2018

Proceedings

October 22-24 • Seaside, California

California Department of Food and Agriculture
Fertilizer Research and Education Program
Twenty Sixth Annual Conference

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Twenty Sixth Annual Conference

Editors:
Mark Cady
Brooke Elliott
Nicole Crouch
Natalie Jacuzzi

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Cover and pages 5, 11, 15, and 61:
Brooke Elliott
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Pages 105 and 113:
Natalie Jacuzzi

Publication design:
Brooke Elliott

To order additional copies of this publication, contact:
California Department of Food and Agriculture
Fertilizer Research and Education Program
1220 "N" Street
Sacramento, California 95814
(916) 900-5022
(916) 900-5349 FAX
frep@cdfa.ca.gov
www.cdfa.ca.gov/go/frep

Note:
The summaries in this publication are the results of projects in progress and have not been subjected to independent scientific review.

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INTRODUCTION

Fertilizer Research and Education Program

Welcome to the California Department of Food and Agriculture (CDFA) Fertilizer Research and Education Program (FREP) and Western Plant Health Association's (WPHA) Annual Nutrient Management Conference. Over the last 26 years, this conference has provided a forum where grant recipients report findings from their current FREP-funded projects and industry representatives share valuable nutrient management information with the audience of crop advisors, growers, researchers, and other agricultural professionals. Since 2005, FREP has teamed up with WPHA to strengthen our impact on industry and deliver the most essential nutrient management information.

FREP is involved in a range of activities beyond the annual conference. In the last several years, FREP has recognized that it is not enough to just fund cutting-edge research projects. The results of those projects must be available and useful to the people who make nutrient management recommendations and decisions on the ground. We have been working towards this goal by promoting outreach and education approaches such as web pages, informational pamphlets, field days, meetings, and trainings.

A prime example of this effort is the development of the CDFA Crop Fertilization Guidelines (cdfa.ca.gov/go/FREP-guide). Many agricultural consultants and growers refer to the online guidelines when making recommendations and decisions about fertilizer applications. Three years ago, FREP started adapting the nitrogen management information from the Fertilization Guidelines into trifold pamphlets that can be handed out to clients, saved in a glove compartment or kept at the ready in a field office. As of October 2018, there are informational pamphlets available for 15 major California crops that can be downloaded and printed from the FREP website. They are also available on request as glossy printouts. If you would like to make these printed pamphlets available at your meeting or conference, send a request to FREP at FREP@cdfa.ca.gov.

Over the past year, FREP has also increased efforts to create opportunities for in-person information sharing through field days and workshops. In June, FREP collaborated with UC Davis to hold a field day at the Russell Ranch Sustainable Agriculture Facility focused on the use of biochar in crop production. The event attracted over 100 participants and featured presentations, tours of experimental plots, and a poster session. Additionally, in early October, FREP worked with the California Association of Pest Control Advisors (CAPCA) and the Western Region Certified Crop Advisors to hold a nutrient management seminar in conjunction with the CAPCA annual conference. Both opportunities are part of an effort to build on nutrient management conversations and decision-making efforts through increased program outreach.

In addition to these efforts, FREP is addressing nutrient and irrigation management concerns identified by the Regional Water Quality Control Boards (RWQCB) across the state. This year, the State Water Resources Control Board amended the Waste Discharge Requirements (WDRs) for the East San Joaquin River Watershed (originally adopted by the Central Valley Water Board) and made many elements in the amended WDRs precedential for all regional water boards across the state.

Biochar Field Day, held on June 6, 2018.

One precedential element that affects FREP is the grower training requirement for those who wish to self-certify their Irrigation and Nitrogen Management Plans (INMPs). Currently, FREP is working with UC Davis and the Coalition for Rural and Urban Stewardship (CURES) to make this training available to growers with the help of agricultural water quality coalitions throughout the Central Valley. As of September, almost 3,600 growers have attended training sessions in the Central Valley. With the amended order, this training will be expanded beyond the Central Valley to other regions across California.

The amended WDR states that all regions will require some growers to have INMPs certified, and that self-certification will be available for growers who attend a CDFA training. This October, grower training started in a small watershed in Ventura County through a FREP collaboration with the Ventura County Agricultural Irrigated Lands Group (VCAILG), UC Cooperative Extension, and Fruit Growers Laboratory. This training project will be available to VCAILG growers throughout the Ventura growing region this winter.

THE FREP WPHA ANNUAL CONFERENCE

Each year we strive to evolve our approach to the annual conference to best meet the changing needs of the agricultural community. This year we introduced a new information-sharing strategy by hosting a pre-conference farm tour. The tour visited two farming operations, Tanimura and Antle, and Huntington Farms, where farm staff discussed their efforts to implement technology and management innovations that improve efficiency and reduce potential off-site movement of plant nutrients. The tour provided conference attendees with a chance to connect the information they will hear over the next two days to practical in-field application.

During the conference this year, we will hear from both, researchers and industry representatives from around the state, on the latest developments and ideas in nutrient and irrigation management.

Since 1991, CDFA has invested over 18 million dollars in nutrient management research and the development of decision-support tools for growers. Given this

Processing tomatoes in Central Valley, California.

breadth of technical information, it is imperative that we understand how growers make decisions regarding adoption and implementation of management practices. During the conference, Dr. Sat Darshan Khalsa of UC Davis will describe research that aims to illuminate grower decision-making processes and the current level of adoption of nitrogen management practices. This improved understanding will be valuable to FREP as we develop outreach and education programs to support growers. (Lubell and Brown, pg. 36)

Two projects finishing up this year, represented in the conference and in these proceedings, focus on the CropManage online decision-support tool for irrigation and nitrogen management. Dr. Michael Cahn, UC Cooperative Extension irrigation and water resources Farm Advisor, started CropManage with a FREP grant in 2011, providing growers a new tool to manage and track irrigation and nitrogen applications in lettuce. The project has now grown to serve several other coastal fruit and vegetable crops. In the last three years, Dr. Cahn has worked with UC Davis researchers like Dr. Daniel Geisseler and Dr. Patrick Brown to incorporate Central Valley crops, including processing tomatoes (Geisseler, pg. 24), almonds and alfalfa (Cahn, Brown, and Fulton, pg. 44).

Dr. Cahn's counterpart at the UC Cooperative Extension in Monterey County, Richard Smith, is working with the increasing acreage of organic leafy greens on the Central Coast. These growers are faced with the challenge of utilizing organic fertilizers with variable nitrogen mineralization characteristics. Fertilizer management in organic leafy greens can be challenging, especially considering the high value of these short season crops. Mr. Smith will share with us his research and demonstration project that is helping coastal organic growers improve their nutrient use efficiency and reduce the off-site movement of nitrogen and phosphorous. (Smith et al., pg. 32)

Sebastian Saa, formerly of UC Davis, now at the Almond Board of California, will update us on a project that builds on previous work from Dr. Brown's lab, providing early leaf sampling techniques to help growers accurately predict the nitrogen needs of walnuts, prunes, and pears (Brown, Laca and Saa, pg. 28). Dr. Douglas Amaral of UC Davis will present the preliminary results of a similar project for citrus in the Southern San Joaquin Valley (Brown and Amaral, pg. 57). Both projects will provide resources and tools to help growers adopt improved nitrogen management practices.

While some FREP research focuses on leaching of nitrogen from fertilizers, there are also other loss pathways of nitrogen from cropland. One of these pathways is the transformation of nitrogen compounds into nitrous oxide (N_2O) a powerful greenhouse gas. A research project with California State University, Monterey Bay, professor Dr. Arlene Haffa, shows how efficient irrigation and nitrogen management can minimize the loss of nitrate through leaching and reduce the transformation of nitrogen into N_2O emissions in cropland (Haffa, pg. 16).

Another unique project is with UC Extension Specialist Dr. Lorence Oki, who is completing a project that focuses on the unique nutrient management challenges that nursery and greenhouse growers face. His project offers training for growers to help improve fertilizer efficiency while maintaining high-value production (Oki, pg. 40).

In these proceedings, you will also find two updates from researchers working on the agricultural applications of biochar. Biochar is produced when carbonaceous feedstocks, like peach pits, wood chips or even dairy manure, are heated to combustion temperatures in a low-oxygen environment. Biochar is being sold in California as a soil amendment and as an ingredient in fertilizer products. Dr. Sanjai Parikh, from UC Davis Department of Land, Air and Water Resources, has characterized biochar products in the lab and tested biochar with plants and soils in the greenhouse and in field plots (Parikh, pg. 48). Additionally, Dr. Suduan Gao, a Research Soil Scientist with the USDA Agricultural Research Service, is focusing on biochar characterization and how it affects soil properties and nitrogen dynamics (Gao and Wang, pg. 78).

Finally, Parry Klassen of CURES will present the results from a project that measured nitrogen management parameters in walnut orchards to determine the magnitude of nitrate leaching under various fertilization and irrigation practices (Klassen, pg. 20).

The above is a sampling of the FREP-funded projects represented at the conference and in these proceedings. Additionally, several conference presentations will be delivered by agricultural professionals with important field experience on topics, including the use of drones, micronutrient technology, nutrient planning and compost use, cannabis fertilization, and the intersection of nutrient management and pest control. A panel discussion on irrigation innovation and a poster session will build on the information shared at the conference and provide opportunities for valuable interactions among conference participants. Poster abstracts will be posted online after the conference.

ACKNOWLEDGEMENTS

We are grateful to members of the fertilizer industry for their support in providing funds for the Fertilizer Research and Education Program. Their foresight in creating FREP and their long-term commitment and dedication have been instrumental in the program's success.

We recognize the members of the Fertilizer Inspection Advisory Board's Technical Advisory Subcommittee who review and recommend projects for funding. The professionalism, expertise, and experience of Dr. John Bushoven, Rex Dufour, Dr. Eric Ellison, Charles Hornung, Dr. Marja Koivunen, DD Levine, David McEuen, Dr. Jerome Pier, Dr. Steve Petrie, and Jenny Rempel have provided FREP with direction to ensure the program achieves its goals.

In addition, we thank the members of the Fertilizer Inspection Advisory Board for their continued support of the FREP program: Jake Evans, Andrew Godfrey, Doug Graham, Jay Irvine, David McEuen, Melissa McQueen, Ron Naven, Gary Silveria, and Steve Spangler.

We thank the Western Plant Health Association as a continued valued partner in the conference. The input and support of Renee Pinel, President and CEO, have led to greater outreach and dissemination of FREP research findings.

Vital contributors are the project leaders and cooperators themselves and the numerous professionals who peer-review project proposals, significantly enhancing the quality of FREP's work.

Special recognition also goes to the leadership at the California Department of Food and Agriculture, including Secretary Karen Ross; Science Advisor Dr. Amrith Gunasekara; Inspection Services Division Director Natalie Krout-Greenberg; Dr. Amadou Ba, Environmental Program Manager II; Brooke Elliott, Research Data Analyst I; Mark Cady, Senior Environmental Scientist (Supervisory), Natalie Jacuzzi, Senior Environmental Scientist (Specialist), and Nicole Crouch, Environmental Scientist.

CONFERENCE PROGRAM

TUESDAY, OCTOBER 23, 2018

Facilitators:	*Dr. Rob Mikkelsen, International Plant Nutrition Institute* *Keith Backman, Dellavalle Laboratory, Inc.*
9:00 - 9:30	**Welcome** *Renee Pinel, Executive Director, WPHA* *Karen Ross, Secretary, CDFA*
9:30 – 10:00	**Developing a Decision Support Tool for Processing Tomato Irrigation and Fertilization in the Central Valley Based on CropManage** *Dr. Daniel Geisseler, Assistant Cooperative Extension Specialist, UC Davis Department of Land, Air, and Water Resources*
10:00 – 10:30	**Prediction of Summer Leaf Nitrogen Concentration from Early Season Samples to Better Manage Nitrogen Inputs at the Right Time in Walnuts, Prunes, and Pears** *Dr. Sebastian Saa, Senior Manager, Almond Board of California*
10:30 - 10:50	**Break**
10:50 - 11:20	**Integrating Compost into Nutrient Planning** *Jocelyn Bridson, Director of Environmental Science and Resources, Rio Farms*
11:20 - 11:50	**Fertility Management for Cannabis** *Dr. Jerome Pier, Agronomist, Nutrien Ag Solutions*
11:50 – 1:10	**Lunch**
1:10 –2:25	**Panel Discussion: Innovations in Irrigation Management and Efficiency** *Moderator: Dr. Khaled Bali. Panel: Dr. Michael Cahn, Dr. Aliasghar Montazar, Kevin Greer, and Dino Giacomazzi*
2:25 – 2:55	**Understanding Influences on Grower Decision Making and Adoption of Improved Nitrogen Management Practices** *Sat Darshan Khalsa, Assistant Project Scientist, UC Davis Department of Plant Sciences*
2:55 – 3:15	**Break**
3:15 – 3:45	**Using Drone Technology for Nutrient and Irrigation Management** *Justin Metz, Technology Integration Specialist, Bowles Farming Company*
3:45 – 4:15	**Evaluation of the Multiple Benefits of Nitrogen Management Practices in Walnuts** *Parry Klassen, Executive Director, Coalition for Urban Rural Environmental Stewardship*
4:15 – 4:45	**Quantifying N_2O Emissions Under Different Irrigation and Nutrient Management BMPs that Reduce Groundwater Nitrate Loading and Applied Water** *Dr. Arlene Haffa, Associate Professor, CSU Monterey Bay, School of Natural Sciences*
4:45 – 6:00	**Poster Session: Nutrient Management Research and Projects**

POSTERS

Barriers to Adoption of Improved Nitrogen Management Practices
Jessica Rudnick et al.

Effects of Soil Biochar Amendment and Irrigation on Nitrogen Losses to the Environment
Suduan Gao and Dong Wang

Evaluating Irrigation Benefits of High Density Planting in Avocados
Etaferahu Takele and Sonia Rios

Evaluating HFLC Nitrogen Management Strategies to Minimize Reactive Nitrogen Mobilization from California Almond Orchards
Hanna Ouaknin et al.

Quantifying Nitrate Leaching from Central Valley Irrigated Lands with the Soil & Water Assessment Tool (SWAT)
Yohannes Yiman et al.

Water and Nitrogen Use efficiency in Lettuce Growth and Development in Precision Agricultural System
Mehdi Ansari

Precision Fertigation Management for Processing Tomatoes
Isaya Kisekka and Fatemeh Mehrabi

Working with Commodity Groups, Processors, and Packers to Procure Representative Crop Samples to Assess Harvest Nitrogen Content
John Dickey

In situ Monitoring of Pathogen Suppressing Volatiles to Determine Efficacy of Anaerobic Soil Disinfectation in Strawberry Fields
Kali Prescott et al.

Quantifying N_2O Emissions Under Different Irrigation and Nutrient Management BMPs that Reduce Groundwater Nitrate Loading and Applied Water
Stefanie Kortman

WEDNESDAY, OCTOBER 24, 2018

Facilitator:	*Stephen Vasquez, Sun World, Inc.*
8:15 - 8:30	**Welcome and Recap**
8:30 - 9:00	**Evaluation and Demonstration of Nitrogen and Phosphorous Management in Organic Leafy Green Vegetable Production on the Central Coast** *Richard Smith, Farm Advisor, UC Cooperative Extension Monterey County*
9:00 – 9:30	**The Role of Calcium in Disease and Environmental Stress Response in Plants** *Dr. Steve Petrie, Director of Agronomic Services, Yara North America, Inc.*
9:30 – 10:00	**Micronutrient Technology** *Eric McGee, Agronomist, Quali Tech, Inc.*
10:00 - 10:20	**Break**
10:20 - 10:50	**UC Nursery and Floriculture Alliance Fertilizers and Plant Nutrition Education Program** *Dr. Lorence Oki, Specialist, UC Davis Department of Plant Sciences*
10:50 - 11:20	**Soil Health Impacts on Plant Disease and IPM** *Dr. Lacey Mount, Consultant, Dellavalle Laboratory, Inc.*
11:20 - 11:50	**Speed Updates: Ongoing FREP Projects** *Dr. Michael Cahn, Dr. Douglas Amaral, Dr. Sanjai Parikh, and Dr. William Horwath*
11:50 - 12:00	**Closing Remarks**

SUMMARIES OF PRESENTED FREP PROJECTS

Quantifying N2O Emissions under Different On-Farm Irrigation and Nutrient Management BMPs that Reduce Groundwater Nitrate Loading and Applied Water

Project Leader

Arlene Haffa, PhD, MS
Associate Professor of Biochemistry and Microbiology
California State University Monterey Bay
ahaffa@csumb.edu

Co-PL Investigators

William Horwath, PhD
Professor of Soil Biogeochemistry, Department of Land, Air and Water Resources
University of California Davis
wrhorwath@ucdavis.edu

Supporters

Forrest Melton, MS
Senior Research Scientist and Adjunct Research Faculty
NASA Ames Research Center and California State University Monterey Bay
fmelton@csumb.edu

Michael Cahn, PhD
Farm Advisor, Irrigation and Water Resources
University of California Cooperative Extension
Monterey, San Benito, and Santa Cruz Counties
mdcahn@ucanr.edu

Richard Smith, MS
Farm Advisor, Vegetable Crop Production and Weed Science
Cooperative Extension
Monterey County
rifsmith@ucanr.edu

Cooperating Growers

D'Arrigo Brothers
21777 Harris Road
Salinas, CA 93908
(831) 455-4500

Huntington Farms
32886 Silliman Road
Soledad, CA 93960
(831) 678-2552

We worked with a third grower who chooses to remain anonymous.

INTRODUCTION

There are economic and environmental sustainability challenges associated with the nutrient intensive production of specialty crops grown in the Pajaro and Salinas Valleys. Fertilizer applications in excess of crop needs may result in additional irrigation and fertilizer costs, nitrous oxide (N_2O) gas emissions to the atmosphere, and nitrate (NO_3^-) leaching to groundwater. N_2O is 300 times more effective than carbon dioxide at warming the atmosphere, and the majority of N_2O in the U.S. comes from microbes in agricultural soils that convert available nitrogen to N_2O gas as a bi-product of metabolic processes. Few studies address how row crop management alters total emissions, both those directly from the soil and indirectly from leached NO_3^- transformations in downstream aquatic environments (De Klein et al., 2006). We evaluated the potential for evapotranspiration-based irrigation to mitigate N_2O emissions and NO_3^- leaching as a result of improved crop N uptake. The goal is to assist growers in optimizing water and fertilizer use in a way that reduces crop production costs and maintains competitive yield while minimizing losses of excess N to the environment.

OBJECTIVES

1. Establish standard and alternative irrigation management treatments in split-block designed strawberry and subsequently lettuce-broccoli crop rotations.
2. Measure direct soil N_2O emissions and total applied water from these cropping systems.
3. Estimate direct and indirect N_2O emissions in conjunction with NO_3^- leaching data.
4. Quantify direct and indirect N_2O emissions in relation to yield quantity and quality differences, input costs and total water applied.
5. Characterize N_2O emissions based on environmental factors including temperature and water-filled pore space of the soil.

6 Analyze the pathway of N transformation in soil through physical ammonia (NH_3) oxidation due to water and oxic/pH conditions.

DESCRIPTION

Field scale trials were conducted on commercial farms in the Salinas Valley using CropManage which provides real time evapotranspiration (ETc) based irrigation and fertilizer recommendations (Cahn 2014). 100% and 130% ETc (ET 100 and ET 130, respectively) replacement requirements were applied to strawberries (2015-2016) and a lettuce\broccoli rotation (2017-2018) grown in a replicated randomized split-block design with 4 replicates each. A split block broccoli field trial (2016) with a comparison between ET 100 and the Grower Practice (GP) was completed. Direct N_2O emissions were monitored weekly using static chambers placed between plants. N_2O was determined using a Shimadzu GC 2014 gas chromatograph. Vadose zone leachate was collected weekly from Decagon G3 Passive Capillary Lysimeters and analysed for nitrate (NO_3^-) on a Lachat 8500. Lab incubations were carried out on the strawberry and the lettuce/broccoli rotation soil to determine the driving forces of N_2O production in these soils. Yields were measured using standard commercial grower practices.

RESULTS AND DISCUSSION

Crop yields for each crop/field were comparable for ET 100 and ET 130 treatments. Cumulative area-based direct N_2O emissions were lower for ET 100 treatments in 2016 broccoli and Romaine lettuce (Table 1). Yield based emissions followed this same trend. Peak emissions occurred at all sites following higher rates of N application (Figures 1). The 2016 broccoli trial GP had the highest daily, cumulative and yield-scaled direct N_2O emissions. Results of one-way ANOVA indicate there were no statistically significant differences in cumulative direct N_2O emissions between treatments in different crops/fields, except for broccoli 2016 (α= 0.05, p= 0.0241, F= 5.44). Leaching and associated indirect emissions estimates are higher in ET 130 treatments. There are notable reductions in N losses under ET 100 for strawberries and lettuce while also achieving comparable yield for both crops. This validates the efficacy of CropManage for recommending BMPs for irrigation and nutrient management without compromising yield.

Treatment and Crop Type	Yield Mg ha^{-1}	Cumulative direct N_2O emissions kg N ha^{-1}	Yield-scaled N2O emissions g N Mg-1 yield	NO_3 leaching kg N ha^{-1}	Indirect N_2O Emissions kg N ha^{-1} EF 0.05	EF 0.75	EF 2.5
ET 100 Strawberries	94	2.2	17	65	0.03	0.5	1.6
ET 130 Strawberries	93	2.1	17	123	0.06	0.9	3.1
ET 100 Broccoli (2016)	13	3.4	291	31	0.02	0.23	0.78
GP broccoli (2016)	15	4.7	374	32	0.02	0.24	0.79
ET 100 Romaine Lettuce	75	0.46	9	10	0.01	0.08	0.26
ET 130 Romaine Lettuce	75	0.56	11	39	0.02	0.29	0.98
ET 100 Broccoli (2017)	18	3.5	186	62	0.03	0.47	1.56
ET 130 Broccoli (2017)	18	3.0	153	76	0.04	0.57	1.90

Table 1. Results for yield, cumulative direct and yield-based N_2O emissions, and preliminary results for NO_3 leaching for each crop and treatment. Yields are based on marketable yield.

Soil water-filled pore space (WFPS) and temperature were generally lower in ET 100 treatments compared to alternative treatments. (Figure 1). We will be testing significant relationships between these variables using correlation analyses.

The effects of soil moisture content and fertilizer N source were evaluated with and without a nitrification inhibitor on N_2O production in soil from strawberries and the lettuce/broccoli rotation. N_2O production was predominantly due to nitrification of NH_3, not metabolism of NO_3^-. The inhibitor reduced N_2O production to control levels in both treatments. Therefore, even in the NO_3^- treatment, the majority of

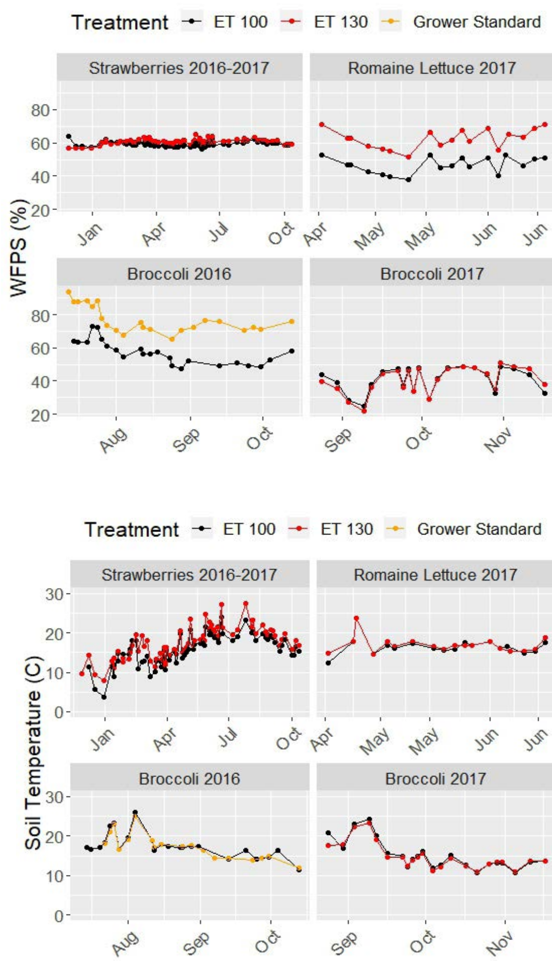

Figure 1. Respective mean percent soil water filled pore space (WFPS) and mean soil temperature at 0-15 cm depth during the times for N_2O sampling for all crops/ ields.

the N_2O production was via nitrification. The rates increased with increasing soil moisture. (Zhu 2013). The majority of fertilizer applied was ammonium sulfate. Previous field and lab scale research has shown that nitrification can be a significant source of N_2O after ammoniacal fertilizer additions (Bremner et al 1978, Zhu et al. 2013, Huang et al. 2014).

TAKE-HOME MESSAGE

This study validates the benefits of using CropManage as a decision support tool for irrigation and nutrient management of strawberries, lettuce, and broccoli in the Central Coast. These results demonstrate the efficacy of a 100% ET_c and N application regime at producing comparable yield to grower practice and 130% ET_c and N management. Additionally, reductions in direct and indirect N_2O emissions and NO_3^- leaching, associated with more efficient irrigation and nutrient management invariably reduce costs associated with water and N fertilizer use, helping farmers maintain a viable business while producing healthy crops at industry-standard competitive yields.

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Evaluation of the Multiple Benefits of Nitrogen Management Practices in Walnuts

Project Leader

Parry Klassen
Executive Director
Coalition for Urban Rural Environmental Stewardship (CURES)
klassenparry@gmail.com

Cooperator

Dave Hendley
Alpine Pacific, Ceres, CA

INTRODUCTION

Nitrate is a major contaminant in groundwater in the Central Valley region. Elevated concentrations in groundwater are primarily attributed to applied nitrogen fertilizers leaching past the root zone. Growers in the Central Valley are required through the Irrigated Lands Regulatory Program (ILRP) to keep an "on farm" Nitrogen Management Plan (NMP) to track nitrogen fertilizer applications. Coupled with information on yield, ILRP Coalitions are required to calculate the ratio of Nitrogen Applied to Nitrogen Removed. Implementation of management practices are focused on improving this ratio. However, there are knowledge gaps in understanding the effectiveness of these management practices for reducing the amount of nitrogen moving past the root zone in walnut orchards. This project documented the amount of nitrogen applied and the amount of nitrogen moving past the root zone using a combination of soil cores, soil water content, and soil pore water sampling. By capturing the movement of nitrate during both irrigation events and periods of winter rain, it is possible to assess the effectiveness of management practices on nitrate leaching.

OBJECTIVES

1. Identify the management practices being implemented to reduce the amount of nitrogen moving through the root zone for walnuts in three different management blocks.
2. Determine the amount and timing of nitrogen moving through the root zone.
3. Identify the multiple benefits of split applications including potential cost savings (reduced water costs, reduced amount of money spent on fertilizer) and groundwater protection (reduction in the amount of nitrogen that is moving through the root zone).
4. Determine if additional practices could be implemented in order to further reduce the amount of nitrogen moving through the root zone.
5. Disseminate results to walnut growers.

DESCRIPTION

Walnut orchards were split into three management blocks, East, Center, and West (Table 1). In 2016, a combination of microsprinkler fertigation, and broadcast fertilizer application followed by rain/flood irrigation was used to deploy fertilizer on the three blocks. All blocks received 3 applications of 50 lbs/acre of UAN 32. The West block nitrogen was delivered by fertigation and the East block received one 50 lb/acre broadcast application followed by flood irrigation. In 2017, only microsprinkler fertigation was used, although flood irrigation (without fertilizer) was used after applications were complete. The grower considered only synthetic fertilizer in determining the amount of nitrogen applied. The grower targeted a full season application of 200 lbs/acre, but used leaf tissue analysis to guide the amount of nitrogen applied. In both years, leaf tissue analysis indicated that sufficient fertilizer was applied at 150 lbs/acre. Groundwater containing 13 mg/L NO3-N was used as the primary irrigation source which resulted in the application of an additional 36 lbs/acre of nitrate per acre foot of irrigation water applied.

Table 1. Three treatments applied to the walnut blocks.

Date	Fertilization	West Block (lbs/acre NO_3N)	Center Block (lbs/acre NO_3N)	East Block (lbs/acre NO_3N)
3/11/2016	Banded before rain	50	50	50
5/17/2016	Fertigation	43	50	50
6/16/2016	Banded before flood	50	50	50
5/4/2017	Fertigation	43	50	25
5/15/2017	Fertigation	0	0	25
5/25/2017	Fertigation	43	50	25
6/5/2017	Fertigation	0	0	25
6/15/2017	Fertigation	43	50	25
6/26/2017	Fertigation	0	0	25

Water was collected using lysimeters placed at 4 ft (2016) and 4 ft and 10 ft (2017) to measure the amount of nitrate leaching past the root zone. A Welch's t-test used to determine whether the mean nitrate concentration differed between the three blocks for the 10 foot lysimeters found that the mean nitrate concentrations leaching past the root zone were significantly different ($p < 0.05$). A second Welch's t-test was conducted to examine whether mean nitrate concentrations were different for 4 foot lysimeters in the east block between 2016 and 2017. Results showed that the mean nitrate did not differ between the two years ($p = 0.1547$). A third Welch's t-test was conducted to examine whether the mean concentrations differed between the three blocks in the 4 foot lysimeters in 2016 and 2017. Results showed that the blocks were significantly different ($p < 0.05$) across years.

Three methods were used to estimate water leaching and N loading for each treatment; weekly mass balance, Darcy flux, and a direct modeling approach using HYDRUS 1D (Tables 2 and 3). The weekly mass balance was carried out as outlined by Baram et al. (2016). The weekly mass balance calculation overestimated nitrate load because of low resolution of concentration over time, particularly in 2016, but gives a reasonable estimate of leaching. The Darcy flux method also overestimated leaching because volumetric water content sensors, when calibrated against laboratory soil moisture using a one-point calibration, were 10% high on average. HYDRUS underestimated the water and nitrate leaching.

	Weekly Mass Balance (in/acre)		Darcy Flux (in/acre)		Hydrus (in/acre)	
	2016	2017	2016	2017	2016	2017
WEST	73	36	43	56	-13.75	-21.05
CENTER	67	32	39	61	0	5.68
EAST	64	34	71	76	0	5.6

Table 2. Three different method estimates of total water leached in inches/acre.

	Weekly Mass Balance (lbs/acre)		Darcy Flux (lbs/acre)		Hydrus (lbs/acre)	
	2016	2017	2016	2017	2016	2017
WEST	384	143	75	164	-13.31	-20.70
CENTER	842	149	82	20	0	1.7
EAST	93	49	61	12	0	5.6

Table 3. Three different method estimates of total nitrate leached in lbs/acre.

RESULTS AND DISCUSSION

Nitrate leaching depends upon the amount and timing of N and water inputs, the storage capacity of the soil, and the amount and timing of N uptake by the crop. During 2016, the cooperator used a combination of microsprinklers and flood irrigation during the period when fertilizer was applied. In 2017, during the period when fertilizer was applied, the grower used microsprinklers exclusively and rotated to flood irrigation after applications were completed. Despite the change in irrigation practices, nitrate was detected in the lysimeters at 4-ft in both 2016 and 2017, and in the 10-ft lysimeters in 2017. Although the 4-ft lysimeters may be considered as within the root zone, 10-ft lysimeters are almost certainly below the root zone indicating that some leaching is occurring, however, practices used in 2017 resulted in reduced leaching relative to 2016. In general, the median concentration of nitrate in lysimeters at 4-ft is lower than the concentration found at 10-ft although there is greater variability in concentration at 10-ft compared to 4-ft (Figure 1).

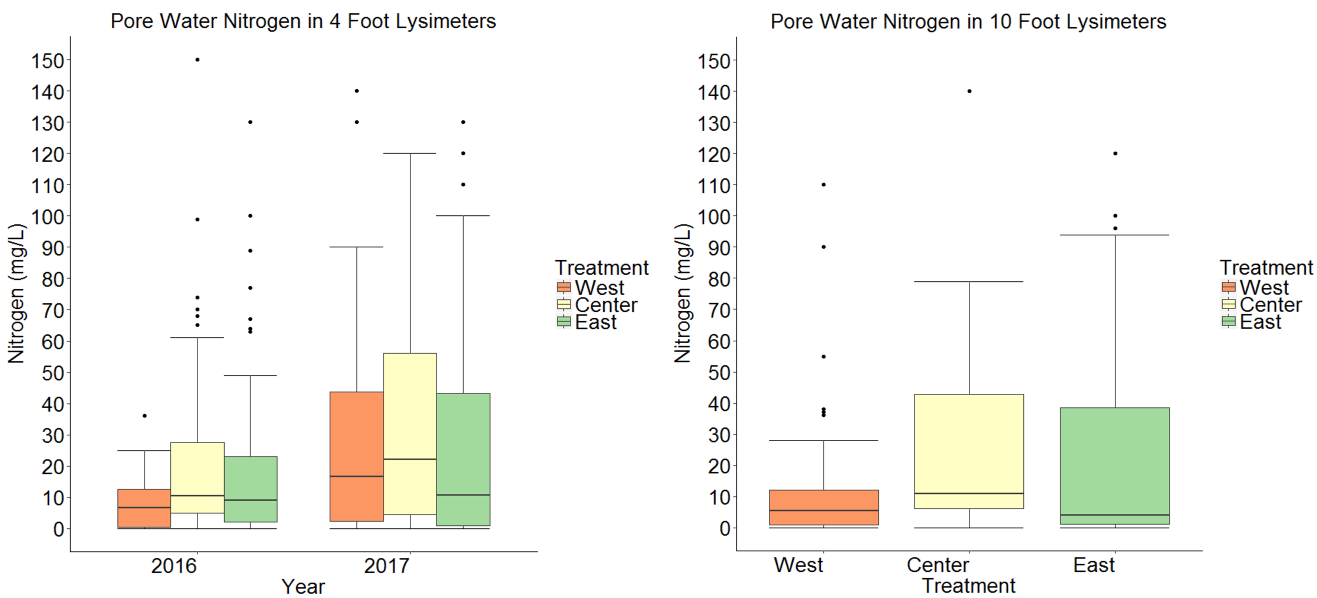

Figure 1. Nitrogen present in pore water samples collected from 4-foot lysimeters in the West, Center, and East blocks of the walnut orchard in 2016 and 2017 (left). Nitrogen present in pore water samples collected from 10-foot lysimeters in the West, Center and East blocks of the walnut orchard in 2017 (right). Outliers greater than 150 mg/L N have been excluded from these graphs, but have been included in boxplot calculations.

Table 2 indicates that there is a large amount of variation in nitrate leaching in the orchard blocks, even between monitoring locations that are in relatively close proximity. In most cases, the standard deviation of nitrate concentration is larger than the mean concentration suggesting significant heterogeneity in the soils even though the soils appear to be relatively homogeneous with between 83 and 88% sand. The apparent homogeneity of the soils and heterogeneity of the nitrate leaching suggests preferential flow paths are important in determining nitrogen leaching.

RECOMMENDATIONS

Management practices implemented by the grower include split applications and tissue sampling to determine whether supplemental, late-season N applications are needed. Tissue sampling that showed adequate nitrate levels in the tree resulted in a decrease in the late season application of 50 lbs/ac of fertilizer in both 2016 and 2017 growing seasons although the reduction was likely offset by the nitrogen present in the irrigation water. This translates to an overall reduction in fertilizer expense and potential leaching of nitrates to groundwater. An additional practice to further reduce nitrogen leaching includes adjusting the timing of the nitrogen fertilizer injection and to occur toward the end of an irrigation set to reduce the chance that water pushes nitrate past the root zone. The cooperator's practice is to inject nitrogen fertilizer at the beginning or middle of the irrigation set with the belief that the water moves the fertilizer into the root zone. Another potential practice is changing the form of liquid nitrogen injected to the system to include materials that show potential for improved plant uptake of nitrogen and slower conversion of nitrogen to a form that is more leachable to groundwater.

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Developing a Decision-Support Tool for Processing Tomato Irrigation and Fertilization in the Central Valley Based on CropManage

Project Leader

Daniel Geisseler
Assistant CE Specialist
Department of Land, Air and Water Resources
University of California, Davis
djgeisseler@ucdavis.edu

Cooperators

Brenna Aegerter
UCCE Farm Advisor
San Joaquin County, Stockton
bjaegerter@ucanr.edu

Mike Cahn
UCCE Farm Advisor
Monterey County, Salinas
mdcahn@ucanr.edu

Tim Hartz
CE Specialist
Department of Plant Sciences
University of California, Davis
tkhartz@ucdavis.edu

Gene Miyao
UCCE Farm Advisor
Yolo, Solano & Sacramento counties
Woodland
emmiyao@ucanr.edu

Tom Turini
UCCE Farm Advisor
Fresno County, Fresno
taturini@ucanr.edu

INTRODUCTION

Processing tomatoes are an important California crop grown on about 260,000 acres in 2016. Over the last 15 years, the wide adoption of drip irrigation by the tomato industry has resulted in a dramatic shift in production practices. During the same period, tomato yields increased from roughly 36 tons/acre to more than 50 tons/acre. This rapid shift from predominantly furrow irrigation to drip irrigation and the associated yield increase changed nitrogen (N) fertilizer management considerably, with fertigation through the drip system now being the most common practice.

To achieve high yields while reducing the risk of N losses, the time and quantity of irrigation water and fertilizer applications need to match crop demand. With stricter regulatory and reporting requirements and technological advances, which provide growers with more accurate but also increased amounts of data, computer based decision support tools are becoming a central component of field-specific crop management.

This project proposes to develop such a decision support tool for irrigation and N management in processing tomatoes based on the framework of an existing tool, CropManage, which has been successfully developed and introduced for cool season vegetables on the Central Coast.

OBJECTIVES

The main objective is to develop a web-based decision support tool for improved N and irrigation management of processing tomatoes. The specific objectives are:

1. Create a test version of CropManage for processing tomato production in the Central Valley based on literature data.
2. Collect soil and plant related data in commercial fields to develop robust equations and algorithms for the user version of the program.
3. Compare irrigation and fertigation management recommended by the program with grower's practices in a replicated trial at UC Davis' Russell Ranch.
4. Evaluate the program in monitoring fields in close collaboration with participating growers.
5. Develop the user version of CropManage based on the data collected and feedback received in objectives 2 through 4.
6. Conduct outreach activities and organize training workshops for growers and consultants.

RESULTS AND DISCUSSION

Collecting soil and plant related data in commercial fields

In 2016 and 2017, canopy development, available N and plant N uptake were monitored in eleven commercial processing tomato fields under subsurface drip irrigation (Table 1).

The seasonal changes in biomass N (vines and fruits) can be divided into three stages: slow initial N uptake during the first 3-4 weeks, rapid uptake phase, and leveling off during the final 3-4 weeks of the season (red line in Figure 1). At some sites, a slight decrease at the last sample date was observed.

Table 1. Location, soil type, transplanting dates and N in the aboveground biomass (vines and fruits) at harvest of the fields included in the study.

Year	County	Soil series	Date transplanted	Biomass N (lbs N/ac)	N in fruits (% of total)
2016	Yolo	Sycamore silty clay loam	April 12	332	64
		Maria silt loam	April 16	354	65
	San Joaquin	Hollenbeck silty clay	May 16	304	69
		Capay clay	May 12	297	61
		Egbert silty clay loam	May 4	300	67
	Fresno	Westhaven clay loam	May 9	318	59
2017	Yolo	Yolo silt loam	April 25	271	58
		Reiff very fine sandy loam	April 17	501	55
	San Joaquin	Capay clay	April 28	392	60
		Egbert silty clay loam	April 27	531	69
	Fresno	Westhaven clay loam	April 13	332	50
Average				357	62

Across all eleven sites, the total N in the aboveground biomass averaged 357 lb/ac (Table 1). Of this N, 62% was in the fruits at harvest and 38% in the vines. The fruits contained 3.1 lb N/ton. It took approximately 40 days for the plants to accumulate 40 lb N/ac. The N concentration in the vines decreased throughout the season.

Canopy development was measured by infrared camera. Canopy cover is used to calculate the crop coefficient (k_c), which, combined with the reference evapotranspiration (ET_0) from the nearest weather station, allows determining irrigation water needs.

Replicated trial at UC Davis

The data collected in the commercial fields are used to develop the algorithms in CropManage. To validate these calculations, a replicated field trial was carried out at UC Davis.

Nitrogen uptake was estimated based on the results from commercial fields in 2016. The expected yields were 55 and 58 tons/ac in 2017 and 2018, respectively. Subtracting residual soil nitrate and N in the irrigation water, the fertilizer N requirements were estimated to be 225 lb/acre in 2017. This application rate includes starter N and assumes an N use efficiency of 90% (Table 2). In 2018, a credit for in-season N mineralization was included. Based on results from a different study, it was estimated to be 40 lb N/ac. With these N credits, the optimal N application rate, including starter fertilizer, was estimated to be 180 lb/ac.

Table 2. Nitrogen budget for the replicated trial at UC Davis in 2017 and 2018.

N sinks and sources	2017		2018	
Expected yield	55 t/ac		58 t/ac	
N uptake		247 lb/ac		261 lb/ac
N in irrigation water	0 lb/ac		0 lb/ac	
Residual soil nitrate	47 lb/ac		59 lb/ac	
N mineralization	----		40 lb/ac	
N credits		47 lb/ac		99 lb/ac
N uptake from fertilizer		200 lb/ac		162 lb/ac
Fertilizer N efficiency	90%		90%	
Fertilizer application rate (incl. starter)		225 lb/ac		180 lb/ac

In both years, irrigation water need was calculated based on modeled canopy development and average weather data of the previous four years. Irrigation water requirements were recalculated weekly based on the current years' weather data and corrections were made if necessary.

The trial included four treatments, each replicated five times. Each plot was 200 feet long and three beds wide. Three N rates, irrigated at 100% ET, were included, namely estimated fertilizer need (Table 2), fertilizer need minus 50 lb N/ac, and fertilizer need plus 50 lb N/ac. The fourth treatment received the estimated fertilizer amount but was irrigated at 130% ET.

In 2017, the marketable yield averaged 58 tons/ac. There was no significant difference among treatments. Plant analyses revealed that N uptake increased with increasing N application rate, but this had no effect on yield. In 2018, the average marketable yield was 63 tons/acre. Yield increased with increasing N application rates from 58 to 69 tons/acre. While the differences were not statistically significant, the results suggest that the expected yield could be produced with less fertilizer N than calculated. Plant samples have not yet been analyzed, but it is likely that biomass N increased with increasing fertilizer application rates, as it did in 2017, indicating that plants do not need to take up as much N as estimated to produce maximum yield. It is also possible that access to nitrate the dry topsoil is better than assumed. This hypothesis needs further investigation. Our results also indicate that ET values based on canopy cover did not underestimate tomato water requirements.

The results of this project provide a science-based approach to estimate site-specific irrigation and N application rates that minimizes the risk of N losses and ensures high yields. However, many factors affect N and water needs. Therefore, it is important to monitor soil moisture and plant N status of the field during the season so that adjustments can be made if necessary.

The results were used to add processing tomatoes to CropManage, which allows for site-specific irrigation scheduling and N management with in-season adjustments based on soil nitrate tests (online at https://v3.cropmanage.ucanr.edu/). In addition, a simple N calculator for drip irrigated processing tomatoes was created. The calculator can be used as a planning tool (Figure 1).

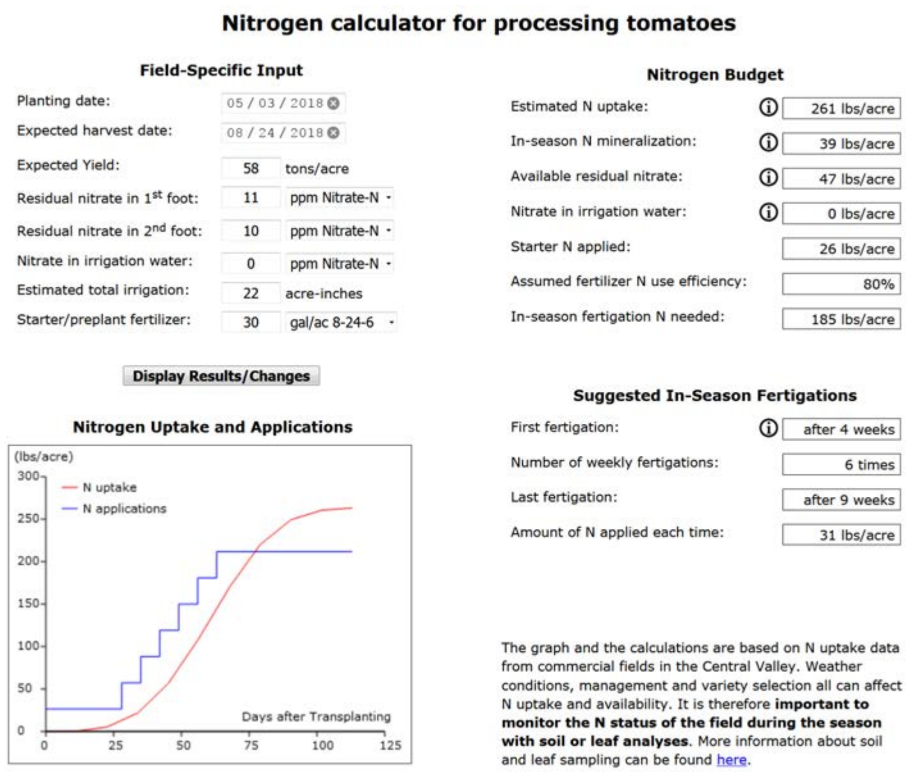

Figure 1. Based on the results of this project, a simple N calculator was developed. A test version of the calculator can be accessed online at http://geisseler.ucdavis.edu/Tomato_N_Calculator.html

ACKNOWLEDGEMENTS

We thank Kelley Liang, Irfan Ainuddin and the San Joaquin County Cooperative Extension field team for their excellent work in the field and laboratory. We also thank the growers for their collaboration. Funding for this project was provided by the CDFA Fertilizer Research and Education Program.

Prediction of Summer Leaf Nitrogen Concentration from Early Season Samples to Better Manage Nitrogen Inputs at the Right Time in Walnuts, Prunes, and Pears

Project Leaders

Patrick Brown
Professor
Department of Plant Sciences
One Shields Ave.
University of California, Davis,
CA 95616
530 752-0929
phbrown@ucdavis.edu

Emilio Laca
Professor
Department of Plant Sciences
One Shields Ave.
University of California
Davis, CA 95616
530 754-4083
ealaca@ucdavis.edu

Sebastian Saa
Project Scientist
Department of Plant Sciences
One Shields Ave.
University of California
Davis, CA 95616
530 752-0929
ssaasilva@ucdavis.edu

Cooperators

Katherine Pope
Cooperative Extension
Yolo County
70 Cottonwood Street
Left Side of Building
Woodland, CA 95695
530-666-8733
kspope@ucanr.edu

Franz J.A. Niederholzer
University of California
Cooperative Extension
Sutter-Yuba Counties
142A Garden Highway
Yuba City, CA 95991-5512
(530) 822-7515
fjniederholzer@ucanr.edu

Chuck Ingels
University of California
Cooperative Extension
4145 Branch Center Rd.
Sacramento, CA 95827-3823
(916) 875-6527
caingels@ucanr.edu

Elana Peach-Fine
Program Analyst
International Programs Office
One Shields Ave.
University of California
Davis, CA
(530) 554-9535
elana.ipo@gmail.com

Rachel B. Elkins
UC Cooperative Extension
883 Lakeport Boulevard
Lakeport, CA 95453
(707) 263-6838
rbelkins@ucanr.edu

Dani Lightl
UC Cooperative Extension
Glenn County
PO Box 697
821 E. South Street
Orland, CA 95963
530-865-1153
dmlightle@ucanr.edu

Amber Bullard
Graduate Student
Department of Plant Sciences
One Shields Ave.
University of California
Davis CA, 95616
anbullard@ucdavis.edu

INTRODUCTION

Increasing awareness of the environmental impact of excess nitrogen (N) and new N management regulations demand user-friendly tools to help growers make fertilization decisions. Leaf nutrient analysis, is the most widely used monitoring tool to track tree nitrogen status. To use this methodology, growers currently collect leaf samples in summer and then send leaves for lab analysis to compare their values against established standard critical values for summer. However, sampling in summer is too late in the season to adjust current season nitrogen management if needed. This problem was evident in almonds when an industry-wide grower survey was conducted in 2007. The results of this survey suggested that leaf nutrient sampling could be very useful for fertilization management, but only if there were ways to collect and interpret leaf analysis results in the spring rather than the late summer as currently practiced.

From 2009 to 2012 a successful CDFA-FREP project ("Development of leaf sampling and interpretation methods for Almond and Pistachio") was conducted and achieved the goal of developing a robust early season sampling protocol for almonds and pistachios under the direction of Brown, Saa, and Laca at the University of California, Davis. The results of this project were implemented by the almond and pistachio industries in 2013 and so far have contributed significantly to the improvement of nitrogen management in these crops. In addition, implementation of this tool has been adopted by important commercial labs in California (i.e. Fruit Growers Laboratory, Inc.) and has been made available for all private and commercial users free of charge.

Similar to the work done in almonds and pistachios, this new FREP project aims to develop tools that can predict tree nitrogen status for commercially grown walnuts, prunes and pears. California growers of walnuts, prunes and pears are the primary audience that will benefit from this research. Commercial analytical labs will also benefit by offering an improved product to their customers. The walnut, prune and pear industry will benefit by improving compliance with current and future N regulations as well as improving the quality of their products. Consumers and the general public will also benefit from an improved supply of healthy fruits and nuts with decreased environmental impacts.

Overview of the work accomplished to date and remaining work to be done: data collection, survey collection, and model development have now been completed. Spring validation data has already been collected and collection of summer validation data is currently in progress. Spring data has already been analyzed and filtered. A literature review to update model parameters is also under way. Model validation should be complete by December, 2017. An agreement has been reached with the UC Davis Plant Science IT department to host and develop the user-friendly interface with our models. We will begin to work more closely with them on this after we have completed model validation in December. A videographer has completed filming on a series of demonstrational videos on leaf sampling. A peer-reviewed publication is being drafted and will be completed in January 2018.

OBJECTIVES

This project is designed to achieve the following three objectives:

1. To develop a leaf nitrogen prediction model using spring collected samples to predict late summer tissue values. This will allow growers to better manage nitrogen in nut (walnuts) and fruit (prunes, pears) orchards in California by sampling 30 representative orchards for each of three species during 2016 and 2017.
2. To create a user friendly online interface to help growers, extension specialists and consultants design nutrient plans based on early season leaf samples for walnuts, prunes and pears as well as pistachios and almonds (for which models have already been developed).
3. To promote the use of this tool, and an understanding of these models, to better manage nitrogen inputs at the right time in these nut and fruit trees.

The achievement of these objectives will allow for early season monitoring of N application that will help achieve the “right rate and “right time” of N application.

RESULTS AND DISCUSSION

Three final candidate models were developed and cross validated in this experiment. Results show that the three models can accurately predict leaf nitrogen concentration in summer for each cultivar, but the level of precision and inputs needed to make the predictions differ. The most precise model (“Model 1”) requires a combination of leaf nutrient, soil nutrient, and orchard management input (i.e. yield, and in season nitrogen applications) to estimate summer leaf values. While this model is very precise, the amount of data needed to produce an output makes it impractical and not user-friendly for the majority of growers. The second model “Model 2” requires spring leaf nutrient values, excludes soil variables, but also asks for in season nitrogen management inputs. Model adoption of Model 2 is predicted to be low as not only nutrients in spring, but also in season nitrogen management need to be provided by the user. The third model (“Model 3”) only requires spring leaf nutrient data to make accurate predictions of leaf nitrogen values in summer. This model has a bigger variance than the other two models, but it is easier to use. Table 1 below summarizes the statistical characteristics of each of the models, as well as, the inputs needed to perform summer leaf nitrogen predictions.

Table 1. Summary of the statistical characteristics for each of the selected and statistically validated models, as well as the equations and inputs needed to perform summer leaf nitrogen predictions.

Model 1							
Model Inputs*	crop + NMayJul + spSoilNO3 + spSoilExK + ilr1 + ilr2 + ilr4 + ilr5 + ilr6 + crop:ilr1 + crop:ilr4.						
Model performance**	R^2 0.93	sigma.hat 1.689	cv.rsq 0.87	cv.sigma.hat 2.068	n 61	MOEconf 0.4	MOEpred 3.8
Model 2							
Model Inputs*	crop + spLeafN + NMayJul + ilr4 + ilr7 + ilr4:spLeafN + ilr7:ilr4 + crop:spLeafN.						
Model performance**	R^2 0.91	sigma.hat 1.815	cv.rsq 0.89	cv.sigma.hat 1.983	n 61	MOEconf 0.5	MOEpred 4.1
Model 3							
Model Inputs*	crop + spLeafN + ilr4 + ilr8 + ilr8:ilr4 + crop:spLeafN						
Model performance**	R^2 0.73	sigma.hat 2.851	cv.rsq 0.71	cv.sigma.hat 2.967	n 120	MOEconf 0.5	MOEpred 6.2

*NMayJul is the in season nitrogen applied between spring and summer."ilr" are inverse log ratios as explained by Modesto et al. (2014). "sp" refers to spring values.

**"MOE" is margin of error or Confident Interval radius. "conf" refers to making a prediction for the population parameter. "pred" refers to making a prediction for an orchard. "cv" means cross-validation. Units are parts per thousand.

Therefore, model three was selected to create a user-friendly online interface to help growers, extension specialists and consultants design nutrient plans based on early season leaf samples for walnuts, prunes and pears as well as pistachios, and almonds (for which models have already been developed). This user-friendly model is still under development, but except for a few parameters for pear, all the other parameters have been integrated. In summary, the model under development follows the "Nitrogen Budget" approach and consists in the following:

1. User is prompted to answer questions to estimate nitrogen credits from the irrigation water, manure, compost, and cover crops.
2. User selects the cultivar (almond, prunes, pears, or walnuts)
3. Then, user inputs the estimated yield for the current season and the spring leaf nutrient values.
4. The model outputs the recommended rate of nitrogen application and the recommended phenological date to apply such rate during the season.

The above logic and parametrization of the model were obtained by doing the following:

1. State of the art analysis: analysis of the literature available until December 2017.
2. Data collected in this grant.

3 Data collected in collaborative grants funded by CDFA-FREP, Almond Board of California, Pistachio Research Board of California, Walnut Board of California, and CDFA -SCBG.

4 Partnership with “Crop manage” modeling tool and its associated CDFA-FREP grant.

The model is expected to be launched by the end of 2018.

ACKNOWLEDGEMENTS

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Evaluation and Demonstration of Nitrogen and Phosphorus Management in Organic Leafy Green Vegetable Production on the Central Coast

Project Leaders

Richard Smith
UCCE Vegetable Crops Farm Advisor, Monterey, San Benito and Santa Cruz Counties
1432 Abbott Street
Salinas, CA 93901
831 759-7357
rifsmith@ucdavis.edu

Mike Cahn
UCCE Irrigation Farm Advisor
Monterey, San Benito and Santa Cruz Counties
1432 Abbott Street
Salinas, CA 93901
831 759-7377
mdcahn@ucdavis.edu

T.K. Hartz
Extension Specialist
Department of Plant Sciences
University of California
1 Shields Ave
Davis, CA 95616
530 752-1738
tkhartz@ucdavis.edu

Daniel Geisseler
Extension Specialist
Department of Land, Air and Water Resources
1 Shields Ave.
Davis, CA 95616
530 754-9637
djgeisseler@ucdavis.edu

INTRODUCTION

Organic production in Monterey County was worth $365 million in 2016, which was 9% of total agricultural value. Leafy green vegetables such as spinach, baby lettuces, spring mix and leaf lettuces are a large portion of the production, but cole crops, celery and other vegetable crops are also produced. Large-scale production continues to expand given strong market demand. The central coast is a key center of production of leafy green vegetables due to optimal climatic conditions and the sales & shipping infrastructure in the area. Little science-based information is available for managing nitrogen (N) in organic production. Fertilizer practices vary widely among growers and potential tools such as measurements of residual soil nitrate or estimates of mineralizable N are not commonly taken into considered when making fertilizer decisions. The industry relies heavily on organic N fertilizers and amendments, mostly derived from animal by products that often have high N:phosphorus (P) ratios. Management of P in organic production systems is an important challenge because of its potential to adversely affect surface water quality.

A substantial body of research is available describing the expected N mineralization behavior of common organic fertilizers and amendments, but there are substantial differences among research sources, which cloud the issue and leads to grower uncertainty. Fertilizer programs could be more efficient by adjusting fertilizer application rates based on residual soil N as well as information on N that may mineralize from soil organic matter. This would improve N use efficiency and help reduce elevating soil P levels beyond what is needed agronomically.

OBJECTIVES

1. Demonstrate and evaluate the proportion of crop N needs that are provided by soil organic matter mineralization in organic leafy vegetable production under coastal climate conditions.
2. Demonstrate and evaluate mineralization behavior of a group of commonly used dry and liquid organic fertilizers under field conditions on the Central Coast
3. Demonstrate and evaluate the N and P balance of organic production fields (N and P inputs, mineralization and removal)
4. Refine and update algorithms of nitrate mineralization from soil organic matter in CropManage
5. Conduct outreach to growers via demonstration plots and UC nutrient management meetings, newsletters articles, blogs and scientific reports.

DESCRIPTION

Twenty total evaluations were conducted in 2016 and 2017 in commercial vegetable production fields with cooperating growers. The following assays were conducted: total N content of the soil, organic matter content and weekly measurements of mineral N in the top 12 inches of soil, nitrate in the water and water extractable N and C. In-field and laboratory assays of N mineralized from soil organic matter were conducted. Crop yield and biomass N were evaluated at harvest.

Field evaluations of N and P release from organic dry fertilizers were conducted to determine the efficiency of release given the short crop cycle of both baby and full-term romaine lettuces. Fertilizer was placed in polypropylene pouches and placed into the soil; they were removed at weekly intervals and the remaining fertilizer residue was measured for N and P content. Laboratory incubations of dry and liquid fertilizers were also conducted.

RESULTS AND DISCUSSION

Evaluation sites included soil types from loamy sands to clays. In-field estimates of soil mineralization over the course of the cropping cycle were conducted at each site; on unfertilized plots, plastic mulch was installed to eliminate the influence of crop N removal and leaching, thereby providing an estimate of N mineralization from the soil. This technique was successful in most of the evaluation sites. The average amount of nitrate-N that mineralized from soil organic matter over all sites was 1.7 lbs N/A/day, with a range of 0.3 to 3.3 lbs N/A/day. Fertilizer applications increase the yield of the crops in 17 of 20 sites. Lettuce and spinach take up 3.5 and 5.0 lbs N/A/day during their period of peak growth, respectively which illustrates that in most cases, these fast maturing, high-N demanding crops cannot achieve maximum growth from mineralization of organic matter alone. This amount of residual soil nitrate-N at the beginning of the cropping cycle was a useful indicator of the amount of fertilizer needed for crop growth (Figure 1); however, water applied to germinate the crop may reduce the utility of this measurement if nitrate is leached beyond the reach of the crop roots. Nevertheless, early-season testing is a useful option for evaluating the soil N status for short-season vegetables. There is not enough time to react to soil test results later in the crop cycle because of the amount of time it takes for organic fertilizer to release sufficient mineral nitrogen to supply crop needs.

Field evaluations of N mineralized from 4-4-2 dry fertilizers were conducted. Polyethylene pouches of this fertilizer were placed on the soil surface (to simulate a drop-on-top fertilizer application) or buried 3-4 inches deep in the soil (to simulate incorporated fertilizer application). The dry weight and N content of the fertilizer in the pouches declined rapidly from day 0 to day 10 and then declined more slowly and steadily thereafter (Table 1). The average amount of N released over two years of evaluations for pouches placed on the soil surface and buried was 42 and 62%, respectively indicating that incorporation of the fertilizer was more efficient at supplying N to the crop. An evaluation of 12-0-0 in 2017 showed the same trend (Table 1).

Relatively high amounts of fertilizer P was applied to the crops at all sites because 4-4-2 has a 1:1 N:P_2O_5 ratio. We expected that the use of this material would lead to a large buildup of P in the organic soils. However, 4-4-2 fertilizer is a blend of chicken manure and meat and bone meal, and the P from the bone meal is insoluble at the soil pH's (>7.2) encountered at all sites in this study. Despite the high amounts of P applied to these crops, average soil bicarbonate P values were 42 ppm over the 20 organic sites which was just slightly higher than comparable conventional sites. We assume that the P applied in these fertilizers that is from bone meal is not soluble due to the high soil pH's. In addition, in the fertilizer pouch evaluations, only 17% of the P in 4-4-2 was released from the fertilizer in either surface or buried applications.

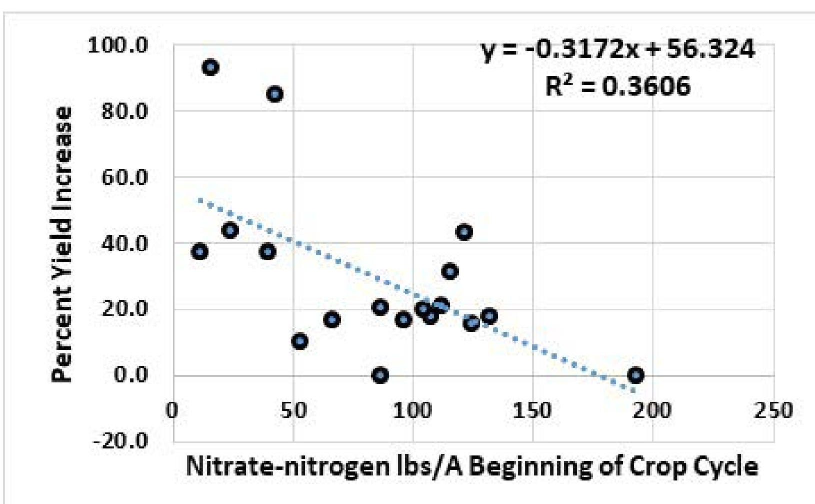
TAKE-HOME MESSAGE

Moderate amounts of nitrate-N are mineralized from soil organic matter over the course of the crop cycle. However, short-season leafy green vegetables have a high N demand during the last half of their crop cycle which greatly exceeds the ability of the soil to provide sufficient N to achieve optimal yield. Measurements of residual soil nitrate-N at the beginning of the crop cycle provides the most useful tool that we encountered in this study for adjusting fertilizer applications. However, the measurements need to be taken prior to planting or very early in the crop cycle to allow enough time for the fertilizer to effectively mineralize and provide mineral N that the crop can use during the crop cycle. The P contained in fertilizers such as 4-4-2 is not readily soluble and does not appear to be building up high levels of bicarbonate extractable P in soil. This is due to the fact that a large portion of the P in 4-4-2 is from bone meal and is not soluble at soil pH's greater than 7.2 which were found at all sites in these evaluations.

Table 1. Percent of N released from 4-4-2 in surface and buried applications 2016-17, and percent of N release from 12-0-0 from surface and buried applications in 2017

2016			2017				
4-4-2			4-4-2			12-0-0	
Days	Surface	Buried	Days	Surface	Buried	Surface	Buried
0	0	0	0	0	0.0	0.0	0
10	30	50	7	24	30	13	31
18	31	61	15	26	46	12	59
25	36	65	22	25	50	12	75
31	34	64	28	33	51	15	79
38	42	66	36	35	51	14	82
44	45	68	42	33	51	17	84
52	47	69	51	34	52	26	84
60	50	66	55	36	54	32	86
63	48	70	---	---	---	---	---

Figure 1. Relative yield increase vs residual soil nitrate-N at the beginning of the crop cycle



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Understanding Influences on Grower Decision-Making and Adoption of Improved Nitrogen Management Practices

Project Leaders

Mark N. Lubell
Professor
Dept. of Environmental Science and Policy
University of California Davis
mnlubell@ucdavis.edu

Patrick H. Brown
Professor
Department of Plant Sciences
University of California Davis
phbrown@ucdavis.edu

Collaborators

Jessica M. Rudnick
Graduate Student Researcher
Dept. of Environmental Science and Policy
University of California Davis
jrudnick@ucdavis.edu

Sat Darshan S. Khalsa
Assistant Project Scientist
Department of Plant Sciences
University of California Davis
One Shields Avenue
Davis, CA 95616
sdskhalsa@ucdavis.edu

INTRODUCTION

Adoption of improved nitrogen (N) management practices by California growers is a required step in reducing N movement into surface and groundwater and maintaining economically viable cropping systems, while satisfying the Irrigated Lands Regulatory Program (ILRP) requirements. Research over the past decade has identified many practices that can improve N management and maintain economically viable cropping systems. These practices include the use of N budgets to balance N inputs and outputs for individual field units; implementation of the "4R's" (right rate, time, place, and source); the use of leaf and soil N sampling for verification of crop nutrient status and residual soil N; appropriate integration of fertilizers with irrigation; enhancing soil health to improve nutrient retention; and careful deployment and management of micro-irrigation systems for efficient water use. Despite progress in the development of N management practices, there is insufficient understanding regarding the current rate and barriers to practice adoption.

Recent research has suggested a number of possible factors influence grower decision-making, including perceptions of risk, economic and labor constraints, social norms, sources of trusted information, social capital and networks, farm characteristics including size and income, and participation in local policy forums (Knowler and Bradshaw 2007, Lubell and Fulton 2008, Prokopy et al. 2008). However, we do not have a robust understanding how these factors relate to adoption rates of improved N management practices across the diverse geographies and grower demographics of the Central Valley. This includes the role of different types of policy tools and outreach strategies for influencing farmer behavior.

This project aims to (i) develop an understanding of the current status of grower adoption of improved N management practices, (ii) determine the key influences on grower decision-making, and (iii) identify the key incentives and barriers to enhanced adoption of improved management practices. The information developed will inform stakeholder groups including regional Water Quality Coalitions, UC Extension, private consultants, State Water Boards, commodity groups and others to inform policy-making and improve N management.

OBJECTIVES

1. Develop a qualitative understanding of key influences and barriers to adoption of improved N management practices in the regions represented by the San Joaquin County & Delta Water Quality Coalition (SJDWQC) and the East San Joaquin Water Quality Coalition (ESJWQC).
2. Distribute, collect and aggregate quantitative survey following Dillman method data from growers in SJDWQC and ESJWQC (Dillman et al. 2008).
3. Analyze both qualitative and quantitative response data to determine key motivations and barriers to grower adoption of improved N management practices.

DESCRIPTION

The project and research approach consisted of multiple steps of qualitative and quantitative data collection coupled with analysis and outreach. In order to qualitative understanding of adoption of improved N management practices, we conduct semi-structured interviews with growers in each of the SJDWQC and ESJWQC regions to better understand their use of N management practices and the social, political, and economic factors influencing adoption of practices. In winter 2017 in conjunction with regular SJDWQC and ESJWQC meetings, we hosted voluntary grower focus groups using "clickers" and paper surveys. We quantified which practices are most in use in each region and why, perceived costs and benefits of each used and unused practice, greatest challenges to adopting new practices, additional soil health practices that appeal for multi-benefit purposes, sources of information most important in each region and their opinions on effective N management practices.

RESULTS AND DISCUSSION

Results include a combination of grower meetings surveys and qualitative assessments with growers and other stakeholders. Three major themes emerged from these preliminary results:

Management practices are more easily adopted on large parcels and in permanent crops.

Growers operating on large parcels (Fig. 1) and in perennial crop systems (Fig. 2) report significantly higher adoption rates for nearly all practices and adopt a greater number of practices on average on their farms. These growers also name fewer challenges hindering practice implementation and associate a greater number of benefits with practice adoption.

Growers operating on large parcels report contact with more information sources on N management, with more than 50% of large parcel growers reporting contact with 4 or more different information sources (Fig. 3) water quality coalitions (WQCs) and PCAs are only entities where there are not significant differences between large and small parcel growers, meaning these two entities act as an important source that have likelihood of equally providing information to large and small operations. Through qualitative work we have heard feedback such as, UCCE is less helpful to small growers; well-resourced industry groups are limited for annual crops; economies of scale matter; access and usefulness of "unbiased" information sources on management practices have decreased and much of this information comes from private consultants and industry representatives.

The effect of water management on N movement is underappreciated by growers.

Fertilizer and soil management practices are more commonly adopted and more closely associated with improved N management, than irrigation practices. About 50% of respondents associate positive benefits of NUE and improved soil health with fertilizer and soil management practices. About 40% of respondents associate positive benefits of water savings, drought adaptation, excessive rainfall adaptation, extreme temperature adaptation with irrigation practices. Mental models do not connect irrigation practices to N movement or soil benefits and vice versa.

Water source, surface water or groundwater, influences practice adoption ($p=0.13$), surface water users are more likely to adopt irrigation practices. We hypothesize this is because surface water users receive water in one delivery and must be strategic and careful with water use. Surface water users also associate greater benefits across all management practices. Qualitative work suggests that growers perceive a large change in attention to water management post-drought and an increase in drip irrigation will assist in N management goals, but maybe aren't associated yet.

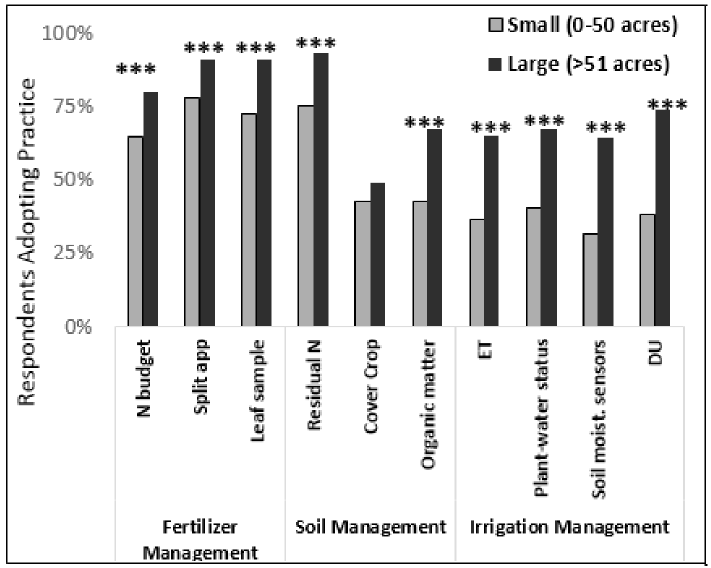

*Figure 1. Adoption rates of farm management practices in three different areas- fertilizer, soil and irrigation management, differ significantly between large parcel and small parcel growers for all practices but one (*** p<0.001), where large parcel growers more frequently adopt each practice.*

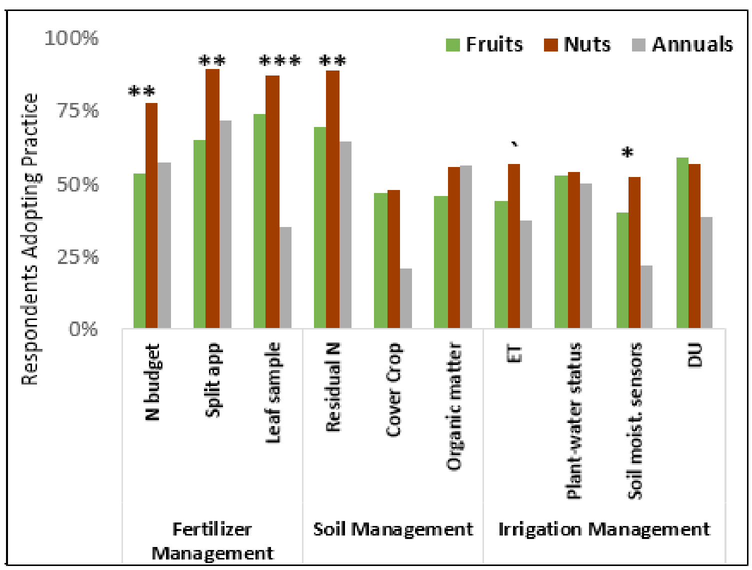

*Figure 2. Adoption rates of farm management practices in three different areas- fertilizer, soil and irrigation management, differ by crop type (fruits, nuts and annual crops) (*** p<0.001, **p<0.005, *p<0.01), where large parcel growers more frequently adopt each practice.*

Uncertainty is the largest perceived challenge with adoption of any practice and improved crop yield & crop quality are the most commonly associated benefits with decisions to implement practices.

Adopters largely report no challenges with practices. This result confirms our hypothesis that higher adoption would be correlated with few barriers. Uncertainty was named most commonly as a challenge for every practice (and more commonly on small parcels than large parcels for all practices except cover cropping). Improving yield and crop quality are largest recognized benefits for all management areas; with ~70% of respondents indicating these benefits are important for them in making their management decisions. Qualitative work affirms that it is most important to discuss the on-farm reasons for doing something, and that messag-

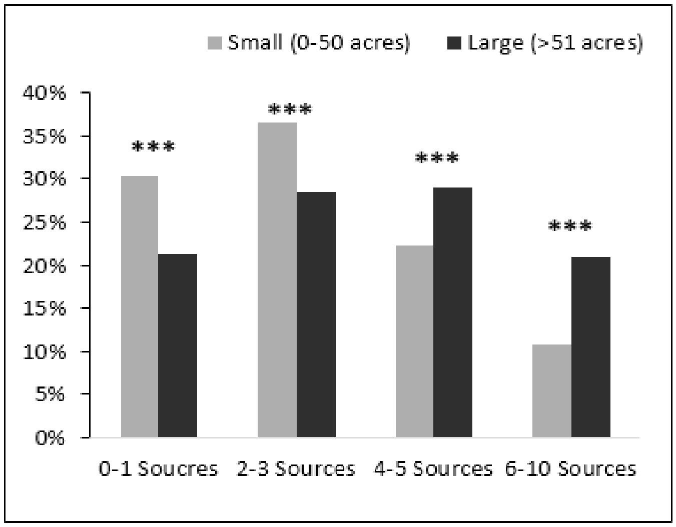

*Figure 3. Growers were asked how many informa-tion sources they were in frequent contact with regarding N management decisions. Large parcel growers contacted more information sources on average (4 or more) than small parcel growers (***p<0.001).*

ing must address risks associated with practice, benefits to crop from practice, and should emphasize end goals. If practices do not help the farm itself, they must be incentivized or subsidized.

CONCLUSIONS

Adoption of N management practices was identified for multiple regions in California. In general, management practices are more easily adopted on large parcels and in permanent cropping systems like nut crops. Overall, the effect of water management on N movement is underappreciated by growers. More work is needed to identify the connection between fertilizer and irrigation practices as related to N management. Uncertainty is the largest perceived challenge with adoption of any practice and improved crop yield and crop quality are the most commonly associated benefits with decisions to implement practices.

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University of California Nursery and Floriculture Alliance Fertilizers and Plant Nutrition Education Program

Principal Investigator

Lorence Oki
Associate Specialist in Cooperative Extension
CoDirector, UC Nursery & Floriculture Alliance
lroki@ucdavis.edu

Co-Principal Investigators

Dave Fujino
Executive Director, CCUH
CoDirector, UC Nursery & Floriculture Alliance
dwfujino@ucdavis.edu

Maria de la Fuente
UCCE Monterey County Director
Farm, Master Gardener & Compost Advisor
medelafuente@ucanr.edu

Donald Merhaut
Associate Extension Specialist
UC Riverside
donald.merhaut@ucr.edu

Project Manager

Leticia Macias
Program Representative
UC Nursery and Floriculture Alliance
lemacias@ucdavis.edu

INTRODUCTION

Fertilizers are an essential part of greenhouse and nursery plant production. Crops in these production systems are grown in substrates that are "synthetic" in that they contain very little or no natural mineral soils. Since there is little to no fertility provided by these substrates, all of the nutrition must be provided by fertilizers for healthy and productive growth. In California, the majority of these crops are grown in containers, although there is some field production of specific nursery and floricultural crops. In either case, since these crops are grown in highly intensive systems of high plant densities and compressed crop times, there is also a high demand for resources including water, energy, labor, and nutrients. The recommended fertilization rates of some floricultural crops can be very high compared to other agronomic crops. For example, a liquid feed program for poinsettia typically provides nitrogen at 250 ppm but can be as high as 400 ppm.

Improper management of plant nutrition can affect crop health and both under- and over-applying fertilizers can result in poor crop quality. Poor crop quality not only has negative economic impacts, but improperly managing plant nutrition can also result in wasted fertilizer products and the pollution of surface and ground water and other environmental impacts.

To provide greenhouse and nursery growers with knowledge to improve crop plant nutrition and fertilizer management, this project develops an educational program for greenhouse and nursery growers on the proper and efficient use of fertilizers.

This project addresses the Education and Outreach (Technical Education) area of grower education and consists of evaluation and improvement of a current workshop program on Fertility and Plant Nutrition for greenhouse and nursery growers. The improved course of workshops will be translated into Spanish and delivered in up to four areas of the state in 2017 and 2018. Short specific topic videos will be produced in both English and Spanish and delivered on the University of California Nursery and Floriculture Alliance (UCNFA) website.

OBJECTIVES

1. Provide greenhouse and nursery growers with knowledge to improve crop plant nutrition and fertilizer management.Develop an educational program for greenhouse and nursery growers on the proper and efficient use of fertilizers.
2. Produce online videos on plant nutrition and fertilizers in English and Spanish

DESCRIPTION

Improve the program. The existing workshops provided by UCNFA on this topic were reviewed and improved.

1. Define learning objectives.
   The current program delivered was be shared among project participants to

reexamine learning objectives. Learning objectives were defined and organized into specific workshops.

2 Program assessment
The workshop program, in conjunction with evaluations from the 2016 presentations, were reviewed to assist with an assessment of the program.

3 Program adjustment and rebuilding
Adjustments were made accordingly for improvement and additional learning modules were developed to meet learning objectives. Topics for each workshop were determined and agendas developed.

4 Teaching materials (powerpoint slides and handouts) were translated into Spanish.

5 Syllabi for each workshop were written describing the content to be taught.

Deliver program. The improved workshops were delivered to further identify pertinent and refine information for videos.

1 Workshops using the revised program were organized and delivered in four regions based on grower density.

2 Instructors among the project team were identified for each workshop date and location.

3 Up to four events will take place.

4 After the first year (2017), workshops were revisited and evaluated to determine success in meeting learning objectives.

5 Adjustments were made based on the assessment of the year 1 presentations.

6 Additional workshops, up to a total of six for both years, will be provided using the newly adjusted program.

Produce videos. Short videos on specific topics are being developed.

1 The workshop syllabi and programs were used to develop scripts for videography of the workshop content.

2 Videos are being produced, taped, and edited to develop online training.

Post videos. Videos will be posted on the UCNFA website.

Measure impacts. Learning will be assessed to determine the effectiveness of the programs.

1 Short term learning. Attendees will complete evaluations of the workshop to assess program effectiveness.

2 Long term impacts. Workshop attendees would be asked to participate in a survey after the first year that workshops have been conducted to assess longer term impacts. A follow-up survey will be developed by the project team and distributed by email. Information will be sought regarding the implementation of management methods presented in the workshops.

3 Impact of videos. Effectiveness of the online videos will be measured by tracking the number of views of the videos. Specific information will be gathered on the number of complete and incomplete views of each video, multiple views by a single user, identifying the videos with the most and least views, and other measures.

4 All response results will be compiled, analyzed, and reported.

Figure 1. Introductory screen of training videos

RESULTS AND DISCUSSION

We have successfully completed the assessment of the program that existed at the initiation of the project and revised it into two half-day workshops to improve topic flow and to include up-to-date information. Each workshop presented topics in English in the morning followed by the Spanish version in the afternoon. We delivered the revised program in Salinas with Part 1 presented on January 11, 2018, and Part 2 on February 20, 2018, at the UC Cooperative Extension Monterey County auditorium. These workshops were used to evaluate edited versions of these programs that were offered in previous years to assess the feasibility of presenting the topics via video. We discovered that the video content can be made more concise compared to the manner of an in-person workshop. However, there are limitations on the depth and breadth of content that can be included in videos.

ACCOMPLISHMENTS

We have ongoing regular monthly meetings scheduled with supporters and cooperators where we update them on project activities. We develop promotional materials in English and Spanish for the UCNFA website, UCNFA weekly announcements, and through UCNFA social media sites such as Facebook, Twitter, and Instagram with an audience engagement of 95% (taken from google analytics). Our workshop promotional efforts have been featured in different organization's social media sites such as the California Center of Urban Horticulture, Agricultural and Natural Resources en Español, and HortEcology Lab OSU.

By August 2018 we have presented and distributed relevant information about the workshops at two events: on January 11th at the Fertilizers: Plant Nutrition and the Nursery Infrastructure workshop and February 20, 2018, at the Fertilizers: Types, Use, and Methods of Monitoring Fertilizer Status in a Nursery Operation workshop in Salinas California. Nursery growers that have attended the workshops received information on monitoring plant nutrition and the proper management of fertilizers.

As of September 1, five videos are being produced on: 1) Overview of Plant Nutrition, 2) Nitrogen. Uptake and Mobility, 3) Nitrogen. Deficiency and Toxicity, 4) Phosphorus, and 5) Potassium.

ACKNOWLEDGEMENTS

We would like to thank Ray Lucas of UC Agriculture and Natural Resources Division Communications Services and Information Technology for his invaluable guidance and assistance in producing the videos. We thank CDFA FREP for providing the grant supporting this project (Agreement number 16-0678-SA).

Adapting CropManage Irrigation and Nitrogen Management Decision Support Tool for Central Valley Crops

Project Leaders

Michael Cahn
Irrigation and Water Resources Advisor
UC Cooperative Extension
Monterey County
1432 Abbott St
Salinas, CA 93901
831-759-7377
mdcahn@ucanr.edu

Allan Fulton
Irrigation and Water Resources Advisor
UC Cooperative Extension
Tehama County
1754 Walnut Street
Red Bluff, CA 96080
(530) 527-3101
aefulton@ucanr.edu

Patrick Brown
Professor of Plant Nutrition
Dept. of Plant Sciences
One Shields Ave.
3019 Wickson Hall
Davis, CA 95616
(530) 752-0929
phbrown@ucdavis.edu

Cooperators

Daniel Geisseler
Dept of Land, Air, and Water Resources
2146 PES Building, UC Davis
One Shields Avenue
Davis, CA 95616
(530) 754-9637
djgeisseler@ucdavis.edu

Dan Putnam
Dept of Plant Science
MS #1 One Shields Avenue
2240 PESB. UC Davis
Davis, CA 95616-8780
(530) 752-8982
dhputnam@ucdavis.edu

INTRODUCTION

Central Valley farmers are under regulatory pressure to use fertilizer nitrogen efficiently and demonstrate that they are following best management practices. Because soil nitrate can readily leach a combination of practices that help growers follow the 4Rs (right source, right amount, right time, right place) and optimize water management is required to achieve improved N use efficiency. UC research has greatly increased the understanding of crop N needs and resulted in several spreadsheet and online tools that growers can use to determine appropriate amounts of fertilizer to apply to their crops.

In addition to nutrient management, water scarcity during the latest drought has increased the urgency for easy-to-use tools that can assist growers in using limited supplies of water as efficiently as possible to maximize production. The California Irrigation Management and Information System (CIMIS) operates more than 140 weather stations that collect reference evapotranspiration (ETo) data in most agricultural production regions of California. To determine how long to irrigate using ETo data, growers need to complete a series of calculations that can be quite time consuming.

CropManage (CM) is an online tool for assisting growers with efficiently managing water and nitrogen fertilizer to match the specific needs of their crops. With financial support of CDFA-FREP, CM was originally developed to help farmers estimate irrigation schedules in head lettuce using CIMIS ETo data and determine fertilizer N needs using the soil nitrate quick test and models of lettuce N uptake. Since the first version was released in 2011, CM was expanded to include other coastal crops, including baby salad greens, spinach, celery, broccoli, cabbage, cauliflower, and strawberries. CM also allows growers to track fertilizer and water applications on each of their fields. This record keeping capability of the software allows multiple users to share and review water and N applications on each field of their ranch, and for growers to maintain data required to comply with water quality regulations. Since CropManage was first released, use of the on-line tool has steadily increased on the Central Coast. CM currently has more than 1600 registered users and provides more than 1200 recommendations per month to users for water and fertilizer during the production season.

There is much interest to expand CM to include Central Valley crops such as almonds, walnuts, pistachio, alfalfa, and processing tomatoes. However, these commodities require algorithms and user interfaces that are significantly different than the current version of CM. The funding requested for this project is primarily needed for programming resources to add Central Valley crops to CM and improve the user-interface.

OBJECTIVES

The general objective is to adapt the CropManage (CM) online decision support tool for Central Valley crops, including trees, forage, and warm season vegetables.

Specific objectives include:

1. Adding algorithms and user interface modules that accommodate warm season vegetables, forage, and tree crop commodities.
2. Supporting the addition of almonds, processing tomatoes, and alfalfa to CM.
3. Improve the user-interface so that users can intuitively and quickly navigate within the software tool on a personal computer or mobile device, and data is presented in an easily understandable format.
4. Conduct outreach to the agricultural industry through workshops, presentations at grower meetings, and newsletter, blog, and trade journal articles.

ACCOMPLISHMENTS

The new user interface for CropManage (Objective 3) was developed and implemented during the first 6 months of the project. UC Division of Agriculture and Natural Resources (UCANR) provided programming support to assist the software development company, Breyta Inc., in moving the original CropManage code from the ANR server to Amazon Web Service, as well as augmenting the CM code to work with the new user-interface. Breyta Inc. redesigned each interface module in CM. After several months of testing, the new interface was announced to the public as version 3.0. This latest version of CropManage can be accessed at the URL address: v3.cropmanage.ucanr.edu.

Version 3.0 of CM simplifies the user interface to maximize the ease of navigating to different plantings and ranches (Figures 1 and 2). The user can filter through a list of ranches by entering the first letter or name. Similarly, the user can select a specific planting by entering the name, field name, or crop type. Users can also click on a star to designate ranches or plantings to a favorites list that displays only the plantings and/or ranches that they frequently use.

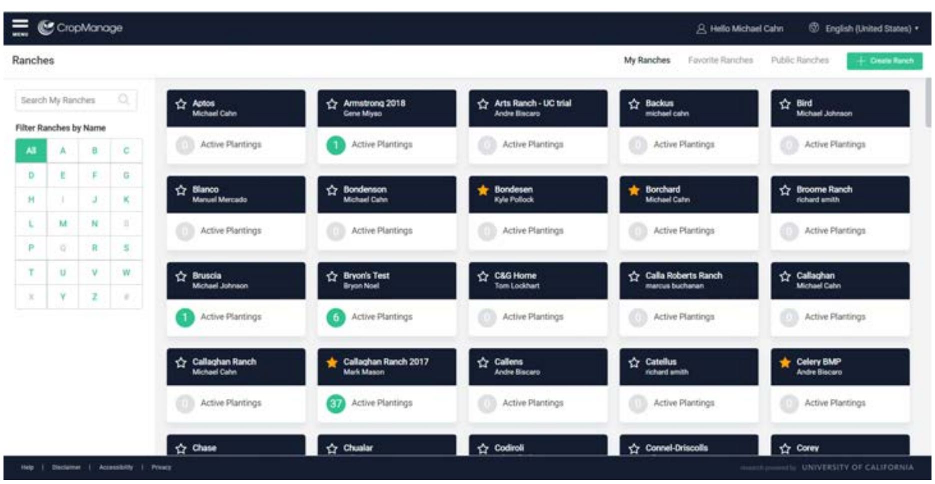

Figure 1. Updated user interface in CropManage 3.0 displays ranches available for the user to view. User can filter by first letter or complete name of the ranch.

The planting summary tile (Figure 3) was designed to allow the user to quickly review upcoming and past events and tasks. The tile shape displays efficiently on a smart phone screen. The most urgent events are shown first, and the user can scroll to view events that are further in the future. Clicking on past events shows the most recent events first. An "attention needed" icon is displayed next to a past event that was not confirmed to have been completed. Users can also add an irrigation, fertilizer, and soil sample events from the planting tile. Users can also view summary tables and lists of all events entered in a planting. Clicking on a "silhouette" icon by an event displays the user name, date, and time an event was entered.

Processing tomato was added to CM 3.0 in February 2018. The user interface includes a calculator for estimating total crop N uptake from expected fruit yield, and a form to enter crop water stress parameters to optimize quality during the ripening phase. The crop coefficient model was also modified for processing tomatoes to account for the decrease in evapotranspiration that usually occurs during the fruit maturing stage. The algorithm for recommending nitrogen fertilizer in processing tomato was modified to accommodate growers who do not test their soil for residual nitrate. In this situation, the user would receive a recommendation based on the crop N uptake and soil mineralization estimates. Nitrate in the irrigation water can be subtracted off from the fertilizer recommendation.

Software development for alfalfa and almonds in CM was completed and is in the testing phase. We expect to release these commodities in late fall of 2018. Major changes to the code were needed to accommodate crops that are grown over multiple years and develop deep root systems. In addition, accurate estimates of water use in alfalfa require that the user enters cutting dates. The almond nitrogen

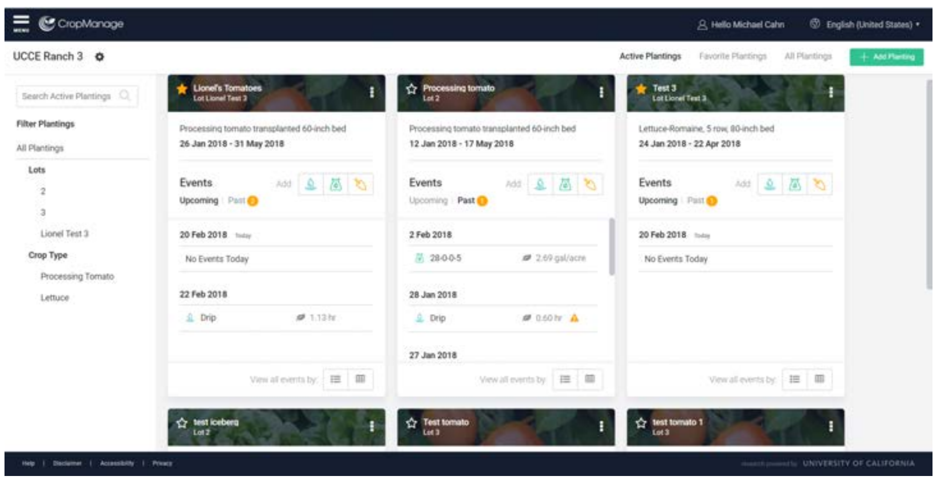

Figure 2. Updated user interface in CropManage 3.0 displays plantings for processing tomato and romaine lettuce crops. User can filter plantings by lot name, planting name, or crop type.

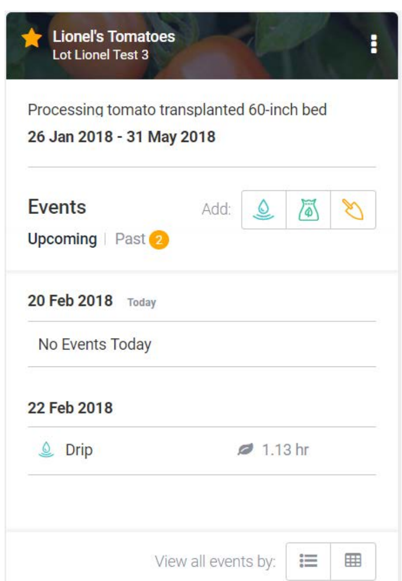

Figure 3. Updated user interface in CropManage 3.0 displaying an individual planting for processing tomato. The interface is de-signed to display efficiently on smartphones.

model will adjust nitrogen fertilizer recommendations based on analysis of spring leaf tissue samples.

CropManage 3.0 was presented at grower nutrient and water management seminars (5) and tested by participants at hands-on workshops (6), as well as through individual demonstrations (5) during 2018. The demonstrations and workshops identified errors in the software which were later corrected by the Breyta programmers. Presentations at seminars informed growers and industry representatives about progress on improving the CropManage decision support application.

In summary, we expect that all software development tasks will be completed by the end of 2018. Effort in the upcoming year will be devoted to training users on the new CM interface and using CM for almond, alfalfa, and processing tomato. Additionally, we will be surveying users for feedback on how to improve the performance of the algorithms and interface and make the final adjustments in the software.

Evaluation of Biochar for On-Farm Soil Management in California

Project Leaders

Sanjai J. Parikh[1]
Associate Professor of Soil Chemistry
sjparikh@ucdavis.edu

Project Manager

Daniele Gelardi[1]
Ph.D. Student, Soils and Biogeochemistry
dlgelardi@ucdavis.edu

Cooperators

William R. Horwath[1]
Professor of Soil Biogeochemistry
wrhorwath@ucdavis.edu

Daniel Geissler[1]
Associate Cooperative Extension Specialist
djgeisseler@ucdavis.edu

Milt McGiffen[2]
Vegetable Crops Specialist & Vice Chair for Cooperative Extension
milt@ucr.edu

Michelle Leinfelder-Miles[3]
Cooperative Extension Farm Advisor
mmleinfeldermiles@ucanr.edu

Toby A. O'Geen[1]
Soil Resource Specialist
atogeen@ucdavis.edu

Kate M. Scow[1]
Professor of Soil Microbiology
kmscow@ucdavis.edu

[1] Department of Land, Air and Water Resources, University of California, Davis

[2] Department of Botany and Plant Science, University of California, Riverside

[3] Cooperative Extension San Joaquin County

INTRODUCTION

Farmers, researchers, and policymakers are increasingly interested in the use of biochar, a carbonaceous material created from the thermochemical conversion of biomass in an oxygen-limited environment, as an agricultural soil amendment. Due to the unique chemical and physical structure of biochar, the material offers many potential solutions to the most pressing agricultural issues. These issues include nitrate leaching, low nutrient use efficiency, vulnerability of soils to drought conditions, and depleted soil carbon stocks.

Previous research shows inconsistent results on the ability of biochar to address these issues, due to differences in biochar feedstock, production methods, soil properties, climate, and cropping systems. Furthermore, these results have limited relevance to production agriculture, as biochar studies are dominated by short-term laboratory experiments that are difficult to extrapolate to field-scale. To inform the use and regulation of biochar, it is essential that farmers and policymakers have access to reliable, location-based data.

This three-year study aims to fill a gap in literature by providing long-term, field-scale data about the potential of biochar as a soil amendment in CA agriculture. In the first year of the project, seven biochars of diverse feedstock and production temperatures were produced and amended in two one-acre plots in Yolo and Fresno Counties. Data will be collected from a minimum of three seasons under tomato production, on the impact of biochar on yield, plant nutrition, fertilizer use efficiency, and soil properties such as nitrogen dynamics, water holding capacity, and soil carbon. This information will be evaluated along with fertilizer and biochar parameters, in order to assess the conditions most likely to lead to beneficial outcomes.

OBJECTIVES

The overarching objective is to provide data specific to CA regarding the potential for biochar to provide benefits such as increasing nutrient retention and C sequestration, and improving drought resilience for agriculture in the Central Valley. Specific project objectives are:

1. Characterize biochars produced from biomass locally available throughout California.
2. Evaluate the impact of biochar amendments on soil-water dynamics, fertilizer inputs, nutrient use efficiency (including leaching), carbon stocks, and crop productivity.
3. Evaluate soil conditions and biochar parameters, including biochar and fertilizer application rates, which are most likely to lead to beneficial outcomes.
4. Create the California Biochar Initiative in order to provide a forum for growers, advisors, fertilizer producers, regulators, and other stakeholder groups to obtain clear and objective information regarding the use of biochar in California agriculture.

DESCRIPTION

This three-year project will evaluate the use of various different biochars in a series of on-farm, growth chamber, and laboratory experiments through four distinct tasks, as detailed in Table 1.

Table 1. Project work plan

Project Tasks	Year 1		Year 2		Year 3	
Task 1: Produce and characterize biochar	✓	✓				
Task 2. Field trials in Yolo and Fresno Counties		✓	✓	✓	✓	✓
Task 3. Growth chamber and laboratory trials		✓	✓	✓	✓	✓
Task 4. Life cycle assessment of biochar use in CA				✓	✓	✓

Task 1. Produce and Characterize Biochar

Seven biochars of varying feedstock and temperatures were produced by working with commercial biochar companies to obtain local CA feedstocks and produce biochar at various temperatures (see Table 3, in Results and Discussion).

Task 2. Field Trials in Yolo and Fresno Counties

In Fall 2017, one-acre plots were amended with biochar in two locations: UC Davis Campbell Tract (Yolo County) and the Kearney Agriculture Research and Extension Center (Fresno County). The two soils, a Yolo silt loam and a Hanford sandy loam, represent over 500,000 acres of CA soils. The experimental design is a randomized complete block design (RCBD) with three blocks and one treatment replicate per block.

Table 2. Biochar and fertilizer application rates for field trials

Biochar Application Rate	Low (~.25 lbs per linear foot)
	High (~.5 lbs per linear foot)
	Tiny* (.01 lbs per linear foot) *CS650 and SW650 only
Fertilizer Rate	Low- 150 lbs N/ acre
	High- 225 lbs N/ acre

Biochars were subsurface banded, or applied in concentrated trenches directly above the drip tape to maximize contact with irrigation and fertigation and to minimize application costs (Figure 1). Biochars were applied in two or three rates and combined with a low or high rate of UAN32 (Table 2). Field sites are planted with tomatoes in spring beginning in 2018. Before planting and after harvest, soil

Figure 1. UCD Researcher hand applying biochar in trenches above the drip tape

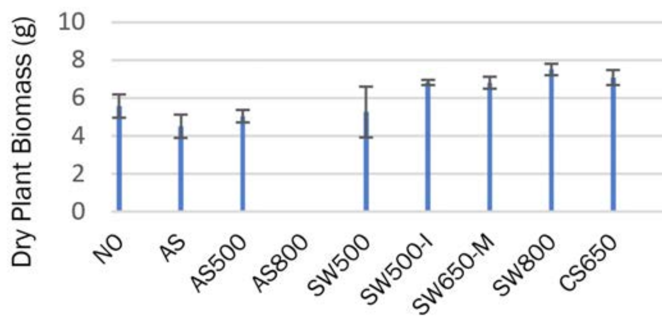

Figure 2. In pot trials, SW500-I, SW650-M, SW800, and CS650 sup-ported significantly higher romaine yields than NO (no biochar)

Figure 3. Lettuce in pots amended with 2% (w/w) biochar or almond shell (AS), and a 0% biochar control (NO). Plants in AS treatment exhibited chlorosis indicative of nitrogen deficiency. AS800 could not support plant growth.

samples are taken from 0-30 cm, 30-60 cm, and 60-90 cm to determine nutrient concentrations, pH, microbial biomass, and soil-water metrics. Tomato fruit and vines are analyzed for yield and total nutrition.

Task 3. Growth Chamber and Laboratory Trials

A series of growth chamber and laboratory studies have been conducted in order to observe plant-soil-biochar interactions with regards to yield, plant nutrition, and nitrate/ammonium retention. These studies include sorption experiments, soil columns (including micro-CT scans), and pot trials involving romaine lettuce grown in soils amended with 0 and 2% biochar.

Task 4. Life Cycle Assessment of Biochar Amendments in CA

Data continues to be collected for a forthcoming life cycle assessment of the economic and environmental feasibility of widespread biochar adoption in CA.

RESULTS AND DISCUSSION

Table 3 shows production details and chemical analysis for biochars used in laboratory and field trials, with trends showing higher ash %, EC, and pH, and lower C % at higher production temperatures. In pot trials amended with 2% biochar and a 0% control, SW500-I, SW650-M, SW800, and CS650 supported significantly higher yields than NO, while AS800 could not support plant growth, possibly due to high EC values (Figures 2 and 3). Preliminary batch sorption studies show little to no chemical binding between biochar and nitrate, though column studies show a possible delay in nitrate movement through the soil profile when amended with biochar, suggesting that physical process may retard nitrate movement in biochar amended soils. Nuetron tomography imaging has been initiated to assess this potential mechanism. Field trials are nearly complete for season 1 and no visible

Table 3. Chemical analysis and production details for seven biochars (and controls) sourced for field and laboratory trials

Treatment ID	Production temp (°C)	Feedstock	Production method	Carbon (%)	Nitrogen (%)	Volatile Content (%)	Ash Content (%)	pH	EC (mS/cm)
NO (control)	NA	NA	NA	-	-	-	-	-	-
AS	Unpyrolyzed	Almond shell	NA	-	-	-	-	-	-
AS500	400-500	75% Almond shell, 25% Sawdust (Assorted softwood)	Fractional Hydro Pyrolysis	65.8	0.8	30.7	19.0	9.3	3.2
AS800	700-800	Almond shell	Gasification	35.3	0.6	28.2	55.4	10.1	27.2
SW500	400-500	Sawdust (Assorted softwood)	Fractional Hydro Pyrolysis	70.9	0.1	38.0	4.5	7.8	2.5
SW500- I	400-500	Sawdust (Assorted softwood) w/ Inoculant	Fractional Hydro Pyrolysis	63.5	0.7	38.8	9.2	10.4	2.1
SW650- M	550-650	Pine (modified)	Slow pyrolysis	78.3	0.3	26.9	4.5	8.0	0.1
SW800	800	Softwood forestry thinning	Mixed	41.8	0.1	21.7	31.5	10.3	2.7
CS650	550-650	Coconut shell (modified)	Slow pyrolysis	71.2	0.8	31.8	5.3	7.8	0.3

negative impacts on tomato growth were observed with any treatment. Forthcoming data from these field trials will show whether these results are relevant for field-scale cropping systems.

ACCOMPLISHMENTS

Biochar Field Day in collaboration with FREP was conducted in June 2018 to provide outreach to stakeholders. Completed first round of laboratory and growth chamber trials. Field sites were installed and tomato fruit, vines, and postharvest soil samples from year one have been taken from Yolo County and are currently in process for Fresno County; field-scale data analysis regarding biochar-plant-soil interactions will be concluded by the end of 2018.

ACKNOWLEDGEMENTS

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Evaluation of Certified Organic Fertilizers for Long-Term Nutrient Planning

Project Leaders

William R. Horwath
Professor
Department of Land, Air and Water Resources
University of California
Davis, CA 95618
530-754-6029
wrhorwath@ucdavis.edu

Xia Zhu-Barker
Project Scientist
Department of Land, Air and Water Resources
University of California
Davis, CA 95618
530-754-6029
wyjzhu@ucdavis.edu

Project Cooperators

Cole Smith
University of California Cooperative Extension
Santa Clara County
Program Coordinator
Composting Education Program
cbrsmith@ucanr.edu

INTRODUCTION

Nitrogen management, and predicting soil nitrogen availability through mineralization of soil nitrogen and organic fertilizer amendments is a challenge in cropping systems due to the complexities and interacting forces of weather, soil biology and physical properties, organic input quality and chemistry, and intensive management practices (Cabrera et al., 2005; Schomberg et al., 2009). The value of organic fertilizer nitrogen amendments cannot be overstated. In general, using organic fertilizer nitrogen sources increases nitrogen use efficiency. Combined with conventional mineral fertilizers, organic fertility sources can achieve equivalent or larger yields and often provide for greater yield stability than conventional mineral fertilizers alone (Poudel et al., 2001). One of the reasons for higher yield potential is that soils amended with organic nutrient sources, often increase the mineralization of native soil nitrogen compared to those receiving only mineral fertilizers (Doane et al., 2009; Moreno-Cornejo et al., 2015).

In a research setting, soil nitrogen mineralization potential, i.e. the availability of plant-available nitrogen over a given time, is often assessed with laboratory incubations of soil and or mixtures of soil and amendments (Stanford and Smith, 1972). The method is extremely accurate in predicting the nitrogen mineralization potential of different amendments and soil nitrogen. For example, Heinrich and Pettygrove (2012) demonstrated that about 48% of nitrogen mineralized from a range of dairy manures after 63 days of incubation in a class 1 fine sandy loam soil. However, the time and costs associated with such analyses has limited their adoption into most standard commercial soil testing laboratories. The lack of information on the nitrogen mineralization kinetics of organic fertility sources has hampered our ability to effectively use organic fertilizers in crop management to increase the efficacy of nutrient plans.

The inclusion of mineralized nitrogen from soil and organic sources of nitrogen into fertilizer recommendations is essential to improving nitrogen use efficiency in agronomic systems. Underestimation of the contribution of organic soil amendments and fertilizers to plant-available nitrogen can result in excess reactive nitrogen being released into the environment. Over fertilization has been shown to result in increased nitrous oxide emissions (Stehfest and Bouwman, 2006) and the pollution of groundwater with nitrate (Harter and Lund, 2012). To avoid such serious consequences of over-fertilization, it is necessary to accurately predict nitrogen release from organic sources and sync nitrogen supply with crop nitrogen demand.

Recent research has shown that nutrient release from organic amendments is highly dependent on the quality of the material, inorganic N content and overall C:N ratio (Gómez-Muñoz et al., 2017). Given this, it is important that these factors are considered in the analysis of the materials. Taking a categorical approach, we are seeking to evaluate amendments based on both organic/inorganic carbon and nitrogen amounts in order to develop a generalized material characterization table. These values will be compared to the values recorded in the literature review. Additional confounding factors in the rate of nitrogen release from organic amendments include both moisture and temperature variability under field conditions

(Agehara and Warncke, 2005). Using laboratory incubations under different temperatures we seek to determine a rate constant to better understand these materials as a function of temperature variability. With a better understanding of decay rates, inorganic nitrogen release and temperature responses, the DayCent biogeochemical model would be parameterized to predict N availability. These improvements will ideally make the use of the COMET-Farm tool, a product of DayCent, more relevant for nutrient management planning in California. Overall, we seek a better understanding of the nutrient dynamics of select organic amendments and hope to determine ideal rates of application with the aim of optimizing nutrient inputs, sustaining yields and improving overall environmental sustainability as it relates to nutrient management planning.

OBJECTIVES

The overarching objective is to provide baseline data to inform nitrogen management plans specific to CA where organic fertilizer amendments are used in agricultural production areas. Specific project objectives for this project are:

- Conduct an extensive literature review on soil N mineralization and crop N availability as affected by organic based N fertilizers.
- Determine seasonal N mineralization and N mineralization potential in soils repeatedly amended with organic fertilizer in CA.
- Conduct field trials to assess and confirm lab and DayCent model results and to inform the COMET–Farm.
- Conduct extensive engagement and outreach to inform on the value and to reassess organic fertilizer amendment rates to avoid N loss and promote healthy soils.

DESCRIPTION

We proposed a combination of literature values, lab incubations and field trials to calibrate and verify the DayCent model to better predict the seasonal and long-term nutrient value of organic fertilizer amendments for soil productivity improvement and nutrient management. We specifically determined nitrogen mineralization responses to predict the long-term effects of repeated annual applications of organic fertilizers on soil N availability. Key to effectively use the information on nitrogen mineralization generated in this project is the parameterization of the DayCent model, so that the model can accurately predict nitrogen mineralization rates at different soil temperatures under soil conditions in California throughout the year. Most models use default values resulting in poor prediction outcomes. Based on the outcome of literature review and lab incubation, we will develop Q10 temperature coefficients for microbial nitrogen and carbon mineralization across a range of soil textures and various types of organic fertilizer amendments (see Table 1); these Q10 temperature coefficients will be further used to parameterize the

Property	Soil 1	Soil 2	Green-Waste Conmpost	Chicken Pellets	Manure Compost
NH_4-N (mg/g)	0.007	0.02	0.38	5	0.39
NO_3-N (mg/g)	0.02	0.04	0.2	1.25	0.21
pH (H_2O)	6.4	6.5	7.04	6.9	7.1
Water Content (%, d.m.)	5.8	7.6			
Texture	Sandy Loam	Clay Loam			

Table 1. Characteristics of soils and organic amendments

DayCent model that can be used to reassess fertilizer nitrogen inputs. Our results will provide for adjustments of nutrient management guidelines depending on organic fertilizer sources, soil type, and climate data. The information generated in this research will be used by UC Extension, CCAs and farmers to reassess nitrogen management across a variety of crops. The DayCent model is also the basis of COMET-Farm, a tool being considered by CDFA to assist farmers in engaging in California's climate action planning. We will conduct on-farm field trials to validate the predictive value of lab and modeling results. This is a three-year project and to date we have accomplished literature review and one season field trial. The laboratory incubation is on-going and a second season of field trials is being conducted. The outcome of this research will allow for adjustments of nutrient management plans to maintain and increase crop productivity, reduce the potential for N loss to groundwater, and minimize greenhouse gas emissions.

RESULTS AND DISCUSSION

Field Trails (Season 1). The results from the first summer field season (see Figure 1) indicate a trend that the high C:N ratio amendment-compost increased pepper yield (mean = 32.6 kg and sd = 10.7), yet this difference is not significant (p=0.6). This data suggests that future trials with experimental adjustments to reduce variability are necessary to further explore the role that carbon rich amendments have in improving crop yields. Additionally, nitrogen use efficiency (NUE) was calculated as a ratio of the total fruit weight to total amount of nitrogen applied (Moll et al. 1982). The results show that among all the treatments, the highest NUE was found in the field applied with compost (Figure 2).

Figure 1. Boxplots of Chile pepper yield from the first growing season. Means shown as solid horizontal lines and vertical lines represent upper and lower quantiles.

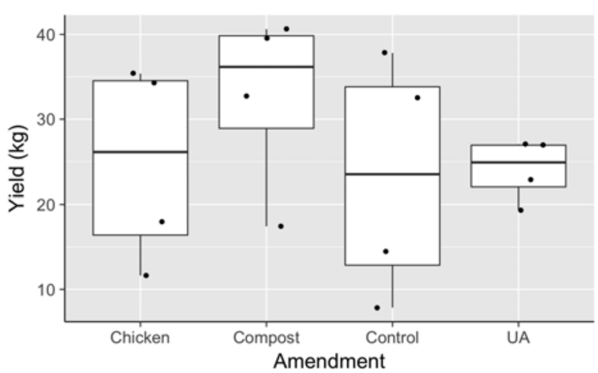
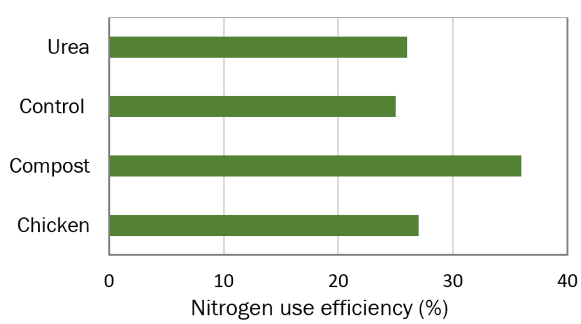


Figure 2. Calculated nitrogen use efficiencies as related to amendment inputs. Determined by weight of fruit divided by the total amount of nitrogen added.



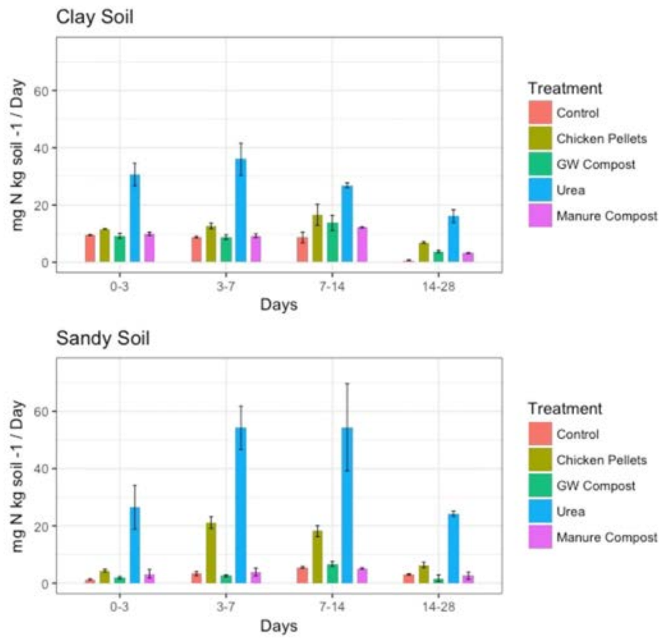


Figure 3. Difference in nitrogen mineralization rate

Laboratory Incubations (Phase 1). The laboratory incubation is currently in progress, the data in Figure 3 are collected from the first 28 days. These initial results indicate that soil type has an influence on the rate of nitrogen mineralization from the organic amendments. The nitrogen mineralization rate of urea or the low C: N ratio amendment (i.e chicken pellets) was higher in the sandy soil than in the clay soil. However, for the high C: N ratio amendments (i.e. compost), higher N mineralization rate was found in the clay soil than in the sandy soil.

TAKE-HOME INFORMATION

From this ongoing project, we found that 1) replacing a half of the applied synthetic nitrogen fertilizer with carbon rich materials has the potential to increase crop nitrogen use efficiency compared to applying the total amount of N as synthetic nitrogen fertilizer. This finding has significant implications for long-term agronomic planning, potentially reducing nitrogen input needs and cost associated with fertilizations. 2) The results from the ongoing incubation experiment indicate that the mineralization rate of organic amendments is dependent on the type of soil in which they are applied. This implies that soil type considerations must be included during nutrient planning. Continued research related to this project is necessary in order to determine the long-term outcomes of organic amendment applications.

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Developing Nutrient Budget and Early Spring Nutrient Prediction Model for Nutrient Management in Citrus

Project Leaders

Patrick Brown
Professor
Department of Plant Sciences
University of California
phbrown@ucdavis.edu

Douglas Amaral
Postdoc Scientist
Department of Plant Sciences
University of California
amaral@ucdavis.edu

INTRODUCTION

Excessive use of nitrogenous fertilizers in high value agriculture crops has resulted in the contamination of ground water with nitrate and in many parts of California, ground water nitrate levels exceed the EPA standard of drinking water quality of 45 ppm nitrate. This is partly due to lack of best nutrient management protocols. Currently nutrient applications in citrus are based largely on leaf sampling and application of critical value analysis. Critical value is the nutrient concentration in a standard leaf sample at which yield is 90% of the maximum yield. This approach provides an indication of adequacy or deficiency but little specific information on appropriate fertilizer rates or timing of applications. Although the critical value approach has been a valuable tool to identify deficiencies and toxicities this approach is not sensitive to over fertilization and is collected too late in the season to be used as a management tool. Leaf sampling has been found to be an inadequate tool for N management in high value crops since it is inadequately sensitive to N fertilizer applications. In almond for example, N application in excess of crop demand (4,000 lb yield) from the just adequate amount of 275 lbs. N/acre to 350 lbs. N/acre did not significantly increase the concentration of N in leaves, additional yield, or tree growth. The insensitivity of leaf critical value to over fertilization in perennial crops may have contributed to the over application of N fertilizers and excess N being lost to the environment, resulting in the accumulation of N in the ground water in California.

'Crop logging', or 'nutrient budgeting' is a more sophisticated and appropriate method to make nutrient decisions. The nutrient budgeting approach requires an early season estimation of expected yield and tree nutrient status, a mid-season update of the yield estimate and in season adaptation of N applications. To establish this methodology, it requires development of annual nutrient uptake curves and methods to conduct nutrient sampling in the early spring. This approach has not been developed for the various species of citrus under the conditions of California.

In the US, a majority of the citrus are produced in Florida and California. There have been relatively few research studies on total N demand of citrus species in California since the 1960s and 70s in Florida. The seasonal pattern of N demand in a relatively low yielding blood orange orchard was determined in a single orchard in Italy. Research conducted in Florida for a 340 field box yield of mature orange, suggests an N demand for crop and tree growth of 100 lbs N per acre and assumes that an efficiency of only 50-60% N use can be achieved. This rate of N loss will not meet the proposed N management guidelines being developed for California. Labanauskas and Handy (1972) conducted experiments in Valencia oranges in California in 1960s and found that Valencia orange removed 1.85 lbs N per 1000 lbs fresh fruit, but they did not monitor the seasonal N demand. Roccuzzo *et al.* (2012) conducted research in Red Blood Oranges in Italy and found 1.3 lbs N per 1000 lbs fresh weight and also reported seasonal changes in N demand. Given the demand of the Irrigated Lands Regulatory Program, there is a clear need for more precise, season species and yield-dependent information on N removal in citrus.

Currently, citrus growers in California apply between 150-200 lbs N per acre in 3-6 splits and monitor N adequacy by collecting leaf samples from 5-7 months old leaves in late summer. One of the major perceived constraints with current protocols for leaf sampling in fruit trees is that samples are collected too late in the growing season to be of use for current season nutrient management decisions. This problem is particularly evident since over 80% of N uptake occurs by the time results of a late summer tissue sampling are available to the grower. Late sampling limits the grower's ability to make in-season fertilizer adjustments and may encourage late-season fertilizer application that is inefficient and can result in groundwater contamination. In almond and pistachio an early spring tissue analysis to predict N concentrations in summer has been developed that provides enough time to adjust in-season fertilizer application. The same approach can be developed for Citrus.

Citrus yield and quality can be improved and nitrate leaching potential can be significantly reduced by adopting better fertilizer management approaches including nutrient budgeting, early season leaf analysis and in-season monitoring and adaptive fertilization. This requires the development of a protocol to guide the rate and time of N applications and in-season monitoring to adjust fertilizer rate during season.

OBJECTIVES

1. Develop nutrient demand curves to guide the quantity and time of fertilizer application in mandarin and orange based on crop phenology.
2. Develop an early season leaf sampling and nutrient prediction model for mandarin and orange.
3. Develop and extend nutrient Best Management Practices for citrus species.

DESCRIPTION

Activity 1. Develop nutrient demand curves that guide the quantity and time of fertilizer application in mandarin and orange (*Years 1 and 2*).

Twelve to 15 year old highly productive groves of each mandarin and orange were selected in Fresno County and another additional orange grove was selected in Tulare County. Trees that represent optimum leaf N concentrations (2.4-2.6% for oranges) and not showing any deficiency of other nutrients were selected.

We monitored three replicated blocks of trees of each species in Fresno county and one additional orange grove in Tulare county for changes in nutrient concentration in annual (leaves and fruits) and perennial organs (roots, trunk, scaffold, canopy branches and small branches) six times during the season at different phenological stages. This is being replicated in the second year of the project (January-December 2018) by monitoring the same trees for changes in nutrient concentration and biomass.

Activity 2. Develop Early Season Nutrient Prediction Model for major species of citrus (*Years 1 and 2*).

Twenty-five highly productive orchards of each mandarin and orange were selected in Fresno, Tulare, Kern and Ventura Counties. Composite leaf samples from 20 trees in each grove were collected from fully expanded leaves from the spring flush. In the summer, four month old leaves from the same tree were collected. During the next two years the leaf prediction model will be developed, and in season three the model will be validated using samples from 25 groves of each, mandarin and orange, sampled in different counties.

Activity 3. Develop and extend nutrient Best Management Practices for citrus (*Year 3*).

The combination of nutrient budget, seasonal changes in tree N content and in-season prediction of tissue nutrient status will help in developing a robust new fertilizer management tools for citrus growers of California. The finding from the research will help in development of the 'Right Rate' and 'Right Time' to guide N applications. A computer based model will be developed that will be available for the grower to estimate their crop fertilizer needs based on phenology, plant age, environment, crop load and yield.

RESULTS

The nitrogen content in aboveground organs (stems + leaves) and in leaves are shown in Figure 1. Data refer to the average of 9 trees per orchard. In general, the accumulation of N in the shoots was rapid until the end of June, and continued later with a lower rate. No net accumulation of nitrogen in the shoots after late October/early November was observed. From December to February the amounts of nitrogen present in the tree canopy remained stable or decreased, likely suggesting nutrient translocation to perennial organs.

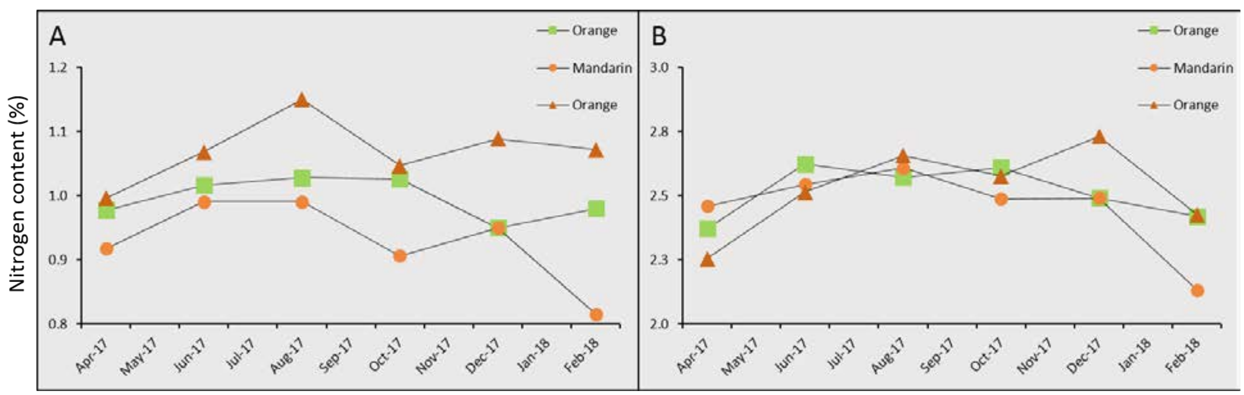

Figure 1. Seasonal trends in nitrogen accumulation in shoots (stem and leaves) (A) and leaves (B) during the season in orange and mandarin trees.

The seasonal demand of nitrogen in orange is high early in the season from May through July. Knowing the dynamics of nutrient uptake during the season is a requirement to allow the management of the timing of nutrient supply with nutrient needs. Preliminary data suggest that nitrogen should be available in the soil for root uptake by citrus trees from April to November, corroborating those findings from Raccuzzo et al. (2012). In contrast, from December to February, no net increase in nitrogen was observed.

It is important to note that the data shown in this report is a preliminary data from year 1 of a three-year project, and no conclusive data are shown. Our goal is to develop knowledge of the pattern of nutrient uptake and allocation during three seasons in citrus trees to develop an early season leaf sampling and nutrient prediction model for mandarin and orange to guide fertilizer application based on crop phenology for the state of California.

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SUMMARIES OF CURRENT FREP PROJECTS

Field Evaluation and Demonstration of Controlled Release N Fertilizers in the Western United States

Project Leaders

Charles A. Sanchez
Professor
University of Arizona
Maricopa Agricultural Center
37860 W Smith Enke Rd
Maricopa, AZ 85138
928-941-2090
sanchez@ag.arizona.edu

Richard Smith
Farm Advisor
Cooperative Extension
Monterey County
1432 Abbott Street
Salinas, CA 93901
831-759-7357

INTRODUCTION

Intensive vegetable production in the southwestern U.S. receives large annual applications of nitrogen (N) fertilizers. Amounts of N applied range from 200 to 400 kg/ha and crop recoveries are generally less than 50% (Mosier et al., 2004). There are numerous possible fates of fertilizer applied N in addition to the desired outcome of crop uptake (Sanchez and Dorege, 1996; Havlin et al., 2005). The urea and ammonium components of the N fertilizer might be lost through ammonia volatilization. The nitrate-N might be lost to leaching with irrigation water below the crop root zone possibly impairing surface and ground water (Sanchez, 2000). Nitrate might also be lost as N_2 and N_2O gasses via de-nitrification processes affecting air quality and climate. Furthermore, all forms of N might be immobilized into the organic soil fraction by the soil microbial population where availability to the crop is delayed. The global warming potential of N_2O is 300 times that of CO_2 and N fertilizer is estimated to account for one-third the total greenhouse gas production in agriculture (Strange et al., 2008). One study reported that N fertilization (inorganic or organic) accounted for 75% of the greenhouse gas emissions from agriculture production (including production, application, and nitrous oxide emissions) and after N is accounted for there are no significant differences between conventional, organic, or integrated farming practices (Hiller et al., 2009).

N management in the western United States remains a continuing challenge. Both California and Arizona have mandated Best Management Practices (BMP's) to varying degrees. These practices generally involve timing, amounts, and placement of N, and irrigation water application. The use of controlled release N (CRN) fertilizer sources is another promising option. The successful implementation of CRN management where appropriate will reduce adverse environmental impacts of fertilizer N and improve profitability in California and the western United States in general.

OBJECTIVES

The objectives of this project are to conduct experiment-demonstrations with CRN technologies in vegetable producing areas in Arizona and California with a wide range of CRN technologies available. Experiment demonstrations will all occur with grower-cooperators and CRN management will be compared to their standard practices. Success will be discerned by data collected, grower interest, and grower implementation.

DESCRIPTION

We have determined release rates and we modeled release for a number of CRN products in our possession. This included ESN, and various Duration, Polyon, and GalXe products. We are using these data collected on release rates to guide our product selections for each crop planting window.

Experiment-demonstrations have been conducted and are on-going in the desert

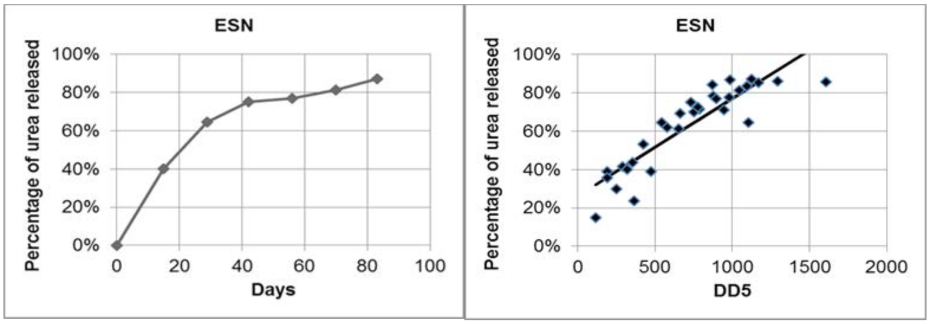

Figure 1. Example of N release from ESN. Similar approach used to match other products with crop-seasons.

and central coast production regions. Studies in the desert have been conducted with grower cooperators in Pinal and Yuma counties Arizona and Imperial and Riverside Counties California. Studies in the central coast have been in Monterey County. Rate and methods of application of CRN management gave been compared to the grower standard N management (Figure 1). Crops evaluated include iceberg, romaine, and baby lettuce, broccoli, cauliflower, spinach, watermelons, tomatoes, peppers, and onions. In all experiment-demonstrations the crop N status was monitored with N tissue and soil testing. Marketable yields were collected at harvest in all experiment-demonstrations.

RESULTS AND DISCUSSION

There have been variations in results depending on crop-site-season. The results for spinach to CRN 45 in winter 2015 are shown in Table 1. These observed improvements yield responses of spinach to CRN management are typical of results we observe for spinach over several studies conducted in 2015 through 2017. Lettuce and broccoli have also shown positive responses to CRN management for many site-seasons (Tables 2 and 3 show some results for lettuce and broccoli). However, there are risks of crop damage when using one of the faster release products (CRN 90) in warm fall season (data not shown).

TAKE-HOME MESSAGE

Overall, the data show that CRN management has promise as a tool for efficient N management in vegetable cropping systems in the western United States. In some instances we observed increased growth and yield compared to grower standard practices (GSP). In many cases production is maximized at lower N rates. There are risks of damage when CRN 90 is used in warm falls. The solution would be using CRN120 or band placement. Many growers have incorporated CRN into their management programs.

Figure 2. Various fertilizer application methods in experiment-demonstrations.

Figure 3. One of the spinach demonstrations.

Table 1. Response of spin-ach to CRN management in Riverside County.

Treatment	Practice	N rate	Marketable Yield (MT/ha)
1	GSP	3-35-0 (25 lb N) td-AMS (63 lb N) td-AMS (63 lb N) Total - 151 lb N/ac	14.4
2	CRN#1	3-35-0 (25 lb N) pp-CRN (100lb N) td-AMS (32 lb N) Total - 157 lb N/ac	17.7
3	CRN#2	3-35-0 (25 lb N) pp-CRN (150 lb N) Total = 175 lb N/ac	16.9
LSD			2.5

GSP is grower standard practice. LSD=least significant different (P>0.05)

Table 2. Response of spinach to N rate and N source.

N Rate	N Source	Yield (MT/ha)	Soil NH4-N (mg/kg)	Soil Nitrate-N (mg/kg)	Leaf N (%)	N Uptake (kg/ha)
0	---	2.2	3.4	3.6	3.29	5.11
150	CRN 45	9.5	2.8	7.1	2.84	27.2
300	CRN 45	12.8	8.2	27.2	4.28	38.7
150	AS	9.5	1.2	7.5	4.25	27.8
300	AS	8.7	2.3	30.0	4.76	28.5
150	FUSN	9.3	4.2	4.4	4.19	27.1
300	FUSN	9.9	2.1	13.9	4.33	28.7
150	Urea	9.6	2.3	7.2	4.12	27.7
300	Urea	8.8	1.6	8.9	4.10	25.2
150	SU	8.0	2.9	5.4	4.50	24.7
300	SU	9.9	5.1	5.8	4.60	31.9
Stat. N Rate		L** Q**	NS	L**	L*Q*	L**Q**
N Source		1.8	3.2	9.8	0.40	NS

Treatment	Yield (MT/ha)
GSP Sidedress and water run total 250 lbs/A	11.6
CRN 90 (75 lbs N/A) Sidedress UAN 32 (125 lbs N/A)	16.2
CRN 120 (75 lbs N/A) Sidedress UAN 32 (125 lbs N/A)	12.4
CRN 90 (150 lbs N/A)	13.9
CRN 120 (150 lbs N/A)	17.7
LSD	1.9

LSD=Least significant difference at P=0.05. NS=not significant

Table 3. Yield response of broccoli N to CRN management in Imperial County.

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ACKNOWLEDGMENTS

We gratefully acknowledge support of the FREP program for sponsoring this work, the fertilizer companies that provided products including Koch Industries, JR Simplot, and Agrium. We also appreciate the cooperation of participating growers.

Train the Trainer: A Nitrogen Management Training Program for Growers

Project Leaders

Parry Klassen
Executive Director
Coalition for Urban Rural Environmental Stewardship (CURES)
klassenparry@gmail.com

Terry Prichard
Water Management Specialist, Emeritus
University of California, Davis
Department of Land, Air, and Water Resources (LAWR)
tlprichard@ucdavis.edu

INTRODUCTION

Nitrate is the most common contaminant in Central Valley groundwater and elevated levels are attributed primarily to leaching of nitrogen fertilizers past the root zone into aquifers. Growers who belong to Central Valley Water Quality Coalitions are under requirements adopted in 2012 per the Irrigated Lands Regulatory Program (ILRP) to keep "on farm" a Nitrogen Management Plan (NMP) to track nitrogen fertilizer applications. The Waste Discharge Requirements General Orders for the Central Valley allows growers to self-certify their own nitrogen management plans if they attend a training program approved by the California Department of Food and Agriculture. The 12 Central Valley coalitions, with funding from FREP, have instituted a grower training program for their members. This training program is based on a curriculum developed for training Certified Crop Advisors (CCAs) by the University of California. To date, the NMP Self-Certification Program has qualified 3,000 growers in a joint effort with CDFA, CURES and UC. Upon successful completion of the course, a grower can certify the NMP for lands that they farm.

After the initial grower self-certification, additional hours of continuing education are required. The Continuing Education component of this program began in April of 2017. This component includes the development and management of a process to review the agendas and contents of a proposed meeting or segment of a meeting that fulfills the Continuing Education requirement of the NMP certification process.

This NMP self-certification project promotes the environmentally safe and agronomically sound use of nitrogen fertilizers. It helps to assure that all of the acreage that needs a certified plan will be covered. Completing NMPs should help growers use nitrogen more efficiently and reduce the amount of nitrate that leaches into groundwater.

OBJECTIVES

1. Conduct outreach to attract potential trainers for the grower self-certification trainings.
2. Organize and conduct Train-the-trainer sessions using the educational materials developed by UC for the grower self-certification trainings. Trainer would be considered qualified as a trainer for grower certification program.
3. Manage the interaction between those requesting a trainer for a grower training session and the trainer.
4. Provide grower testing, keep records of attendance, successful completion, and conduct trainer evaluation.
5. Manage and coordinate the self-certification requirement of continuing education.

DESCRIPTION

1 **Trainer Outreach Program:** The pool of trainers includes the following Certified Professionals: Certified Crop Advisors (CCAs) with a Nitrogen Plan Certification, or a Certified Professional Agronomist or Soil Scientist. Outreach materials were sent to all Central Valley CCAs in September 2015 and December 2016.

2 **Conduct Train-the-Trainer Sessions.** The instructional materials developed by UC were used in the train-the-trainer sessions. The same materials were also used in the grower certification sessions. Training sessions were held in the Stockton (north Valley) and Tulare (south Valley) areas to facilitate training of CCAs who generally conduct grower trainings in those regions.

3 **Manage the Interaction Between Coalitions and Trainers:** Coalitions contact CURES when a new meeting is set, and CURES facilitates pairing each meeting with two trainers and the necessary materials. CURES uses grant funds for trainer fees, and printing/shipping meeting materials and certification letters, while the Coalitions are responsible for venue costs. CURES also advertises grower self-certification meetings on its website and ensures that coalitions and CCAs are provided the most up to date version of the curriculum.

4 **Facilitate NMP Self-Certification Trainings:** CURES keeps records of meeting attendance, grades and records test results, and conducts trainer evaluations for each training course.

5 **Manage the Continuing Education Requirement:** A complimentary FREP grant was approved in 2017 to develop a process for reviewing the agenda and content of a proposed Continuing Education meeting that fulfills that Continuing Education requirement of the NMP certification process. Meeting organizers are asked to submit a request for continuing education credits. Once content is approved using criteria developed by CDFA, CURES, and UC, the organizing entity is allowed to issue Continuing Education Units (CEUs) to growers.

RESULTS AND DISCUSSION

To date, CURES has hosted 5 CCA training meetings, which produced 32 CCAs who are eligible to lead an NMP grower self-certification workshop. Of these, 27 have presented at one or more grower training meetings. As of July 2018, CURES has facilitated 73 NMP self-certification sessions, using curriculum developed by CDFA, UC and CURES. Figures 1-3 show examples of this curriculum. In addition, coalitions have organized 52 test retake sessions with an 85% pass rate. 3,690 growers have taken the course since its start and 2,957 have passed with an 80% pass rate. Table 1 below outlines the number of NMP Self-Certification trainings and office retakes per year, as well as the number of growers that have passed the exam with a 70% or above.

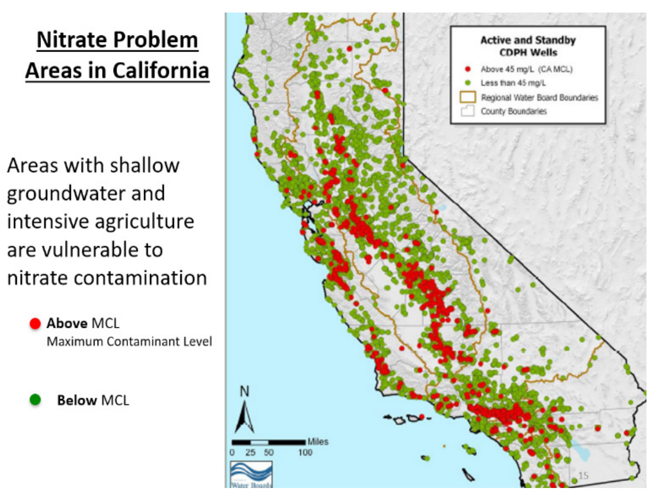
As of July 2018, 46 Continuing Education sessions have been applied for and approved, scheduled throughout 2017-2018. Two applications have been denied. CURES/UC will continue to review and approve qualified CEU requests as they are received.

Table 1. The number of NMP self-certification trainings and office retakes from November 2015 to July 2018. The total number of attendees, total number of passed exams, and the average percent passed per year are also included.

Year	# of Grower Trainings	# of Office Retakes	Total # of Attendees	Total # of Passed Exams	Average Percent Passed
2015	3	0	186	154	81%
2016	32	22	1962	1570	80%
2017	22	22	1010	805	80%
Jan-July 2018	16	8	532	428	80%
TOTALS	73	52	3690	2957	80%

Figure 1. Nitrogen Management Training Curriculum, front cover

Figure 2. Nitrate Problem Areas in California, pg. 8 in the Nitrogen Management Training Curriculum



NITROGEN MANAGEMENT PLAN WORKSHEET

NMP Management Unit: __Waknuts by River__________

1. Crop Year (Harvested):	2015	4. APN(s):	5. Field(s) ID	Acres
2. Member ID#	xxxx	020-025-016	1	100
3. Name:	Your Name			
CROP NITROGEN MANAGEMENT PLANNING		**N APPLICATIONS/CREDITS**	15. Recommended/ Planned N	16. Actual N
6. Crop	Walnut	**17. Nitrogen Fertilizers**		
7. Production Unit	tons	18. Dry/Liquid N (lbs/ac)	120	
8. Projected Yield (Units/Acre)	3.00	19. Foliar N (lbs/ac)	0	
9. N Recommended (lbs/ac)	159	**20. Organic Material N**		
10. Acres	100	21. Available N in Manure/Compost (lbs/ac estimate)	0	
Post Production Actuals				
11. Actual Yield (Units/Acre)	3.2	**22. Total Available N Applied** (lbs per acre)	120	
12. Total N Applied (lbs/ac)	159	**23. Nitrogen Credits (est)**		
13. ** N Removed (lbs N/ac)		24. Available N carryover in soil; (annualized lbs/acre)	30	
14. Notes:		25. N in Irrigation water (annualized, lbs/ac)	9	
		26. Total N Credits (lbs per acre)	39	
		27. Total N Applied & Available	159	
PLAN CERTIFICATION				
28. CERTIFIED BY:		**29. CERTIFICATION METHOD**		
		30. Low Vulnerability Area, No Certification Needed		
		31. Self-Certified, approved training program attended		
DATE:		32. Self-Certified, UC or NRCS site recommendation		
		33. Nitrogen Management Plan Specialist		

Figure 3. Section 7 (pg. 108-137) of the curriculum shows step by step instruc-tions on how to fill out the NMP worksheet. This image is shown on page 129 of the Nitrogen Management Training Curriculum.

ACCOMPLISHMENTS

The research-based information delivered to growers by this project will support FREP's goals to advance the environmentally safe and agronomically sound use of nutrients and the reduction of agricultural contributions of nitrate to groundwater in the Central Valley and agricultural regions throughout California. In the long-term, implementation of the grower NMP self-certification program will contribute to measurable reductions in the likelihood of nitrates from fertilizer entering groundwater from farming practices in the Central Valley. This will reduce the regulatory compliance costs of all users of water, not just agricultural. Additionally, the reduction of impacts to groundwater reduces treatment costs and may allow expanded use of lower cost groundwater in some areas for both agricultural and domestic uses.

ACKNOWLEDGEMENTS

Funding for this project was provided by the California Department of Food and Agriculture's Fertilizer Research and Education Program. Special thanks to the University of California for assisting in the development of the training curriculum and to the Central Valley Water Quality Coalitions for hosting the training sessions for their members. Recognition is also deserving for the Certified Crop Advisors who are lending their skills and talents to train growers on ways to improve efficiency of nitrogen fertilizer applications to crops.

New Fertigation Book

Project Leader

Charles Burt
Chairman
Irrigation Training & Research Center (ITRC)
BioResource and Agricultural Engineering Department
Cal Poly State University
San Luis Obispo, CA 93407-0730
805-756-2379
(cell: 805-748-3863)
cburt@calpoly.edu

INTRODUCTION

The goal of this work is to improve the understanding of good fertigation practices by practitioners (i.e., farmers, foremen, farm managers). The improved understanding will hopefully result in farmers implementing better irrigation and fertilization practices. Those good practices will improve crop yields while protecting the environment.

To meet the objective, the old (20+ years) Cal Poly ITRC *Fertigation* book was updated and re-published. A variety of Fertigation short courses have been held.

OBJECTIVES

1. Consolidate up-to-date information on fertigation practices, science, and art into a single pragmatic sourcebook for practitioners.
2. Develop or organize new concepts and information to fill gaps in current knowledge as related to fertigation, and include in the new book.
3. Provide outreach in the form of short courses to industry and students.

DESCRIPTION

The new book has nineteen chapters, as follows:

1. Introduction
2. Safety
3. Chemical injectors
4. Proportional fertigation
5. SO_2, gypsum, and solids injection
6. Irrigation principles, leaching, and fertilizer uniformity
7. Injection techniques for various irrigation methods
8. Nitrogen transformations and processes
9. Nitrogen uptake, including nitrogen balances, A/R ratio, and groundwater legislation and protection
10. Other nutrient processes
11. Specific fertilizers
12. Biostimulants
13. Organic fertilizers
14. Air and oxygen injection
15. Plant and soil testing
16. Specific crop requirements
17. Sample fertigation calculations
18. Drip system maintenance
19. Infiltration problems

RESULTS AND DISCUSSION

The new book has hundreds of updates. Perhaps the most interesting for readers will be:

1. The discussion of the Applied/Removed (A/R) ratio of nitrogen, that is of interest for people concerned with groundwater protection and various rules. The section describes the uncertainties and challenges associated with applying even this "relatively simple" concept.
2. It is commonly understood that applying more nitrogen and water will result in more nitrate leaching to the groundwater. As a very small but important component of this book, ITRC used the USDA/ARS Root Zone Water Quality Model (RZWQM) to model combinations of different nitrogen fertilizer mixes, N rates, water application depths, and timing of N applications. The results are shown in the following figures.
3. The move to proportional fertigation (automatically maintaining a constant ppm of a nutrient in the irrigation water) is slowly becoming more popular. The book describes multiple ways to achieve this, and provides a recommendation of the best combination of equipment – all of which are commercially available.

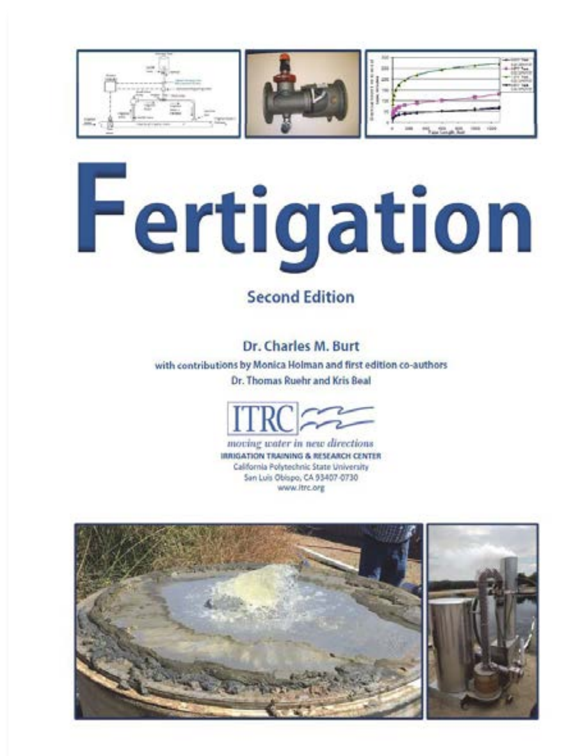


Figure 1. Cover page of new book

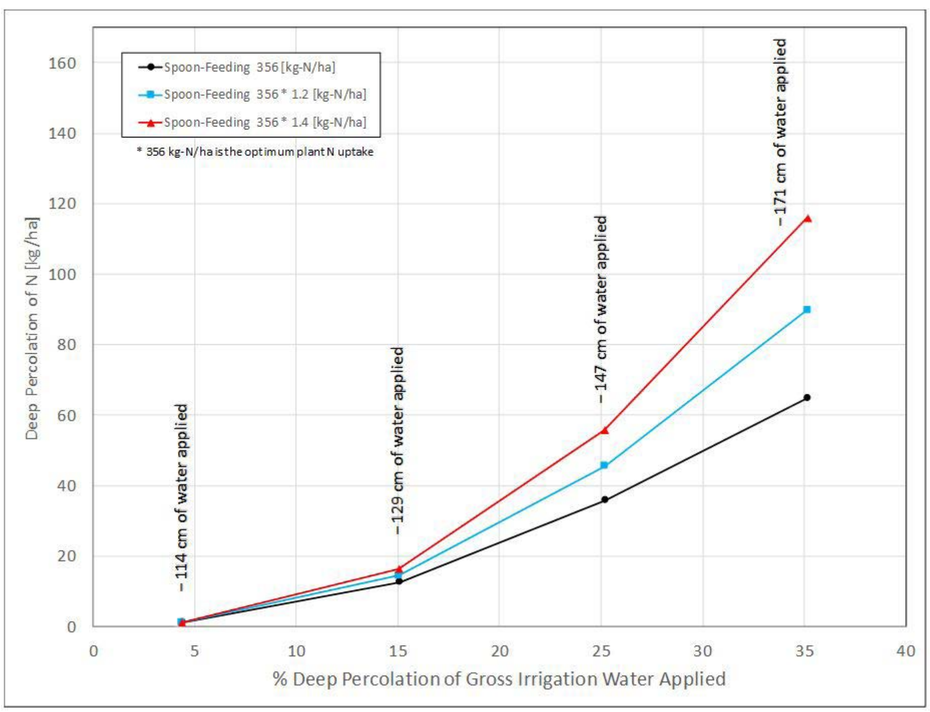


Figure 2. Deep percolation of N as a function of irriga-tion water deep percolated and different N application amounts – all spoon-fed

Figure 3. Deep percolation of N as a function of irrigation water deep percolated, and N application schedule

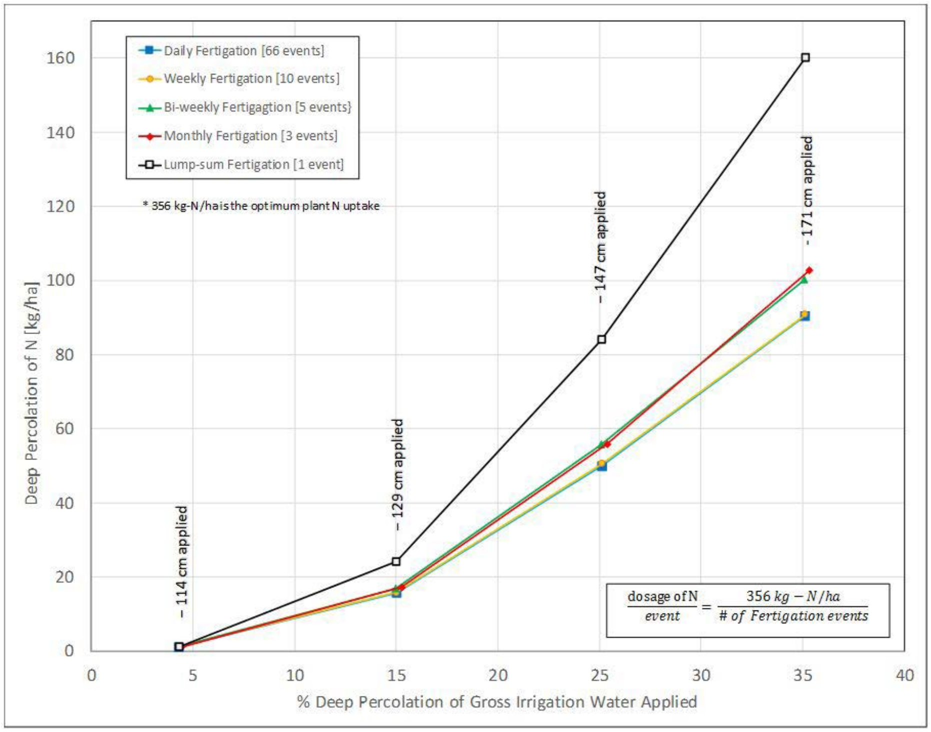
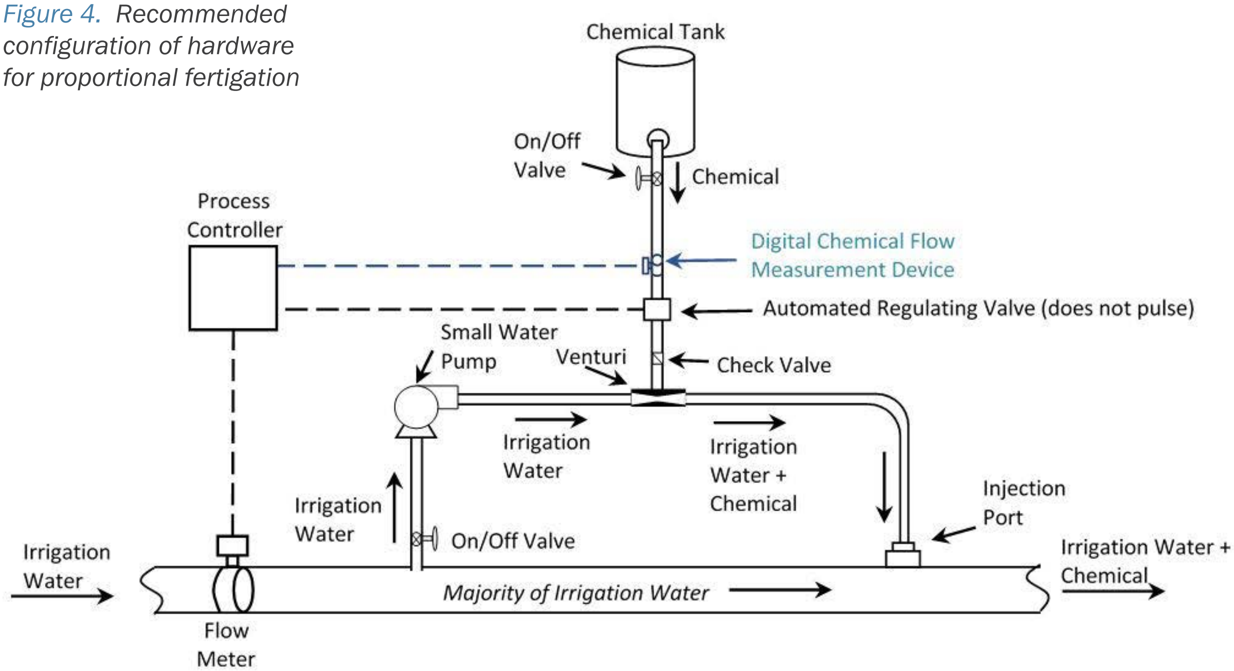


Figure 4. Recommended configuration of hardware for proportional fertigation



RECOMMENDATIONS

The two primary recommendations are:

1. Obtain the book at www.itrc.org, under "Books and Equipment".
2. Attend one of the future 1-day short courses on Fertigation, to be held at ITRC. These will be listed online at www.itrc.org, under "Classes".

ACKNOWLEDGEMENTS

This project has benefited from discussions with dozens of manufacturers and fertilizer sales personnel, as well as farmers. ITRC staff have included Monica Holman, Abraham Lozano, and Sarah Crable. The project was completely funded by the CDFA/FREP program.

Improving Nitrate and Salinity Management Strategies for Almond Grown Under Micro-Irrigation

Project Leader

Patrick Brown
Professor
Department of Plant Sciences
University of California, Davis
One Shields Ave.
Davis, CA 95616
(530) 752-0929
phbrown@ucdavis.edu

Postdoctoral Researcher

Francisco Valenzuela-Acevedo
Department of Plant Sciences
University of California, Davis
One Shields Ave.
Davis, CA 95616
facevedo@ucdavis.edu

PhD Student

Daniela Reineke
Department of Plant Sciences
University of California, Davis
One Shields Ave.
Davis, CA 95616
dreineke@ucdavis.edu

INTRODUCTION

The majority of almond growers currently provide N fertilization in liquid form through micro-irrigation systems (drip and micro-spray) and increasingly growers are utilizing groundwater that is saline. Irrigation strategies, fertigation management, nitrate leaching and salinity management are therefore linked and strategies must be developed that optimize productivity while minimizing nitrate leaching and avoiding salt-induced stress to almond trees.

While micro-irrigation (MI) methods are effective in boosting productivity and improving water/nutrient use efficiency, MI does result in a smaller rooting zone and in a highly non-uniform salt deposition (toward the edge of wetting pattern) in the active rooting zone. This has negative consequences for nitrate management since nitrate that is pushed into the high salt regions at the periphery of the wetted zone will not be available to plant roots and hence is vulnerable to leaching. Salinization of the margins of wetting pattern decreases the volume of soil in which roots can optimally function hence plant response to salinity will be determined not by bulk soil salinity but by the salinity within the active root zone and by the proportional distribution and activity/tolerance of roots in the saline (close to the edges of wetting zone) and non-saline (near the center of wetting zone) zones within the rooted profile.

The challenge of developing meaningful salinity management strategies under MI is further complicated by our relative lack of knowledge of the responses of almond to salinity. Almond is considered a salt-sensitive crop with a threshold EC of 1.5 dS/m. This value, however, was derived for Lovell rootstock under flood irrigation and is no longer relevant to modern almond systems. Rootstocks and cultivars of almond are known to vary dramatically in their sensitivity to salt-induced water stress and vary in their susceptibility to the effects of toxic ions, Na and Cl.

Given the complexity of solute management under MI and the lack of information on almond rootstock response to salinity and the lack of information on the effects of salinity on root distribution and nitrate uptake it is very difficult for growers to make informed irrigation management decisions that satisfy the dual goal of minimizing root zone salinity while simultaneously minimizing nitrate leaching. Developing this understanding is the primary goal of this project.

OBJECTIVES

1. Characterize the patterns of root nitrate uptake and plant response when plants are grown with roots in soils of different salinity status (as typically occurs under micro-irrigation).
2. Use HYDRUS (Šimůnek et al., 2012) to model solute transport, plant response (water and nitrate uptake) to salinity, and specific ions (Cl, Na, B) under a variety of irrigation scenarios and different conditions such as soil type, environment, timing, distribution, irrigation system, and water quality.

3 Use the information in objectives 1 and 2 to develop site- and cultivar-specific models and guidelines for nitrate sensitive salinity management and to produce a series of written and online grower guidelines and tools for irrigation design and scheduling.

4 Produce a robust modeling platform for the advanced grower, consultant, advisor, irrigation industry representative and researcher to develop novel and site specific irrigation design and scheduling practices for nitrate sensitive salinity management.

DESCRIPTION

1 Twelve tomato truck bins measuring 28 x 8 x 5 ft (L×W×D) were equipped with drainage pipe at the bottom and filled with a sandy loam, a common soil type in almond orchards in California. Two almond trees were planted in each of the bins, one with a Viking rootstock and one with a Nemaguard rootstock. The trees are drip-irrigated and three different irrigation frequencies are tested (Figure 1).

2 Soil water content, salt and nitrate concentrations of the soil solution will be measured at different locations in the root zone. Plant performance under the different treatments will be evaluated using leaf tissue analysis and measurements of stem water potential and tree growth.

3 A computer model that is able to predict water and nutrient uptake of almond trees will be developed and calibrated for the use in almond orchards using the measured data obtained in step 2. In addition, measured values of soil hydraulic properties as well as plant physiological parameters determined in previously conducted greenhouse studies will be incorporated into the model. Once the model has been calibrated and validated sufficiently, soil salinity and plant water and nutrient uptake will be simulated for various soils and climatic conditions and for different irrigation and fertilization management. The results will be used to improve recommendations on nitrate and salinity measurements in almond orchards.

Figure 1. Photograph of the experiment taken in summer 2018.

RESULTS AND DISCUSSION

Experiments conducted in the greenhouse indicate that almond plants, when the roots are exposed to heterogeneous salinity conditions, react by preferentially taking up water from less saline regions and the response can occur quite quickly as salinity conditions change. An example of results from a split root experiment with young almond plants carried out in the greenhouse is shown in Figure 2. In this experiment roots of a single plant were divided in two equal parts (Root A/Root B) and exposed to two different solutions, one with a low level of salinity and one with a high level of salinity. It can be seen that after starting the different treatments, the fraction of water uptake from the low salinity solution increases, whereas the fraction of water taken up from the high salinity solution decreases. After switching Root A from the low salinity to the high salinity solution and Root B vice versa, the uptake percentages reverse.

These results may have important implications for management of salinity in the field as they suggest that not only an average root zone salinity but also the distribution of salts in the root zone matters, which can be controlled by irrigation management. However, due to the large number of interacting factors that determine plant development in the field, it is impossible to suggest management strategies based on greenhouse experiments alone. The implications of the results of the results from the greenhouse experiments for salinity management under field conditions and their potential to help improve management strategies will be further elucidated in the lysimeter experiment.

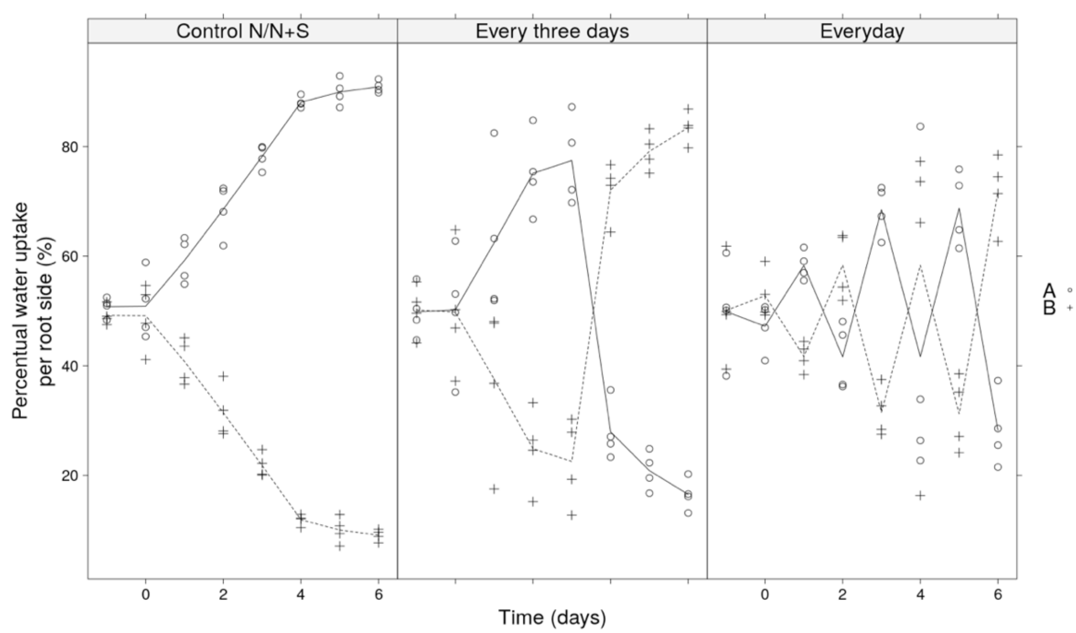


Figure 2. Percentage of water uptake per root sub-zone under temporal variation of salinity in roots. In this experiment roots of a single plant were divided in two equal parts (Root A (o)/Root B (+)) and different saline/control treatments combinations were applied to each half during the experiment switching between root halves. Two solutions were used: a) N = Nutrient (~ 0.6 dS/m) and b) N+S = Nutrient + Salts (salinity was provided as NaCl using a concentration of 50 mM ~ 5 dS/m). Three treatments were tested: N/N+S (Control) root treatments were kept the same during the whole tested period; N/N+S (Every three days) salinity was applied to one half of the roots for 3 days and the rest of the experiment salinity was applied to the other root half; N/N+S (Everyday) salinity was switch every day to different root sub-zones.

ACCOMPLISHMENTS

Greenhouse experiments have been conducted that investigate the physiological response of almond to heterogeneous salinity conditions. A lysimeter experiment has been set up that allows the quantification of nitrate leaching and simultaneously provides detailed information of the water, salt and nitrate distribution in the root zone of drip irrigated almond trees. The data from this experiment will help to improve the understanding of the interactions between irrigation management, salt and nutrient distribution in the root zone and plant response.

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ACKNOWLEDGEMENTS

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Soil Biochar Amendment to Improve Nitrogen and Water Management

Project Leaders

Suduan Gao
Research Soil Scientist
USDA-ARS, San Joaquin Valley Agricultural Sciences Center (SJVASC)
9611 S. Riverbend Ave.
Parlier, CA 93648
suduan.gao@ars.usda.gov

Dong Wang
Research Soil Scientist
USDA-ARS, SJVASC
9611 S. Riverbend Ave.
Parlier, CA 93648
dong.wang@ars.usda.gov

Cooperators

Tom Turini
Farm Advisor, Cooperative Extension Fresno County
Fresno, CA 93710
taturini@ucanr.edu

Kurt Hembree
Weed Management Farm Advisor
Cooperative Extension
Fresno County
Fresno, CA 93710
kjhembree@ucanr.edu

Niles Brinton
Charborn, LLC
Salinas, CA 93902
info@charborn.com

INTRODUCTION

Nitrogen (N) is one of the most complicated elements in its cycling. While N fertilizer provides the essential nutrient for crops it is also the source of several active N compounds that directly impact environmental quality. Ammonia (NH_3) has several detrimental effects on human health and accounts for the largest mass loss in gaseous form for N from soil. Nitrogen leaching is caused by the high mobility of nitrate (NO_3^-) in soil and has been identified as the major cause for the statewide groundwater pollution in CA. Subsequent regulatory decisions have been or are in the process of being made that require monitoring and reporting of N in production fields.

Biochar, produced from heating organic materials at high temperature under limited oxygen, has shown the benefits of carbon sequestration, improving soil properties, and mitigating environmental contamination problems. Many studies illustrated the potential benefits of biochar in increasing N retention, reduced N leaching, and decreased gas emissions. However, variabilities in observed biochar effects are large with many showing no benefits. We hypothesize that adsorption and retardation of N transformation from urea and NH_4^+ based fertilizers to NO_3^- are two potential mechanistic roles that biochar plays in changing N dynamics. These mechanisms increase N retention in soil that would lead to increased nitrogen use efficiency (NUE), reduced N leaching to groundwater, and reduced NH_3 emissions to the atmosphere. In addition, biochar is also shown to increase soil water holding capacity to increase water use efficiency. However, biochar may also improve infiltration rate that could increase N leaching. With a generally high pH (if no post treatment was applied), biochar could increase NH_3 volatilization. There are large gaps in our understanding of what effects biochar products could have on N dynamics especially under field conditions.

OBJECTIVES

The goal of this study is to determine the overall benefits and best practices of using biochar as a soil amendment in N and water management in vegetable crop production systems. Specific objectives are:

1. To determine effects of soil amendment with biochars produced from different feedstocks found in the San Joaquin Valley of California on adsorption capacity for NH_4^+ and NO_3^- and N transformation (urea hydrolysis and nitrification) rates as well as soil-water retention.
2. To determine effective amendment rate of biochar products and irrigation rates on crop response and N fate under field conditions.

DESCRIPTION

Both laboratory and field studies are utilized to achieve the project objectives. For objective 1, laboratory studies are being carried out to characterize biochar products (e.g., surface area, chemical composition), and then determined for their adsorption capacity of N species (NH_4^+ and NO_3^-), and effects on N transformation kinetics. Seven biochar products from different feedstocks were collected including two freshly made from almond shells from California orchards, two from softwood (pine), and one each from wood/tree trimming, bamboo, or coconut shells. They vary in pyrolysis temperature, particle size, composition, etc. For objective 2, a field experiment was established to test soil incorporation of biochar and irrigation rates on crop response, plant N uptake, and N losses to the environment.

Onion-biochar field experiment.

A field experiment was established at the USDA-ARS, San Joaquin Valley Agricultural Sciences Center, Parlier, CA in 2016 to test incorporation of biochar to improve N uptake and to reduce N losses to the environment for processing bulb onions. The field treatments included three irrigation levels with or without biochar amendments. In 2017, treatments selected for monitoring N dynamics included three biochar amendment rates: 0, low (added biochar in 2016 only at 29 t/ha), and high (incorporated biochar in both 2016 and 2017 at 57 t/ha) and three irrigation levels: 50, 75, and 100% of a reference that provides sufficient water for plant growth.

The field design was a split-plot design with irrigation (surface drip) levels as the main treatment and biochar rates as the sub-plots in three replications. The soil is Hanford sandy loam (coarse-loamy, mixed, super active, nonacid, thermic Typic Xerorthents). The biochar was made from softwood materials by Charborn LLC (Oakland, CA). Onion seeds were planted in December 2016. During growing season, fertilizers were applied weekly from April through June in 2017. Sampling included weekly N concentration in soil porewater, twice a week NH_3 volatilization, and biweekly measurements on plant growth and N uptake. Ammonia volatilization was measured using a modified version of semi-static chamber described in Jantalia et al. (2012).

RESULTS AND DISCUSSION

Biochar on N species adsorption and transformation. Preliminary data on adsorption isotherm have shown all biochar products exhibit a positive correlation between solution concentration and adsorbed NH4+. This experiment continues for determination of the correlations and biochar effects on N transformation.

Onion field experiment.

Ammonia volatilization measurements during the growing season in 2017 showed that it was very low before fertilization began in April. During the season, the measured NH_3 volatilization rates varied greatly, but all rates were below 1 mg N m^{-2} h^{-1}. There were no apparent differences among biochar rates or irrigation treatments. Cumulative NH_3 volatilization loss through the season accounted for 3.0-3.5% of the total amount of fertilizer applied. Measurements in the previous year (2016), however, showed much higher peak volatilization rates when fertilizer was applied only a few times during the growing season. The data indicate that high frequency fertigation with small amount of N each time irrigation was applied reduced NH_3 volatilization rates and biochar showed little effect.

Total N uptake increased almost linearly after April through June and reached the maximum in July before harvest in August. There were no apparent differences in plant N concentration and N uptake during growing season among the different treatments. Total N in onion bulbs (yield × bulb N concentration) also showed no differences among biochar treatments at both 100% and 75% irrigation levels. At 50% irrigation level, however, total N uptake was higher in the control compared to those with biochars indicating multiple factors affecting the N uptake. The results were determined and agreed with the bulb yield data.

Figure 1. Onion field for testing biochar and irrigation effect on nitrogen uptake and environmental losses.

Collecting enough soil pore water samples at all times during the growing season especially from 50% and 75% irrigation treatments proved to be difficult. Data from 100% irrigation treatments showed that pore water at 25 cm depth had initial high nitrate concentration and much lower at later times possibly due to higher N uptake and/or leaching loss. Sample collections at 100 cm depth were more successful than shallower depths that may indicate leaching occurred. Nitrate concentrations in soil profile at the end of growing season were the highest in surface soil and decreased as soil depth increased for all treatments. However, surface soils from the 50% irrigation treatments showed much higher concentrations than those from 100% and 75% irrigation treatments. The data show that N accumulated in the soil profile and the accumulation was higher in the low irrigation level than in the higher irrigation levels suggesting potentially more downward movement with high irrigation.

TAKE-HOME MESSAGE

The data from the 2016-2017 onion field experiment showed basically no differences in plant growth and N uptake among biochar amendment treatments at the 75% and 100% irrigation levels. At 50% irrigation level, biochar amendment showed lower N uptake in bulbs. There were also no differences in NH_3 volatilization measured, which was likely due to the way of fertilizer application in a small amount and applied weekly. Estimates of total volatilization loss were below 5% of total N applied. We were not able to consistently collect sufficient soil pore water to determine N movement in soil or leaching in the soil profile. In 2018, we had changed to using ion exchange resins to directly collect leaching N. Leachate collectors have been installed below the rooting zone in the onion field for all treatments in early 2018 and will be removed after harvest and extracted for N analysis to determine the amount of N leached.

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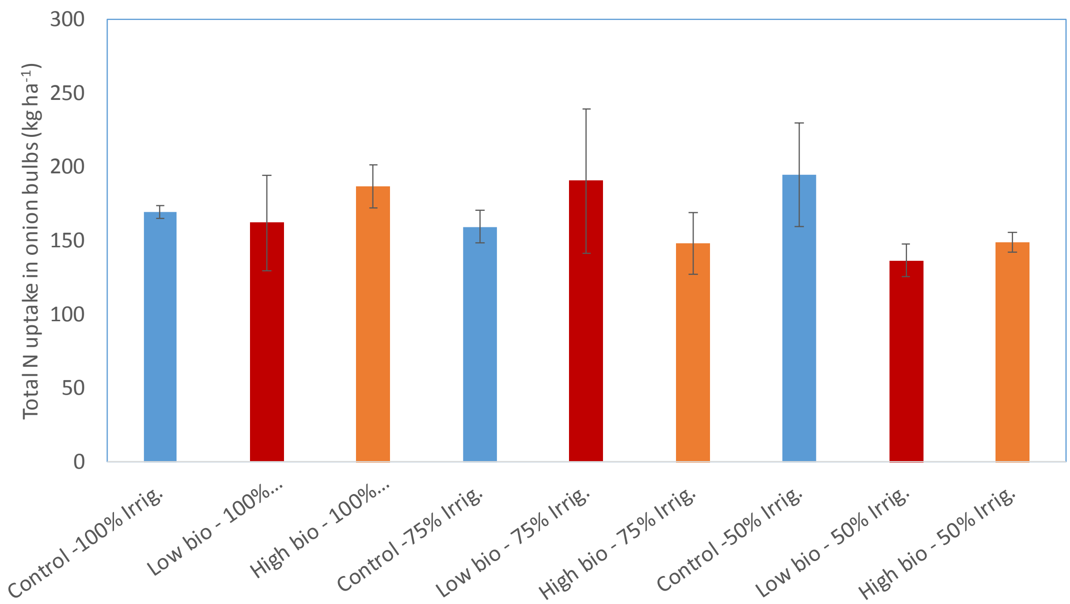

Figure 2. Total N uptake in onion bulb from different biochar and irrigation treatments in 2017. Error bars are standard deviation (n=3).

Expanding the California Fertilization Guidelines to Support Nutrient Management Decisions for Minor Annual Crops

Project Leader

Daniel Geisseler
Assistant CE Specialist
Department of Land, Air and Water Resources
University of California, Davis
djgeisseler@ucdavis.edu

INTRODUCTION

With increasing regulatory pressure to improve nutrient use efficiency in crop production, California growers need reliable information on crop nutrient demand and sustainable nutrient use. With support from FREP (projects 11-0485-SA and 15-0231), we have been closing this gap by writing online fertilization guidelines for about 30 major crops grown in California. However, for many smaller-acreage crops, very little information on nutrient management under California's conditions is currently available.

The goal of this project is to combine general nutrient management guidelines with crop-specific information, such as nitrogen (N) removed at harvest, total N uptake and growth stage when harvested, to identify and describe management practices that ensure high N use efficiency.

OBJECTIVES

The objectives of this project are (i) to provide growers and crop advisers with information about nutrient management for crops for which insufficient information is available for detailed crop-specific guidelines and (ii) to create an educational tool to highlight the effect of major factors that determine N use efficiency in the field. The specific objectives are:

1. Create a webpage discussing the principles of efficient nutrient management practices for cropping systems in California.
2. Design a crop-specific online N calculator.
3. Within the N calculator, create an N budget tool that allows users to explore the effects of crop characteristics, soil type and irrigation management on N use efficiency.
4. Write final report.

DESCRIPTION OF PROJECT

Guidelines for annual crops

We have created a generalized nutrient management web page discussing efficient nutrient management practices for annual crops (Figure 1). The web site is in the same user-friendly, interactive format as the existing crop-specific guidelines. Information on deficiency symptoms, soil tests, plant tissue testing and the four Rs of nutrient management (right amount, right place, right time, right material) are discussed for nitrogen, phosphorus and potassium. A large number of scientific articles and extension publications were used to write the guidelines. The website can be accessed at https://apps1.cdfa.ca.gov/FertilizerResearch/docs/Annual_Crops.html.

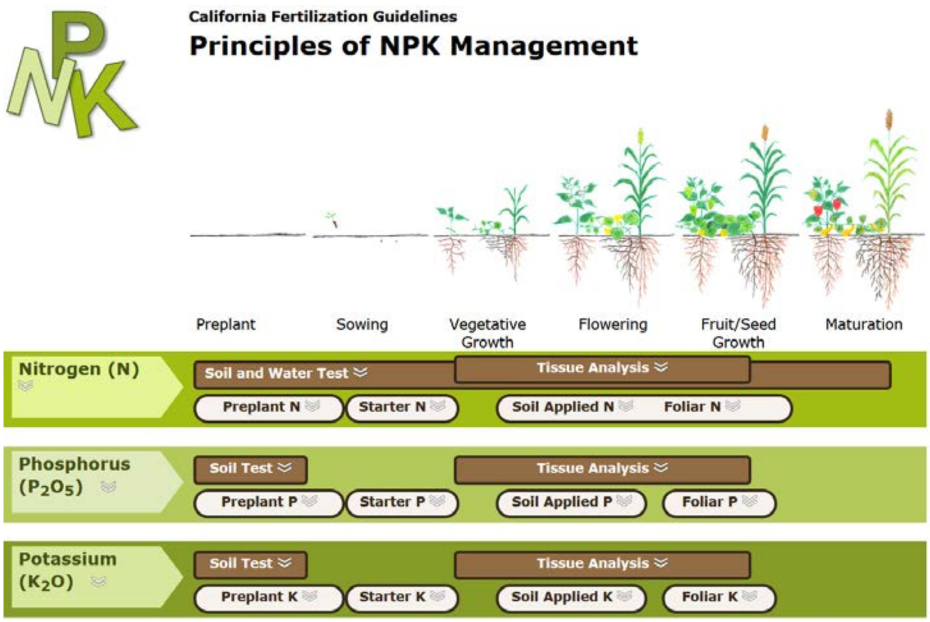

Figure 1. *Screenshot of the general guidelines for annual crops.*

Nitrogen calculator

We have also created an online N calculator for 20 annual crops, including beetroot, cucumbers, eggplant, peppers, squash, sugar beets, sweet potatoes, sweet corn, and triticale, among others. Application rates and optimal time of application heavily depend on field-specific factors. These factors are taken into account in the N calculator, which is divided into two parts. By selecting a crop, entering the expected yield and some basic information on crop management, users will be provided with estimates of total N uptake, N removed from the field and a seasonal N uptake curve (Figure 2). In a second step, users can enter information on irrigation management, residual soil nitrate, nitrate in the irrigation water and soil type

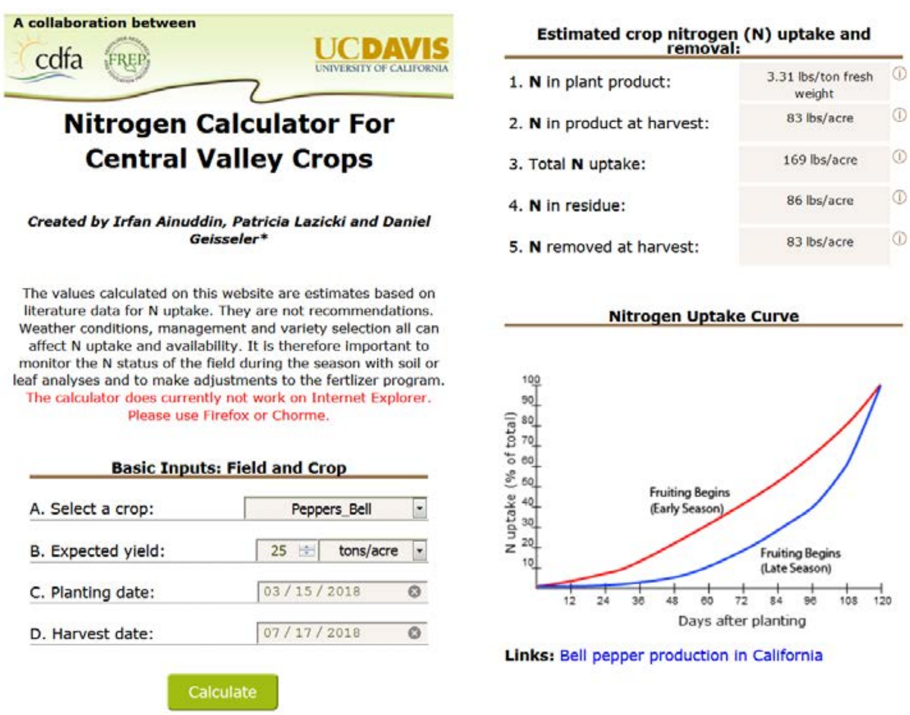

Figure 2. *Input (left) and output (right) of the first part of the N calculator.*

(Figure 3). Based on this information, the program then calculates the N credits from residual soil nitrate, nitrate in the irrigation water and in-season N mineralization. In addition, the program calculates the amount of N fertilizer needed without leaching, the amount of N at risk of leaching and the amount of N fertilizer needed to compensate for N leached. The N calculator can be accessed at https://apps1.cdfa.ca.gov/FertilizerResearch/docs/N_Calculator.html.

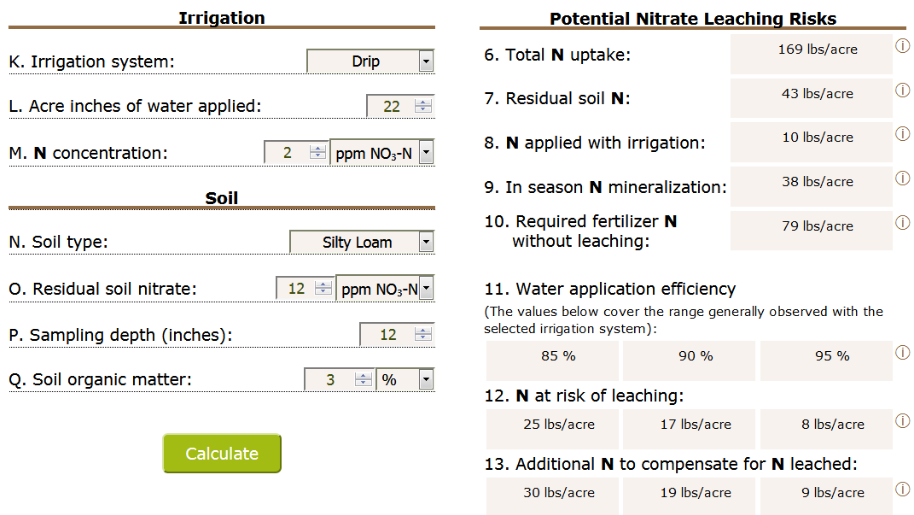

Figure 3. Input (left) and output (right) of the second part of the N calculator. The water application efficiencies (output line 11) cover the range of values generally found in the literature for the irrigation system selected by the user (input line K).

Nitrate leaching tool

The third addition to the guidelines is an educational tool that lets users explore how plants, irrigation and soil affect the risk of nitrate leaching. Users can select rooting depth (shallow vs. deep), growth stage (young vs. mature), irrigation type (drip vs. furrow), soil texture (fine vs. coarse), residual soil nitrate level (low vs. high), and irrigation level (low vs. high) for a total of 64 scenarios. For each scenario, a picture is displayed showing the distribution of roots, water and nitrate. The picture is complemented with a short explanation (Figure 4). The tool can be accessed at https://apps1.cdfa.ca.gov/FertilizerResearch/docs/Nitrate_Tool.html.

ACKNOWLEDGEMENTS

We thank Irfan Ainuddin and Patricia Lazicki for program development and literature review. Funding for this project was provided by the CDFA Fertilizer Research and Education Program.

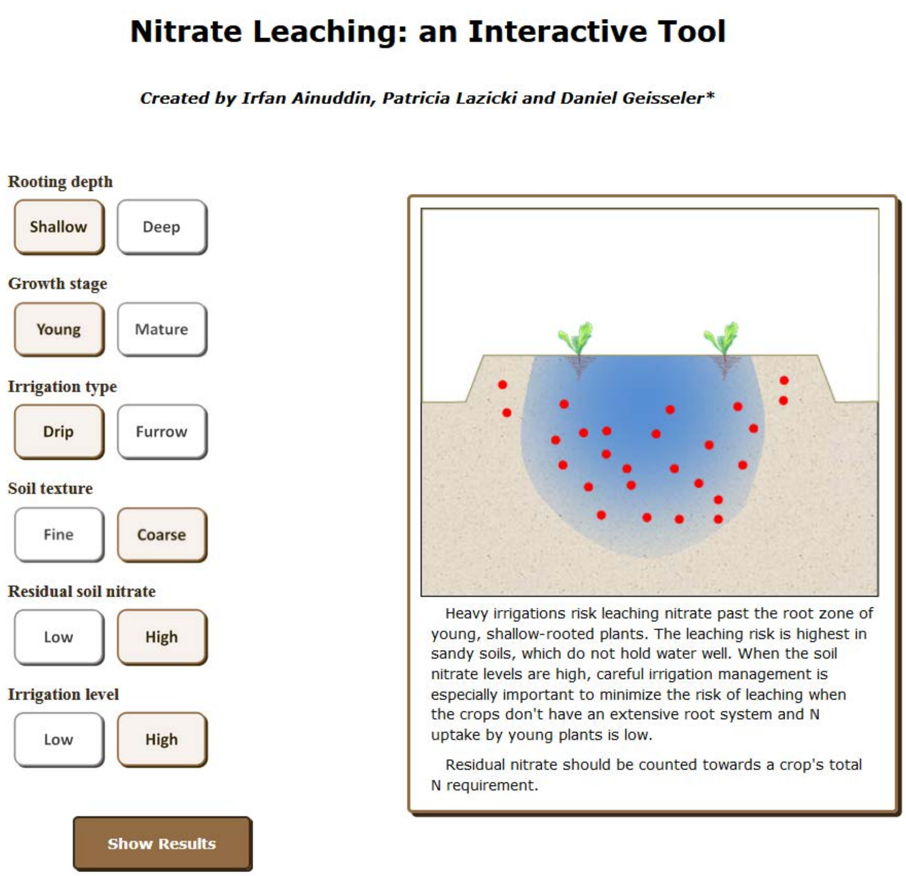

Figure 4. Screenshot of the educational tool. Users can select a scenario on the left and the result is displayed on the right. A total of 64 scenarios are possible.

Demonstration of a Combined New Leaf Sampling Technique for Nitrogen Analysis and Nitrogen Applications Approach in Almonds

Project Leader

Patrick Brown
Professor
Department of Plant Sciences
University of California Davis
phbrown@ucdavis.edu

Cooperators

Blake Sanden
Farm Advisor (retired)
University of California
Cooperative Extension
Kern County
blsanden@ucdavis.edu

Allan Fulton
Irrigation and Water
Resources Advisor
University of California
Cooperative Extension
Tehama County
aefulton@ucdavis.edu

David Doll
Pomology Farm Advisor
University of California
Cooperative Extension
Merced County
dadoll@ucanr.edu

INTRODUCTION

Nitrogen in almond has historically been managed using the leaf sampling and critical value approach of nutrient management. In this approach leaf samples are collected in July and analyzed for nutrient concentration. The results are compared with established standards and annual fertilizer rates are increased if nutrients are deficient. Although this approach has value, it does not identify inefficient N use and does not provide information on the rate and time of nutrient demand. In addition, seasonal variability, existing N in irrigation water and residual soil N are not alwyas accounted for. Further, tissue samples are generally collected late in the season when there is limited time to respond if deficiencies exist. To provide farmers with better tools, improved approaches that guide the time and rate of fertilizer application and provide methods for early season leaf collection and analysis that facilitates timely in-season monitoring of nitrogen status have been developed. This study introduces a leaf sampling/yield budget approach in addition to adjusting for existing N in irrigation water and soil residues.

While the development of new tools is essential if enhanced N use efficiency is to be realized, these tools will be of limited use if they are not widely adopted. The current project is designed to improve adoption of these tools by demonstrating the performance of the new N management protocols in contrast with traditional N management strategies to farmers, managers and crop consultants.

OBJECTIVES

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

DESCRIPTION

Objective 1. Field trials in 4 contrasting orchards have been established in which ‘standard’ and ‘improved’ management strategies are contrasted. Extensive monitoring of nitrogen applications, yields, soil nitrogen and overall N budgets have been conducted.

In 2018 a new field site was incorporated into the demonstration project (Bowman Ranch) in which a suite of advanced N management techniques are being implemented along with intensive vadose zone and deep water monitoring. Spoon-feeding and plant and groundwater monitoring are being conducted as well.

In ‘New’ management practices treatments, yield predictions were made by an experienced extension specialist utilizing historical yield records, current bloom

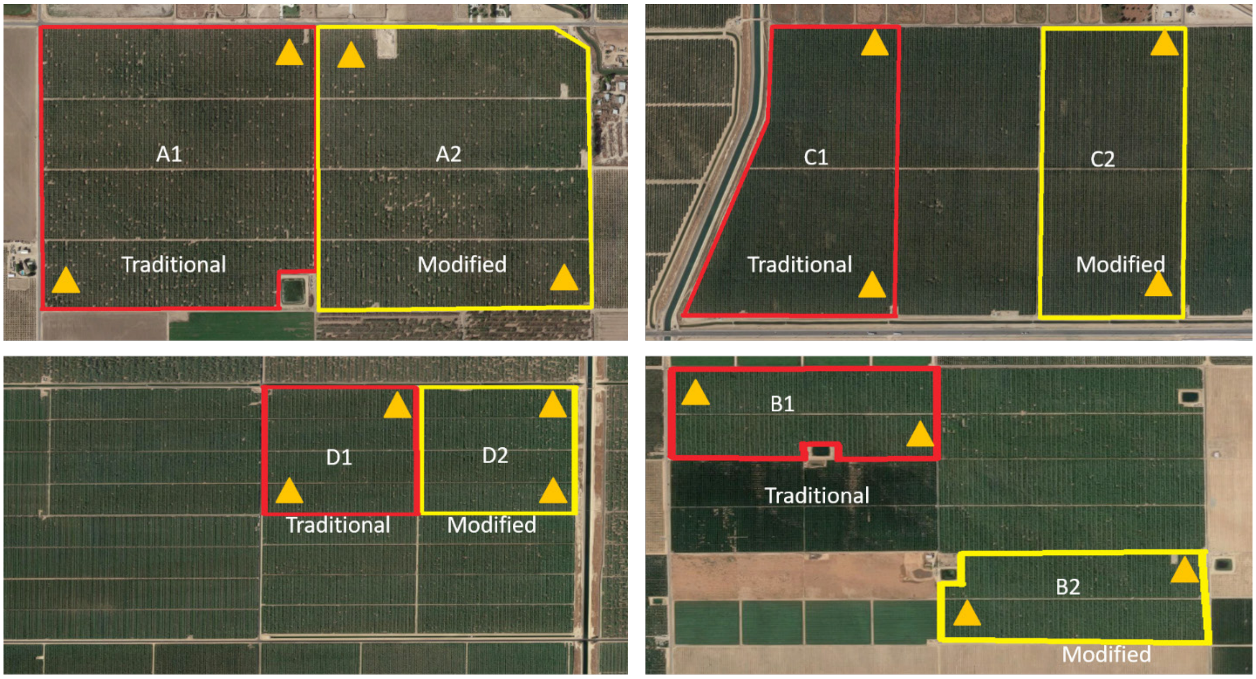

Figure 1. Four project demonstration orchards (A-D) with treatment contrast between 'Traditional Grower (1) and 'New' nitrogen management strategies (2) were established in 4 distinct 15 year-old Kern County Almond orchards av-eraging 80 acres with 50%Nonpareil, 50% Monterrey (only Nonpareil data was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

intensity and knowledge of winter and spring environmental conditions. Yield predictions were converted to nitrogen fertilization strategies using the Almond Board CASP nitrogen budgeting calculator decision support tool. Nitrogen management plans were generated for the orchard.

Objective 2. Working with FREP and UCCE, four grower field days were conducted at project demonstration sites in each region. In 2018 an additional site in Modesto (Bowman site) at which a whole system analysis of N budgets and fates in groundwater, plant and as gaseous N loss is being conducted.

RESULTS AND DISCUSSION

In year 1, no difference in tissue N concentrations were observed between treatments and there was only a small increment in soil nitrate-N at one test-site following traditional grower management. Nitrogen use efficiency (NUE) was generally high in all fields ranging from 48% to 95%. On average, the improved N management practices resulted in a significant increase in N use efficiency in contrast with traditional grower practices. NUE was improved in large part due to the inclusion of N present in irrigation water as a credit against N fertilizer requirements. The results also illustrate that N use efficiency is compromised by incorrect yield estimation (Field B2) and failure to conduct in season fertilization modifications as yield estimations are refined (fields A1, C1, D1, D2). Informal interviews with growers also indicate that uncertainty in yield estimations and uncertainties in nitrogen contribution from irrigation water are major limitations to improved nitrogen management.

ACCOMPLISHMENTS

Year 1 experimental results are reported here with year 2 results analysis in progress. In February and March of 2018, 4 field days were conducted with over 300 total attendees to highlight the approaches to best N management and discuss results of the trials to date. Plans are to repeat these events in 2019.

RANCH		1st Bloom Yield Estimate (lb/ac)	Spring Estimated N Demand @68 lb N/1000 lb	Required N @ 70% NUE	Total N Credit (lb/ac)	Total Applied N (lb/ac)	Final Nonpareil Yield (lb/ac)	Brown fruit N export @68 lb N/1000 lb	Calculated NUE
Field	A1	3400	231		69	235	3095	210	69%
Field	A2	2700	184	262	69	165	2910	198	85%
Difference in Applied N						-70			
Field	B1	2900	197		15	245	2831	193	74%
Field	B2	3000	204	291	15	269	2661	181	64%
Differnce in Applied N						24			
Field	C1	3100	211		56	210	2745	187	70%
Field	C2	2200	150	214	56	134	2706	184	97%
Difference in Applied N						-76			
Field	D1	2800	190		90	210	2097	143	48%
Field	D2	2800	190	272	90	144	2433	165	71%
Difference in Applied N						-66			

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

RECOMMENDATIONS

Adopt efficient nutrient management using "the 5 R's:"

1. Applying N at the Right Rate by matching supply with tree demand (accurate yield estimations are critical) and measuring all inputs such as fertilizer, organic N, irrigation water N and residual soil N.
2. Apply N at the Right time by following temporal N demand based on physiological seasonal cycles coincidental with maximum root uptake.
3. Apply N at the Right place into active root zone considering soil and orchard variability. How and when fertigation is applied during an irrigation cycle determines where in the root zone N is deposited.
4. Use the Right N source such that N uptake is maximized, N loss is minimized and limiting nutrients are eliminated.
5. Use the Right monitoring of tree N by conducting leaf sampling in April.

TAKE-HOME MESSAGE

Base fertilization rate on realistic, orchard specific yield, account for all N inputs and adjust in response to spring nutrient and yield estimates.

1. Make a preseason fertilizer plan based on expected yield LESS the N in irrigation and other inputs. Ex) 1000lb kernel removes from 68lb N, 8lb P and 80lb K.
2. Conduct (properly!) a leaf analysis following full leaf out.
3. In May, review your leaf analysis results and your updated yield estimate, then adjust fertilization for remainder of season.
4. At harvest review yields and adjust post harvest fertilization accordingly.
5. Time application to match demand in as many split applications as feasible.
6. 80% N uptake occurs from full leaf out to kernel fill.
7. Apply up to 20% hull split to immediately post harvest, corrected for actual yield - but only if trees are healthy. Use foliars if N loss is possible.
8. Optimize everything!
9. Every field, every year, is a unique decision

Refer to https://www.sustainablealmondgrowing.org for tools and calculators.

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ACKNOWLEDGEMENTS

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Assessment of Harvested and Sequestered Nitrogen Management in Perennial Crops

Project Leaders

Charlotte Gallock, P.E.
Manager of Water Resources
Kings River Conservation District
4886 E. Jensen Avenue
Fresno, CA 93725
cgallock@krcd.org

Dr. John Dickey
Technical Program Manager
SSJV MPEP Program
PlanTierra
611 Del Oro Place
Davis, CA 95616
jdickey@plantierra.com

Dr. Ken Cassman
Senior Agronomic and Soils Advisor
823 Oceanside CA 92058
kgc1consulting@gmail.com

Cooperator

Dr. Daniel Geisseler
Asst. Nutrient Management CE Specialist
UC Davis
One Shields Avenue
Davis, CA 95616
djgeisseler@ucdavis.edu

INTRODUCTION

Through the Irrigated Lands Regulatory Program (ILRP), the Central Valley Regional Water Quality Control Board (Water Board) now requires producers to implement management practices that are protective of groundwater quality and to document the effectiveness of those practices by providing, among other things, information on field nitrogen (N) balances. In addition, the Agricultural Expert Panel convened by the State Water Resources Control Board recommended metrics composed of N applied (A) and N removed (R) to gauge program progress in reducing the mass of leachable N (Burt et al., 2014). This approach was adopted by the Water Board. To comply with this new reporting requirement, growers and their water quality coalitions need reliable data about N removed from fields in harvested crop materials. Also, growers can use rates of N removal in crops to plan nutrient management programs that reasonably minimize N at risk of leaching below the root zone.

Nitrogen Concentrations in Harvested Plant Parts - A Literature Overview (N-concentrations Report) by Dr. Geisseler (2016) presents yield-to-N-removed conversion factors for 72 crops, representing more than 98 percent of CV irrigated lands. However, that report noted that some of these factors are based on datasets that were small, more than 20 years old, or from outside the Central Valley with cultivars, yields, cropping systems, and soil types that may not reflect contemporary Central Valley conditions. The N-concentrations Report showed that well-established coefficients are available for only 10 of the 72 crops, accounting for approximately 12 percent of irrigated lands in the Central Valley. Further, there are even fewer data on the amount of N sequestered into perennial crop biomass, which growers need to know when planning N fertilizer programs for younger orchards, groves, and vineyards during rapid early growth of perennial tissues. To improve currently available estimates of coefficients for the remaining 62 crops from the N-concentrations Report, additional data need to be obtained from analysis of recent crop samples from Central Valley fields over several years.

OBJECTIVES

1. Assess N concentration of harvested material removed from fields (N removed [R]) for approximately 25 crops over several growing seasons. Samples of harvested material will be collected and analyzed for twelve of those crops. Data for the remaining crops will come from existing sources. As the project is evolving, it appears that more crops may be included in the study than originally planned.
2. Establish values for the annual amount of N sequestered in standing biomass for seven perennial crops. Tissue samples will be collected and analyzed for one of those crops. Data for the remaining crops will come from existing sources.
3. Refine crop yield (Y)-to-R conversion factors, and add N-sequestration rate estimates, for use by growers and grower advisors during nutrient management planning and by coalitions for large-scale performance assessment.
4. Promote and enable expanded knowledge and appropriate use of N-removal

coefficients and N-sequestration rates (as part of routine N-management planning and evaluation) by growers, grower advisors, and coalitions.

DESCRIPTION

We are developing updated conversion factors for 25 crops. For some, information is coming from other research projects. However, we are sampling and analyzing harvested carrots, corn [grain and silage], peaches, pima cotton, pistachio, plums, pomegranates, raisins, safflower, sorghum [grain and silage], and processing tomatoes. By partnering with commodity organizations, growers, processors, and packers, it has been possible to procure hundreds of samples that represent a range of varieties and growing environments for each crop. In most cases, substantial information about source fields, such as age of perennial crops, crop management, variety, yield, quality, and dates of bloom or planting, are acquired and related to results. In this way, some of the factors that affect N content of the harvest can be investigated and explained.

These data will be incorporated into updates of Geisseler (2016) as part of this project. The existing Y-to-R calculator (http://agmpep.com/calc-y2r/) will be revised to reflect these findings, and the results will be used to update the assessment and planning tools available to growers, grower advisors, and coalitions.

RESULTS AND DISCUSSION

Work completed since the January 2018 grant award includes coordination of year-1 sampling of 11 crops with grower/packer/shipper partners, along with initial lab analysis. Antecedent work was focused on peaches and aimed at answering the following questions, each of which will help to inform sampling design during two or three additional years of sampling and analysis:

1. Is it necessary to subdivide kernel from shell in the pit for a good analysis, or can pits be analyzed whole? Pit subsamples for which kernel and shell were analyzed separately had higher N content than pits processed and analyzed whole ($P < 0.0005$), but pit N is a minority of whole-peach N. It is possible that when pits are analyzed whole, that the kernel tends to be under-represented in the ground, mixed sub-subsample of whole-pit material that is analyzed. This should be verified by comparing larger groups of subsamples. In this study, the average %N recovered in whole relative to separated pits was 66%. Pending further verification, this adjustment has been applied to results for whole pits throughout the rest of this analysis. If pits can be analyzed whole, this reduces analysis costs by more than a third relative to segregation of pit components. The influence of errors in measuring pit N on the estimate of whole-fruit N content is minimal because about 92% of the N is in the flesh.
2. How consistent are subsamples from the same groups of fields? Samples of as few as seven peaches provided quite consistent (CV = 5%) results for N content of whole peaches. Analyzing multiple subsamples would not add much precision. More fruit may be needed to allow for a range of fruit sizes (see below). This sampling efficiency greatly reduces sampling, processing, and analysis costs.
3. Do peaches grown in California today have a very different N content from peaches grown under other conditions? This question arises because much of the literature related to N content in peaches comes from elsewhere (e.g., Spain). Whether N is considered in relation to fresh weight or dry matter, California samples overlap observations from elsewhere, but are situated on

the high end of these observations and range to 1.5 (for N as part of the fresh weight) to 2 (for N as part of the dry weight) times the upper end of observations in the literature.

4. How are applied N and N removed in fruit related? N fertilization of peaches is thoroughly discussed in Niederholzer et al. (2001). Higher N rates generally increase levels of N in fruit, but this effect diminishes at higher application rates. The amount of N removed in the crop is relatively high per unit applied N in samples from California, except for early peaches that produce lower tonnage. N application rates in California are not high relative to other peach growing areas, despite the elevated fruit N content, suggesting that N fertilizer delivery efficiency into fruit is relatively high in the California fields studied. One likely reason is that soil and weed management may minimize some other losses, such as uptake into weeds and cover crops.
5. How important is the ratio of flesh to pits? Because the pit is a seed, does it contain most of the N? N is most concentrated in the kernel of the peach, but 92% of the N of all peach samples was in the flesh. The flesh-to-pit ratio varies, but is not strongly related to N content of the harvested fruit. The proportion of the fruit that is the pit has no regular relationship to fruit size/weight, and does not predict N content of the fruit.
6. How does harvest date affect N content? The rate of crop development depends on physiological processes that are affected by ambient temperatures, so that physiological time is measured in units that combine time and heat. One such measure is the growing degree hour (or day, respectively GDH and GDD), which can be calculated from readily available CIMIS[1] data and bloom dates for the orchard in question. The accumulation of sugars into the fruit, which drives crop yield and gradually dilutes N in the fruit, is the best predictor of plant development. It is closely related to fruit yield of the cooperating orchards growing early through late-late peaches.
7. How do harvest date and fruit size affect N removal rates? A thorough discussion of N dynamics in peaches is available in Rufat and DeJong (2001). As GDH accumulate after bloom, dry matter accumulates in fruit, gradually diluting N, leading to lower overall concentration in fruit dry matter and fruit, until late in the season, when this process tapers off. For fruit harvested at the same time, smaller fruit have slightly higher N content.
8. Since reported yields are for packed fruit, how should losses during shipping and packing be accounted for when calculating N removed by the crop? Most growers know their pack-out weight and percentage. For cooperators, the latter was about 75% (i.e., 25% of the harvested fruit is not packed).

TAKE-HOME MESSAGE

Sampling: Samples should be taken across a range of harvest dates, and results related to GDH. Samples should be composed of fruit proportionally representing the full range of fruit sizes from the field(s) in question. One, well-mixed subsample of 7 to 20 representative fruit from a field should be sufficient to characterize a field.

Analysis: Flesh can be analyzed as wet puree, and pits dried intact and then ground before subsampling for analysis. Only by scrubbing can clinging flesh be

1 *California Irrigation Management Information System*

removed from pits for analysis.

N removal coefficients: These can be developed in two modes. The first would be an average rate of removal for the crop, based on harvest dates and size classes. The second could be a series of removal rates pertaining to different harvest date ranges. Either method will provide more reliable estimates of peach N removal rates for use in estimating N fertilizer requirements.

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Training on Crop Management that Integrates Climate, Soil and Irrigation System Data to Minimize Nutrient Loss and Optimize Irrigation Efficiency

Project Leader

Trina Walley
Programs Coordinator
East Stanislaus Resource Conservation District
3800 Cornucopia Way
Suite E
Modesto, CA 95358
(209) 491-9320 ext. 139
programs@eaststanrcd.org

Co PI

Khaled M. Bali
Irrigation Water Management Specialist
UC Kearney Agricultural Research and Extension Center
University of California
Department of Agriculture and Natural Resources
9240 South Riverbend Ave.
Parlier, CA 93648
(559) 646-6541
kmbali@ucanr.edu

Project Collaborators

Rex Dufour
Western Regional Office Director
NCAT/ATTRA
P.O. Box 2218
Davis, CA 95617
(530) 792-7338
rexd@ncat.org

Steve Amador
Professor of Agriculture Mechanics
Modesto Junior College
435 College Ave
Modesto, CA 95350
(209) 575-6215

INTRODUCTION

As technology in irrigation, chemigation and fertigation advance, there is an increased need to provide information for agricultural workers on best management practices. The East Stanislaus Resource Conservation District (ESRCD) addresses local resource concerns through a variety of outreach programs such as irrigation and nutrient management workshops, which include material on integrated management practices. The workshops and trainings help ensure that decision makers are using water efficiently, are able to accurately monitor nitrogen application levels and are able to better manage the health of their soil for optimum productivity all while preventing deep percolation of nitrates that are known contaminates to groundwater. The assessment portion of the program collects in-field data to determine uniformity and efficiency of their irrigation water management. It is then followed by a detailed report summary with recommendations from industry sources to improve management and/or maintenance. Trainings and the assessment are followed up with one-on-one technical assistance to document changes and improvements. The project has benefited 75 growers to date between the workshops and irrigation evaluations.

OBJECTIVES

1. Promote best management practices through workshops for agricultural workers in English and Spanish based on existing resources from University of California Cooperative Extension, USDA-Natural Resource Conservation Services, NCAT/ATTRA and CDFA-FREP.
2. Establish training materials and workshops that can be approved for continuing education credits towards maintaining certifications through Irrigation Association, California Certified Crop Advisors and Department of Pesticide Regulation.
3. Encourage irrigators to share individual challenges and successes in workshops, which will create a networking environment for ongoing farmer-to-farmer education.

DESCRIPTION

1. Conducted initial evaluations on farms to determine individual needs; evaluations included an irrigation system assessment using the Cal-Poly ITRC program, a soil health assessment using USDA-Natural Resource Conservation Service programs, and an interview of the decision maker for the property on current management and practices.
2. Submitted educational material and workshop agenda for qualification for CEUs for Nitrogen Management certification program through CURES.
3. Hosted pre-irrigation season workshops that presented information on system

planning and scheduling, general maintenance, nutrient management and monitoring methods.

4. Provided recommendations on best management practices tailored to grower needs. Continued technical assistance will be provided to the attendees of the workshops so materials can be developed to address challenges and success in post-irrigation season workshops.
5. Presented training results to regional partners such as West Stanislaus Resource Conservation District, as well as submitted presentations for Californian Association of Resource Conservation Districts and Almond Board of California annual conferences.

RESULTS AND DISCUSSION

To date, there has been one workshop with attendance at full capacity of 43 producers, and 32 properties were provided technical assistance, covering 1,350 acres with an average DU of 87%. The lowest global distribution uniformity (DU) found was 59% which was a result of running the system at a low pressure; however the flow distribution uniformity was at 89%. Only one field was found to have both, low global DU and, low flow DU as a result of a poorly designed and aged system. A majority of the fields had a global DU of over 83% which is considered satisfactory. The most common issues identified in all evaluations were related to lack of maintenance and operation errors, such as, flushing hoses, leaks, plugged emitters, plugged hose screens, running systems below recommended operating range, high pressure losses across filters, not operating system as designed and poor scheduling. These issues will be addressed in upcoming workshops in both English and Spanish.

After presenting the workshop materials to partner organizations, there has been interest from Farm Bureaus and Resource Conservation Districts to provide similar trainings to their growers from Madera to Sacramento.

TAKE-HOME MESSAGE

This project focuses on the FREP goal of improving input management through Irrigator Workshops and increasing the level of penetration of information regarding best management practices in local agricultural companies. Thus far, the project has documented and confirmed the need for continued education for growers and

Hose leak

Plugged emitter

Hose flush

Plugged emitter

Hose screen

farm managers on best management practices. Despite years of experience, there were many growers who were able to identify issues with their system operation or maintenance which they can improve immediately, that will have a long-term impact of how efficiently they apply irrigation water and fertilizers.

There will be a positive environmental impact resulting from the Management, Assessment and Training (MAT) program due to the connection being made between irrigation system uniformity and the effectiveness of nutrient application. This positive environmental impact has a direct correlation with a positive economic impact. By increasing producers' soil health, and irrigation and fertilizer application efficiency, and minimizing water and nutrient waste, the cost of yearly inputs for crop health can be reduced. Additionally, the MAT program will have a positive agronomic impact on the participants by providing an awareness of new technology available to producers and employees to help increase efficiency, soil health, and stability, monitor actual nutrient and water levels, and finally provide options to create or improve a precise schedule for nutrient and water application.

ACKNOWLEDGEMENTS

Funding for this project was provided by the California Department of Food and Agriculture's Fertilizer Research and Education Program. Special thanks to the University of California Cooperative Extension both local advisors and state specialists for assisting in the development of the training curriculum as well as the National Center for Appropriate Technology for curriculum and translation services. Recognition is also deserving for the Almond Board of California for their continued leadership in sustainability and willingness to share resources and their Irrigation Specialist to mentor the interns during in-field irrigation evaluations. Modesto Junior College has proven to be an excellent partner with their equipment and resources as well as students from the Irrigation Technology Program.

Evaluation of Nitrogen Uptake and Applied Irrigation Water in Asian Vegetables Bok Choy, Water Spinach, Garlic Chives, Moringa, and Lemongrass

Project Leaders

Aparna Gazula
UCCE Farm Advisor 1553 Berger Drive Bldg 1, 2nd Floor San Jose, CA 95112

Ruth-Dahlquist Willard
UCCE Farm Advisor 550 E. Shaw Avenue Suite 210-B Fresno, CA 93710

Daniel Geisseler
Cooperative Extension Specialist
One Shields Avenue Davis, CA 95616

INTRODUCTION

Asian specialty vegetables are grown intensively in open field and protected agricultural systems. In protected agricultural systems, some of the vegetables are grown 6-7 times per year in continuous rotations with a 15-day gap between each rotation. Grown primarily in Fresno, Monterey, Riverside, San Bernardino, Santa Clara, San Luis Obispo, and Ventura counties on around 7026 acres, Asian vegetables are valued at $79 million per year (California County Crop Reports, 2015).

In Fresno and Santa Clara Counties, these crops are grown primarily by limited-resource, small-scale, socially disadvantaged Chinese, Hmong, and other Asian immigrant farmers. Information is currently lacking on nitrogen uptake in many of these crops. With proposed regulations under the Irrigated Lands Regulatory Program (ILRP) by the Central Coast Regional Water Quality Control Board (CCWQCB) and the Central Valley Regional Water Quality Control Board (CVRWQCB) to control N losses, it is important to understand N uptake and removal in crops that have significant acreage but do not have commodity board support. Asian growers producing specialty vegetables and herbs are required to fill out the N management plan as part of the ILRP. However, they lack the information to complete this form accurately as there is no information on N fertilizer recommendations or N uptake for most of their crops.

The overall goal of this project is to provide detailed measurements of total N removal, N uptake, and the N uptake pattern of bok choy, water spinach (ong choy), garlic chives, moringa, and lemongrass.

OBJECTIVES

Information on N uptake is crucial for viable crop production, but irrigation efficiency is important to retaining the applied N within the crop root zone. This project will also evaluate the current irrigation management practices of bok choy, water spinach, garlic chives, moringa, and lemon grass, compare them with the crops' water requirements and identify potential practices that may help reduce nitrate leaching. Together, the information collected will provide the basic information necessary for growers to better manage N inputs to these crops and protect water quality. Specifically, the following two objectives shall be addressed with the work proposed for this project:

1. Evaluate N uptake, N availability, canopy development and water application of bok choy, water spinach, garlic chives, moringa, and lemongrass.
2. Extend the findings of this research to Chinese and Hmong growers in the Central Coast and Central Valley regions to increase their understanding of N uptake, and publish results to provide documentation of the findings.

DESCRIPTION

On-farm work on the project began in fall 2018. The following tasks are ongoing:

Evaluations are being conducted in grower fields with typical crop production practices for the region and crop (direct seeded bok choy and water spinach, transplanted garlic chive, moringa, and lemongrass); irrigation and fertilizer management practices also represent the typical practices for the region. These include sprinkler irrigation for the majority of the fields in Santa Clara County, and either flood/furrow irrigation or drip irrigation in Fresno County. The evaluations will be conducted on 14 commercial fields: six fields for bok choy - two locations, three farms in Fresno and three farms in Santa Clara county; water spinach, garlic chives, moringa, and lemongrass - one location and two farms per location; for a total of 28 fields in 2018 and 2019 growing seasons.

Work Plan Year 1

Task 1: Conduct N, irrigation and root evaluations of 14 bok choy, water spinach, chive, moringa, and lemongrass fields in 2018.

Sub-task 1.1 Conduct N uptake pattern and total N uptake evaluations.

1. Select 6 high yielding fields of bok choy and 2 high yielding fields each of water spinach, garlic chive, moringa, and lemongrass from Fresno and Santa Clara counties.
2. During the growing season, conduct above ground biomass, biomass N and soil nitrate evaluations 3 times for bok choy, 7 times for water spinach and moringa, and 12 times for garlic chive and lemongrass to generate N uptake curve. Each field will be divided into three blocks (replicates). Separate samples will be taken from each block. When the crops are harvested, the harvested portion of the crops and the residues left in the field will be sampled separately.
3. At harvest, samples will be collected from at least 4 additional fields per crop and analyzed for fresh and dry weight, as well as N content to obtain a more robust estimate of the amount of N removed with the harvested portion of the crops (expressed in lbs/ton fresh weight).
4. At key stages of crop development, diagnostic sampling of leaves will be done for analysis of total N.

Sub-task 1.2 Conduct crop canopy evaluations and irrigation application evaluations.

1. Install flow meters in the above-mentioned fields.
2. Using an infra-red camera, take canopy photos of crop every two weeks and up to three harvests for multiple harvest crops.
3. Install and maintain soil moisture monitoring sensors.

Sub-task 1.3 Analyze all data and prepare mid-term report to FREP.

Sub-task 1.4 Reports and extension.

1. Provide mid-term report to FREP.
2. Report preliminary results to Chinese and Hmong growers at workshops and UCCE newsletters.

Figure 1. Water spinach crop in production in an Asian style greenhouse production system during a recent tour of a grower cooperators' farm.

ACCOMPLISHMENTS

The grant fund accounts were established in May, 2018 and funds were available for expenditure from then onwards. As a result, the timeline for the field trials was moved from a Spring 2018 start time to Fall 2018. The project team including Co-PIs and project staff received training on the assembly and use of tools for monitoring crop canopy development, soil moisture levels, and irrigation water flow from Michael Cahn (Farm Advisor, UCCE Monterey County) and David Chambers (Staff Research Associate, UCCE Monterey County). Currently the two locations for the field trials Fresno and Santa Clara are assembling the tools for monitoring crop canopy development, soil moisture levels, and irrigation water flow data. Also, the project teams in both locations have identified the key grower collaborators for the field trials (Figure 1).

ACKNOWLEDGEMENTS

We thank Michael Cahn and David Chambers for their support with crop canopy development and irrigation monitoring tools. Funding for this project was provided by the CDFA Fertilizer Research and Education Program.

A System Nitrogen Balance for Container Plant Production

Project Leader

Lorence R. Oki
CE Specialist
Dept. of Plant Sciences
One Shields Ave.
University of California, Davis
lroki@ucdavis.edu

Co-Investigators

Richard Evans
CE Specialist
Dept. of Plant Sciences
One Shields Ave.
University of California, Davis
ryevans@ucdavis.edu

William Horwath
Professor
Dept. of Land, Air, and Water Resources
One Shields Ave.
University of California, Davis
wrhorwath@ucdavis.edu

Bruno J.L. Pitton
Staff Research Associate
Dept. of Plant Sciences
One Shields Ave.
University of California, Davis
bjpitton@ucdavis.edu

INTRODUCTION

The Central Valley Regional Water Quality Control Board requires the implementation of nitrogen management plans (NMP) by growers within the Central Valley Basin. The NMP consist of documenting yearly nitrogen (N) inputs and outputs to develop an N mass balance. Potential N available for leaching into groundwater is calculated by subtracting N outputs from inputs. Inputs consist of total N in soil and fertilizer, organic amendments, and applied irrigation water. N output is based on harvested yield and the N content of that material.

The quantity of N in major crops, like almonds or table grapes, is readily available (Geisseler 2016). However, some agricultural commodities, like container-grown nursery crops, do not fit neatly into the NMP worksheet. In container plant nurseries, thousands of different plant species/cultivars, in a range of sizes from small propagation stock to large trees, are grown in specially formulated growing substrates. The whole product, including the roots and substrate, is "harvested" and shipped from nursery grounds to retail and other customers. The portion of N remaining in the container substrate at the time of shipment depends on the amount of fertilizer applied, which can range from 0-41% of applied N (Narvaez et al. 2012, 2013; Cabrera 2003). However, neither Cabrera (2003) nor Narvaez et al. (2012, 2013) could account for the fate of a significant proportion of applied N, and they attributed the discrepancy to denitrification. Denitrification reduces the amount of N potentially available to leach into groundwater but can also contribute to atmospheric N pollution as nitrous oxide.

Nursery-specific practices may encourage denitrification and reduce N leaching into groundwater. These practices include frequent irrigation to maintain container substrate moisture content and saturated conditions in the soil below growing beds.

As nursery production uses large amounts of synthetic N fertilizer, it is necessary to: 1) identify losses of applied N during production and 2) mitigate environmentally harmful discharges of N. The development of an N balance for the whole container plant production system, including the growing bed and the plants produced thereon, will help fill these knowledge gaps. As no previous studies have documented dinitrogen or nitrous oxide emissions in container-grown nursery crop systems, this project aims to measure N gas flux and accurately quantify denitrification rates. After the N balance is developed, mitigation strategies for environmentally harmful N discharges will be tested to adjust the N balance and improve nitrogen use efficiency.

OBJECTIVES:

1. Develop a system nitrogen (N) balance for container plant production.
2. Determine the mechanisms and pathways of N loss from a container plant nursery in California.
3. Use the results from this study to inform development of a nursery specific N management plan.

4 Test strategies that mitigate environmentally harmful N losses from nursery production systems.

5 Use information on N mitigation strategies to help growers increase N use efficiency, thereby reducing costs and increasing profitability.

6 Analyze costs associated with BMPs and mitigation strategies.

7 Extend research results to industry, regulators, and scientific community.

DESCRIPTION

To develop a nitrogen (N) balance for container plant nursery systems, all N inputs and outputs must be quantified. Once an initial N balance is developed, environmentally harmful discharges can be identified, BMPs implemented, inputs and outputs quantified, and an adjusted N balance calculated.

Two different experimental growing bed systems were installed at a nursery in the Central Valley of California from May 4 to July 24, 2018. The first style (unlined) consisted of a typical system, with plants placed directly on gravel over soil. In the other system (lined), plants were placed on a bed lined with polyethylene sheeting and weed barrier fabric, and covered with gravel, to capture all excess water. Four experimental growing beds, measuring 40 ft. x 15 ft., of each type, lined and unlined, were constructed. Each bed contains 150 to 155 *Lagerstroemia indica* 'Dynamite' plants potted into five-gallon containers. The two different systems had identical irrigation program, substrate composition, and fertilizer application. The difference in runoff observed between the lined and unlined systems will allow for calculation of water volume and N mass exiting the unlined system via soil infiltration.

Bed water inflow and outflow rate was being measured and has been collected for analysis of nitrate-nitrogen (NO3--N), ammonium-nitrogen (NH4+-N), and total Kjeldahl nitrogen (TKN) concentration. Total N is the sum of NO3--N, NH4+-N, and TKN. With flow volume and N concentration, mass loads will be calculated to identify the total amount of aqueous N that entered and exited the system. A 50-gallon plastic tank was placed below grade in the low point of each bed. A submersible pump placed inside the tank was wired through a float switch, to turn on when the tank becomes full, and the outflow is pumped through a flow meter, connected to a pulse recording datalogger, to measure water runoff volume.

Plant and substrate samples were collected prior to experiment initialization and are awaiting analysis for NO3--N, NH4+-N, and TKN concentration; samples from the conclusion of the experiment have been harvested and are awaiting analysis as well. Growing bed soil at the beginning of the experiment was collected and NO3--N, NH4+-N, and TKN concentration will be measured. There is potential that N is sequestered in the growing bed soil below the gravel. Bed soil was collected after production to determine changes in N content and potential sequestration during the production cycle.

To determine the amount of N lost via denitrification, weekly nitrous oxide gas samples were collected from substrate and growing bed soil. Eight 10-cm diameter by 8-cm long pieces of PVC pipe (anchor) were installed into potting substrate and the bed soil one week or more before gas emission measurements were collected. As dinitrogen, the end product of denitrification, cannot be measured directly, the acetylene inhibition technique was used to inhibit the reduction of nitrous oxide to dinitrogen (Ryden et al. 1979). Briefly, on the day of gas emission sample collection, acetylene saturated water was applied to the anchors in the bed soil. Acetylene saturated water was used instead of gas because the beds were consistently saturated from irrigation water. For acetylene gas application to the substrate, two stainless steel tubes, with holes drilled perpendicular into tube, were forced into the substrate so that all holes were below the substrate. The stainless steel tubes were connected to each other with vinyl tubing and a brass tee. Calcium carbide and water reacted in a latex balloon to produce acetylene. The balloon was placed on the end of a valve connected to the stainless steel tubes with the tee. The valve was opened and acetylene created a 1-10% concentration of acetylene in the air-filled pore space of the substrate. After at least two and a half hours, gas emission chambers, consisting of a 10-cm diameter by 15-cm long piece of PVC sealed on one end, were placed on the anchors. Gas samples were collected from a total of 16 chambers each day, eight from the substrate and eight from the bed soil. Four chambers each were used for collection of gas samples with and without acetylene application per bed soil or substrate. Gas samples without applied acetylene indicate the rate of nitrous oxide emissions. Gas samples with applied acetylene indicate the rate of dinitrogen emissions from denitrification. A 20-mL gas sample was collected from each chamber by inserting a needle on a 20-mL syringe into a septum at four 10-minute time intervals, starting at time zero (0 minutes). These samples are currently being analyzed via gas chromatography. Nitrous oxide gas flux estimates will be calculated from these gas samples.

RESULTS AND DISCUSSION

Mean daily runoff water volume pumped for the lined and unlined beds was 91.8 and 67.1 gallons per day, respectively, and these values are significantly different ($p < 0.001$). The difference in mean daily runoff volumes pumped indicates that approximately 24.7 gallons of water infiltrated the unlined beds per day, at an infiltration rate of 0.07 inches per 24-hours. Once the N concentration analytical results for the runoff water samples are reported, the mean daily runoff volume difference will be used with total N concentration results to estimate N leached into unlined bed soil. Mean total lined and unlined bed runoff water volume pumped was 7,525.5 and 5,499.3 gallons, respectively.

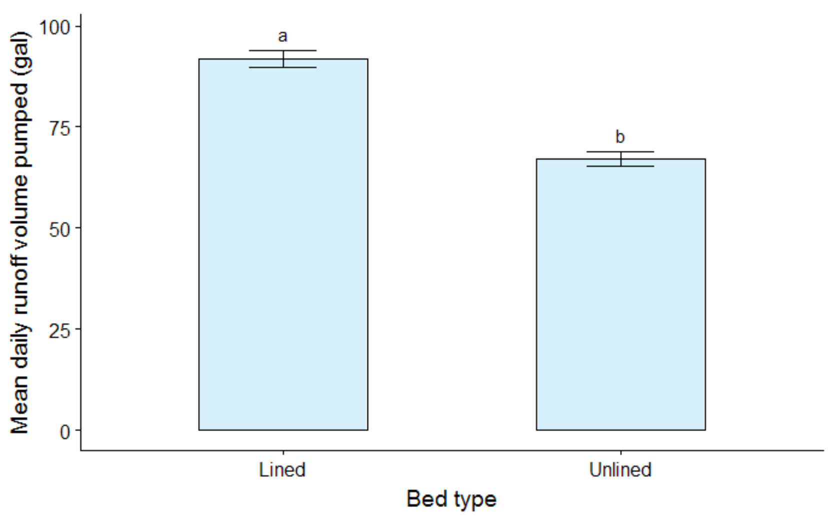

Figure 1. Mean daily runoff water volume pumped was greater for the lined beds (91.8 gal) than the unlined beds (67.1 gal). The results were significantly different (p<0.0001) indicating that 24.7 gal of runoff water per day infiltrated the soil below the unlined growing beds.

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SUMMARIES OF PRESENTATIONS

Soil Health Impacts on Plant Disease Development and Integrated Pest Management

Lacey Mount
D.P.M., C.C.A.
Consultant
Dellavalle Laboratory, Inc.

"Managing for soil health" connotes certain characteristics: higher organic matter soils, reduced tillage; in general, the presence of a thriving soil ecology. Soil health then, is the ability of a whole soil ecosystem to absorb or rebound in response to distress. Stressors can be abiotic, such as a response to drought or flood, saline or alkaline conditions. Stress in an agroecosystem is often due to a living organism. Ideally, managing for soil health would always result in a suppressive soil: a soil ecosystem in which a damaging organism cannot function even when the crop is susceptible and the environmental conditions support an outbreak.

Regarding insects, managing soil ecology parallels managing for the preservation of beneficial insects. A complex microbiome is supported by adequate water and nutrients, and soil minerology. A supportive microbiome can help change plant growth rate, maturity and epicuticular deposition 'upstream' for the crop. Proper nitrogen fertilization can help directly prevent insect and mite outbreaks by changing preference and tolerance (Altieri and Nicholls, 2003).

Nitrogen fertilization, as part of a plant health program, helps minimize stress to the crop itself and help maintain a favorable carbon nitrogen ratio for the soil microbiome (Doran, 2002; Geissler and Scow, 2014; van Bruggen and Semenov, 2000). Maintenance of indigenous microbiomes in agroecosystems can result in increased tolerance of soilborne diseases and nematodes (Abawi and Widmer, 2000). The encouragement and stability of a healthy soil food web in an agroecosystem depends on building soil organic matter through a variety of practices. An active and diverse soil food web then results in a general or specific suppressive soil (Larkin, 2015; Schlatter et al., 2017).

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Nutrient Management for Cannabis: Getting Real

Jerome Pier, PhD
North Valley Division
Agronomist
Nutrient Ag Solutions
jerome.pier@nutrien.com

Underground cannabis cultivation relied hydroponic fertilizer suppliers until recreational use was legalized at the state level by a California ballot initiative in 2016. The relatively small scale of growing operations, high street value of cannabis and inexperienced growers allowed hydroponics suppliers to sell complex and extremely expensive fertilizer programs. Currently, federal regulation of cannabis as a controlled substance limits the ability of many retail agrichemical suppliers from selling simple, cost effective fertilizer programs to cannabis growers. However, in anticipation of potential future changes in cannabis regulations, it is important for crop advisors to become familiar with the nutrient needs of cannabis.

The biggest challenge faced by a crop advisor wanting to learn about cannabis nutrition is finding consistent information. Federal restrictions have prevented nutrition research from being performed by land grant universities. Fertilizer programs for cannabis have been so lucrative than no one is willing to share information. Fertilizer regulations allow a manufacturer to grossly under-report fertilizer grades to disguise the true nutrient value in the jug, making it impossible to determine what is being applied based on the fertilizer label. A cannabis grower has been completely dependent on the hydro dealer to provide a fertilizer program.

The reality is cannabis is just a plant and has nutrient requirements that are similar to fruiting vegetables, such as greenhouse tomatoes. Reverse engineering an existing cannabis hydroponic program resulted in a simple two tank hydroponic program that has been successful in small scale tests. Cannabis is grown indoors over a 19-20 week cycle. Cuttings from a female plant are rooted for 2-3 weeks, followed by a four-week vegetative growth phase and ending with ten weeks of flowering. Nutrient requirements are very low in the cuttings stage, are focused on increasing nitrogen concentrations for the vegetative phase and transition to lower nitrogen and higher phosphate and potassium supply through flowering. There is no fertilizer applied in the last two weeks of production. One major difference between cannabis and tomato fertilizer programs is lower concentrations of zinc supplied to cannabis as the sterile female flowers do not contain seeds and greenhouse operations require low stature plants.

Use of Drones in Nutrient and Irrigation Management

Justin Metz
Technology Irrigation
Specialist
Bowles Farming Company

Bowles Farming Company is a sixth-generation family farm operated by the Bowles and Lawrence families in the Central Valley. They farm 12,000 acres primarily of annual crops, with a focus on tomatoes, melons, and cotton. Bowles Farming made the investment in drone technology in 2016. Since then, the farm has been using its drones in nearly every aspect of operation, from assessing drip irrigation leaks and guiding management decisions to monitoring crop emergence.

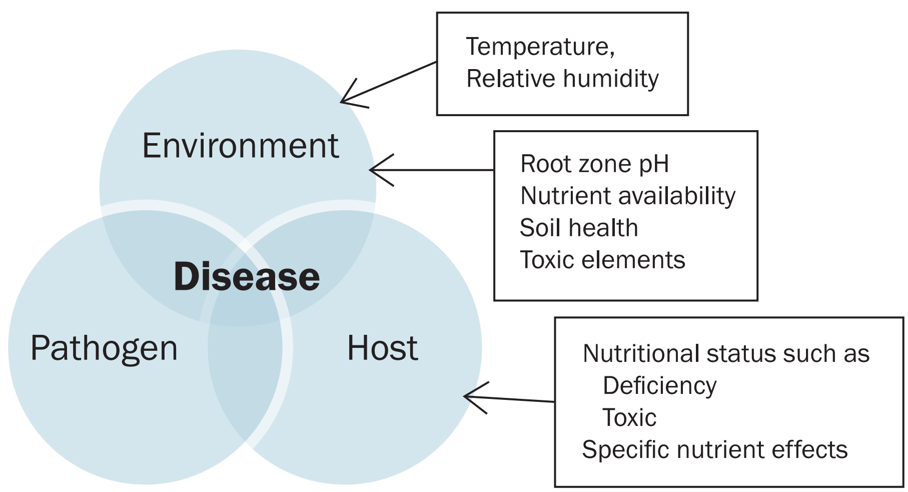
This talk reviews how drone technology can be used to improve irrigation and nutrient management decision-making processes and discusses improvements in efficiency since implementing the new technology.

The Role of Calcium in Disease and Environmental Stress Response in Plants

Steve Petrie
Director of Agronomic Services
Yara North America, Inc.

Plant diseases reduce crop yield and quality and thereby reduce agricultural sustainability. Plant diseases can be caused by pathogenic organisms such as bacteria and fungi, by environmental conditions, or physiological factors within the plant. Improved plant nutrition can play a beneficial role in helping crop plants mitigate the effects of many plant diseases, regardless of the causal agent.

Pathogenic plant diseases occur when the environment is suitable for the pathogen to infect the host, the pathogen is present in sufficient quantity to infect the host, and the host is susceptible to the pathogen (Fig. 1). The environment is usually taken to include the temperature and humidity; however, the environment also includes factors such as the overall soil health, root zone pH, and the availability of essential nutrient as well as potentially toxic elements such as chloride (Cl-), sodium (Na+) and salts. Finally, the nutritional status of the host can also have a marked effect on the ability of the pathogen to infect the host.

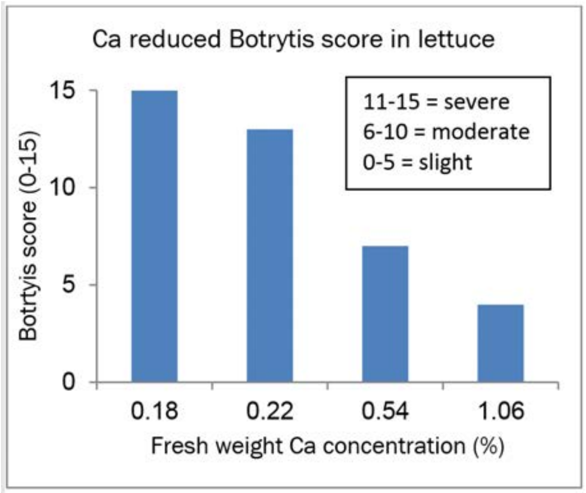


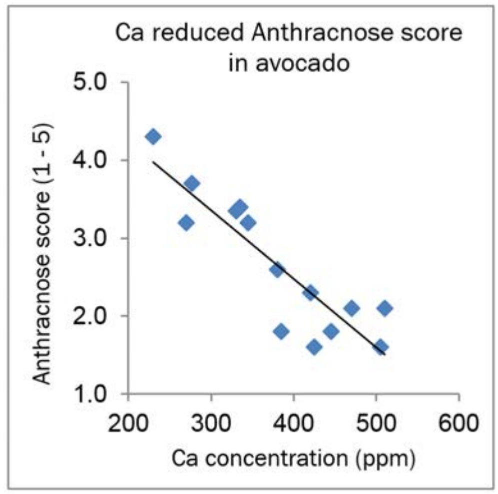
Plants that have adequate, but not excessive, concentrations of plant nutrients are often better able to resist attack by pathogens and mitigate the effects of environmental stresses such as heat, cold, and salts.

While all nutrients play a role in overall plant health, calcium (Ca) is the nutrient with perhaps the largest role to play in helping plants avoid pathogens and environmental stresses. Calcium is a constituent in cell walls and membranes and plants that are well supplied with Ca have increased cell wall strength with greater cell membrane integrity which provides a physical barrier that resists pathogen attacks.

In addition to improving the physical barrier, Ca also helps the plant's chemical defense mechanisms. Many plant pathogens attack plant cells by secreting pectolytic enzymes that degrade the cell membrane and/or cell wall allowing the pathogen to penetrate the cell or the cell contents to leak out. Increasing Ca in the plant tissue leads to reduced enzyme activity and greater yield. Greater Ca concentration in beans was associated with reduced activity of two key enzymes which eliminated symptoms of *Erwinia carotovora*.

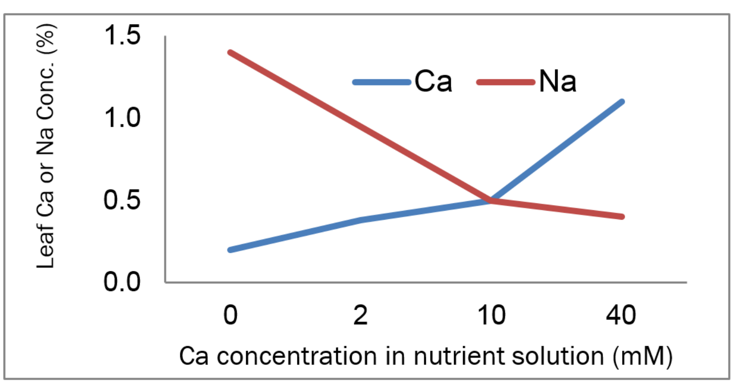
Ca conc. (%)	Polygalacturonase activity	Pectolytic activity	*E. carotovora* rating
0.7	62	7.2	4
1.6	48	4.5	4
3.4	21	0	0



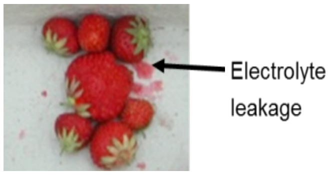


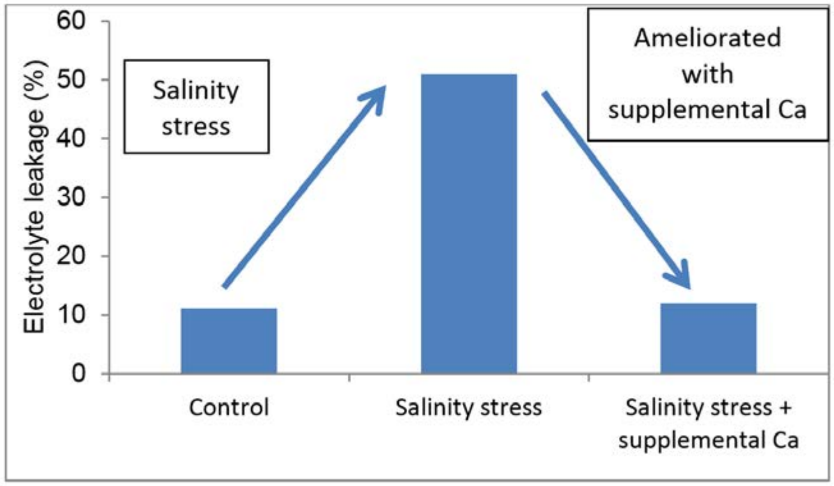
Increasing Ca concentration has been shown to reduce Anthracnose infection in avocado and reduce Botrytis infection in lettuce.

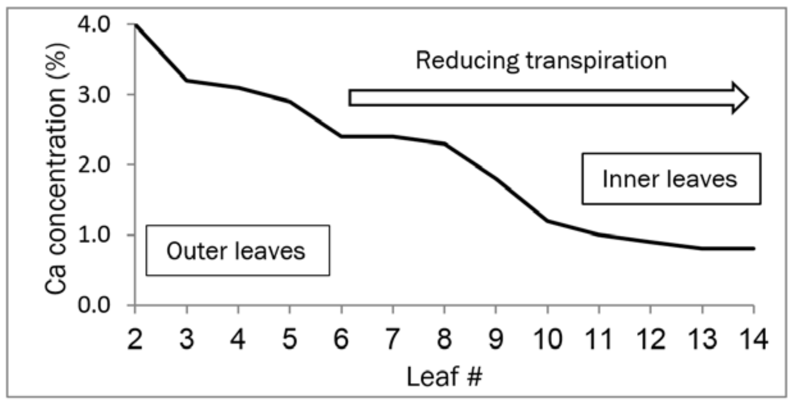
Improved Ca nutrition also helps plant deal with environmental stresses such as salinity. Increasing salinity makes the water in the soil less available to plants thus reducing water uptake and increasing water stress. Calcium suppresses sodium (Na) uptake and may also reduce the toxicity of Na in the plant by reducing Na transport from the root to the shoot and by enhancing Na sequestration in the vacuole. Olives are moderately salt-tolerant, but adding supplemental Ca markedly reduced Na in the leaves.



Salinity weakens cell membranes leading to ‘leaky’ membranes which can be ameliorated by adding supplemental Ca. Strawberries exhibited leaky membranes as salinity increased as shown by the greater electrolyte leakage. The electrolyte leakage was greatly reduced by the addition of Ca to the nutrient solution.

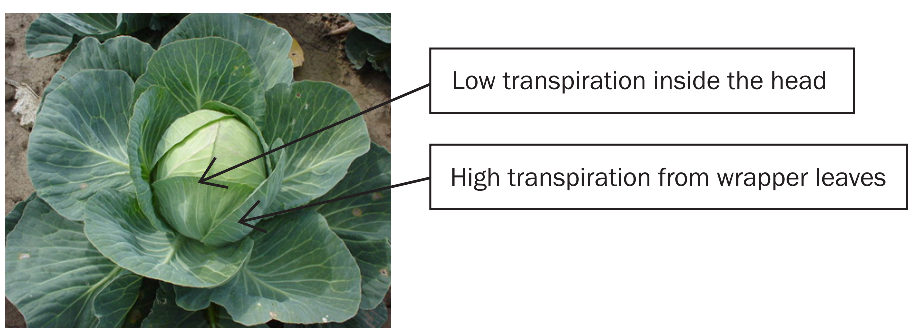






Tip burn of cabbage, and other leafy green crops, is a physiological disorder associated with localized poor Ca nutrition that reduces crop value. Inner leaves of cabbage transpire less water than wrapper leaves and thus usually have less Ca than wrapper leaves so localized necrotic areas develop where Ca is deficient.

Calcium is often under-appreciated as an essential plant nutrient, yet it frequently plays a key role in crop yield and quality. Good Ca nutrition has been demonstrated to reduce crop pathogenic diseases, reduce the adverse effects of environmental stress on crops, and reduce crop physiological disorders.



Micronutrient Technology

Eric McGee, PhD
Qualitech

Micronutrient deficiencies are a common limitation in today's crop production systems. The essential micronutrients required for plant growth include zinc (Zn), iron (Fe), manganese (Mn), copper (Cu), boron (B), molybdenum (Mo), nickel (Ni) and chloride (Cl). They play an important role in balanced crop nutrition. A deficiency in anyone one of them can limit plant growth even though all other nutrients are available in adequate amounts. Commonly, the source of these nutrients that are used to correct these deficiencies are in the form of an inorganic salt. With development in technology, chelates have been used to improve the efficiency and safety of micronutrients. This talk reviews technological developments of synthetic and natural micronutrient chelates and provide a review of the information available comparing efficacy and safety.

Integrating Compost into Nutrient Planning

Jocelyn Bridson
Director of Environmental Science and Resources
Rio Farms

Composting is a traditional and organic farming practice that can make agronomic and business sense, even for large, conventional growers. Compost application has multiple benefits including building healthy soils, reducing waste, reducing greenhouse gas emissions and protecting water quality. With changing water quality regulations, it is imperative that growers understand the agronomics of mineralized nitrogen from compost to ensure accurate nitrogen reporting and continued use of this beneficial soil amendment.

Rio Farms is a family-owned vegetable farming company that was established in 1978 by Allen, David & Steven Gill. The company grows about 20 different vegetables in King City and Oxnard, California and Yuma, Arizona. Rio Farms started composting in 2000 and now makes and applies approximately 20,000 tons of compost each year on their fields near King City. The company has incurred significant costs associated with running their compost program, including labor, complying with environmental and food safety regulations, taking valuable land out of production, and investment in new equipment.

Composting has served as a waste reduction strategy for produce that doesn't meet market standards, has reduced the spreading of plant pathogens on fields, and has provided an alternative pathway for the waste stream from other businesses. Besides waste reduction, Rio Farms primarily uses compost to maintain soil organic matter (SOM), which in turn improves water quality by increasing soil water-holding capacity, infiltration, and reduces erosion. SOM also promotes aggregate formation, increases cation exchange capacity, suppresses plant pathogens and feeds soil microbial populations. Composting also returns carbon to the soil in a more stable form, thereby reducing greenhouse gas emissions. In California, the multiple benefits of compost have been recognized through the California Department of Food & Agriculture's Healthy Soils Program, providing incentives for growers new to the practice.

Fully composted materials can also provide a slow release of nutrients, including nitrogen, phosphorous, potassium and secondary nutrients. In February 2018, the State Water Resources Control Board passed the Eastern San Joaquin Agricultural General WDR, listing many requirements that will be precedential for growers throughout the state. Growers will have to report all applied nitrogen including fertilizers and soil amendments to their third party coalitions and/or their respective Regional Water Quality Control Boards. Growers will be scrutinized on their nitrogen application numbers and will be labeled as outliers if they have excessive applications; therefore it is imperative that growers understand how to report nitrogen contribution from compost. Growers and regulators alike must ensure that we use the best available agronomy, and that we are not mistakenly disincentivizing compost use by over-estimating nitrogen contribution from this soil amendment.

The fraction of mineralized nitrogen from compost in a growing season depends on many factors including soil temperature and moisture, compost C:N ratio, different feedstocks, soil characteristics and more. Across the California, these values can be very different for various locations and climate zones. Fortunately, there is a wealth of published research that can simplify the process and guide growers as they determine how much nitrogen to report. Conveniently, mineralized nitrogen is the form that is available for both plant uptake and potential surface runoff or leaching to groundwater. Therefore, growers will be reporting a number that is valuable for both their own nutrient budgets and the RWQCB's ongoing research.

The presentation shares some of the current research on compost nitrogen budgeting and give examples from conventional and organic agriculture. Maintaining and enhancing soil quality through compost application and other healthy soils practices is the basis for nutritious food, productive farmland and ultimately, sustainable agriculture.

LIST OF COMPLETED FREP PROJECTS

List of Completed FREP Projects

The following is a chronological list of final reports for FREP-funded research. Following the title is the name of the primary investigator and the project reference number. We invite you to view the full final reports by visiting the California Department of Food and Agriculture's Fertilizer Research and Education Program Database at www.cdfa.ca.gov/go/FREPresearch. You may also contact the program at frep@cdfa.ca.gov or (916) 900-5022 to obtain printed copies.

Expanding the California Fertilization Guidelines • *Daniel Geissler, 16-0610*

California Certified Crop Adviser FREP Education Project • *Ruthann Anderson, 16-0076*

Online Fertilization Guidelines for Agricultural Crops in California • *Daniel Geissler, 15-0231*

Nitrogen Fertilizer Loading to Groundwater in the Central Valley • *Thomas Harter, 15-0454*

Plant Nutrients in the Classroom • Judy Culbertson, 14-0481

Development of Management Training Curriculum for Use in Grower Training for Self-Certification of Regional Water Board Nitrogen Management Plans • *Terry Prichard, 14-0585*

Developing Testing Protocols to Assure the Quality of Fertilizer Materials for Organic Agriculture • *William Horwath and Sanjai Parikh, 13-0223*

Phosphorus and Boron Fertilizer Impacts on Sweetpotato Production and Long-Term Storage • *Scott Stoddard, 13-0266*

Improving Nitrogen Use Efficiency if Cool Season Vegetable Production Systems with Broccoli Rotations • *Richard Smith, Michael Cahn and Tim Hartz, 13-0268*

Nitrogen Management Training for Certified Crop Advisors • *Doug Parker, 13-0241*

Provide Nitrogen Training Program for CDFA • *Ruthann Anderson, 13-0145*

Determining the Fertilizer Value of Ambient Nitrogen in Irrigation Water • *Michael Cahn, Richard Smith and Tim Hartz, 12-0455*

Optimizing the Use of Groundwater Nitrogen for Nut Crops • *David Smart, 12-0454*

Measuring and Modeling Nitrous Oxide Emissions from California Cotton and Vegetable Cropping Systems • *Dave Goorahoo, 12-0452*

Development of Economically Viable Variable Rate P Application Protocols for Desert Vegetable Production Systems • *Charles Sanchez and Pedro Andrade-Sanchez, 12-0386*

Characterizing N Fertilizer Requirements of Crops Following Alfalfa • *Dan Putnam and Stu Pettygrove, 12-0385*

Evaluation of N Uptake and Water Use of Leafy Greens Grown in High-Density 80-inch Bed Plantings and Demonstration of Best Management Practices • *Richard Smith and Michael Cahn, 12-0362*

Phosphorus and Boron Fertilizer Impacts on Sweet Potato Production and Long-Term Storage • *C. Scott Stoddard, 13-0266*

Developing Testing Protocols to Assure the Quality of Fertilizer Materials for Organic Agriculture • *William Horwath, 13-0223*

Interagency Task Force on Nitrogen Tracking and Reporting System • *Suzanne Swartz, 13-0054*

Improving Pomegranate Fertigation and Nitrogen Use Efficiency with Drip Irrigation Systems • *James E. Ayars and Claude J. Phene, 12-0387*

Evaluation of a 24 Hour Soil CO2 Test For Estimating Potential N-Mineralization To Reassess Fertilizer N • *William R. Horwath and Jeffery Mitchell, 12-0384*

Assessment of Baseline Nitrous Oxide Emissions in Response to a Range of Nitrogen Fertilizer Application Rates in Corn Systems • *Martin Burger and William Orloff, 12-0453*

Fertigation Education for the San Joaquin Valley • *William Green and Kaomine Vang, 12-0390*

Survey of Nitrogen Uptake and Applied Irrigation Water in Broccoli, Cauliflower and Cabbage Production in the Salinas Valley • *Richard Smith and Michael Cahn, 11-0558*

Improved Methods for Nutrient Tissue Testing in Alfalfa • *Steve Orloff and Dan Putnam, 11-0469*

Remediation of Tile Drain Water Using Denitrification Bioreactors • *T.K. Hartz and Mike Cahn, 11-0462*

Determination of Root Distribution, Dynamics, Phenology and Physiology of Almonds to Optimize Fertigation Practices • *Patrick Brown, 11-0461*

Nitrogen Fertilizer Loading to Groundwater in the Central Valley • *Thomas Harter, 11-0301*

Assessment of Plant Fertility and Fertilizer Requirements for Agricultural Crops in California • *William Horwath and Daniel Geisseler, 11-0485*

California Certified Crop Adviser FREP Educational Project • *Daniel H. Putnam, 11-0470*

Optimization of Organic Fertilizer Schedules• *David Crohn, 11-0456*

Updating Prior Curriculum for Grades 5-8 • *Judy Culbertson, 11-0454*

Management Tools for Fertilization of the 'Hass' Avocado • *Richard Rosecrance and Carol J. Lovatt, 11-0437*

European Pear Growth and Cropping: Optimizing Fertilizer Practices Based on Seasonal Demand and Supply with Emphasis on Nitrogen Management • *Kitren Glozer and Chuck Ingels, 10-0105*

Development of a Nutrient Budget Approach to Fertilizer Management in Almond • *Patrick Brown, 10-0039*

Development of Leaf Sampling and Interpretation Methods for Almond and Pistachio • *Patrick Brown, 10-0015*

Relationship of Soil K Fixation and Other Soil Properties to Fertilizer K Requirement • *G. Stuart Pettygrove, 10-0012*

Nitrogen Research and Groundwater • *Renee Pinel, 10-0011*

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Adjustable-Rate Fertigation for Site-Specific Management to Improve Fertilizer Use Efficiency • *Delwiche, 10-0004*

Towards Development of Foliar Fertilization Strategies for Pistachio to Increase Total Yield and Nut Size and Protect the Environment - A proof-of-concept project • *Carol J. Lovatt and Robert H. Beede, 09-0584*

Improving Pomegranate Fertigation and Nitrogen Use Efficiency with Drip Irrigation Systems • *James E. Ayars and Claude J. Phene, 09-0583*

Developing Testing Protocols to Assure the Quality of Fertilizer Materials for Organic Agriculture • *W.R. Horwath, 09-0582*

Citrus Yield and Fruit Size Can Be Sustained for Trees Irrigated with 25% or 50% Less Water by Supplementing Tree Nutrition with Foliar Fertilization• *Lovatt, 09-0581*

Measuring and modeling nitrous oxide emissions from California cotton, corn, and vegetable cropping systems • *Goorahoo, 09-0001*

Development of a Comprehensive Nutrient Management Website for the California Horticultural Industry • *Timothy K. Hartz, 08-0629*

Evaluation of Low-Residue Cover Crops to Reduce Nitrate Leaching, and Nitrogen and Phosphorous Losses from Winter Fallow Vegetable Production Fields in the Salinas Valley • *Richard Smith, 08-0628*

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Western Fertilizer Handbook Turf & Ornamental Edition • *Renee Pinel, 08-0007*

Comparing the Efficiency of Different Foliarly-Applied Zinc Formulations on Peach and Pistachio Trees by Using 68Zn Isotope • *R. Scott Johnson, 07-0669*

New Standard for the Effectiveness of Foliar Fertilizers • *Carol Lovatt, 07-0667*

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Fertilizer Research and Education Program
1220 “N” Street
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Tel: (916) 900-5022
Fax: (916) 900-5349
frep@cdfa.ca.gov

www.cdfa.ca.gov/go/frep

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