Cooperators and Personnel:

Reza Serajian, Joseph Trotochaud, Arash Toudeshki and thanks to Hughson Nut (David Pohl)

Quantitative and Qualitative Impacts of Windfall on Almond Yield and Quality

Project Leaders: Patrick Brown[1], Christopher Simmons[2] and Sat Darshan Khalsa[1]
[1]Dept. of Plant Sciences, UC Davis, One Shields Ave., Davis, CA (530) 752-0929, phbrown@ucdavis.edu
[1]Dept. of Plant Sciences, UC Davis, One Shields Ave., Davis, CA (707) 205-7007, sdskhalsa@ucdavis.edu
[2]Dept. of Food Science and Technology, UC Davis, One Shields Ave., Davis, CA (530) 752-2109, cwsimmons@ucdavis.edu

PROJECT SUMMARY

Objectives for current year:

- Characterize the quantity of windfall and what environmental, biological and management factors impact windfall
- Assess the quality of the windfallen nuts collected from multiple regions

Background:

By 2025, the California almond community commits to reduce dust during almond harvest by 50%. One option is transition to alternative off-ground harvest systems like catch-frames. Even though a transition to catch-frames would reduce harvest passes and subsequently dust, there is a potential unknown loss of marketable yield in the form of windfall that would not be picked up if ground harvest is abandoned. Windfall is the premature fall of almonds before harvest, usually due to variety characteristics or weather conditions but, also as a result of mechanical knocking by machine passes through the orchard. Windfall is relevant and a concern for alternative off-ground harvesting systems that mitigate dust because windfallen nuts may never be harvested. Additionally, windfall is a concern for current harvest systems since windfallen nuts that lie on the orchard floor for extended periods might disproportionately affect crop quality, food quality and food safety of the resultant harvested nuts. Research is therefore needed to 1) quantify the magnitude of windfall in relation to variety, location, and timing and 2) determine the impact of windfall on nut quality and food safety.

The distribution of windfall of almonds across the Central Valley is relatively unknown. Furthermore, the factors that impact windfall of almonds like wind speed, cultivar, temperature, harvest date, and relative humidity have not been quantified. Almond hull split begins in the top of the tree and progresses downward with harvest is generally scheduled at 95% hull split contributing to the potential for the early maturing nuts to fall to the floor prior to tree shaking. It is unknown if 1) windfall nuts are of equivalent maturity and quality as shaken nuts and; 2) if windfallen nuts are subject to a higher degree of damage from insects, moisture, mechanical damage from orchard machinery and contamination from orchard chemicals and/or pathogens.

Discussion:

This project seeks to identify quantitative and qualitative impacts of windfall and to evaluate the opportunities and challenges of transitioning to off-ground harvest. The overall question is how to estimate both the quantity and quality of nuts that prematurely fall prior to harvest. We hypothesize variability in the windfall will be driven by a host of production and climatic parameters. We also expect timing of windfallen nuts to have the main impact on nut quality and food safety. Qualitative and quantitative differences between windfall and shaken nuts will influence the overall economic impact of windfall on almond yield and quality.

Project Cooperators and Personnel: Ricardo Camargo and Gustave Cirhigiri, Graduate Student Researchers, Dept. of Plant Sciences, UC Davis

Development of Simple Dust Measurement Techniques to Aid in Long-Term Dust Reduction Program for Almond Harvesting Operations Using Drones

Project Leaders: Sergio Capareda[1]
[1]Biological and Agricultural Engineering Department, Texas A&M University, 303D Scoates Hall, Spence St. College Station, Texas 77843, Ph. (979) 458-3028, Email. scapareda@tamu.edu

PROJECT SUMMARY
This project compared different technologies for quick measurements of visible and non-visible dusts during almond harvest operations. The project evaluated the following methods: EPA Method 9, digital opacity compliance system (DOCS) or EPA ALT 082 Standards, opacity meter, and laser particulate matter (PM) counter using drones. The overall goal was to evaluate the baseline total suspended particulate (TSP) concentrations and develop management strategies to reduce visible dusts.

Objectives for previous year:

- Quantify visible dust concentrations using total suspended particulate (TSP) data during almond harvesting using quick measurement techniques.
- Evaluate several quick measurement techniques that will provide measurable particulate matter (PM) concentrations such as opacity, real-time image analysis and laser scattered particulate counter during almond harvesting operations.
- Determine dust reduction levels through significant changes in harvest machinery adjustments or designs, and
- Identify various best management practices during almond harvesting that will have impact on overall dust reduction strategies.
- Recommend the current baseline TSP emission factor for almond harvesting operations

Background:

Previous PM measurement techniques to establish particulate emission factors are quite laborious. The development of quick dust measurement techniques will bring immediate impact concerning the goal of reducing visible dust emissions during harvest operations.

This new test protocol will also aid in testing various machinery adjustments or designs to reduce dust generation during harvest and determining the percentage reduction from the baseline visible or non-visible dust concentrations.

The study also evaluated, via dispersion modeling, the extent of dust migration during harvest as a function of wind speed and direction and other weather parameters, to determine how best to prevent migration to populated or sensitive areas.

For the test protocol studied, we have deployed the following teams to measure visible dust during actual almond harvest operations:

a. EPA Method 9 Licensed Professionals
b. EPA Alt 082 Standards Certified Personnel to capture digital images and videos of the dust being measured simultaneously by groups (a) and (b) above.
c. Drone for Hire or Unmanned Aerial Vehicle (UAV) system company to measure visible dusts above the canopy during actual harvest operations, and
d. Opacity Meters Measurement Group

The results of comparative studies lead to recommending the use of test protocols a, b and c above to measure visible dust concentrations. The study also reported the estimated and current baseline TSP emission factor from correlated drone TSP data.

Project Cooperators and Personnel: Mike Flora – Flory Industries; Dan Visser, Dutch Valley Farming; Matthew Efird and Jeff Noorigian, Efird Ag Enterprise; Thomas Davis**,** Drone for Hire; Paul Schafer, SCS Engineers; and Cameroon Donnahoo, Reliable Emissions Measurements.

Performance Evaluation of Commercial Dryers for Drying of In-Hull Almonds

Project Leader: Zhongli Pan

Department of Biological and Agricultural Engineering, UC Davis, One Shields Ave., Davis, CA 95616, Tel: (530) 7400-3400, zlpan@ucdavis.edu

PROJECT SUMMARY

Objectives for current year:

- Determine the characteristics and the initial moisture content (IMC) distribution of the freshly harvested almonds and their components (hull, shell and kernel).
- Evaluate the drying characteristics and the product quality of off-ground harvested almonds using different commercial drying technologies, including tunnel drying, stadium drying, and trailers. Compare the quality for product dried by using the commercial dryers compared with that of conventional harvested almonds.
- Determine the energy use and cost baseline of drying processes by using commercial dryers.

Background:

There is a potential to use the existing commercial dryers for drying fresh in-hull almonds. At present, no reported research has focused on investigating the feasibility of using the current commercial dryers for almond drying. Therefore, this research project is to identify suitable dryers for drying in-hull almonds by evaluating the performance of different commercial dryers.

Discussion:

The tests were conducted with three different commercial dryers, including prune drying tunnels, stadium dryer and drying trailers. Three almond varieties of Independence (soft shell), Fritz (hard shell) and Monterey (semi-hard shell) were used for the drying tests. The statues of the tests and timeline to complete the analysis are shown in the following table:

Drying method	Status of tests	Status of analysis	Timeline of completion
Tunnel drying	Completed except oil quality	Completed	Completed
Stadium drying	Completed except oil quality	In progress	By Oct. 20th
Trailer drying	Completed except oil quality	In progress	By the end of October

The findings below are only for off-groud harvested Independence dried with tunnel drying:

- The IMC of in-shell and in-hull almonds ranged from 22.2 to 48.5%, while the IMC of kernels ranged from 7.5 to 17.5%. The overall IMC was 39.8%. The weight ratios of hulls, in-shell almonds, and in-hull almonds were 0.32, 0.17, and 0.51 repectively. The bulk density of fresh almonds was 320 kg/m^3.
- At temperature of 46°C, it took 12.9 hours to dry 19.9 tons of fresh almonds (capacity of 1.54 ton/h) in each tunnel to the final kernel MC of 5.8% and overall MC of 12.5%. The ambient air drying took 51.8 hours to dry 18.1 tons of almonds (capacity of 0.35 ton/h) to final kernel MC of 7.5% and overall MC 16.8%.
- The knernel moisture of hot air dried almonds was more uniform than the ambinent air dried products. No cavity and color deterioration were found for the dried almonds. The alomnds from hot air drying and conventional harvest had similer concealed damage. The insect damage percentage of conventional harvested almonds was about three times higher than that of off-ground harvest almonds.
- To produce one pound of dried almond kernels, the tunnel drying used 3199 BTU of natural gas and 0.035 kwh of electricity. The overall energy cost was from 3.4 to 3.8 cents/lb of dried almond kernels.

Project Cooperators and Personnel:

Campos Brothers Farms, Emeraled Farms, West Valley Hulling Company。

Nutrition Research Program
Research Updates
2019

Heart Health & Beyond

Cost Savings of Reduced Heart Disease Attributed to Increased Intake of Almonds Using a Decision-Analytical Model

Dr. Elizabeth Johnson, Tufts University, USDA Human Nutrition Research Center on Aging, Boston, MA USA

Background: The U.S. Food and Drug Administration (FDA) approved a qualified health claim for tree nuts and heart health in 2003, which states, “Scientific evidence suggests but does not prove that eating 1.5 ounces per day of most nuts, as part of a diet low in saturated fat and cholesterol, may reduce the risk of heart disease.” Tree nuts, including almonds, are good sources of “healthy” unsaturated fats, which have been shown to lower blood cholesterol levels, and contain a variety of other potential cardio-protective components such as vitamin E, selenium, magnesium, copper, potassium, β-sitosterol and omega-3 fatty acids. This study hypothesized that daily almond consumption could be associated with considerable cost savings, estimated in terms of reduction in CHD and related medical costs, thereby highlighting the importance of increasing daily intake of almonds. for the general population.

Study Design: This three-year study aimed to determine potential health care cost-savings associated with the consumption of almonds. An analytic model was developed using the estimated direct medical cost savings associated with prevention of CHD among adults in the United States and will be based on: (1) baseline almond consumption; (2) prevalence of CHD among those with no or low almond intake; (3) proportion of those likely to respond (in terms of a decreased risk of CHD) to increased intake of almonds; (4) estimated decrease in CHD prevalence associated with each ounce (28 grams) per day increase of almond intake; (5) expected change in almond intake. The medical costs prior to and following the hypothetical intervention (i.e., increased almond intake) were compared for the American population. All scientific substantiation information of almond heart health benefit was extracted from the peer-reviewed literature provided by ABC.

Current Status: The study found almond consumption may reduce the risk of CVD by improving blood lipids and by decreasing body weight. A systematic meta-analysis and review was conducted to generate data; a manuscript was published in September 2019 in the journal *Advances in Nutrition.* These results were then used in the cost-savings analysis, with a second manuscript submitted for publication to *The American Journal of Public Health* in late summer 2019.

Diabetes & Metabolic Syndrome

A Randomized, Crossover Trial to Assess the Effects of Replacing Refined Carbohydrates with Almonds on Insulin Sensitivity in Men and Women with pre-diabetes

Dr. Indika Edirisinghe, Illinois Institute of Technology, Center for Nutrition Research, Chicago, IL USA

Background: Insulin Resistance (IR) is the hallmark feature of an adverse cardio-metabolic risk factor profile and is associated with increased risk of developing T2D. Evidence suggests that the Western lifestyle characterized by unfavorable dietary patterns, particularly high intake of refined carbohydrate, obesity, chronic low-grade inflammation and heightened cellular oxidative stress promotes increased risk of insulin resistance and T2D. Moreover, evidence is accumulating showing that certain dietary strategies can modify insulin sensitivity.

Study Design: This two-year study aimed to test the hypothesis that replacement of foods high in refined carbohydrate (refined starches and sugars) with almonds will improve insulin sensitivity index (SI). Secondary aims were to determine the effects of almond consumption on fasting insulin sensitivity and β-cell function, fasting lipoprotein lipids: Total cholesterol, LDL-C, high- density lipoprotein cholesterol (HDL-C), non-HDL-C, total/HDL-C ratio and triglycerides, and resting, seated systolic and diastolic blood pressures.

Current Status: This is the first of three studies funded under the 2016 Chronic Glucose Regulation RFP. The clinical trial phase completed in spring 2019, with a manuscript published in the *Journal of the American College of Nutrition*. The study found significantly higher intakes of protein, fats, fiber, and magnesium resulting from almond intake, as assessed from a 3-day diet record. Intake of control treatment led to a shift towards an increased concentration of small, dense LDL subfraction, but this increase did not reach statistical significance. No significant differences were found in all other parameters assessed. The study population had a wide age range (18-69) and included smokers who were advised to continue smoking through the study. These factors may have introduced significant variability in the data.

Diet and Lifestyle Intervention Strategies to Treat β-Cell Dysfunction and Insulin Resistance in Asian Indians

Dr. Jeannie Tay, Singapore Institute for Clinical Sciences, A*STAR, Singapore

Background: Asian Indians have a 2-4-fold greater type 2 diabetes (T2D) risk and develop diabetes 5-10 years younger than Caucasians. In Singapore, Indians have the highest prevalence of T2D and exhibit the greatest insulin resistance compared to Malays and Chinese. Abnormalities in glucose homeostasis, in the absence of obesity and advanced age, are prevalent among Indians, indicating a possible genetic predisposition to greater insulin resistance and reduced β-cell function. Accompanying this insulin resistant metabolic phenotype is a body composition characterized by preferential accumulation of abdominal and ectopic adiposity and deficit of peripheral fat.

Study Design: This three-year, parallel arm, randomized controlled trial aims to determine the differences in the following outcomes in subjects on a low glycemic diet (that includes almonds) vs. those on a control diet: Primary outcomes include: Beta-cell response and insulin sensitivity. Secondary outcomes include: Body fat distribution, body composition, genotyping analyses to assess genetic risk score comprising 53 genetic variants representative of an insulin resistance

phenotype, and biochemical measures such as glucose, insulin, C-peptide, total cholesterol, HDL-C, TAG, markers of inflammation (CRP, IL6, and TNF-alpha) and satiety hormones (leptin, ghrelin, peptide YY, gastric inhibitory polypeptide, and glucagon-like peptide 1.

Current Status: This study is ongoing, with completion expected in July 2022.

ALMOND ONLY: Prevention of Progression to Type 2 Diabetes in Women with Gestational Diabetes: A Feasibility Study for a Randomized Trial on a Mediterranean Diet (MERIT)

Dr. Shakila Thangaratinam, Queen Mary University of London, London UK

Background: The proportion of women diagnosed with diabetes in pregnancy, known as gestational diabetes (GDM), is on the increase. Up to 50% of those affected will progress to type 2 diabetes (T2D) in the next five years. The ESTEEM study (effect of Mediterranean diet on pregnant women with metabolic risk factors on pregnancy outcomes) also conducted by the same research group, (3442 women, 1252 randomized) showed that it is feasible to deliver an intervention using a healthy dietary pattern associated with lower T2D risk. Despite the apparent need and desire from women for more health promotion, it has been widely reported in several studies that there is a lack of engagement in the postnatal period as many mothers do not attend routine appointments due to lack of childcare and time and geographical barriers. As part of the MERIT study this concern was considered by providing access and support to dietary advice and information through a mobile app.

Study Design: The primary objective of this 18-month study is to assess the feasibility of recruitment, and the adherence to a Mediterranean dietary intervention, after childbirth for women with previous gestational diabetes. Secondary objectives are to: determine the factors associated with the acceptability of and adherence to the Mediterranean diet; examine reasons for participation and non-participation, trial attrition, and non-adherence; to determine preliminary estimates on glycaemic effects to inform definitive trial; determine the level of and factors relating to adherence with the study protocol with healthcare professionals; establish the support required in hospitals to ensure successful recruitment and delivery of the intervention.

Current Status: ABC provided almonds for this 21-month study. Project completion and manuscript submission are expected September 2020.

Effect of Almond Supplementation in Overweight Indian Adults on Insulin Resistance, Glycemic Markers, Inflammation and Satiety

Ms. Sudha Vasudevan, Madras Diabetes Research Foundation, Chennai, India

Background: Southeast Asia is one of the epicenters of the diabetes epidemic. India alone has nearly 70 million with diabetes and 80 million with pre-diabetes. The higher prevalence of diabetes and insulin resistance among Indians is partly due to the Asian Indian phenotype and thrifty genotype characterized by metabolic abnormalities such as insulin resistance, abdominal obesity, glucose intolerance, lower adiponectin and increased levels of high sensitivity C-reactive proteins. These combined with altered lifestyles (poor dietary practices including low consumption of nuts) are one of the key drivers of escalating prevalence of obesity further fueling the diabetes epidemic in India.

Study Design: This three year, randomized, controlled, two-arm study aims to determine the

effects of almond supplementation on 1) insulin resistance (HOMA IR) and beta cell dysfunction, 2) biomarkers of glucose metabolism (i.e. fasting glucose and HbA1c), lipid profile (triglycerides, total cholesterol, LDL-C, and HDL-C), plasma fatty acid profile, satiety related gut hormones and selected inflammatory markers (hs-CRP, TNF alpha, MCP-1).

Current Status: This ongoing study is the first of three studies funded under the 2017 India Glucose Regulation Request for Proposals (RFP). Study completion and manuscript submission are expected by December 2020.

Evaluation of Pre-Meal and Bedtime Load of Raw Almonds on Postprandial Hyperglycemia and Other Metabolic Responses in Asian Indians with Prediabetes

Dr. Anoop Misra, Diabetes Foundation of India, New Delhi, India

Background: Type 2 diabetes (T2D) is rapidly increasing in India due to multiple factors; predominant among them are dietary and lifestyle transitions. As of June 2017, there were 6 studies in which the effect of almond consumption on postprandial hyperglycemia (PPHG) had been researched. However, none had been carried out on Asian Indians/South Asians.

Study Design: This three-year study hypothesized that dietary intervention with almonds (60g per day, 20 g before breakfast, lunch and dinner) may decrease the glucose and insulin excursions after meals, and thus reduce overall hyperglycemia. The primary objective of the study is to evaluate the effect of a preload of 20g of raw almonds to major meals on postprandial glucose levels in Asian Indians with prediabetes. Secondary objectives include measuring overall glycemia (HbA1c), 3-day continuous glucose monitoring system (CGMS), serum insulin, GLP-1, free fatty acids, triglycerides, HOMA-IR, tumor necrosis factor alpha, glucagon, pro-insulin, and satiety. Effect of a single preload of almonds is being evaluated with oral glucose tolerance test as part of an acute study. A three-day almond preload, monitored with CGMS, will be evaluated as part of a sub-acute study, and a 90-day almond intervention with self-monitoring of blood glucose and glycosylated hemoglobin is being evaluated as part of a chronic study.

Current Status: This study is the second of three studies funded under the 2017 India Glucose Regulation Request for Proposals (RFP). The clinical trial phase completion is expected by December 2020, with manuscript submission expected in March 2021.

Effect of Almond Consumption on Blood Glucose Regulation and Cardio-Metabolic Risk Factors in Adolescents and Young Adults (16-25years) with Prediabetes

Dr. Jagmeet Madan, Sir Vithaldas Thackersey College of Home Science, Mumbai, India

Background: The studies in the recent past show a rampant increase in the incidence of prediabetes and insulin resistance in adolescents and young adults across the globe. The present data from India shows a large increase in the adolescent and young adult population of pre- diabetes and those with two or more markers of metabolic syndrome. There is a felt need to emphasize on food-based approaches towards the intervention for these concerns. A dietary approach to arrest the damage early caused by these chronic non communicable diseases is of immense significance in present context. The review of literature exhibits a lacunae on the study of almond consumption on blood glucose regulation and cardio-metabolic risk factors especially in this population as majority of the published data is in adult population.

Study Design: This two year, randomized parallel group design study aimed to determine the

effect of almond consumption on the blood glucose regulation and cardio metabolic risk factors in adolescents & young adults (16-25 years) by studying markers (Baseline and stimulated insulin and other metabolic indices, pro- & anti- inflammatory cytokines, markers of oxidant damage and antioxidants) suffering from prediabetes. The primary outcome was an improvement in prediabetic state - Improvement in fasting blood glucose or 2 hourly blood glucose level. Secondary outcomes included an improvement in insulin sensitivity, lipid profile, and Quality of Life & reduction in oxidized LDL and inflammatory markers.

Current Status: This study is the third of three studies funded under the 2017 India Glucose Regulation Request for Proposals (RFP). The clinical trial phase of the study is complete, with data analysis ongoing. The study results are expected to be presented at the American Society of Nutrition (ASN) 2020 conference (Seattle, WA) June 2020 or diabetes Nutrition Study Group (DNSG) 2020 (Reus, Spain).

Understanding the Mechanism of Long-Term Almond Consumption on Chronic Glucose Regulation and its Translation into Improved Vascular Function and Cognitive Performance: The ALL-INCLUSIVE Trial

Dr. Jogchum Plat, Maastricht University Medical Center, Maastricht, Netherlands

Background: Globally, the number of subjects with type 2 diabetes (T2DM) is rising, largely driven by the obesity epidemic. A good glycemic control is relevant, in particular for the prevention of microvascular complications of T2DM and there is a vast amount of evidence to support a benefit on a reduction in cardiovascular events on the long-term. In addition, accumulating evidence links T2DM to accelerated cognitive decline. Almond consumption is associated with ameliorations in various factors associated with CVD risk such as hyperglycemia, hyperlipidemia, and hypertension. The question is whether these effects are sustainable over longer time. An additional question is how the protective effects on glycemic control and CVD risk can be explained mechanistically.

Study Design: This study is a four-year, long-term randomized well-controlled intervention trial with a cross-over design, including 34 overweight and obese (BMI<35 kg/m2) men and women with impaired glucose tolerance (IGT). During the intervention period of 5 months, subjects receive daily 50g almonds but not in the 2 months wash out and 5 months control periods. This study aims to: examine and understand the impact of long-term almond consumption on chronic glucose regulation in subjects with impaired glucose tolerance; determine whether improved chronic glucose metabolism after long-term almond consumption translate into improved peripheral & brain vascular function and enhanced cognitive performance.

Current Status: This is the second of three studies funded under the 2016 Chronic Glucose Regulation RFP. This study is ongoing; recruitment is almost complete. The clinical phase is expected to complete in summer 2021, with project completion and manuscript submission by December 2021. The study protocol was presented at DNSG 2019 conference in the Netherlands.

The Role of Almonds Consumed as a Breakfast and Snack by Adults with Different Body Fat Distributions on Indices of Carbohydrate and Lipid Metabolism

Dr. Richard Mattes, Purdue University, Department of Foods and Nutrition, W. Lafayette, IN USA

Background: There is considerable evidence supporting a causal role for truncal visceral fat depots contributing to glucose dysregulation. Individuals with large visceral fat depots have impaired suppression of Free Fatty Acid (FFA) release in response to insulin, elevated triglycerides and low concentrations of high-density lipoprotein cholesterol. The high FFA concentration may induce insulin resistance in muscle and liver. There is more recent evidence that truncal subcutaneous fat depots are also problematic, though this literature is mixed. In contrast gluteo-femoral fat depots have not been implicated in insulin resistance and dysregulation of carbohydrate metabolism. Failure to account for differences in the contributions of these depots can add noise to measurements of dietary interventions to mitigate glucose dysregulation. This study proposed a six-month trial to contrast the effects of almond consumption at optimal times of the day versus no nut consumption on indices of carbohydrate metabolism, food intake and appetite in adults characterized by discrepant fat depots.

Study Design: The primary specific aims of this two year project are to: 1. Determine the acute effect of almond consumption on the glycemic and lipemic response to a meal tolerance test in adults with body fat depots associated with different risks of insulin resistance and onset of diabetes; 2. Determine the chronic effect of almond consumption on fasting glucose and insulin, HbA1c, triglycerides, total cholesterol, LDL-cholesterol, HDL-cholesterol, bodyweight, body composition, GLP-1 and C-peptide concentrations and calculated HOMA-IR & HOMA%B in adults with body fat depots associated with different risks of insulin resistance and onset of diabetes.

Current Status: This is the third of three studies funded under the 2016 Chronic Glucose Regulation RFP. The study is nearing completion, and the clinical trial phase will end in December 2019. A manuscript is expected in Spring 2020. Results may be presented at ASN 2020.

The Impact of Almond Nut Consumption on Emerging Markers of Cardiovascular and Metabolic Disease

Dr. Sarah Berry, Kings College London, Division of Life Sciences, London, UK

Background: Morbidity from cardiovascular disease (CVD) and type II diabetes (T2D) is increasing, at huge cost to quality of life and national economies. Snack choices are one particular area of diet and lifestyle modification with a potential to positively influence the cardiometabolic risks. There is increasing evidence to demonstrate that the accumulation of liver, pancreatic and visceral fat is a causative factor in the development of cardio-metabolic disorders; however, the effect of almonds on this novel outcome has not been investigated. This research brought together experts in vascular physiology, imaging and human nutrition using robust trial methodology to address this gap in the evidence base for the cardio- metabolic health effects of almonds.

Study Design: This three-year study aimed to address current gaps in the evidence base specific to almonds and risk of cardio- metabolic diseases. It was conducted in two parts: Part A was a randomized, controlled, parallel dietary intervention to investigate the cardio-metabolic

health benefits of regular almond snacking in 30-70y men and women (n=100) at increased cardio-metabolic disease risk; and Part B was an observational study, with two aims: investigate dietary consumption of nuts, in particular almonds, in a national dietary survey (n=4,156) in the UK using the NDNS; associate nut consumption with markers of CVD/T2D risk, including BMI, waist circumference, blood lipids (HDL cholesterol, triacylglycerols (TAG)), blood pressure (BP) and C-reactive protein (CRP). Primary outcome variables included endothelium-dependent vasodilation (EDV) as measured by flow-mediated dilation (FMD) and liver fat as measured by magnetic resonance imaging (MRI). Secondary outcome variables included body weight/composition, pancreatic & visceral fat, lipids, parameters of gluco-regulatory capacity, adipokines, 24h heart rate variability and 24h ambulatory blood pressure.

Current Status: The clinical trial phase of this three-year study completed in summer 2019, with data analysis completion expected by fall 2019. Conference presentations included the DNSG conference June 2019 in Kerkrade, the Netherlands, and the FENS Conference, October 2019 in Dublin, Ireland. Results indicate that snacking on whole almonds as a replacement for snacks high in refined starch and sugar, and low in fiber and unsaturated fatty acids, improves endothelial function. The results of this study provide further evidence for the importance of nuts in dietary strategies to reduce risk of cardiovascular disease. A manuscript is expected in spring 2020.

Weight Management, Satiety & Gut Health

Effects of Almond Consumption on the Gastrointestinal Microbiota and Postprandial Glucose Handling in Adults with Overweight and Obesity

Dr. Hannah Holscher, University of Illinois at Urbana-Champaign, Urbana, IL USA

Background: Dietary patterns rich in nuts are protective against obesity and type 2 diabetes. Almonds are important sources of nutrients, including fiver and unsaturated fatty acids. Dietary fiber can be metabolized by GI microbes and promote robust microbial communities and production of butyrate, which is beneficial for gut health and improvement of gut barrier function. The beneficial attributes of almond consumption on gut microbiota, glucose tolerance, and adiposity have been demonstrated in isolation; however, there is a key gap in scientific understanding of the microbial and molecular underpinnings. This study aims to determine whether almond consumption improves gut health by increasing *Roseburia spp*. and butyrate concentration, and decreasing microbial production of secondary bile acids, which in turn will reduce postprandial inflammation with subsequent reduction in hepatic steatosis and improvements in whole-body insulin sensitivity.

Study Design: The study is a randomized, controlled, parallel arm design. Study participants (n=84; 42/arm), overweight and obesity adults between 30-60 years of age will consume either 2oz/d of roasted almonds or 3oz/d of pretzels for 12 weeks. The primary aim of the study is to determine the impact of almond consumption on GI microbiota. The secondary aim is to determine the effects of almond consumption on oral glucose tolerance and hepatic steatosis using measure of gut health including pH, microbial fermentation end product, microbial-derived bile acids, and alpha- and beta-diversity. The study will also assess gut health measures, including self-reported bloating, flatulence, regularity, and stool consistency.

Current Status: This is the second of two studies funded under the 2017 Gut Health RFP. This study is ongoing, with completion expected in July 2021, and manuscript submission expected by Fall 2021.

Effects of Almond Snacking on Cardiovascular, Metabolomic, and Microbiome Profiles in Millennials: Implications on Systemic Glucoregulatory Mechanisms

Dr. Rudy Ortiz, University of California Merced, School of Natural Sciences, Merced, CA USA

Background: The nutritional independence associated with going away to college has been associated with the phenomenon, "Freshman 15", which refers to weight gain due to transition to college life. Increased prevalence of overweight and obesity is greatest in 18-29 year olds, especially among those reporting some college education. A review of the literature supports the conclusion that nut consumption helps ameliorate. Although studies on nut consumption and health have been performed on adults (median age +40 years), no data exist on the potential benefits of almonds in ameliorating metabolic disorders such as cardiovascular disease (CVD) and type 2 diabetes mellitus (T2DM) in adolescents. Therefore, this study proposed to address these knowledge gaps.

Study Design: This two year study aimed to compare the effects of 8 week consumption of 2 oz/day of almonds in 40 (18-29 yrs.) breakfast "skippers" on metabolomic and lipidomic profiles in relation to the gut microbiome in newly enrolled college students in either a low or high risk category for metabolic disorders. The researchers examined metabolomic and lipidomic profiles in relation to the gut microbiome, and glucoregulatory mechanisms. Researchers then created viable models to predict the biological pathways and mechanisms being altered. Subjects categorized as either low glucose tolerant, higher risk for metabolic derangement (low/high) or good glucose tolerant, lower risk for metabolic derangement (good/low), using fasting measurements at the study onset, were assigned to one of four study groups: good/low + isocaloric control snack, good/low + almond snack (2oz/d), low/high + isocaloric control snack, and low/high + almond snack.

Current Status: Researchers found that incorporating a morning snack of almonds in the dietary regimen of predominantly breakfast-skipping, first-year college students had beneficial effects on glucoregulatory and cardiometabolic health. To date, three manuscripts have been published: the first highlighted food options of minority college students in the journal *Nutrients* in 2018; the second highlighted almonds effects on student microbiome, in the journal *Current Developments in Nutrition* in 2019; the third highlighted the effects of almond consumption on the glucoregulatory and cardiometabolic profiles of students in the journal *Nutrients* in 2019. The results were also presented at the Mexican Congress of Cardiology conference in November 2019.

Impact of Almond Supplementation, Relative to a Low-Fat, High Carbohydrate Control, on Body Composition in Overweight and Obese Black and Hispanic Adults

Dr. Marie-Pierre St-Onge, St. Luke's-Roosevelt Hospital Center, St. Luke's-Roosevelt Hospital Center, New York, NY USA

Background: Epidemiological studies, such as the recently published data from the Adventist Health Study-2, show that individuals who consume more tree nuts have lower odds of obesity and metabolic syndrome than those who are low tree nut consumers. Results from recent clinical

studies, such as the PREDIMED study, show that increasing nut consumption as part of a Mediterranean diet leads to lower cardiovascular events and deaths from cardiovascular causes than adhering to a low-fat diet. However, these studies have mostly been conducted in Caucasians. Yet, African Americans and Hispanics are at disproportionately high risk of CVD and T2D and could benefit from consumption of almonds. Compared to Caucasians, African Americans have 1.3 times greater rate of death attributable to heart disease. It is of interest to note that those at highest risk of chronic metabolic disorders, African Americans and Hispanics, are also those with the lowest intake of nuts/seeds.

Study Design: This three-year, randomized, controlled pilot study examined whether almonds 1.5 oz - 2.5 oz. daily dose (dependent on body weight), consumed within the context of a weight loss diet, improve body composition and liver fat, relative to a low-fat/high-carbohydrate (LF-HC) cereal bar in overweight and obese African Americans and Hispanics. The objectives were to determine whether almond consumption, within the context of a weight loss diet, will lead to greater loss of adipose tissue, particularly visceral adipose tissue, and liver fat compared to a LF-HC control, and whether weight loss that includes almond consumption for 24 weeks will result in lower total and low-density lipoprotein cholesterol and triglycerides, higher high-density lipoprotein cholesterol, lower glucose and insulin, and lower levels of inflammatory markers than a diet that includes a LF-HC control.

Current Status: Researchers found that while daily almond intake for 24 weeks did not induce profound body composition changes, it did affect overall satiety and ectopic fat deposition. A manuscript is currently under review. Study results were featured/presented at FENS 2019 (Dublin, Ireland).

Almonds and Satiety: A Randomized Intervention Trial Examining Acute and Chronic Effects.

Dr. Nancy Keim, USDA ARS Western Human Nutrition Research Center, Davis, CA USA

Background: In the U.S. there is a widespread “permissive” food environment that may be a contributing factor to the high prevalence of obesity. It is plausible that the habit of consuming unhealthy snacks may contribute to overeating and energy surplus. Current models depicting appetite regulation involve both physiological signals and psychological/cognitive influences, while satiety signals, consisting of physical and psychological components, are primary drivers of food intake regulation. Satiety has both physical and psychological components; the former driven by physiological and the latter largely driven by hedonic cues. This study aims to assess satiety outcomes based on almond consumption.

Study Design: This is an 18-month study with a randomized design. The almond intervention is provided in the form of snack-packs of roasted, lightly salted almonds, 56 g/day. The control group receives isocaloric snacks provided in the form of a mixture of dry cereal, pretzels, and bread sticks similar to cereal party mix. Primary outcomes include identifying short term satiety signals in a controlled laboratory test – ghrelin, CCK, PYY, insulin, leptin, endocannabinoids and buffet food intake before and after the intervention. Secondary outcomes include identifying long term food intake behavior associated with changing satiety profile – energy compensation between almond vs snack as well as variability based on polygenic risk score of Single Nucleotide Polymorphisms (SNPs).

Current Status: This study is ongoing. Study completion and manuscript submission are expected in early summer 2020.

Effects of Consuming Almonds on Body Weight Management and Satiety

Dr. Rachel Brown, University of Otago, Dunedin, New Zealand

Background: Cross-sectional studies have found that nut consumers are leaner than non-nut consumers. Several intervention studies have found no evidence of weight gain in the short-term following the addition of nuts to the diet. However, there is a lack of longer-term studies (at least one year) to assess the effects of almonds on body weight as the primary outcome.

Study Design: This 30-month study examines the long-term effects of consuming almonds on body weight management and satiety. The primary aim of this study is to compare the effects of consuming whole almonds with plain biscuits (as a comparison snack) on body weight and composition, and satiety among healthy adults over a 12-month period. Secondary aims include investigating the effects on blood lipids and lipoproteins, dietary intake and energy compensation, resting metabolic rate, blood pressure, arterial stiffness, inflammation, endothelial function, glycated hemoglobin, Vitamin E, and consumer acceptance. The study also investigates the acute effects of whole almond consumption on total energy intake, satiety and glycemic response. Since physical activity levels may influence study outcomes, changes in physical activity is measured at baseline, 3, 6, and 12 months for 7 continuous days each time, using a blinded accelerometer.

Current Status: This is the first of two studies funded under the 2018 Weight Management & Satiety RFP. The clinical trial phase is currently underway, with project completion and manuscript submission expected in October 2020.

Does Inclusion of Almonds in an Energy Restricted Diet Enhance Weight Loss and Protect Against Weight Regain?

Dr. Alison Coates, University of South Australia, Adelaide, South Australia

Background: While many studies have demonstrated weight loss can be achieved through dietary energy restriction, most individuals are unable to maintain the weight-loss, with 80% regaining weight within the first year and less than 5% being able to sustain weight loss over the longer term. This might be in part due to the removal of professional support after initial weight loss. In the absence of such support, the inclusion of foods that promote satiety may assist in preventing weight regain. The nutrient profile of almonds, which are rich in monounsaturated fats, protein and fiber, may assist with weight maintenance through increased satiety. Currently, data are lacking on the role of almonds in weight control diets to limit weight regain. This study will provide evidence of whether regular snacking on almonds can help sustain satiety and limit consumption of excess calories.

Study Design: This three-year study proposes a 9-month randomized, controlled parallel-arm dietary intervention, comprising a 3-month energy restriction phase (~30% energy deficit to induce weight loss) followed by a 6-month weight maintenance phase with maintenance of physical activity and lifestyle habits. Overweight/obese adults (BMI: 27.5-39.9) aged 25-65y, who have been weight stable for 3 months prior to study start are randomized to an almond enriched diet or a carb-rich snack diet. Primary outcomes focus on changes in weight management and

appetite regulation and assess weight, height, BMI, waist circumference, body composition, acute appetite pre-test meal and then every 30 mins for 2 hrs., gut hormones; subjective ratings of hunger, fullness and appetite, energy intake and chronic food cravings and liking. Second outcomes include total body fat mass, total body fat free mass and truncal fat and fat free mass, and visceral adipose tissue. Regular physical activity at moderate to vigorous levels is encouraged.

Current Status: This is the second of two studies funded under the 2018 Weight Management & Satiety RFP. This study is ongoing, with study completion expected in June 2021, and manuscript submission expected by Fall 2021.

ALMOND ONLY: Effect of Almond Consumption on GERD in Veteran Subjects

Dr. Heidi Silver, Vanderbilt University School of Medicine, Vanderbilt Center for Human Nutrition, Nashville, TN USA

Background: Gastro-esophageal reflux disease (GERD) occurs in 25-30% of U.S. adults, including veterans, and the prevalence of GERD is increasing. The VA spends >$177 million yearly on outpatient prescriptions for GERD. Higher body mass index (BMI) is associated with increased risk for GERD, and the increasing prevalence of GERD is likely related to the obesity epidemic. The American Gastroenterology Association guidelines advise weight loss for overweight/obese people with GERD.

Study Design: This three year randomized controlled study aims: to determine effects of the consumption of dry roasted almonds as part of a low carbohydrate diet on percent time with esophageal pH < 4.0, as well as number of reflux episodes, GERD symptoms and GERD medication use, in 200 obese veterans who have chronic high frequency of GERD symptoms; and to assess associations between GERD resolution variables and factors related to potential mechanisms by which modifying dietary carbohydrate intake could resolve/reduce GERD in obese veterans.

Current Status: ABC supplied dry roasted almonds for this study. Study completion and manuscript submission expected in July 2020.

Almonds and Their Impact on Gastrointestinal Physiology, Microbiology and Function: Phase 1

Dr. Kevin Whelan, Kings College London, Diabetes and Nutritional Sciences, London, UK

Background: Constipation is a common bothersome alteration of normal gut physiology and function that affects 14% of the population. The research group's previous research has shown fiber (administered as a supplement, not within a food matrix) significantly increases *Bifidobacteria* concentrations in adults with functional constipation and improves stool frequency and consistency. Almonds are commonly consumed as snacks. Their intake has been associated with several health benefits, including reducing risk factors for cardiovascular disease and type 2 diabetes. The researchers hypothesized that almonds would be a low-cost approach for optimizing gut health due to the high fiber content, prebiotic effect on the gut microbiota, and low bio-accessible fat content.

Study Design: This two-year study aimed to determine whether 28g twice/day of whole and ground natural unroasted almonds improved gut health in 80 healthy men/women, 18-65 yrs. with sub-optimal gut function. Researchers utilized a comprehensive range of state-of-the-art

technologies to assess a broad range of outcome measures including the wireless gastrointestinal motility capsule (SmartPill) to inform mechanisms of action.

Current Status: This is the first of two studies funded under the 2017 Gut Health RFP. This study is ongoing, with study completion expected in June 2021, and manuscript submission expected by Fall 2021. The clinical trial phase of the study is complete, with data analysis and manuscript submission expected by April 2020.

Composition - Content and Action

Understanding the Fate of Almond Oleosomes During Simulated Human Digestion
Dr. Giusy Mandalari, University of Messina, Messina, Italy

Background: Almond lipids (fats), about 55% of the nut weight, are stored in oil bodies (OB) called oleosomes, which are lipid droplets surrounded by a monolayer of phospholipids embedding proteins. These proteins are mainly oleosins with low molecular weight. Their unique structure stabilizes and protects the oil bodies from damage. In addition to a stabilizing role, oleosins are possible receptors for lipase binding during seed germination and consequently may play a key role interacting with human gastrointestinal enzymes. In a previous study, researchers showed that in natural raw almonds, lipid is evenly distributed and is located in oleosomes surrounding the protein bodies. Individual undamaged cells containing lipid still within oleosomes were identified in chewed whole raw samples. In the faecal samples of volunteers fed whole raw almonds (provided by USDA), the lipid content of the cells at the periphery of the almond particles was in the form of large drops, though it was not possible to observe whether the lipid in the innermost cells of the larger particles was still within oleosomes.

Study Design: This 16-month study aims to investigate the nature of almond oleosomes, their functionality during digestion, and whether their integrity is maintained during passage through the gastrointestinal (GI) tract. Almond oleosomes were quantified by laboratory analysis. Researchers also investigated the fate of almond oleosomes after simulated GI digestion using previously developed methodologies to simulate the conditions found in the human stomach and small intestine.

Current Status: Results indicate that the unique structure of almonds is a factor in regulating bioaccessibility of lipid (fat) and other bioactives in the gut. Results were presented at the FENS 2019 (Dublin, Ireland), with a manuscript expected by early 2020.

Cognition

Does 12 Weeks of Eating Unsalted Raw Almonds Improve Cognitive Performance in Adults
Dr. Alison Coates, University of South Australia, Adelaide, South Australia

Background: Improving cognitive function in middle-aged and older adults can protect against subsequent cognitive decline and dementia. Researchers have recently hypothesized that nuts can improve vascular health and cognitive function through a range of mechanisms due to their nutrient and phytochemical profiles. Cardiovascular disease (CVD) risk factors are associated with diminished cognitive functioning and an increase in dementia, while peripheral arterial disease has been associated with increased cognitive decline. There is emerging literature to support nuts being associated with enhanced cognitive function or reduced cognitive decline.

However, while there is substantial evidence of beneficial effects of nuts on cognitive function from prospective cohort studies, there is a scarcity of evidence from randomized controlled trials which are the best source of direct high-level evidence.

Study Design: This four-year, 12 week randomized, controlled parallel study aimed to investigate the effects of almonds on cognitive function. 150 free-living non-habitual nut eaters (40-75 yrs.) were randomized to consume either raw, unsalted almonds or an isocaloric snack food daily for 12 weeks. The primary aim was to investigate the effects of eating these foods on major cognitive domains (attention/concentration, executive function, working memory, secondary memory, spatial memory). Secondary aims were to explore potential cardiovascular, metabolic and inflammatory mechanisms underpinning cognitive enhancement following 12 weeks of consumption.

Current Status: This is the first of two studies funded under the 2014 Cognition RFP. The clinical trial phase of the study is complete, and data analysis is ongoing. Preliminary results indicate that the inclusion of almonds in the diet has the ability to improve aspects of cardiometabolic health and mood in overweight/obese adults but did not show a change in cognitive performance. Preliminary results were presented at FENS 2019 (Dublin, Ireland), with a manuscript expected by early 2020.

The Effect of Almonds on Cognitive Function in Older Adults

Dr. Elizabeth Johnson, Tufts University, USDA Human Nutrition Research Center on Aging, Boston, MA USA

Background: As of 2015, an intervention study that evaluated the effect of monounsaturated fatty acids (MUFA's) or magnesium, let alone almonds, on age-related memory loss had not yet been conducted. The results from studies involving vitamin E interventions have not been consistent, possibly due to designs that did not target populations with low vitamin E status. This study proposed to evaluate a 6 month almond intervention as a treatment strategy for age-related cognitive impairment which could possibly prevent the onset of dementia by increasing MUFA, α-tocopherol (vitamin E), and magnesium status, as well as fiber intake, through a modest dietary intervention that includes almonds.

Study Design: The study aimed to determine the long-term effect of consuming 60 g/d of almonds for 6 months on cognition in adults (>50 y) by testing attention, memory, language and executive function. Other aims were to determine whether change in serum fatty acids, tocopherols, and magnesium were predictive of the relative effectiveness (improvement in cognitive function measures) of almond consumption; determine biomarkers of inflammation and oxidative stress. Expected outcomes included a significant increase in cognitive measures for attention, memory, language and executive function in the almond group at the end of 6 months, as well as significant increases in plasma MUFA, α-tocopherol, and magnesium concentrations at 6 months.

Current Status: This is the second of two studies funded under the 2014 Cognition RFP. The clinical trial phase completed in summer 2019. Preliminary results suggest that an almond intervention can be a dietary strategy for age-related cognitive health which could possibly prevent the onset of dementia by increasing MUFA, α-tocopherol, and magnesium statuses, as

well as fiber intake, through a modest dietary intervention that includes almonds. Manuscript submission is expected in early 2020.

Allergens

Demographic, Clinical and Diagnostic Correlation of Almond Allergy in a Large Cohort of Nut Allergy Patients

Dr. Inderpal Randhawa, Translational Pulmonary and Immunology Research Center, Long Beach, CA USA

Background: Food allergy is a major public health condition, impacting approximately 8% of US children. The most common food allergens which elicit IgE-mediated reactions include milk, egg, peanut, tree nuts, wheat, soy, fish and shellfish. While peanut allergy is the most common cause of anaphylaxis in children presenting to the emergency department, as well as the most common cause of fatal food anaphylaxis, almost no data is reported on incidence of prevalence of almond allergy. Due to the anxieties associated with the potentially fatal consequences of inadvertently consuming allergens, peanut and tree nut allergic individuals are often advised to avoid all nuts, including almonds. Due to the high cross reactivity of almonds and tree nuts, reports focus on cross sensitivity of antibodies and cross reactivity of species proteins.

Study Design: This one-year data mining and analysis exercise aimed to describe and evaluate the correlation of almond allergy specific to demographic, clinical and diagnostic markers in a group of 300 nut allergic children. Analysis was conducted to determine the following primary outcomes: for almond allergen, the predictive correlation between grade of anaphylaxis and skin test; for almond allergen, the predictive correlation between grade of anaphylaxis and immunocap specific IgE; the correlation of positive almond skin test to skin test sensitization of other tree nuts and peanut; the correlation of positive almond immunocap specific IgE to specific IgE of other tree nuts and peanut.

Current Status: Project completion and manuscript submission expected by early 2020.

Other Areas

The Efficacy of Almonds for Skin Inflammation, Aging and Radiance

Dr. Zhaoping Li, University of California, Los Angeles, Los Angeles, CA USA

Background: Ultraviolet (UV) radiation is one of the causative factors of DNA damage and inflammatory responses. The damage of the extracellular matrix (ECM) integrity in skin tissues is responsible for the blister formation and skin wrinkles indicative of photoaging. Almond's phenolic compounds exhibit potential protection against UV radiation suggesting a preventive role against photoaging and photocarcinogenesis. However, skin related anti-oxidative and anti-inflammatory properties of almond consumption have not been clinically investigated.

Study Design: This one-year study is a randomized, parallel group comparing the consumption of 1 serving of almonds vs. isocaloric pretzels in 40, aging 35-50y, Asian females in good health with Fitzpatrick skin type 2-4. The primary objective of the study is to determine the effect of almonds consumption on skin inflammation and aging by assessing UV-induced change. The secondary objective of the study is to assess skin biological characteristics like radiance, elasticity, sebum, hydration/moisture.

Current Status: The clinical trial phase began in summer 2019, with completion and manuscript submission expected in summer 2020.

ALMOND ONLY: Low glycemic index diet, exercise and Vitamin D to reduce breast cancer recurrence (DEDIDA): Design of a clinical trial

Dr. Livia Augustin, NCI Naples, Naples, Italy

Background: Mechanisms influencing breast cancer (BC) development and recurrence include hyperglycemia, hyperinsulinemia, high insulin-like growth factor-1, high circulating estrogen, inflammation and impaired cellular differentiation/apoptosis. Low glycemic index (GI) foods produce lower post-prandial glucose and insulin responses and have been associated with lower BC risk. Moderate physical activity post-diagnosis reduces BC recurrence and mortality, partly explained by reduced insulin and estrogen levels. Vitamin D increases cell differentiation/apoptosis and high serum vitamin D levels improve BC survival. Yet no trial has evaluated the combined effect of a low GI diet, moderate physical activity and vitamin D supplementation on BC recurrence in the context of a Mediterranean lifestyle setting which includes almonds.

Study Design: This six-year study aims to follow women (30-74 yr.) who had undergone surgery for breast cancer within the previous 12 months, in three cancer centers in Italy. Subjects were randomized to follow, for a maximum of 33 months, either a high intensity treatment (HIT) composed of low GI diet (including an ounce of almonds per day) + exercise + vitamin D (60 ng/mL serum concentration) or a lower intensity treatment (LITE) with general advice to follow a healthy diet and exercise pattern + vitamin D to avoid insufficiency. Both interventions are
against a background of a Mediterranean diet. Clinic visits will be scheduled every 3 months. Dietary and exercise counseling and vitamin D supplements will be given at each clinic visit when blood samples, anthropometric measures and 7- day food records will be collected.

Current Status: The clinical trial phase of the study is ongoing. Study completion and manuscript submission are expected in December 2024. ABC contributed almonds to this study.

The Effect of Almonds on Wrinkles and Modulation of the Microbiome and Lipidome

Dr. Raja Sivamani, University of California Davis, Sacramento, CA USA

Background: The natural cosmetic market is a multi-billion-dollar industry. Nutraceuticals and food-based cosmetics are a growing trend within dermatology. Almonds are a rich dietary source of a range of fatty acids, phytochemical polyphenols, and antioxidants. A recently completed double blinded pilot study compared almond interventions to a calorie matched intervention over 16 weeks determined that that there was a statistically significant 8.41% improvement in wrinkle severity in the women that received almond supplementation. This proposal is to study additional outcomes to examine the effect of almond consumption on wrinkles, the gut microbiome, and skin lipidome.

Study Design: This two year study hypothesizes that regular consumption of almonds (20% of energy intake) will improve the facial wrinkle severity in post-menopausal women of Fitzpatrick skin types 1 and 2, improve the evenness of facial skin pigmentation (secondary objective), diversify the gut microbiome and increase the short chain fatty acids in the blood, and improve

the skin barrier biophysical properties.

Current Status: The clinical trial phase of this study is ongoing, with completion and manuscript submission expected in May 2020.

Nutrition Research
Research Publications 2019

The following is a list of scientific papers published with the research partially or wholly funded by the Almond Board of California. Copies of the abstracts may be obtained by contacting the Almond Board of California.

Bowen, J., N.D. Luscombe-Marsh, W. Stonehouse, C. Tran, G.B. Rogers, N. Johnson, C.H. Thompson, G.D. Brinkworth. 2019.
Effects of almond consumption on metabolic function and liver fat in overweight and obese adults with elevated fasting blood glucose: A randomised controlled trial. Clin. Nutr. Espen 30:10-18.

Chen, O.C.-Y., P.E. Milbury, J.B. Blumberg. 2019.
Polyphenols in almond skins after blanching modulate plasma biomarkers of oxidative stress in healthy humans. *Antioxidants* 8(4):E95.

Dhillon, J., L.K. Diaz Rios, K.J. Aldaz, N. De La Cruz, E. Vu, S.A. Asghar, Q. Kuse, R.M. Ortiz. 2019.
We Don't Have a Lot of Healthy Options: Food Environment Perceptions of First-Year, Minority College Students Attending a Food Desert Campus *Nutrients* 11(4):E816-831.

Dhillon, J., Z. Li, R.M. Ortiz. 2019.
Almond Snacking for 8 Weeks Increases Alpha- Diversity of the Gastrointestinal Microbiome and Decreases Bacteroides fragilis Abundance Compared to an Isocaloric Snack in College Freshmen *Current Developments In Nutrition* 3(8):nzz079.

Foolad, N., A.R. Vaughn, I. Rybak, W.A. Burney, G.M. Chodur, J.W. Newman, F.M. Steinberg, R.K. Sivamani. 2019.
Prospective randomized controlled pilot study on the effects of almond consumption on skin lipids and wrinkles. *Phytotherapy Research.* doi: https://onlinelibrary.wiley.com/doi/full/10.1002/ptr.6495

Hollingworth, S., M. Dalton, J.E. Blundell, G. Finlayson. 2019.
Evaluation of the Influence of Raw Almonds on Appetite Control: Satiation, Satiety, Hedonics and Consumer Perceptions *Nutrients* 11(9):E2030.

House, J.D., K. Hill, J. Neufeld, A. Franczyk, M.G. Nosworthy. 2019.
Determination of the protein quality of almonds (Prunus dulcis L.) as assessed by in vitro and in vivo methodologies *Food Sci & Nutr.* 7(9):2932-2938.

Lee-Bravatti, M.A., J. Wang, E.E. Avendano, L. King, E.J. Johnson, G. Raman. 2019.
Almond consumption and risk factors for Cardiovascular Disease: A systematic review and meta-analysis of randomized controlled trials *Adv. Nutr.nmz043, https://doi.org/10.1093/advances/nmz043*

Lesser, M.N.R., K. Mauldin, L. Sawrey-Kubicek, V. Gildengorin, J.C. King. 2019.
The Type of Dietary Fat in an Isocaloric Breakfast Meal Does Not Modify Postprandial Metabolism in Overweight/Obese Pregnant Women. *Nutrients* 11(3):E490.

Musarra-Pizzo, M., G. Ginestra, A. Smeriglio, R. Pennisi, M. T. Sciortino, G. Mandalari. 2019.
The antimicrobial and antiviral activity of polyphenols from almond (Prunus dulcis L.) skin. *Nutrients* 11(10):E2355.

Palacios, O.M. K.C. Maki, D. Xiao, M.L. Wilcox, M.R. Dicklin, M. Kramer, R. Trivedi, B. Burton-Freeman, I. Edirisinghe. 2019.

Effects of Consuming Almonds on Insulin Sensitivity and Other Cardiometabolic Health Markers in Adults with Prediabetes *J Am Coll Nutr* 10(8):5174-5187.

Swackhamer, C., Z. Zhang, A.Y. Taha, G.M. Bornhorst. 2019.

Fatty acid bioaccessibility and structural breakdown from in vitro digestion of almond particles. *Food Funct* 10:5174.

Williams, P.T., N. Bergeron, S. Chiu, R.M. Krauss. 2019.

A randomized, controlled trial on the effects of almonds on lipoprotein response to a higher carbohydrate, lower fat diet in men and women with abdominal adiposity. *Lipids in Health and Disease* 18:83.

Almond Quality, Food Safety & Biomass Research Updates 2019

Quality

Assessing the Impact of In-Shell Storage on the Shelf Stability of Almonds

Dr. Ronald Pegg
University of Georgia, Athens, GA USA

A shelf-life study involving two raw almond cultivars is in progress. The cultivars used are 'Nonpareil' and 'Butte'. The almonds being tested are either inshell or shelled. For those shelled, the brown skin remains on the almonds. The inshell and shelled almond samples are being stored over time at different temperature and percent relative humidity (%RH) conditions. These include the following treatments: (25°C/70 %RH; 25°C/55 %RH; 15°C/70 %RH; 15°C/55 %RH; 10°C/65% RH; 4°C/No %RH control; ambient T in GA/No %RH control; ambient T in CA/No %RH control). Baseline data for the chemical, textural, and sensory attributes of all almond types were collected immediately upon receipt of samples to be used for comparative purposes over the course of the study.

The almonds being investigated in this study are approaching 8 months of storage. To date, all stored inshell almonds have reported lower percent free fatty acid (%FFA) values than their shelled counterparts, signifying a lesser degree of hydrolytic rancidity. Moreover, the %FFA values for all samples analyzed so far have been < 0.3 % as oleic acid. This indication of low oxidation is complimented by low PVs, which are < 0.6 meq. active O_2/kg oil for most samples. Specifically, the PV data indicate that 'Butte' almonds stored inshell are less prone to autoxidation than shelled 'Butte' almonds stored over the same period. For 'Nonpareil' almond samples, in some cases the PVs between the inshell and shelled samples were the same. This could possibly be attributed to differences in the integrity/porosity of the soft and hard inshell types of 'Nonpareil' and 'Butte' almonds, respectively. The 'reference' almond samples (both inshell and shelled for each cultivar) stored at 4°C with uncontrolled humidity (>90 %RH, as measured with a humidity datalogger), have been removed from the study following their 6-month sampling. A consumer panel (n=85) found that these samples were no longer acceptable. This is consistent with the findings from a previous study using Nonpareil kernels.

Routine physical/textural analyses of the aforementioned almonds revealed a high moisture content (relative to baseline values) and a deteriorating degree of 'hardness'. These served as the trigger for a consumer panel to evaluate the acceptability of the samples stored at 4°C. Noteworthy is that both the PVs and %FFAs of these almonds were much lower than the prescribed values by ABC for rejection.

Impact of Concealed Damage (CD) on Almond Storage, Stability and Sensory Characteristics

Dr. Alyson Mitchell
UC Davis, Davis, CA USA

Almonds can be exposed to post-harvest moisture in the field. This can lead to a brown discoloration of the kernel nutmeat after roasting and may be related an acceleration of lipid oxidation in these almonds. To address this, typical chemical markers of rancidity (i.e. peroxide value (PV), free fatty acid value (FFA), and headspace volatiles) were measured in raw almonds (control) and raw almonds exposed to 8% kernel moisture and dried to ~6% (ME) and stored under accelerated storage condition for 12 months.

The PV levels remained below the industry standard of 5 meq/kg in both ME and control almonds over 12 months of accelerated storage. The PV levels reached a maximum of 2.01 ± 0.11 mEq/kg at 5 months for the ME almonds whereas the control almonds reached a maximum of 1.39 ± 0.09 mEq/kg at 8 months. The greatest differences observed between the ME and control almonds occurred during the first 6 months of storage. Similarly, the FFA levels remained well below the industry standard of 1.5% in both ME and control almonds over 12 months of storage. The FFA levels reached a maximum value of 0.22 ± 0.01% at 8 months in the ME almonds, whereas in the control almonds a maximum of 0.13 ± 0.01% was reached at 10 months. Significant differences were observed in PV and FFA levels between treatment groups, with levels being higher in the ME almonds.

Lipid oxidation results in rancidity due to the production of volatile off-flavors (i.e. alcohols, aldehydes, ketones, and acids), which can be measured in the headspace of a sample. Herein, 53 volatile compounds were identified in the headspace of almonds, with 48 compounds being significantly different between the ME and control groups. Principal component analysis (PCA) explained 82.35% of the variability between the groups. A clear separation was observed between the control and ME almonds. The control almonds grouped in the left bottom quadrant of the PCA space. The ME between 0-3 months separated into the left top quadrant, ME almonds between 4-9 months separated into the top right quadrant and ME almonds > 10 months separated into the bottom right quadrant. The major volatiles contributing to differences in 4-6 month ME almonds include aldehydes related to lipid oxidation (e.g. henanal, heptanal, octanal) whereas ME almonds stored >10 showed higher levels of alcohols including butanol, hexanol, octanol and nonanol).

The Influence of Pasteurization Techniques on Raw Almond Storage and Quality

Dr. Alyson Mitchell
UC Davis, Davis, CA USA

California almonds can be stored as raw kernels for up to 2 years without quality changes. In 2007, it became mandatory for almond processors to pasteurize almonds in order to reduce the level of potential microbial contamination. There are two primary treatment processes used to achieve pasteurization in raw almonds, steam processing and propylene oxide (PPO) treatment. Steam processing involves a short burst of steam that treats the surface of the almond nutmeat. This process meets USDA National Organic Program (NOP) standards. The fumigant PPO, which dissipates rapidly, is also used to treat the surface of almonds for insect and microbial control. The impact of either pasteurization treatment on the storage lifetime of almonds is not studied. To address this, we measured typical chemical markers of rancidity (i.e. peroxide value (PV), free fatty acid value (FFA), and headspace volatiles) in raw (unpasteurized), steam, and PPO treated

almonds stored over 12 months of accelerated storage. Almonds were sampled monthly.

PV levels were below the industry standard of 5 mEq/kg for all treatments over all time points. PV increased slightly for all treatments over the 12 months, with values ranging from 0.31 ± 0.02 (steam at 2 months) to 1.60 ± 0.65 mEq/kg (PPO at 11 months). Free fatty acids (FFA) were also measured in all samples with no value exceeding the industry standard of 1.5% throughout the 12 months of storage. At time zero, the levels of FFAs were similar in all groups: 0.15 ± 0.02% (unpasteurized), 0.17 ± 0.00% (steam), and 0.21 ± 0.00% (PPO). Levels increase linearly with storage time in all treatment groups. FFA levels were significantly higher in the control (unpasteurized) group (0.92 ± 0.07%), as compared to the PPO (0.76 ± 0.02%), and steam treatment (0.57 ± 0.01%) groups. A 2-way ANOVA indicated that differences between the treatments were statistically significant. These data indicate that a mild thermal process such as steam pasteurization may be beneficial in decreasing lipid oxidation in stored almonds. This may be due to the steam denaturation (i.e. inactivation) of lipases involved in the hydrolysis of fatty acids from glycerol. Headspace volatiles are being measured to further understand the impact of pasteurization on raw almond quality.

Safety

Efficacy of AF36 Prevail, Timing of Application, Susceptibility of Almond Cultivars to Aflatoxigenic Aspergillus Species

Dr. Themis Michailides
UC Kearney Agricultural Research and Extension Center, Parlier, CA USA

The current objectives were to: determine the percentage of displacement of toxigenic isolates of *A. flavus* and *A. parasiticus* by the atoxigenic *A. flavus* AF36 in almond kernels; evaluate the change of the population structure of *Aspergillus* section *Flavi* from a population dominated by toxigenic strains to a population dominated by the atoxigenic AF36; evaluate the toxin production potential of the population as affected by the treatments with the atoxigenic AF36 biocontrol; evaluate the effect of treatments with the atoxigenic strain AF36 in reducing the risks of aflatoxin contamination in almonds; determine the effect of the biocontrol AF36 treatments as a source of inoculum, mainly almond mummies, for next season in an area-wide long-term management.

In the present season, with the help of ABC personnel, and almond growers including South Valley Almond, Travaille & Phippen, and Matt LaGrande, the trials were expanded to five different regions in the Central Valley. In each region, 100-acre orchards were treated with AF36 Prevail and 100 acres remained untreated as controls. Soils samples were taken from both the treated and the control orchards prior to application of the AF36 biocontrol. Soils samples will also be taken after harvest to determine the efficacy of the treatments to displace the toxigenic strains by the atoxigenic biocontrol. Four almond nut samples were taken from each applied and control orchard to determine the displacement (percentage of AF36) in the crop. Additionally, samples of normal nuts and rejects are being collected directly from the processing line to compare the levels of aflatoxin in the treated orchards with the untreated controls. Currently they are in the process of collecting and analyzing samples for both the fungi and the aflatoxin content.

Survival of Inoculated Generic *Escherichia coli* on Developing Almonds Between Fruit Set and Harvest

Dr. Linda Harris
UC Davis, Davis, CA USA

The impact of using contaminated water for crop protection sprays applied to developing almonds was evaluated. A cocktail of three non-pathogenic rifampicin-resistant *Escherichia coli* (validated environmental surrogates) were applied to developing Nonpareil almonds on July 22nd and August 12th, 2019 (different trees in the same orchard) targeting an *E. coli* population between 3 and 4 log CFU/nut. At the first inoculation, the mean weight of 140 sampled almonds was 13.8 ± 3.2 g; 14% were not split, 69% showed some signs of splitting, 17% were completely split. None of the hulls had begun to turn brown. At the second inoculation, the mean weight of 100 sampled almonds was 5.0 ± 1.6 g; 100% were split and all the hulls were brown. Inoculated *E. coli* populations were monitored using plate, filter, and enrichment methods for 6 and 4 weeks for the first and second trial, respectively.

In the first trial, *E. coli* populations declined rapidly over the first day. By the second day a majority of the samples had counts that were at or below the lower limit of detection for enumeration (1 CFU/nut); however, 17 of 39 samples were countable, ranging from a single colony to 4.09 log CFU/nut. At week 1 to 4 an increasing number of samples had counts at or below the lower limit of detection for enumeration. However, counts above 2 log CFU/nut occurred for 8/40, 6/40, 5/40, 1/40, and 3/40 for Weeks 1 through 5, respectively. Counts exceeding 5 log CFU/nut were detected on Day 1, 3, 4 and Week 2 in 2, 2, 1 and 1 samples suggesting that inoculated *E. coli* had multiplied on these samples. At week 6, the trials terminus, *E. coli* was not detected using enumeration or enrichment methods in 25 samples.

In the second trial, *E. coli* populations declined over the 4-week trial. At Day 2, 36 of 39 samples had counts at or above the lower limit of detection for enumeration: counts ranging from a single colony to 2.65 log CFU/nut. By Week 1, 4 of 40 samples were at or above the lower limit of detection for enumeration, ranging from 0.30 to log CFU/nut. In weeks 2 – 4, *E. coli* was detected only via enrichment in 3 of 40 samples. Distinct differences in survival response for *E. coli* were noted with different almond maturity at time of application which may need to be considered in on-farm food safety plans. Ongoing research is focused on determining the survival of foodborne pathogens in common almond crop protection sprays.

Characterization of Salmonella Isolated from Almonds by Whole Genome Sequencing

Dr. Linda Harris
UC Davis, Davis, CA USA

From 2001 to 2013, almonds were collected from seven almond handlers representing processing facilities located throughout the almond-growing regions of California. *Salmonella* isolates were retrieved from 1% of 15.000 raw almond enrichment samples. To determine the genetic relatedness of the 171 *Salmonella* unique isolates recovered from this survey, we sequenced and aligned their genomes with Parnsp followed by SNPs (single nucleotide polymorphisms) detection with the Food and Drug Administration Center for Food Safety and Applied Nutrition (CFSAN) SNP pipeline. The majority of the isolates (165) belong to subspecies *enterica* and cluster by serovar. Fifteen serovars were represented only by one isolate, and 22 relatively common *Salmonella* serovars were isolated two or more times. Genetic distance between multiple isolates within each serovar was calculated with the CFSAN SNP pipeline. Isolates with less than 10 SNPs differences between their genomes were considered genetically

similar. Genomes of *Salmonella* Enteritidis, with less than 10 SNPs differences with the 2001 raw almond outbreak associated strain, were isolated in the 2005 and 2006 surveys. Closely related genomes for several isolates of serovars Anatum, Infantis, Montevideo, Muenchen, Newport, Thompson and Typhimurium, were identified 2, 8, 12, 10, 10, 1 and 3 years apart, respectively. Antimicrobial resistant genes (AMR) were not identified in most of the isolates. A total of 11 isolates (6%) had five or more genes that conferred resistance to five different class of antibiotic. The data are consistent with broad range of environmental sources of *Salmonella* for almonds

Phosphine Resistance Management Strategies for Indian Meal Moth, Red Flour Beetle, and Sawtoothed Grain Beetle in California Almond Storage Facilities

Dr. George Opit
Oklahoma State University, Stillwater, OK USA

In research conducted from 2013 to date, researchers 1) determined discriminating doses for eggs of red flour beetle (RFB), eggs of sawtoothed grain beetle (STGB), and eggs and larvae of Indian meal moth (IMM), 2) evaluated 20 populations of RFB (eggs and adults), 11 populations of STGB (eggs and adults), and 3 populations of IMM (eggs and larvae) for presence of phosphine resistance and levels of phosphine resistance, and 3) developed a questionnaire to collect data on the history of pest management practices in almond storage facilities for the development of phosphine resistance management strategies.

All facilities with susceptible insect populations appeared to have good management practices and pests were controlled effectively using phosphine at 300–700 ppm and 48–72 h exposure time. However, researchers recommended an application of 500–1,100 ppm for 5–7 days in order to delay development of resistance for as long as possible. All facilities that had insect populations with strong phosphine resistance seemed to have good management practices. However, the main reason for the strong phosphine resistance in pest populations appears to be under-dosing (low concentration and short exposure time); therefore, researchers recommended an application of 1,100 ppm for 5–7 days or switching to sulfuryl fluoride for some time in order to manage these resistant insects. One facility had highly phosphine-resistant populations of both red flour beetle and sawtoothed grain beetle. However, they were controlled effectively by application of 1,100 ppm for 5–7 days — a recommendation that resulted from tests in our lab.

Almond Biomass

Carbon Sequestration and Soil Health Improvement in Almond Orchards Using Dairy Manure and Woody Biomass Compost (co-funded with Dairy Research Foundation)

Dr. Ruihong Zhang
UC Davis, Davis, CA USA

The application of organic amendments in almond orchards and reduction of greenhouse gas emissions could contribute to the California healthy soils initiative. Research is underway to co-compost dairy manure solids with almond woody biomass (sticks and twigs from almond hullers) and apply the compost in almond orchards. Co-composting of dairy manure solids and almond woody biomass is beneficial. Dairy manure solids has high moisture content and low carbon to

nitrogen ratio (C/N) while almond woody biomass has low moisture content and high C/N. Mixing the two in appropriate portions will create a mixture with desirable moisture, C/N, and material properties required for effective composting.

The researchers are partnering with Wickstrom Dairies L.P. and Van Ruler Orchards, Inc. in Hilmar, CA, in the production and application of compost products. Compost are produced from dairy manure and almond woody biomass and then processed into pelletized products. Field application of loose and pelletized compost products on the selected almond orchards will be researched and demonstrated. Field days will be organized to present the research findings to almond growers and dairy farmers. It is expected that the research results will lead to better understanding of how to best utilize dairy manure to supply the nutrients needed by almond orchards and recycle biomass in an effective and safe manner and build stronger collaboration between almond growers and dairy producers in the amendment and management of biomass and improve the soil health and quality of almond orchards.

Production of Antioxidants and Fungal Biomass from Almond Hulls for Animal Feed Application

Dr. Ruihong Zhang
UC Davis, Davis, CA USA

The goal of this project is to develop methods and processes to extract phenolic compounds for antioxidant health products and extract sugar and nutrients for production of fungal biomass which can be used as nutritious food or feed. The objectives of this project are to: develop and optimize extraction methods for sugars and antioxidants from almond hulls; optimize the fermentation conditions to produce fungal biomass; disseminate project results to the Almond Board of California.

Independence almond hulls collected from Cortez Growers Association were used for this study. The phenolic compounds in almond hulls was extracted by using different solvents. The aqueous solution containing 50% ethanol was found to be the best for extraction and phenolic compounds extracted showed the highest antioxidant activities. The total extracted phenolic compounds accounted for 3% of the almond hulls on dry basis. The almond hulls contain around 42% soluble sugar. All the sugar could be extracted by soaking the hulls in hot water at 80 degree C for 2 hours. The extracted sugar and nutrients were used for cultivating fungi *A.awamori.* At 4-day growth period, fungal biomass yield was 0.45 gram per gram of sugar. The protein content of fungal biomass was approximately 19% on dry basis. More research is underway to increase the yield of fungal biomass by utilizing fibers as well as sugars in the hulls and evaluate the nutritional value and health benefits of antioxidant and fungal biomass products.

Biodegradable Sporting Pigeons Made from Plastics and Natural Fibers Such as Rice Straw, Walnut Shells and Almond Shells

Dr. Joseph Greene
CSU Chico, Chico, CA USA

Almond hulls were added to biodegradable plastics, polyhydroxyalkanoates (PHA), and made into flying pigeons to replace the toxic clay pigeons. The goals of the project were to: develop materials to create a biodegradable flying sport pigeon to replace clay pigeons made with calcium carbonate; develop the production process so that it can be scaled up in the future. Researchers developed a process to make the almond shells and biodegradable plastic

pigeons by combining the almond hulls with 40 and 50% by weight concentrations with PLA and PHA plastics on a Leitstrix tin screw extruder, then molding the almond hulls and biodegradable plastic in tensile and impact bars on an Arburg injection molder. The almond hulls biodegradable plastic pigeons were then tested against pigeons from rice hulls for impact and tensile properties, flight qualities, and breakability with pellet or shot.

The biodegradable flying pigeons broke up after being hit with pellet or shot at 20 and 30 yards. Almond shells and biodegradable plastic had lower impact strength and tensile strength than biodegradable pigeons made with rice straw and biodegradable plastics. The project will continue to develop biodegradable flying pigeons with lower impact strength and better flight properties.

Non-thermal Processes for Making Food Grade Food and Nutraceutical Ingredients from Almond Hulls Ph 1 and 2

Dr. Roger Ruan
University of Minnesota, St. Paul, MN USA

The purpose of this research is to improve the desired physiochemical properties of almond hulls with innovative food processing techniques and elevate the functional performance of the product. Three main types of almond hull originated from California: Carmel, Nonpareil and Hard-shell were investigated, and the compositions were analyzed. Various potential product developing ideas have been derived from the preliminary evaluation of the characteristics of almond hull samples through different processing, which provide the industry with the new opportunities to valorize this low-cost ingredient. From our previous findings, powder A was chosen for its excellent antioxidant capacity and physiochemical properties to proceed to further research. The effect of different temperature of steeping water and non-thermal process including ultra-sonication and high-pressure homogenization (HPH) on the antioxidant capacity of the almond hull drinks was studied. In general, the samples dissolved at 60^{o}C assisted with non-thermal process achieved highest total polyphenol content while the most flavonoid contents were released when samples were dissolved at 100^{o}C followed up with non-thermal process. Moreover, other eight top-shelfed commercial drinks were selected for comparing their antioxidant capacity and they were performed poorer antioxidant capacity, the drink with 5% hard-shell powder dissolved in 100 ^{o}C water assisted with non-thermal process scored the highest DPPH scavenging capacity as 1.56 mg ± 0.56 TE/ mL sample, which was more than 40 times than one of the most popular antioxidant drinks in market.

Then, further extraction and enrichment of phenolic compounds from almond hull (PEAH) was done and prepared to study the bioavailability of these compounds by using an *in-vitro* digestion/Caco-2 cell culture model. The total phenolic content (TPC) in PEAH was 481.52 ± 3.02 mg GAE/g dw, among which the contents of vanillic acid and chlorogenic acid are 119.47 mg GAE/g dw, 14.35 mg GAE/g dw respectively. Two in vitro methods, DPPH radical scavenging activity and FRAP, were used to evaluate the antioxidant activities of the PEAH, and both showed significantly higher antioxidant activities in both assay systems, with a TE value of 2697.73 ± 113.08 µmol TE/g dw and a AAE value of 2654.55 ± 64.28 µmol AAE/g dw. Tert-Butyl hydroperoxide (t-BOOH) is an organic peroxide widely used in a variety of oxidation process. It was shown that the PEAH had a positive protect effect on Caco-2 cells against t-BOOH with higher cell viability and lower LDH leakage percentage. Pre-treatment with PEAH protected Caco-2 cells against the increase of intracellular ROS induced by t-BOOH, especially 5 µg/mL of PEAH prevented the increase by almost 73% compared to that of oxidative stressed cells. Additionally, PEAH was exhibiting a protective effect by recovery GSH content against t-BOOH oxidative insult

alongside with lower carbonyl content resulted in less protein damage in Caco-2 cells.

Utilizing Almond Hulls as a Novel Feed Ingredient for Poultry

Dr. Woo Kyun Kim
University of Georgia, Athens, GA USA

This study aimed to develop feed manufacturing methods to improve the feasibility of almond hulls as a poultry feed ingredient. Researchers conducted a laying hen trial with different dosages of ground almond hulls (0, 7.5 and15%). researchers found that there were no differences in egg production and egg quality among the Treatments. However, 15% Almond hull inclusion increased feed conversion ratio. They are conducting a cocci challenge trial with broilers. In the trial, researchers will evaluate if almond hulls containing high antioxidants and fermentation sugar and fiber reduce detrimental effects of *Eimeria spp*. in broilers.

The Production of Bioavailable, High-Protein Feed with Tunable Amino Acid Profiles from the Bioconversion of Almond Hulls

Dr. Kyria Boundy-Mills
UC Davis, Davis CA USA

A process to release and convert soluble sugars in almond hulls to yeast biomass was successfully developed. While the researchers completed the primary objectives of this project, they have identified opportunities for further improvement of the process. They developed an alternate process to enzymatically liquefy the almond hulls with reduced water use. Pectinase hydrolysis of almond hulls successfully liquefied and released glucose and fructose from almond hulls. Additionally, galacturonic acid (hydrolysis product of a major component of pectin) was released in high quantities in the resulting hydrolysate passed on to the yeast team.

They found several yeasts able to grow on the glucose, sucrose and fructose, but only two of the initial 47 yeasts tested were able to grow on galacturonic acid. They determined that the addition of a nitrogen source (ammonium sulfate) increased protein yield by one yeast, *Zygoascus hellenicus* UCDFST 11- 671, and that 24-36 hours incubation was sufficient. Total protein concentration of this yeast grown in almond hulls was increased almost 3-fold compared to that of almond hulls. The % of essential amino essential amino acids crucial for animal feed (e.g. lysine, threonine, leucine) increased from 30% of total protein to just over 40%, indicating that this technology holds promise for production of an improved animal feed ingredient.

While the *Z. hellenicus* UCDFST 11- 671 yeast consumed all the glucose and fructose, this yeast was not able to consume galacturonic acid in the almond hull hydrolysate. Initial screening suggested robust growth on galacturonic acid as a sole carbon source, but further tests indicated that this yeast was unable to significantly consume galacturonic acid in lab media or almond hull extract containing both galacturonic acid and glucose. Pre-culturing this yeast in galacturonic acid did not induce consumption in the mixed sugar environment. Several other yeasts from the initial screening had similar results showing ability to grow on galacturonic acid as a sole carbon source but unable to consume galacturonic acid when present in a mixture of sugars.

This leaves an opportunity for future improvements of the technology. In future work, they would like to focus on testing more yeast strains from the Phaff collection and exploring other yeast

cultivation protocols to improve galacturonic acid consumption. Fortunately, these UCD researchers have access to one of the largest collections of yeast in the world, with over 1,000 species. We selected nine species that have been reported in literature to be able to consume galacturonic acid. Preliminary analysis indicates that some of these yeasts may be able to consume greater amounts of galacturonic acid than strain 11-671. Since galacturonic acid is ~30% of the soluble sugars in the almond hull hydrolysate, successful conversion of this carbon source to protein will greatly increase protein content of the resulting feed product.

Almond Hulls as an Effective and Digestible Source of NDF in Lactating Dairy Cow Diets

Dr. Ed DePeters UC Davis, Davis CA USA

The first part of this research aimed to determine the feasibility of feeding high amounts of almond hulls to high producing dairy cows. The lactation study included 12 Holstein cows with 4 primiparous and 8 multiparous cows. The dietary treatments were designed to feed 0, 4, 8, or 12 lb of commercial almond hulls per cow daily. These amounts created diets that were 0, 7, 13, or 20% almond hulls. The almond hulls used contained 12.8% CF (As Is basis). Diets were formulated so that as the inclusion amount of almond hulls increased, the amount of flaked corn and soy hull pellets decreased while soybean meal inclusion increased. Study design was a replicated 4x4 Latin square. There was no significant differences in DM intake for diet. Actual milk yield tended ($P < 0.08$) to be lower for the 13% almond hull diet. However, energy-corrected milk yield was not different for diet. The percent and yield of lactose and total solids and yield of fat did not differ with diet, but percent and yield of protein were lower for the 13% and 20% almond hull diets while percent of fat was higher for the 13% and 20% diets. Apparent total tract digestibility of DM and organic matter was higher with the inclusion of almond hulls in the diet. This study demonstrated that almond hulls can be fed at high amounts to lactating dairy cows to support high levels of production performance.

The second objective aimed to determine the composition of different varieties of almond hulls along with the *in vitro* digestibility and *in sacco* disappearance of total, pure, or non-hull material in almond hulls. Eleven samples of commercial almond hulls were used. Each sample was divided into 2 subsamples. One subsample represented the commercial almond hulls (Total hulls). The other half was hand sorted to separate the hulls (Pure hulls) from non-hull debris (sticks & shell). The gas method and Ankom Daisy method were used to determine *in vitro* digestibility while two non-lactating fistulated cows were used to test *in sacco* disappearance of Pure hulls and Total hulls.

The Pure hulls for all varieties had lower fiber fractions and greater sugar fractions than the Total hull samples due to the lack of sticks and shells (non-hull material). For Daisy *in vitro* digestibility, both Pure hulls and Total hulls were significantly ($P<0.05$) more digestible than non-hull material. Pure hulls had numerically higher dry matter, organic matter, and NDF digestibility when compared with Total hulls. For gas production, Pure hulls were significantly ($P<0.05$) more fermentable than Total and non-hulls, with Pure hulls and Total hulls having a significantly higher rate of fermentation as well. Metabolizable energy (ME) was calculated from 24-hour gas production values. Nonpareil hulls provided significantly ($P<0.01$) higher ME when compared with other almond varieties, with Pure hulls and Total hulls providing significantly ($P<0.01$) more ME than non-hull material for all varieties. For *in sacco* the Pure hulls had significantly ($P<0.01$) greater dry matter disappearance along with a significantly greater ($P<0.001$) rate of disappearance when compared with Total hulls. This research demonstrated that non-hull material from all varieties is highly indigestible, likely due to the high fiber and lignin content, and that Pure hulls are more digestible than Total hulls both *in vitro* and *in sacco*. Therefore, a lower

amount of non-hull material in the commercial almond hulls will result in a higher energy content that supports high milk production in dairy cows. High quality commercial almond hulls should have a low amount of sticks and shells.

The Impact of Almond By-Product Composition and Nitrogen Amendment on Black Soldier Fly Cultivation and Quality

Dr. Jean Vandergheynst
UC Davis, Davis, CA USA

Insect biomass such as black soldier fly larvae (BSFL, *Hermetia illucens L*.), is a novel protein source that is a sustainable alternative to traditional animal feeds. Research at UC Davis has shown that BSFL can be grown on almond hulls. Experiments testing the impact of nitrogen sources on larvae growth and composition (sterilized poultry manure, whey and urea) indicated that careful management of carbon to nitrogen ratio could enhance the bioconversion of almond hulls to larvae and achieve larvae with varying composition. A carbon to nitrogen ratio between 30 and 35 promoted the production of larvae. In addition, whey was the superior nitrogen amendment compared to urea and poultry manure for the cultivation of larvae on almond hulls. In addition, the study of the microbial community of spent hull substrates (digested almond hulls) was assessed in seven different feedstocks. The presence of larvae impacted the microbial community of the spent hulls compared to treatments without larvae. There was a significant positive correlation between larvae yield and the relative abundance of the phyla Bacteroidetes and class Sphingobacteria and a significant negative correlation between larvae yield and the relative abundance of the phylum Proteobacteria and class Gammaproteobacteria. Finally, experiments were performed to evaluate the fate of residual pesticides in the hulls. The screening of seven varieties of almond hulls and shells for a range of pesticides showed differences in pesticide residue types and levels in the feedstocks. Additional study based on the relative abundance, toxicity, bioaccumulation potential, and expected persistence of the detected pesticides did not show consistent evidence of pesticide degradation in the substrates during larvae growth. However, two pesticides (befenthrin and esfenvalerate) were detected in the larvae tissue following growth on the hulls. These results indicate an accumulation of bifenthrin in the larvae tissues from the substrate (i.e., bioaccumulation).

The findings confirm that the yield and composition of the larvae can be altered in controllable ways by varying the production environment, including nitrogen source. The changes in the microbial community due to larvae may have additional benefits in the soil health and further studies are recommended. Finally, post-processing of the larvae, such as lipid and protein fraction extraction, could be necessary to reduce pesticide concentrations in the final BSFL product.

Evaluation of Almond Shell and Soft Wood Derived Biochars as Soil Amendments Year 2 of 3

Dr. Sanjai Parikh
UC Davis, Davis, CA USA

In Year 2 of the ABC funded project entitled *Evaluation of biochar for on farm soil management in California*, significant progress was made on each of the proposed project tasks. For Task 1: Produce and characterize biochar, the following characterizations were added to suite of biochar properties measured: cation exchange capacity (CEC), total oxygen (O), dissolved organic carbon

(DOC), and total surface area.

For Task 2: Field trials in Yolo and Fresno Counties, season 2 preplant soil sampling and harvest was completed. Season 1 and 2 field trials revealed no apparent differences in processing tomato yield when either soil was amended with biochar at any fertilizer rate, biochar rate, or biochar type, though more sophisticated statistical analysis is underway to determine levels of significance. Similar results were obtained regarding year 1 N budget, with no apparent differences or trends in soil N loss with or without biochar. The season 2 N budget is currently underway, with postharvest soil sampling scheduled for late September and plant C and N content analysis ongoing. Tasks 3, 4 & 5 progressed as planned.

Almond Quality & Food Safety Research Publications 2019

The following is a list of scientific papers published with the research partially or wholly funded by the Almond Board of California. Copies of the abstracts may be obtained by contacting the Almond Board of California.

Franklin, L.M., A.E. Mitchell. 2019.
Review of the Sensory and Chemical Characteristics of Almond (Prunus dulcis) Flavor. *J. Agric. Food Chem.* 67:274-2753.

Huang, G., K. Lapsley. 2019.
Chapter 15 - Almonds. *Integrated Processing Technologies for Food and Agricultural By-Products. Academic Press.* :373-390.

King, E.S., D.M. Chapman, K. Luo, S. Ferris, G. Huang, A.E. Mitchell. 2019.
Defining the Sensory Profiles of Raw Almond (Prunus dulcis) Varieties and the Contribution of Key Chemical Compounds and Physical Properties. *J. Agric. Food Chem.* 67:3229-3241.

McCaffrey, Z., P. Thy, M. Long, M. Oliveira, L. Wang, L. Torres, T. Aktas, B.-S. Chiou, W. Orts, B.M. Jenkins. 2019.
Air and steam gasification of almond biomass. *Frontiers In Energy Research.* doi: 10.3389/fenrg.2019.00084.

Ortega-Beltran, A., J. Moral, A. Picot, R.D. Puckett, P.J. Cotty, T.J. Michailides. 2019.
Atoxigenic Aspergillus flavus Isolates Endemic to Almond, Fig, and Pistachio Orchards in California with Potential to Reduce Aflatoxin Contamination in these Crops. *Plant Dis.* 103:905-912.

Palma, L., J. Fernandez-Bayo, D. Miemeier, M. Pitesky, J.S. VanderGheynst. 2019.
Managing high fiber food waste for the cultivation of black soldier fly larvae. *Science Of Food.* https://doi.org/10.1038/s41538-019-0047-7.

Parrish, D.R., R.B. Pegg, W.L. Kerr, R.B. Swanson, G.Huang, A.I. Kerrihard. 2019.
Chemical changes in almonds throughout storage: modeling the effects of common industry practices. *Int. J. Food Sci. Tech.* 54:2190-2198.

Wu, J., X. Lin, S. Lin, P. Chen, G. Huang, P. Peng, Y. Cheng, Y. Ma, Y. Liu, R. Ruan. 2019.
California almond shelf life: changes in moisture content and textural quality during storage. *ASABE* 62(3):661-671.