# Proceedings

October 27-28, 2021

California Department of Food and Agriculture
Fertilizer Research and Education Program and
Western Plant Health
Twenty-Ninth Annual Nutrient Management Conference

2021

FREP WPH

**Nutrient Management Conference**

OCTOBER 27-28, 2021

California Department of Food and Agriculture

Fertilizer Research and Education Program

1220 “N” Street

Sacramento, CA 95814

Tel: (916) 900-5022

Fax: (916) 900-5349

frep@cdfa.ca.gov

www.cdfa.ca.gov/go/frep

CALIFORNIA DEPARTMENT OF FOOD & AGRICULTURE

FREP 2021 WPH

# Proceedings

October 27-28, 2021

California Department of Food and Agriculture
Fertilizer Research and Education Program and
Western Plant Health
Twenty-Ninth Annual Nutrient Management Conference

**Editors:**
Mark Cady
Nicole Nunes
Jennifer Harmon
Emad Jahanzad, Ph.D.
Natalie Jacuzzi

**Publication design:**
Jennifer Harmon

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

# CONTENTS

# INTRODUCTION

# Fertilizer Research and Education Program

Welcome to the proceedings of the California Department of Food and Agriculture's (CDFA) Fertilizer Research and Education Program (FREP) and Western Plant Health (WPH) Annual Nutrient Management Conference. Over the last 29 years, this conference has provided a venue where FREP grant recipients report findings of their projects and industry representatives share valuable irrigation and nutrient management information with an audience of crop advisors, students, growers, researchers, and agricultural professionals.

Since 1991, FREP has supported farming operations and California communities by funding research, demonstration, and education projects to increase efficiency and adoption of irrigation and nitrogen (N) best management practices.

## 29th Annual FREP/WPH Conference

During the conference this year, we hear from researchers and industry representatives from across the state on the latest irrigation and nutrient management developments and research findings. Of the researchers speaking, six will be presenting their research from FREP-funded projects.

Dr. Sanjai Parikh, University of California Davis (UCD), will present results of his research with Dr. Danielle Gelardi on evaluation of biochar for on-farm soil management in California. In this project, they characterized biochars produced from locally available biomass sources and studied soil-water dynamics, nutrient use efficiency, leaching, carbon stocks, soil aggregation, and crop productivity as impacted by different rates of biochar and N fertilizer in tomato fields.

Dr. Charles Sanchez, University of Arizona, Maricopa Agricultural Center, will present his research findings on efficient water and N management practices for mixed leafy baby green vegetables in the desert region. A primary goal of this project is to better understand fertilizer requirements for mixed baby greens. Additionally, he and his team will help calibrate the software CropManage for desert production of mixed leafy baby greens. Dr. Sanchez is focusing on increasing adoption and hastening technology transfer through demonstration projects.

Dr. Bob Hutmacher, UC Agriculture and Natural Resources (UCANR), will present his study findings on irrigation and N management in pima cotton planted in the San Joaquin Valley. This project evaluates high-yield-potential cultivars as impacted by N application rates, varieties, irrigation methods (subsurface drip versus furrow) as well as total plant N uptake and harvest removal, including a comparison with a widely planted upland variety.

Bruno Pitton (UCD) will present their research findings with Dr. Lorence Oki and Dr. William Horwath (UCD) on the system N balance for container plant production. In this project, they are testing strategies to mitigate environmentally harmful N losses from container plant growing systems, perform economic analysis for best management practices and extend N balance results to the industry, regulators, and scientific community.

Trina Walley, East Stanislaus Resource Conservation District (RCD), will update on her project with Dr. Khaled Bali (UCANR) on the crop management training that integrates climate, soil, and irrigation system data to minimize nutrient losses and optimize irrigation efficiency. Their goal is to promote best management practices through English and Spanish workshops, provide mobile irrigation lab services, develop and distribute training materials on efficient irrigation and nutrient efficiency practices. The team also encourages irrigators to share individual challenges and successes in workshops to create a networking environment for ongoing farmer-to-farmer education.

Dr. Sat Darshan Khalsa (UCD), will present results of his work with Dr. Patrick Brown and Dr. Mark Lubell (UCD) on understanding influences on grower decision-making and adoption of improved N management practices. This research team is developing a qualitative understanding of key influential factors and barriers to adoption of improved N management practices in the regions represented by the San Joaquin County, Delta Water Quality Coalition, and the East San Joaquin Water Quality Coalition.

## Past Research

Since 1991, FREP has committed over 22 million dollars in over 250 projects focused on irrigation and nutrient management research, outreach, and the development of decision support tools. These projects address management challenges and opportunities in several commodity areas and growing regions across California (Figures 1-2).

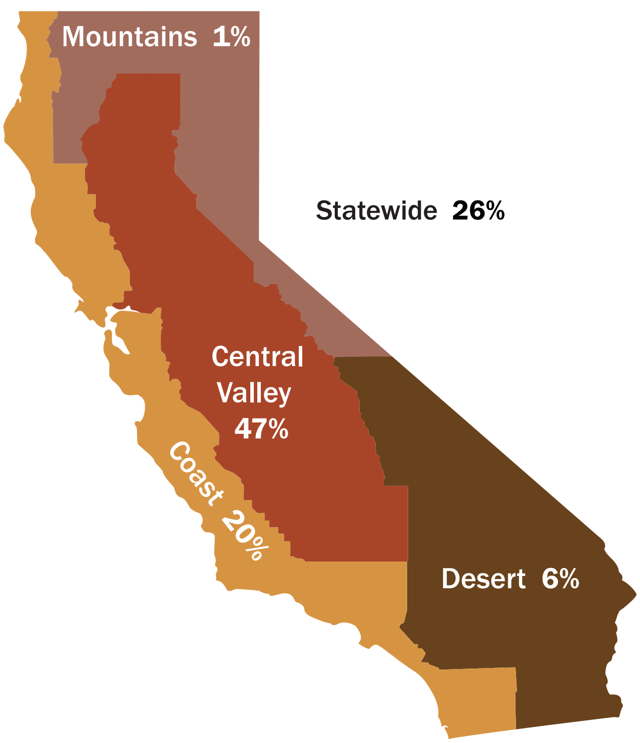



*Figure 1. Geographical distribution of FREP-funded projects across California.*

The Crop Fertilization Guidelines website (cdfa.ca.gov/go/FREPguide) is an important resource resulting partly from FREP-funded projects. The guidelines provide insight to nutrient management for the most widespread irrigated crops in California, based on crop development stage. Many agricultural consultants and growers refer to the online guidelines when making fertilizer application recommendations and decisions.

## Present Projects

FREP is currently funding 30 innovative projects to progress the agronomically safe and environmentally sound use of fertilizing materials. These projects help us better understand grower decision making, provide important technical trainings, and glean more information about fertilizer and irrigation management in California crops. Some of the ongoing FREP-funded projects across the state are highlighted below.

In the Central Valley, Dr. Daniel Geisseler (UCD) is developing site-specific N fertilization recommendations for annual crops through estimates of the contribution of N mineralization to the plant-available N pool and incorporate them into user-friendly online N fertilization calculators. Dr. Anthony O'Geen (UCD) is evaluating techniques to minimize nitrate loss from the root zone during managed aquifer recharge (MAR) and to encourage wider adoption of Flood-MAR among growers by identifying best management strategies. Charlette Gallock (Kings River Conservation District) leads a group in assessing harvested and sequestered N content to improve N management in crops. This team will assess N concentration of

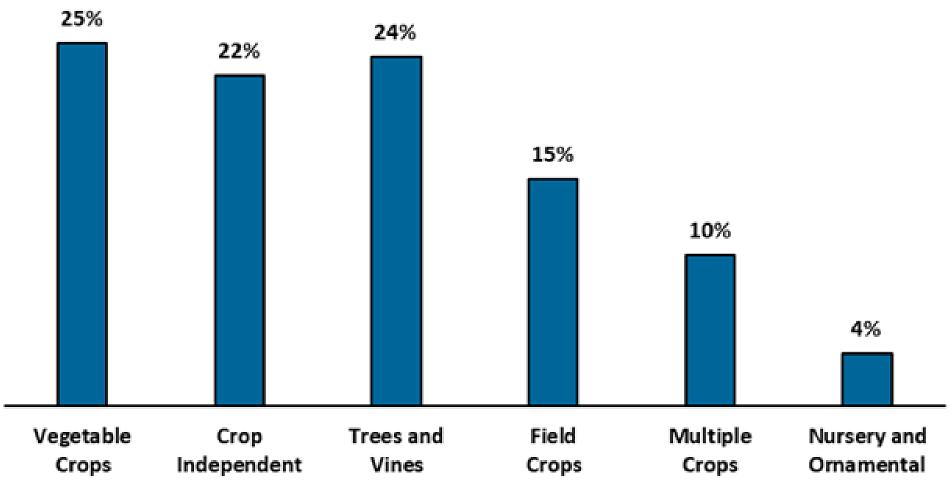



*Figure 2. Distribution of commodities (%) represented in FREP-funded projects*

harvested material removed from fields for approximately 33 crops over several growing seasons, and N sequestration rates for 8 perennial crops. Parry Klassen (Coalition for Urban and Rural Environment Stewardship) is developing “Crop Nutrient Minute” video series in Spanish and English using irrigation and N management information compiled for the seven major acreage crops in the Central Valley and Central Coast. Dr. Bob Hutmacher (UCANR) is assessing N response of industrial hemp cultivars grown for cannabidiol and essential oils. In this project, he evaluates for two biotypes of industrial hemp the impacts of N application rates and variety/growth habit/plant type on plant N uptake, harvest removal, and yield response.

On the Central Coast, Cole Smith is assessing N content of the harvested portion of specialty crops to estimate crop N removal and improve N management in crops for about 35 commodities and develop N removal coefficients. Dr. Charles Burt (Cal Ploy San Luis Obispo) is developing a Certification and Distance Learning program for Fertigation for English and Spanish field workers and irrigators. Dr. Lorence Oki (UCD) is developing fertilizers and plant nutrition workshops for greenhouse and nursery growers across the state. Jodi Switzer (Ventura County Farm Bureau) is developing Ventura County N management training program to provide growers with the information and credentials needed to develop site-specific N management plans for their farms in Southern California. She is expanding training availability to field workers responsible for implementing the plans and who will benefit from education in the concepts of irrigation and nutrient management.

In the low desert of the Imperial Valley, Dr. Ali Montazar is studying strategies to enhance N and water use efficiency in California carrot production through management tools and practices.

To learn more about other current and completed FREP projects, visit: [https://www.cdfa.ca.gov/is/ffldrs/frep/Research.html](https://www.cdfa.ca.gov/is/ffldrs/frep/Research.html)

## Future FREP Projects

In 2021, FREP has committed to funding six new grant projects totaling a commitment of over 1.4 million dollars. The following are examples of the new projects starting this winter.

In the Central Coast, Dr. Tim Bowles (UC

Berkeley) will quantify and model overlooked pathways of N loss (dissolved organic N) from organic inputs across contrasting soil types. Dr. Teamrat Ghezzehei (UC Merced) will develop techniques for distributed water and fertilizer delivery for minimizing N losses by leaching and volatilization in processing tomato.

In the low desert region, Dr. Oli Bachie, (UCANR) will develop N fertilizer and irrigation best management practices for the low desert sudangrass production systems by conducting research trials in Imperial County.

Dr. Lorence Oki (UCD) will investigate techniques to optimize N fertilizer concentrations in vegetable transplant production. Also, in an outreach project, Carmen Carrasco and Tom Stein (American Farmland Trust) will conduct nutrient management and irrigation efficiency outreach and education for Latino and Southeast Asian Farmers in the Central Coast and Central Valley regions.

## Acknowledgements

We are grateful to members of the fertilizer industry for their support in providing funds for the FREP. 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: Dr. Jerome Pier (Chair), Dr. Tom Bottoms, Dr. Ben Faber, Daniel Rodrigues, DD Levine, Dr. Jan Hopmans, Dr. Lisa Hunt, Dr. Sebastian Saa, Dr. Steven Petrie, Dr. Suduan Gao, and David McEuen.

In addition, we thank the members of the Fertilizer Inspection Advisory Board for their continued support of the FREP program: Melissa McQueen (Chair), Gary Silveria (Vice Chair), Jake Evans, David McEuen, Greg Cunningham, Christopher Gallo, Doug Graham, and Jay Irvine.

We thank WPH as a continued valued partner in the conference. Since 2005, FREP has teamed up with WPH to strengthen our impact on industry and deliver the most essential nutrient management information. The input and support of Renee Pinel, President and CEO have led to greater outreach and dissemination of FREP research findings.

Project leaders and cooperators themselves are vital contributors as well as 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 CDFA including Secretary Karen Ross; Science Advisor Dr. Amrith Gunasekara; Inspection Services Division Director Natalie Krout-Greenberg; and Dr. Amadou Ba, Environmental Program Manager II.

We also thank Maria Tenorio Alfred (Research Data Specialist II) from the Feed, Fertilizer, and Livestock Drugs Regulatory Services Branch and Dr. Martin Burger, Senior Environmental Scientist (Supervisory) of the Fertilizing Materials Inspection Program for his help reviewing proposals and advising this program.

FREP staff are Mark Cady, Senior Environmental Scientist (Supervisory); Jennifer Harmon, Associate Government Program Analyst; Nicole Nunes, Environmental Scientist; Natalie Jacuzzi, Senior Environmental Scientist (Specialist), and Dr. Emad Jahanzad, Senior Environmental Scientist (Specialist).

# 29th Annual FREP/WPH Nutrient Management Conference

# Wednesday October 27, 2021

*Facilitator: Dr. Rob Mikkelsen, Director of Agronomic Services, Yara International*

**9:00-9:30** **Welcome**
*Renee Pinel, President/CEO (WPH); Karen Ross, Secretary, California Department of Food and Agriculture*

**9:30-10:00** **Understanding Grower and Technical Advisor Decision-Making on the Adoption of Nitrogen Managment Practices**
*Sat Darshan Khalsa, Assistant Professional Researcher, UC Davis*

**10:00-10:30** **A System Nitrogen Balance for Container Plant Production**
*Bruno Pitton, Research Associate, UC Davis*

**10:30-10:50** **Break**

**10:50-11:20** **Efficient Water and Nitrogen Practices for Mixed Leafy Baby Greens in the Desert**
*Charles Sanchez, Research Scientist, University of Arizona*

**11:20-11:50** **Open ET: Operational Evapotranspiration Data for Water Management in the West**
*Forrest Melton, Senior Research Scientist, NASA Ames Research Center Cooperative for Research in Earth Science and Technology*

**11:50-1:10** **Lunch**

**1:10-2:25** **Panel: The Evolving Role of Coalitions in the Irrigated Lands Regulatory Program**
*Facilitator: Mark Cady, Senior Environmental Scientist, California Department of Food and Agriculture*

**Panelists:**
*Jodi Switzer, Water Program Director, Farm Bureau of Ventura County*

*Sarah Lopez, Executive Director, Central Coast Water Quality Preservation, Inc.*

*Donald Ikemiya, Executive Director, Kaweah Basin Water Quality Association*

**2:25-2:45** **Break**

**2:45-4:15** **Irrigation Management Workshop Rotations**

**Workshop 1: Fertigation Product Compatibility**
*Franklin Gaudi, Assistant Professor, Cal Poly SLO*

**Workshop 2: Measuring Nitrate in Irrigation Water**
*Gerry Spinelli, Horticulture Advisor, UCANR*

**4:30-6:30** **Poster Reception**

# Thursday October 28, 2021

*Facilitator:* *Dr. Jerome Pier, Senior Agronomist, QualiTech*

**8:15-8:30** **Welcome and Recap**

**8:30-9:00** **Pima Cotton Nitrogen Management, Uptake, Removal - Impacts of Varieties, Subsurface Drip & Furrow Irrigation**
*Bob Hutmacher, Cooperative Extension Specialist and West Side Research and Extension Center Director, UCANR*

**9:30-10:00** **Biostimulants: What are they and how do they function to improve the efficiency of nutrient use**
*Patrick Brown, Professor, UC Davis*

**10:00-10:20** **Break**

**10:20-10:50** **Evaluation of Biochar for On-Farm Soil Management in California**
*Sanjai Parikh, Associate Professor, UC Davis*

**10:50-11:20** **Training on Crop Management that Integrates Climate, Soil and Irrigation System Data to Minimize Nutrient Loss and Optimize Irrigation**
*Trina Walley, Executive Director, East Stanislaus RCD*

**11:20-11:50** **What's the story about calcium? Needed or not?**
*Rob Mikkelsen, Director of Agronomic Services, Yara International*

**11:50-12:00** **Closing Remarks**

# SUMMARIES OF PRESENTED FREP PROJECTS

# Evaluation of Biochar for On-Farm Soil Management in California


## Project Leader

**Sanjai J. Parikh**
Associate Professor of Soil Chemistry
Department of Land, Air and Water Resources, University of California, Davis
sjparikh@ucdavis.edu

## Project Manager

**Danielle L. Gelardi**
Ph.D. Candidate, Soils and Biogeochemistry
Department of Land, Air and Water Resources, University of California, Davis
dlgelardi@ucdavis.edu

## Cooperators

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

**Daniel Geissler**
Associate Cooperative Extension Specialist
Department of Land, Air and Water Resources, University of California, Davis
djgeisseler@ucdavis.edu

**Milt McGiffen**
Vegetable Crops Specialist & Vice Chair for Cooperative Extension
Department of Botany and Plant Science, University of California, Riverside
milt@ucr.edu

**Michelle Leinfelder-Miles**
Cooperative Extension Farm Advisor
Cooperative Extension San Joaquin County
mmleinfeldermiles@ucanr.edu

**Toby A. O'Geen**
Soil Resource Specialist
Department of Land, Air and Water Resources, University of California, Davis
atogeen@ucdavis.edu

**Kate M. Scow**
Professor of Soil Microbiology
Department of Land, Air and Water Resources, University of California, Davis
kmscow@ucdavis.edu


## INTRODUCTION

Farmers, researchers, and policymakers are increasingly interested in the use of biochar, a carbon-rich material created from the thermochemical conversion of biomass in an oxygen-limited environment, as a soil amendment. Due to the unique chemical and physical structure of biochar, the material offers many potential solutions to 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 agricultural relevance, 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, place-based data. This study aims to fill a gap in literature by providing long-term, field-scale data about the potential of biochar for CA agriculture. 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 three seasons under processing tomato production, on the impact of biochar on yield, plant nutrition, fertilizer use efficiency, and soil properties. Data 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 for agriculture in the Central Valley. Specific objectives are:

1. Characterize biochars produced from local CA biomass
2. Evaluate the impact of biochar amendments on soil-water dynamics, 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

## DESCRIPTION

This three-year project will evaluate the use of biochars in on-farm, growth chamber, and laboratory experiments, as detailed in Table 1.

*Table 1. Project work plan*

| Project Tasks | Year | | | | | |
|---|---|---|---|---|---|---|
| | 1 | | 2 | | 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 in CA. | | | | ✓ | ✓ | ✓ |

### Task 1. Produce and Characterize Biochar

Biochar production was completed in August of 2017. These seven biochars were produced by working with commercial biochar companies to obtain mostly CA feedstocks and produce biochar at specified temperatures. Feedstocks include softwood, almond shell, and coconut shell. One biochar with a microbial inoculant was also obtained. To date, these biochars have been analyzed for total carbon, nitrogen, oxygen, hydrogen, and surface area, as well as cation exchange capacity, pH, electrical conductivity, ash content, dissolved organic carbon, and particle size distribution.

### 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 and the Kearney Agriculture Research and Extension Center in Parlier. The two soils, a Yolo silt loam (YSiL) and a Hanford sandy loam (HSL), 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. Biochars were subsurface banded directly above the drip tape to maximize contact with irrigation and fertigation, and to minimize application costs. Biochars were applied in two or three rates and combined with a low (150 lbs. N) and high (225 lbs. N) UAN-32 fertilizer rate. Field sites were planted each spring with processing tomatoes and harvested each fall. In 2018 and 2019, preplant and postharvest soil samples were taken from 0-30 cm, 30-60 cm, and 60-90 cm and analyzed for mineral nitrogen, total carbon and nitrogen, pH, and moisture content. Plant samples were collected and analyzed for yield as well as total carbon and nitrogen. A nitrogen budget was calculated to determine N losses, or the total of N volatilized and leached from each treatment. In 2020, samples were also collected for PLFA analysis to determine impacts on microbial communities after three years in the soil. Fields were planted with processing tomatoes in May 2020, to be harvested in fall for yield and plant nutrient analysis (Figure 1).

### Task 3. Growth Chamber and Laboratory Trials

A series of growth chamber and laboratory studies have been completed to observe plant-soil-biochar interactions with regards to yield, nutrition, soil water dynamics, and nitrate and ammonium retention. Studies include sorption experiments, soil columns, micro-CT scans, and pot trials with lettuce grown in soils with 0 and 2% biochar.

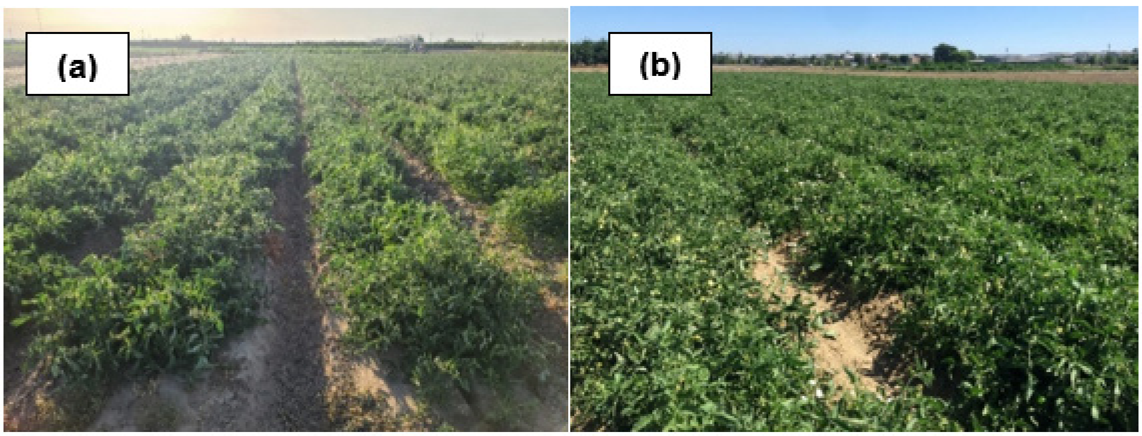



*Figure 1. Progress of processing tomato crop in season 3 field trials on June 30th in a) Parlier and b) Davis*

## RESULTS AND DISCUSSION

Task 1: Carbon content, ash content, and pH generally increased with increasing production temperature. In the case of surface area, feedstock appears to play a larger determining role than production temperature, with softwood biochars having greater surface area than almond shell biochars. Cation exchange capacity and surface area appear inversely correlated to particle size distribution.

Task 2: In years 1, 2, and 3 of processing tomato trials, no significant differences in yield or nitrogen use efficiency were observed in soils with any biochar at any rate. There was a slight and significant increase in pH in soils amended with almond shell pyrolyzed at 800 °C (AS800). Regarding soil health indicators, an increase in water stable aggregate fractions were observed in both Davis and Parlier. PLFA results show that in the HSL, biochar had increased microbial community biomass, led to distinct microbial communities by treatment, and PLFA ratios which indicate a shift to more stress and nutrient resilient microbial communities.

Task 3: In batch sorption experiments, biochars exhibited little to no nitrate removal efficiency, but a relatively high affinity for ammonium. Based on sorption results, almond shell biochars produced at 500 and 800 °C, and softwood biochar produced at 500 °C (AS500, AS800, and SW500, respectively) were chosen for further study.

Each biochar was amended at 0 and 2% (w/w) to HSL and YSiL in soil columns, to quantify the impact of biochar on saturated hydraulic conductivity (Ksat), nutrient leaching, and breakthrough curves for nitrate and ammonium. Biochar had a significant effect on Ksat, which varied by soil texture and biochar type. In HSL, AS500 and SW500 significantly slowed the movement of water through the soil profile. This effect was also observed due to the addition of AS800, though it was not significant. Similarly, AS500 and SW500 reduced Ksat in YSiL, while AS800 increased Ksat. Biochar also had a significant effect on nutrient leaching, slowing the pace and total quantity of ammonium release from HSL compared to the unamended control as follows: AS800<AS500<SW500<Control. The opposite trend was observed for nitrate, with SW500 and AS500 reducing nitrate leaching compared to the control, and AS800 increasing nitrate release. Results for nitrate leaching were not statistically significant except in the case of SW500.

To investigate the physical properties of biochar that may have contributed to the above results, X-ray micro-computed tomography (micro-CT) images were taken of HSL and YSiL soils with 0 and 2% additions of AS500, AS800, and SW500 biochars. Images were also taken of the biochars themselves (Figure 2). Results suggest that pores of AS500 and SW500 were small enough to decrease mean pore size in HSL, but not large or numerous enough to increase Ksat in YSiL. By contrast, the collapse of the carbon pores in the AS500 lead to the formation of additional small pores with greater surface area and larger macro-pores in AS800. Broadly, the ability of each biochar to substantially influence the movement of water through each soil underscores its effect on the physical composition of soils.

## TAKE-HOME MESSAGE

While biochar did not increase tomato yield in the three-year field trials subsequent years of analysis may perhaps show differences in yield as some prior studies have shown a lag in response form adding biochar. The soils used in this study were fertile agricultural soils and improving productive soils with biochar is often not realized. The increase in pH from AS800 may also suggest that this biochar could have a greater effect in more acidic soils. All biochars significantly decreased the quantity of ammonium in the leachate and slowed its movement through the soil profile, with chemical retention linked to high cation exchange capacity and a high oxygen to carbon ratio. Whereas, biochars had little to no effect on nitrate movement. While this study did not show an impact on nitrate leaching, a number of

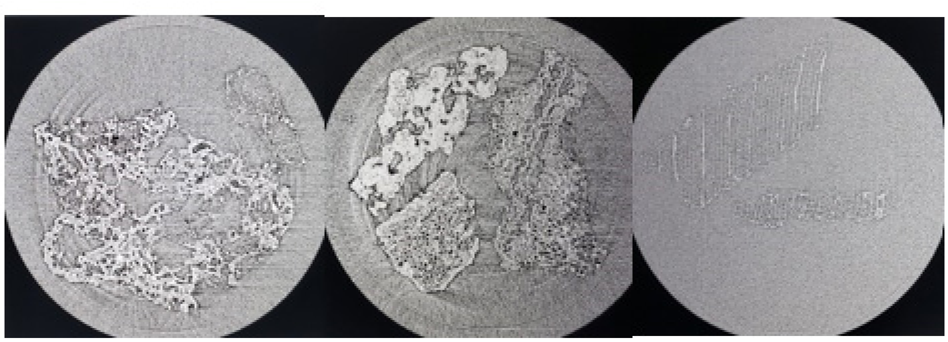


*Figure 2. X-ray micro-computed tomography (micro-CT) images of, from left to right, AS500, AS800, and SW500 biochars.*

other studies have demonstrated the that modified biochars, to increase the anion exchange capacity, can retain nitrate; additional lab and field studies with these materials would be a prudent future direction

## ACKNOWLEDGEMENTS

We thank the following for funding: CDFA FREP (#16-0663-SA), The Almond Board of California, and other support: Pacific Biochar, Karr Group, Premier Mushrooms, and Community Power Corporation.

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


## Project Leaders

**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

**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

**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 amadors@mjc.edu

## Project Collaborators:


## 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 is followed up with one-on-one technical assistance to document changes and improvements.

The project has benefited 205 growers to date with continuing education units 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

- 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.
- Submitted educational material and workshop agenda for qualification for CEUs for Nitrogen Management certification program through CURES.
- Hosted pre-irrigation season workshops that presented information on system planning and scheduling, general maintenance, nutrient management and monitoring methods.
- Provided recommendations on best management practices tailored to their 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.
- Presented training results to regional partners such as East Merced and Madera Resource Conservation Districts, 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 five workshops in English and Spanish with attendance total of 150 producers and 69 properties were provided technical assistance covering 5,126 acres with an average DU at 84.4%. The lowest global distribution uniformity (DU) found was 24% which was a result of running the system at a low pressure, however the flow distribution uniformity was at 28%. There was a variety to issues include poor pressure, plugged emitters, not irrigating according to soil properties. These issues resulted in a poor performing field with visible stress.

Majority of the fields had a global DU of between 82-88% 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, 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


*Figure 1. Soil Map showing change in soil and visible tree stress*


*Figure 2. Screen Images of common maintenance issues causing majority of low global distribution uniformity*

and Resource Conservation Districts to provide similar trainings to their growers from Madera to Sacramento. Currently, organizing regional workshops and an online training resource for growers and advisors to earn continuing education units for various programs.

## 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 has in local agricultural companies. Thus far, the project has documented and confirmed the need for continued education for growers and farm managers on best management practices. Despite years of experience, there were many growers that were able to identify issues with their system operation or maintenance which they can improve on immediately that will have a long term impact of how efficiently they apply irrigation water and fertilizers. There will be a significant positive environmental impact resulting from the 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. Through working to increase the producers' soil health, irrigation system, fertilizer application efficiency, minimizing water and nutrient waste, the amount of money spent on yearly inputs needed for crop health will significantly decrease. Lastly, the MAT program will have a positive agronomic impact on the participants in the form of increasing an awareness of new technology available to both producers and employees to help increase efficiency, increase 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.

# A System Nitrogen Balance for Container Plant Production


## Project Leader

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

## Co-Investigator:

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

## Co-Investigator:

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

## Co-Investigator:

**Bruno J.L. Pitton**
**Staff Research Associate**
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 irrigation and nitrogen management plans (INMP) by growers and other regional Water Boards may follow suit. The INMP consists of documenting annual nitrogen (N) inputs and outputs to calculate potential N available for leaching into groundwater. Inputs consist of existing N in soil and N applied as fertilizer, organic amendments, and irrigation water. N output is based on the yield and N content of harvested products. However, container-grown nursery crops do not fit neatly into the INMP worksheet. The whole product, including the shoots, roots, and substrate, is "harvested" and shipped to customers. Nitrogen remaining in the container substrate at the time of shipment can range from 0-41% of applied N (Cabrera 2003, Narvaez et al. 2012, Narvaez et al. 2013). Losses due to denitrification and leaching can be significant (Cabrera 2003, Narvaez et al. 2012, Narvaez et al. 2013). Leaching losses could contaminate ground and surface waters, and denitrification can contribute to atmospheric N pollution as nitrous oxide (N2O).

Development of an N balance for the container plant production system, including the growing bed, will help growers fulfill the INMP requirement, mitigating environmentally harmful discharges of N, and achieve sustainability goals. Subsequent development of mitigation strategies to reduce environmentally harmful N discharges will be tested and could improve nitrogen use efficiency.

## OBJECTIVES

1. Develop a system 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 best management practices (BMPs) and mitigation strategies.

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

## DESCRIPTION

Nitrogen inputs and outputs at a commercial container plant nursery were quantified to develop an N balance and identify environmentally harmful N discharges. Impervious (lined) and pervious (unlined) growing beds were installed at a nursery from May 4 to July 24, 2018 to quantify N inputs and outputs and allow for estimating soil N infiltration. A greenhouse experiment was conducted to determine the effect of three rates of surface-applied urea formaldehyde fertilizer on N2O emissions from controlled-release fertilizer (CRF) incorporated soilless growing media. The three fertilizer rates were 0, 5, and 35 g of urea-formaldehyde. Another greenhouse experiment was conducted to determine cause of high inorganic N concentrations in the soilless growing substrate solution fertilized with incorporated CRF. The soilless substrate had CRF incorporated either mechanically or manually at the same rate and plants were planted in the substrate. All leachate was collected, and samples were analyzed for inorganic N. Nitrous oxide emissions were measured from three organic substrates over 21 days to understand the effect of different organic amendments on N2O. Each growing substrate had 200 ppm N applied as ammonium nitrate and had 32.8% air-filled porosity during the experiment to standardize gas diffusion rates.

## RESULTS

A large portion of planted N (60%) was taken up by the plant or remained in the substrate when the plant was shipped from the nursery (Table 1). However, plant shoots only utilized 10% of applied fertilizer N suggesting that N fertilizer was applied in excess of plant demand. Nitrogen fertilizer reserve in the substrate ensures the plant will maintain

*Table 1. A container plant production system nitrogen balance. The first row below each category is the pounds of nitrogen per acre and the second row is the amount of nitrogen as a percentage of the total applied nitrogen.*

| | At planting | At harvest | Substrate $N_2O$-N | Bed runoff | Bed infiltration | Bed ($N_2$ + $N_2O$)-N | Unaccounted |
|---|---|---|---|---|---|---|---|
| Nitrogen (lb $ac^{-1}$) | 884.30 | 534.10 | 12.40 | 58.66 | 35.56 | 0.29 | 243.29 |
| Percent of planted | 100.0% | 60.4% | 1.4% | 6.6% | 4.0% | 0.03% | 27.5% |

Unaccounted N was mostly lost as dinitrogen (N2) gas resulting from denitrification (Table 1) (Cabrera 2003). It is unlikely unaccounted N was lost to ammonia volatilization because the substrate solution was acidic throughout the experiment. Little denitrification occurred in the saturated growing bed soil, as indicated by the small fraction of planted N emitted as either N2 or N2O gas (Table 1). The 94 lb ac-1 of N in bed runoff and infiltration (Table 1) indicates nurseries should capture and reuse N-rich runoff. Adding impervious growing bed surfaces will help to recover more of that N.

Applying less N fertilizer results in less available substrate for denitrification- and nitrification-generated N2O and results in less total N2O emitted (Table 2). A large proportion of N2O emission and N leaching occurred in the first five weeks of production (data not shown). Reducing the amount of inorganic N in the substrate solution during this time may improve N use efficiency. Using less destructive CRF-incorporation methods could reduce N leaching from the growing substrate by 2.5 times (Table 3). Growers should incorporate CRF at the end of the substrate mixing line and minimize mechanical handling once incorporated with CRF.

*Table 2. Mean total nitrous oxide (N2O) emitted from five-gallon pot of fir bark-based soilless growing substrate in an 84-day greenhouse experiment treated with 0, 5, or 35 g of surface-applied urea-formaldehyde fertilizer and incorporated CRF. Different letters next to values in each row indicate significant differences (p<0.05) in total N2O on day 84 after planting.*

| Topdress Urea (g) | Mean total $N_2O$ (oz $pot^{-1}$) |
|---|---|
| 0 | 0.018 ab |
| 5 | 0.015 a |
| 35 | 0.020 b |

*Table 3. Mean total salts and inorganic nitrogen leached as a percentage of total applied N from five-gallon pot of fir bark substrate with mechanically- (Mech) or manually-incorporated (Manual) controlled release fertilizer. Different letters next to each row within same column indicate significant differences (p<0.05) in incorporation method on day 76 after planting. Each five-gallon pot had 0.19 oz of total inorganic N applied.*

| Treatment | Total Salts Leached (meq) | Total Applied N Leached |
|---|---|---|
| Manual | 195 a | 20.4% a |
| Mech | 370 b | 48.9% b |

Peat-based substrate emitted less N2O gas than fir bark-based substrate when ammonium and nitrate are present in substrate solution (Table 4), perhaps due to more stable organic carbon, different microbial populations, or other chemical characteristics. However, peat costs more than fir bark and may have a larger carbon footprint because the sequestered carbon from peat bogs could be released during plant production (Cleary et al. 2005).

The N balance research was performed at a single nursery in the Central Valley of California. Nurseries with different site conditions or growing practices may obtain different results. For example, a higher percentage of applied N could infiltrate the soil at a nursery that uses liquid feed fertilization in an irrigation system with poor application efficiency. The experimental beds were on a clay loam soil that has a low infiltration rate, so most leached N ran off the growing area instead of infiltrating the soil. More N may infiltrate coarser soils (i.e. sandy) that have higher infiltration rates. A closer plant spacing than the 2-foot centers in our experiment would alter calculated N values per acre by increasing the plants, substrate, and N fertilizer applied per acre. The CRF in our experiments was Osmocote Plus. Other CRF could differ in N release curves and resistance to mechanical damage from incorporation equipment.

*Table 4. Total nitrous oxide (N2O) emitted from five-gallon pot of soilless growing substrate treated with 200 ppm ammonium nitrate over 21 days. Different letters next to values in each row indicate significant differences (p<0.05) in total N2O on day 21.*

| Media | Total $N_2O$ emitted (oz $pot^{-1}$) |
|---|---|
| Fir | 0.032 a |
| Peat:Fir | 0.028 b |
| Peat | 0.002 c |

Utilizing N fertilizer to more closely match plant demand could reduce environmentally harmful N discharges. Decreasing N fertilizer rates will reduce total N2O emitted and aqueous N in runoff while also saving growers money by reducing fertilizer costs. Ensuring that CRF prills are not damaged during incorporation into soilless substrate could significantly reduce N leaching losses from container plants.

## LITERATURE CITED


Cabrera, R.I. 2003. Nitrogen balance for two container-grown woody ornamental plants. Scientia Horticulturae 97 (3-4):297-308.

Cleary, J., N.T. Roulet, and T.R. Moore. 2005. Greenhouse Gas Emissions from Canadian Peat Extraction, 1990–2000: A Life-cycle Analysis. AMBIO: A Journal of the Human Environment 34, 456-461, 456.

Narvaez, L., R. Caceres, and O. Marfa. 2012. Effects of climate and fertilization strategy on nitrogen balance in an outdoor potted crop of Viburnum tinus L. Spanish Journal of Agricultural Research 10 (2):471-481.

Narvaez, L., R. Caceres, and O. Marfa. 2013. Effect of different fertilization strategies on nitrogen balance in an outdoor potted crop of Osteospermum ecklonis (DC.) Norl. 'Purple Red' under Mediterranean climate conditions. Spanish Journal of Agricultural Research 11 (3):833-841.


## ACKNOWLEDGEMENTS


We would like to acknowledge Pauline Fadakaran, Megan Franco, Iris Garcia, Bridget Giffei, Ian Higgins, Grant Johnson, Xia Zhu-Barker, Cameron Long, Jared Sisneroz, and Ariesha Wikramanyake for their contributions to this research. Funding was provided by Horticultural Research Institute, Plant California Alliance, and California Department of Food and Agriculture – Specialty Crop Block Grant Program and Fertilizer Research and Education Program.

# Efficient Water and Nitrogen Management Practices for Mixed Leafy Baby Green Vegetables in the Desert


## Project Leader

**Charles A. Sanchez**
**Professor**
Department of Environmental Sciences
Center, Maricopa Agricultural Center
37860 W Smith Enke Rd, Maricopa, AZ
University of Arizona
sanchez@ag.arizona.edu

## Cooperators

**Andrew French**
US Arid-Land Agricultural Research Center,
Maricopa Agricultural Center
21881 North Cardon Lane
Arizona, USA 85138
Andrew.French@USDA.GOV

Various grower cooperators.


## 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). Over the past decade the production of high density mixed leafy green vegetables on large beds (80- and 84-inch beds) has increased significantly. These include various types of mixes for baby lettuce (often called spring mix), and baby spinach. Work on the fertilizer requirements for these crops are lacking and many growers have simply utilized the fertilizer practices they currently use on full season lettuce. While these crops are grown at a higher density than full season lettuce, they are harvested young and are short season (20 to 40 days) compared to the 80 to 150 day lettuce crops. We have no information how these factors affect fertilizer needs, no information on how irrigation interacts with N, and no information to modify N fertilizer recommendations for these crops. These data gaps are of concern since over 35% of the industry has converted to these high-density large bed production systems and this acreage continues to grow.

## OBJECTIVES

The objective of these studies is to evaluate various N management practices for mixed baby leaf conventional and organic production systems and calibrate "CropManage" for desert production. These experiment-demonstrations were and continue to be conducted in grower fields to hasten technology transfer.

## DESCRIPTION

During winter-springs of 2019 through 2021, we completed elements of Tasks 1 through 5. Task 1 was largely associated with collecting background data on water and N requirements for baby spinach and spring mix. Tasks 2, 3 ,4, and 5, included evaluations in conventional and organic baby spinach and conventional and organic spring mix production systems and we began "Crop Manage" evaluations.

*Figure 1. Typical Eddy covariance set up in all fields.*

Evapotranspiration was measured using Eddy Covariance methodology (ECV) (Figure 1). Briefly, ECV measures four energy flux components- net radiation (Rn), ground heat flux (G), sensible heat flux (H), and latent heat flux (LE). Rn represents absorbed solar and infrared radiation, G is heat transported into the soil, H is turbulent heat above the crop due to air temperature gradients, and LE is latent heat energy due to ET. ECV data values are reported in energy flux units (W/m2), with water-specific quantities also reported as depths over time (e.g. mm/day). Salt balance was monitored using sensors and data loggers during the season and conductance (EM 38) surveys conducted before and after the cropping season. Irrigation water amounts applied to all fields was also monitored using automated rain gauges. Ground measurements were used to calibrate ET estimates from space-based sensors. Satellite data used included Sentinel 2a/2b, Landsat 8, VENuS microsatellite data, and ECOSTRESS imagery. Nitrogen accumulation during the season was monitored by collecting aboveground plant samples and calculating N accumulation from total dry matter and N content, after laboratory analysis.

## RESULTS AND DISCUSSION

An example of ET and data collected are shown for one site in Figure 2. Seasonal water application efficiencies for baby spring mix and spinach are generally high. Water application efficiencies ranged from 70 to 100% and averaged about 95%. A leaching fraction of only 5% would not be sufficient for managing salt for sensitive crops grown in rotation with baby spinach and spring mix, such as lettuce. This observation is generally consistent with the soil salinity which generally increases during the production season (Figure 3). Growers in the desert often restore salt balance in a summer flood irrigation to minimize leaching during the season so that they can better manage N in-season. However, these irrigation efficiencies are at the limit when considering water distribution uniformities (DU). DU ranged from 44 to 96% with a mean and medium of 77% (data not shown). These uniformities are generally good but less than perfect. Thus, even if required leaching for salt is forgone until after harvest, some irrigation beyond ETc is required in-season so that portions of the field are not shorted. Interestingly, "Crop Manage" irrigations closely aligned with those applied to spring mix but results for spinach were less consistent (Figure 4). Actual irrigations were close to ET replacement and some adjustment in some of the parameters in "CropManage" are needed before this management tool can be implemented in the desert. As the result of field studies conducted in 2019 and 2020 and our direct measurement of crop ET, growth and corresponding satellite measured NDVI, we now have the data to make these modifications for spring mix and baby spinach. Amounts of N applied ranged from 74 to 200 kg N/ha. However, crops removals ranged from 44 to 101 kg N/ha. If we express N recovery by crop removal, we average below 50%. Another way to look at this is relative to goals set by the California Water Quality

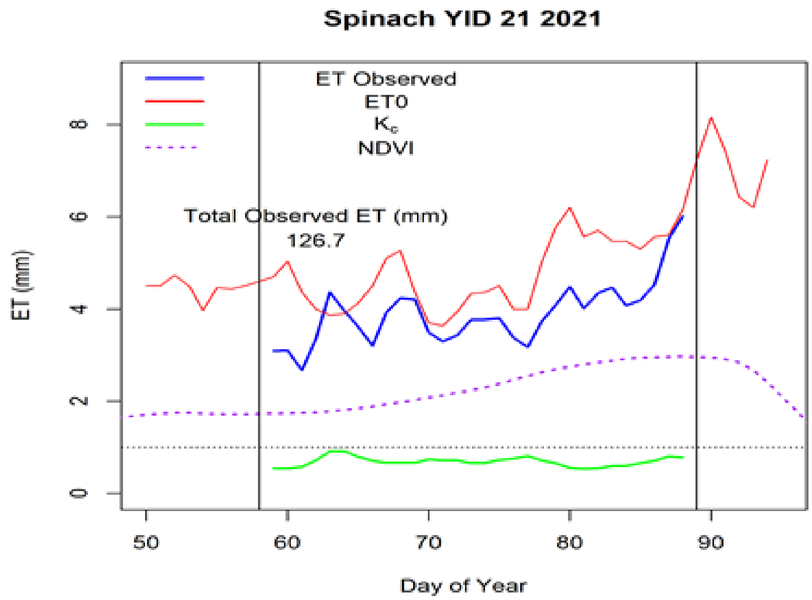



*Figure 2. Measured crop ET by eddy covariance, ETo generated from nearby AZMET, satellite generated NDVI, and calculated crop coefficient for site YID 21.*

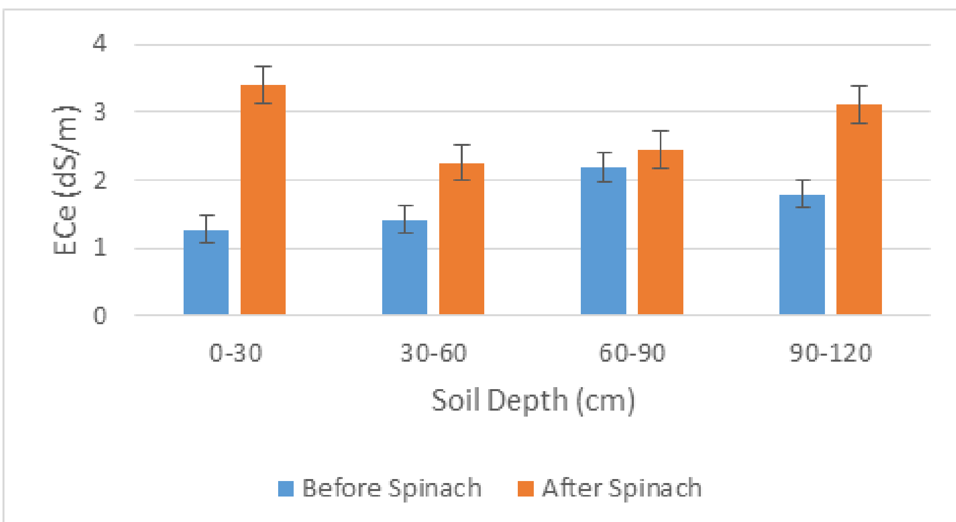



*Figure 3. Salinity in soil before and after spinach for one site (YID 21).*

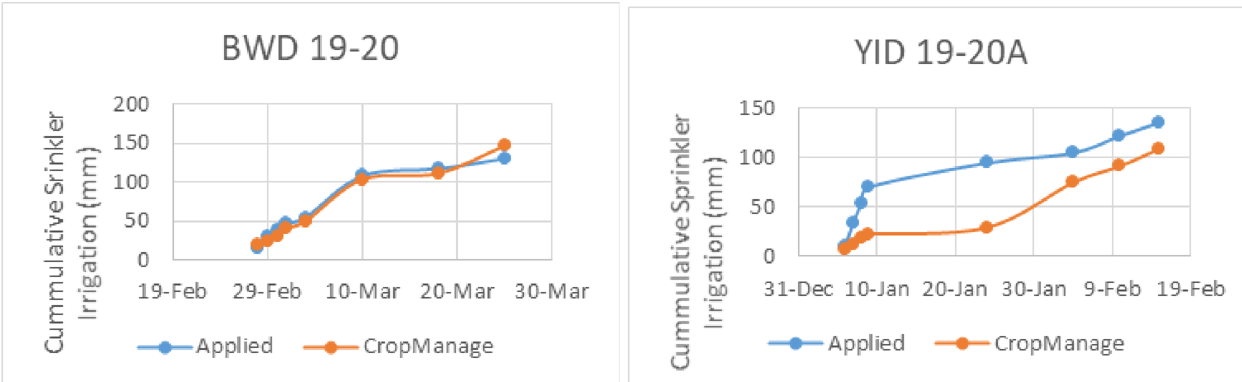



*Figure 4. Comparisons between cumulative irrigation and that recommended by "CropManage" for spring mix (BWD 19-20) spinach (YID 19-20A).*

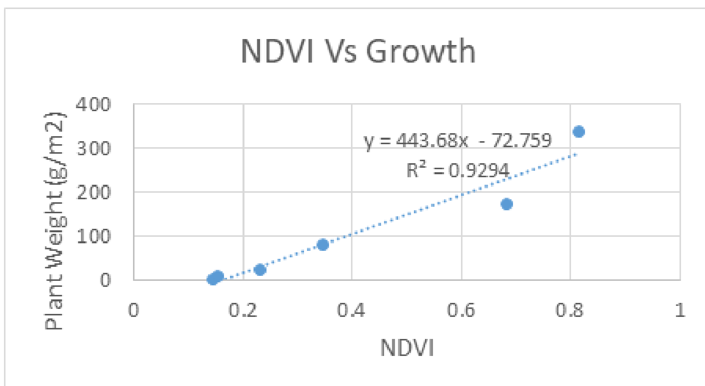



*Figure 5. Relationship between satellite processed NDVI and measured growth in YID 1920A.*

Control Boards (CWQCB). Their goal is achieving a threshold of 50 kg N/A per year over crop removal (A-R <50 lbs N/A). In most of these evaluations, N applied was more than 50 lbs/A over crop removal. As noted previously, these poor recoveries are not due to irrigation inefficiencies. Interestingly, "CropManage" would have called for 0 to 47% less N than was actually applied. While we believe these rates are possible without yield reduction, this reduction would still fall a little short of the thresholds being sought by the CWQCB in some instances. Therefore, we also must seek further strategies for improved N efficiencies. It should be noted that spring mix and spinach generally show exponential growth and N accumulation (data not shown). Thus, this coming season we wish to explore timing options where N applications are better timed for anticipated uptake. CropManage allows for using satellite NDVI to correct growth and in all these studies NDVI seem to track growth reasonably well after two weeks (Figure 5).

## ACCOMPLISHMENTS

We completed field work associated with tasks 1, 2, 3, 4, and 5.

## RECOMMENDATIONS

Because these crops are irrigated by sprinklers, season long and ET replacement is easily achieved, and current water application efficiencies are often high. Thus, further improvements in N utilization efficiency will be largely be based on achieving better timing of N fertilization.

## LITERATURE CITED

Mosier, A. R, Syers, J. K., and Freney, J. R. 2004. Nitrogen fertilizer: An essential component of increased food, feed, and fiber production. Pages 3-18 in: SCOPE 65: Agriculture and the Nitrogen Cycle: Assessing the Impacts of Fertilizer Use on Food Production and the Environment, A. R. Mosier, J. K. Syers, and J. R. Freney, eds. Island Press, Washington,

Sanchez, C. A., and T. A. Doerge. 1999. Using nutrient uptake patterns to develop efficient nitrogen management strategies for vegetables. HortTechnology 9:601-606.

## ACKNOWLEDGEMENTS

We gratefully acknowledge support of the FREP program for sponsoring this work. We also appreciate the cooperation of participating growers

# Understanding Influences on Grower Decision-Making and Adoption of Improved Nitrogen Management Practices in the Southern San Joaquin Valley

## PROJECT LEADERS

**Sat Darshan S. Khalsa**
Assistant Professional Researcher
Department of Plant Sciences
University of California Davis
sdskhalsa@ucdavis.edu

Molly Sears
Ph.D. Candidate
Dept. of Agricultural and Resource Economics
University of California Berkeley
molly_vandop@berkeley.edu

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

## INTRODUCTION

Adoption of nitrogen (N) management practices by California growers is a required step to reduce N loading to groundwater and to maintain economically viable cropping systems, while satisfying the Irrigated Lands Regulatory Program (ILRP) requirements. Research over the past decade has identified many promising practices that can improve N management and maintain economically viable cropping systems, including: the use of N budgets; implementation of the “4R’s” (right rate, time, place, and source); leaf and soil N sampling; split application of fertilizers with irrigation; enhancing soil health to improve soil N retention; and careful deployment and management of microirrigation systems.

Recent research suggests grower 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 influence grower decision making (Lubell et al., 2014; Niles et al., 2015; Shaw and Lubell, 2011). However, we do not currently have a robust understanding how these factors relate to adoption of N management practices across the diverse geography and grower demographics of the SSJV. Furthermore, room for improvement exists to target outreach to growers, Pest Control Advisers (PCAs) and Certified Crop Advisers (CCAs).

This project aims 1) to develop an understanding of the status of grower adoption of improved N management practices in the SSJV; 2) to determine the key influences on grower decision making including the role of PCA/CCAs; and 3) to identify the key barriers to enhanced adoption of N 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, improve N management and to reduce N loading to groundwater.

## OBJECTIVES

1 1 Develop an understanding of links between adoption rates and barriers to adoption of N management practices in the coalitions of the SSJV Management Practices Evaluation Program (MPEP)

2 2 Distribute, collect and aggregate survey data from growers and pest control/certified crop advisors (PCA/CCAs)

3 3 Analyze data to determine key motivations and barriers to grower adoption and PCA/CCA recommendations of N management practices

4 4 Communicate these findings directly with the grower and PCA/CCA communities in which we work, as well as academic and regulatory body audiences

5 5 Outline key variables on linking adoption rates with barriers to adoption of N management practices within grower and PCA/CCA populations to tailor outreach, education and incentive programs

## DESCRIPTION

In 2019, a mail survey was modelled after the survey instrument developed by Dr. Mark Lubell and colleagues that has been tested in the North San Joaquin and Sacramento Valleys. Following the Dillman approach, the survey was sent to 3,084 growers operating on irrigated agricultural lands in the South San Joaquin Valley. The survey asked growers about their nitrogen management practices, barriers and motivations to adopting those practices, thoughts on the links between irrigation and nutrient management, opinions toward nitrogen management challenges and policies, and opinions on the Water Quality Coalitions who implement the Irrigated Lands Regulatory Program. Total returned questionnaires from the first wave was 270 surveys and 194 surveys for the second wave. Non-responses including refusal or implicit refusal totaled 74 responses. Total eligible survey responses were 401 surveys for a raw response rate of 401 / 3084 = 13.0% adjusted to 13.3% to account for the unknown eligibility cases that are eligible.

On November 9th 2020, CAPCA initiated the online survey by sending an e-blast to all members totaling 2,486. On November 23rd, December 7th and December 21st 2020 reminder emails were sent. The total number of returned surveys was 519 surveys with 438 being usable for a response rate of 17.6%. The same solicitation approach was used for WRCCA on January 4th through February 15th 2021. The total number of returned surveys was 241 surveys with 198 being usable for a response rate of 16.0%.

## RESULTS AND DISCUSSION

Our key finding centered on practice adoption included split application as the most readily adopted by growers of most crops. Leaf and soil sampling, soil probes, and irrigation water tests are also common (Fig. 1). This results were comparable to our previous studies in the North San Joaquin and Sacramento Valleys. The application of compost, adoption of cover crops, and use of pressure chambers were adopted at a lower extent. These practices were also the most frequently cited as having barriers to their adoption. Returns from implementing a practice, stewardship, and consideration for public health and safety are important barriers that growers consider for practice adoption. Costs, technical knowledge, and unfamiliarity with the practice are the most commonly cited barriers to adoption. Furthermore, uncertain yield impacts also play a role in influencing grower decisions about adoption. There appears to be similar trends in adoption in the Southern San Joaquin Valley as compared to other regions in California.

We also asked if there is good enough information on N management and N regulations. Like our previous work showed, growers seek information from many sources to base their nitrogen management decisions. A unique question we asked in this survey was regarding the importance of fertilizer cost in management decisions. Growers cited cost as a top barrier to practice adoption. We asked growers how much they were spending on fertilizer annually, and how it impacted their nitrogen application rate. Most growers cited that the cost of N played a somewhat significant role in their choice of application rate, and the cost of N relative to input costs varied substantially across growers.

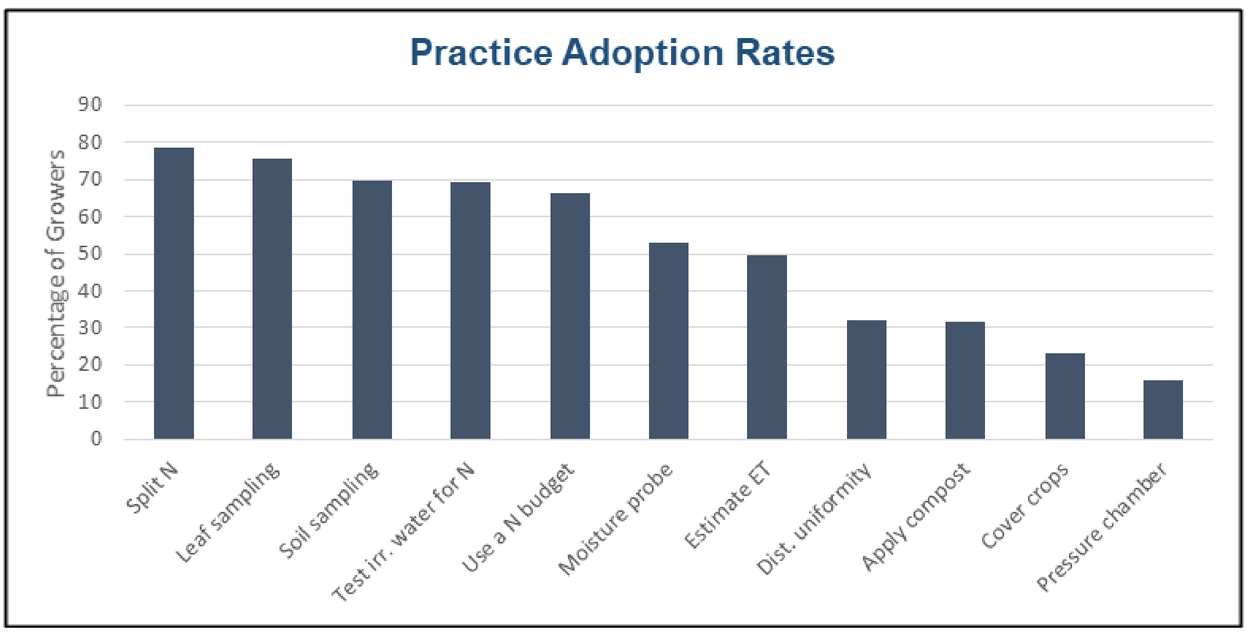
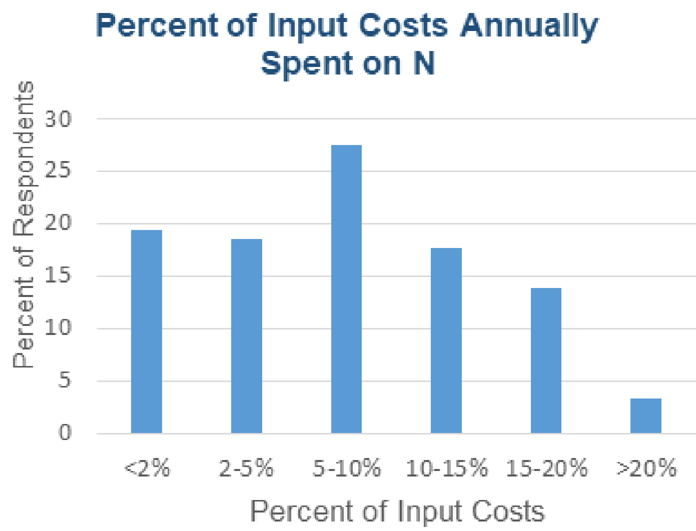



*Figure 1. Percentage of grower adoption of N management practices in the SSJV*



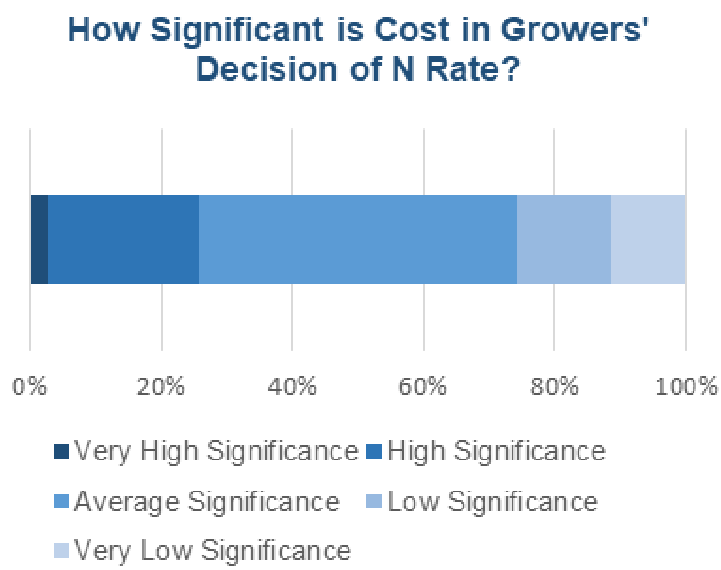




*Figure 2. Grower response to the cost and significance of cost for N fertilizer in decision-making*

## TAKE-HOME MESSAGE

Multiple information sources play a valuable role as crucial partners in disseminating information about N management. On-farm benefits of improved N management are key to motivating practice adoption. Furthermore, uncertain yield impacts and cost of practice implementation are important barriers to adoption. Furthermore, we uncovered the cost of N fertilizer does influence N application rates. Future results from this project will further disclose the role PCAs and CCAs play in making recommendation to growers.

## LITERATURE CITED

Lubell, M. N., M. T. Niles, and M. Hoffman. 2014. Extension 3.0: Managing Agricultural Knowledge Systems in the Age of Connectivity. Society and Natural Resources 27(10): 1089-1103

Niles, M.T., M. N. Lubell, and M. Brown. 2015. How limiting factors drive agricultural adaptation to climate change. Agric Ecosyst Environ 200:178-185.

Shaw, L. and M. N. Lubell. 2011. The Evolution of Local Partnerships for Sustainable Agriculture. Society and Natural Resources 24:1078–1095.

## ACKNOWLEDGEMENTS

We wish to thank Donald Ikeimaya from SSJV MPEP, Ruthann Anderson from CAPCA and Jerome Pier from WRCCA for their support and CDFA FREP for funding this project #18-0596

# Pima Cotton Nitrogen Management, Uptake, Removal - Impacts of Varieties, Subsurface Drip & Furrow Irrigation


## Project Leader

**Robert Hutmacher**
**Univ. CA Cooperative Extension Specialist**
UC Davis Plant Sciences Dept., UC West Side Research and Extension Center
PO Box 158, Five Points, CA 93624; (559) 260-8957; rbhutmacher@ucdavis.edu

## Cooperators

**Brian Marsh**
**Univ. CA Cooperative Extension Farm Advisor & County Director, Kern County, Bakersfield, CA; bhmarsh@ucanr.edu**

**Dan Munk**
**Univ. CA Cooperative Extension Farm Advisor, Fresno County**
Fresno, CA; dsmunk@ucanr.edu

**Jose Carvalho Dias**
**Univ. CA Cooperative Extension Farm Advisor, Merced County**
Merced, CA; jdias@ucanr.edu

**Jorge Angeles, Mark Keeley**
**University of CA Staff Research Associates, UC Davis Plant Sciences Department, Davis, CA**

Phytogen / Corteva Company LLC, Corcoran, CA; Bayer/Delta Pine Co., Scott, MS


## INTRODUCTION

San Joaquin Valley cotton growers aim for high yields to be able to cover production costs and pay for increasing costs of inputs such as irrigation water, fertilizer, and crop protection chemicals. These yield goals can be a significant incentive to apply high rates of fertilizer N to increase chances of achieving high yields, however, elevated amounts of applied fertilizer nitrogen (N) bring the added risk of excess N applications and groundwater contamination. Regulatory decisions made by State Water Board and other agencies raise the likelihood of a range of efforts to require more tightly-managed use of fertilizer and manure-based N sources. Nitrogen management programs that are in various stages of development and implementation help point out some knowledge gaps we have regarding crop N responses, uptake and removal under a range of production conditions. Pima cotton is one relatively large acreage crop for which there has been limited data on responses to N fertilizer, or on plant N uptake and removal with harvest. Since Pima cotton can be quite different in growth habit from Upland cotton, we have been conducting research center and grower site field trials to evaluate responses of some modern Pima cultivars to N management under practices conducive to high yields.

## OBJECTIVES

1. Evaluate for high-yield potential Pima cotton cultivars the impacts of N application amount, variety and irrigation method (subsurface drip versus furrow) on total plant N uptake and harvest removal, including a comparison with Upland varieties.

2. Utilizing 3 grower farm sites with moderate to high yield potential and representing different soil types, determine total above-ground plant N uptake at early open-boll timing, and N removal with harvest (measured as N content of seed, lint, gin trash, measured separately) to better understand Pima N requirements.

## DESCRIPTION

Matching nitrogen management trials with a wide range of applied nitrogen fertilizer were conducted under both furrow irrigation and under subsurface drip irrigation in all three years of the study (2019 through 2021) conducted at the University of CA West Side REC in a clay loam soil. Row width was 40 inches, and the cotton nitrogen response study utilized two Pima cultivars (Phy-881RF, DP348RF) and two Upland cultivars (Phy764 WRF, DP 1845 B2RF) for comparison of responses. A pre-plant irrigation of approximately 5-6 inches was applied each year in February or March to supply planting moisture for germination. Experiment sites were changed each year to allow us to place the trials in field sites with uniform, low residual soil nitrate levels.

Matching experiments were set up to apply N fertilizer amounts to achieve the same total N application amounts under subsurface drip irrigation (SDI) and furrow irrigation (F). In the SDI plots, drip tape with 0.27 gph emitters spaced 12 inches apart were installed at a depth of 8-10 inches below the bed centers, with the system operated 2 times/week during lower evapotranspiration (ET) time of the year, and 3 times/week during higher ET periods. No pre-plant N fertilizer applications were made in either irrigation treatment. Pre-plant residual soil nitrate levels in the upper two feet of soil ranged from 26 to 45 lbs $NO_3$-N/acre at this site across reps across the years. N fertilizer applications in the SDI plots were initiated at the 7-9 node stage in the cotton plants (about the first week of June), and weekly applications of nitrogen (urea) were injected to match estimated plant uptake during rapid growth phases, with the final applications made the 3rd week of August (2019) or during the 4th week of August (2020 and 2021). N fertilizer applications in furrow irrigated plots were split in timing and amount, with the first half applied just prior to the first within-season irrigation in late-May/early June, and the second half applied just prior to the second in-season irrigation about 4 weeks later. Fertilizer application amounts are shown in Table 1. N treatment impacts on petiole nitrate-N values were monitored during the study to assist with determining values for pima nitrate-N guidelines as a function of growth stage. Pre-plant and post-harvest soil samples were collected to a depth of 8 feet in select treatments and cultivars to determine if any applied N treatments resulted in net depletion or accumulation of soil nitrate within the soil profile.

*Table 1. Applied nitrogen amounts in furrow and subsurface drip (SDI) irrigated nitrogen rate trials at the Univ. CA West Side REC in 2020. Similar rates of applied N fertilizer were applied across treatments in 2019 and 2021.*

| Irrigation Method | Total applied fertilizer N (lbs/acre) | | | | |
|---|---|---|---|---|---|
| | Trt N-0 | Trt N-50 | Trt N-75 | Trt N-100 | Trt N-125 |
| Furrow | 0 | 61 | 106 | 153 | 200 |
| SDI | 0 | 62 | 107 | 154 | 201 |

Whole above-ground plant samples were collected approximately 3 weeks prior to harvest each year and analyzed for N content in select cultivars as an approximation of peak plant N uptake, and seedcotton was collected at harvest timing and analyzed to assess harvest removal of N with cotton seed and lint removed during harvest.

## RESULTS AND DISCUSSION

Seedcotton yields for the Pima and Upland cotton cultivars in the 2019 and 2020 N rate response studies under drip and furrow irrigation at the West Side REC in general peaked at the N-75 or N-100 treatment levels (data not shown). With Pima cultivars, additional applied N at the N-100 level did not significantly affect yields in either cultivar under furrow irrigation in the 2020 study with somewhat lower yield levels than 2019, but did increase yield of one cultivar in 2020 and one Upland cultivar in 2019. Higher N applications in the N-125 treatment either reduced yields (furrow irrigation treatments) or did not have a significant impact on yield under SDI (although a non-significant trend toward lower yields at the N-125 level also existed). Significantly increased plant height and leaf area were measured in N-125 treatments, suggesting added vegetative growth that was not beneficial to yields of reproductive tissue (bolls/seed/lint). In the WSREC study, petiole nitrate-N values in the N-0 and N-50 treatments (which had significantly lower yields than the N-75 and N-100 treatments in both 2019 and 2020) were significantly lower during most of the growing season during most of the mid-squaring to peak bloom plus 2 weeks period. The N-75 treatment was getting close to what we feel is the borderline-deficient range by the early open boll (Early OB) stage. Petiole nitrate-N values for furrow irrigated plots were generally about 20 to 25% higher than in SDI plots in the period prior to peak bloom, and more variable but still 10 to 15% higher from peak bloom to early open boll. Above-ground whole plant samples were collected in plots of N-50, N-75 and N-100 treatments in all cultivars, plus N-0 and N-125 treatments in Phy-881 RF in 2019 and 2020 at peak biomass timing. This was estimated to occur within a period of about 3-4 weeks prior to harvest in the SDI and F plots at the West Side REC. In addition, seedcotton samples were collected at harvest in the same plots during harvest operations, with samples ginned on mini-gins and then acid-delinted prior to grinding in a Wiley mill. Some estimates of N removal per bale of lint removed with cotton harvests are shown in Table 2 for Pima grown at multiple sites in the 2019

*Table 2. Seedcotton yields and N removal per bale of cotton lint in Pima variety trial sites sampled for cotton nitrogen trial in 2019 and 2020. Values followed by a different letter at each individual location were significantly different at the P<0.05 level using LSD 0.05 analyses.*

| Location | Variety | 2019 Seedcotton yield (lbs/ac) | 2020 Seedcotton yield (lbs/ac) | 2019 N content of Seed (lbs/ac) | 2019 N per bale (500 lbs of lint) | 2020 N per bale (500 lbs of lint) |
|---|---|---|---|---|---|---|
| West Side REC | DP 341 RF | 4417 a | 4400 a | 106.2 a | 29.4 | 31.6 |
| | DP 348 RF * | 4020 a | 4071 a | 96.7 ab | 29.1 | 30.7 |
| | PHY 881 RF | 4092 a | 4168 a | 91.5 b | 28.1 | 31.9 |
| | | | | | | |
| Kings County | DP 341 RF | 4953 b | 5641 b | 117.5 a | 30.0 | 28.3 |
| | DP 348 RF * | 5120 a | 5745 b | 127.4 a | 32.1 | 31.2 |
| | PHY 881 RF | 5164 a | 5996 ab | 126.6 a | 30.8 | 29.6 |
| | | | | | | |
| Fresno Co. | DP 341 RF | 5755 a | 4736 b | 133.7 a | 28.6 | 30.5 |
| | DP 348 RF * | 5326 a | 5048 ab | 125.0 ab | 28.7 | 28.1 |
| | PHY 881 RF | 5345 a | 4914 b | 125.9 ab | 28.3 | 29.8 |
| | | | | | | |
| Kern Co. | DP 341 RF | 2864 a | 4323 a | 63.8 a | 26.7 | 31.5 |
| | DP 348 RF * | 2225 b | 4088 a | 51.2 b | 28.1 | 32.2 |
| | PHY 881 RF | 2881 a | 4227 a | 62.7 a | 25.8 | 29.4 |
| | | | | | | |
| Merced Co. | DP 341 RF | 3132 a | 3566 a | 77.5 a | 30.8 | 30.9 |
| | DP 348 RF * | 2900 ab | 3134 ab | 73.0 a | 31.2 | 30.6 |
| | PHY 881 RF | 2730 b | 3073 b | 68.1 a | 30.9 | 32.4 |

* DP 347 RF was planted in 2020, DP 348 RF was planted in 2019.

and 2020 study seasons. Similar data will be collected in 2021.

## TAKE-HOME MESSAGE

These studies should represent a fairly wide range of Pima cotton yield levels achieved across different soil types, and at the conclusion of the study will provide improved estimates of peak plant N above-ground uptake and N removal with harvest estimates for Pima cotton across this range of production conditions, improving our estimates of N fertilizer needs for high-yield potential Pima cotton in California.

## ACKNOWLEDGEMENTS

This multi-year Pima cotton nitrogen management trial has been supported by the California Department of Food and Agriculture Fertilizer Research Education Program (CDFA-FREP) and that support is gratefully acknowledged. Additional funding for soil and plant analyses have been provided each year by the California Cotton Ginners and

Growers Association. Cooperation of staff of the University of CA West Side REC has been instrumental in conducting the drip versus furrow irrigation trial at that location. Cooperation of San Joaquin Valley cotton growers each year has allowed us to collect soil and plant samples and final harvest seedcotton samples under full-scale field conditions. We are grateful to our dedicated field research staff (Jorge Angeles, Mark Keeley, Wen Flores, Miguel Mariscal, Jose Ramos) for their hard work on this study.

# SUMMARIES OF CURRENT FREP PROJECTS

# Evaluation of Certified Organic Fertilizers for Long-term Nutrient Planning


## Project Leader

**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**
Staff Research Associate
University of California Cooperative Extension, Santa Clara County, Central Coast Region, cbrsmith@ucanr.edu


## INTRODUCTION

Understanding the release of plant available nitrogen (N) from organic fertilizers is critically important in order to achieve high N use efficiency (NUE) and minimize N loss to the environment, including from organically managed agroecosystems. With this information, growers will be empowered to more precisely manage nutrients according to seasonal and site-specific conditions. The challenge of understanding net N mineralization from organic fertilizers is directly related to complex interactions between weather, soil biology and physical properties, organic input quality and chemistry, and intensive management practices (Cabrera et al., 2005; Schomberg et al., 2009). Although, in general, inorganic N can be released quickly from high-N containing fertilizers (Joseph et al., 2017), there is limited information on the degree to which biotic and abiotic factors influence characteristics of nutrient release, for example the release rate, total plant availability or the significance of short-term verses long-term immobilization processes. In the laboratory, the N mineralization potential, i.e. the availability of plant-available N 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 accurate in predicting the N mineralization potential of different amendments and soil N. Yet, the lack of information on the N mineralization kinetics of organic fertilizers within different soil types and/or temperatures has limited the ability to make clear application recommendations. The inclusion of mineralized N from organic sources of N into fertilizer recommendations is essential to improving NUE and optimizing agronomic planning. Underestimation of the contribution of organic soil amendments and fertilizers to plant-available N can result in excess reactive N 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 N release from organic sources and sync N supply with crop N demand.

## OBJECTIVES

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

1. Conduct an extensive literature review on soil N mineralization and crop N availability as affected by organic based N fertilizers.
2. Determine seasonal N mineralization and N mineralization potential in soils repeatedly amended with organic fertilizer in CA.
3. Conduct field trials to assess and confirm lab and DayCent model results and to inform the COMET–Farm.
4. 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

Here we combine data gathered from the literature, aerobic lab incubations and field trials to better understand plant available N release dynamics from organic nutrient sources added to the soil. Using this empirical data, we will be able to validate the daily time step version of the CENTURY biogeochemical model – DayCent. Establishing projections of seasonal variability and long-term nutrient value of selected organic fertilizers, including impacts on soil carbon reserves and multiyear soil nutrient increases will aid immensely in developing fertilizer recommendations for organic growers. Modeling N mineralization responses will help us to better understand repeated annual applications of organic fertilizers on long-term soil N availability. Information on net N mineralization generated by this project will also assist in the broader effort to parameterize the DayCent model, so that the model can accurately predict N mineralization rates at different soil temperatures under soil conditions in California throughout the year. These models often use default N mineralization values resulting in poor prediction outcome for soils under California's Mediterranean climate. Our results will provide adjustments for nutrient management guidelines depending on organic fertilizer sources, soil type, and climate data. The information generated in this research will be used by UC ANR Extension, CCAs and farmers to reassess N management across a variety of crops. This is a three-year project and to date we have accomplished literature review, multiple laboratory incubations and one season field trial. The laboratory incubations are on-going and a field litter bag decomposition trial is in progress.

## RESULTS AND DISCUSSION

Model Development: Models are being developed using data extracted from 47 studies. The initial stages of model development include fitting the dataset, using C/N ratio as a grouping factor into a single pool exponential kinetic model (Stanford and Smith, 1972). Data from 20 studies that reported amendment C/N ratio (see Figure 1), with a total of 803 observations were used here. Identification of unknown parameters, both representing the total percent nitrogen mineralized (NO) or the turnover rate characteristic of the mineralization process (k), were carried out using non-linear Bayesian regression. After the fitting procedure, a resampling technique using Markov Chain Monte Carlo sampling, which samples over 2000 iterations of the algorithm, was imple-

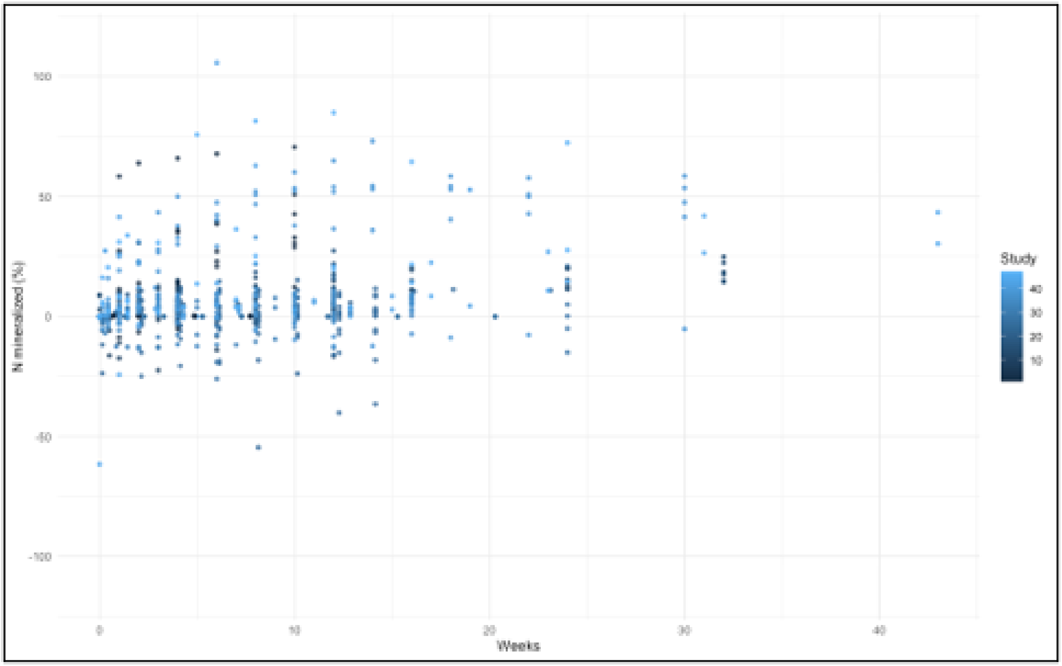



*Figure 1: Data gathered from studies (n=20, obs=803) representing the percentage of total nitrogen mineralized over the incubation period shown in weeks. The point color represents different unique study IDs.*

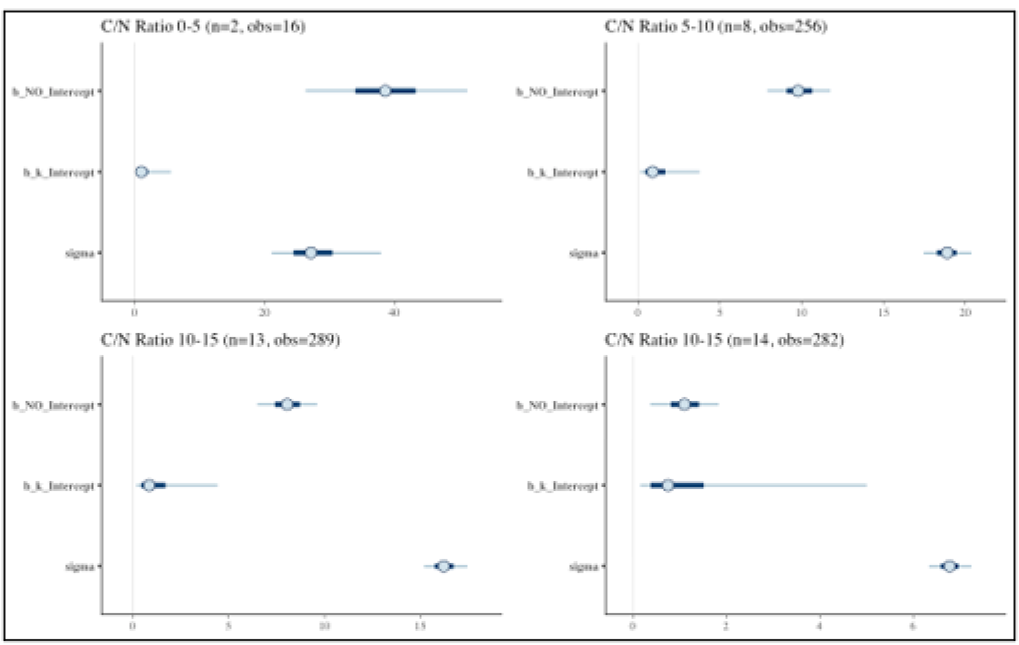



*Figure 2: Model parameter summary plots for each observation set, grouped by C/N ratio, fit using a non-linear regression model. Mean values and credible intervals are determined using MCMC sampling of the posterior density function each unknown model parameter.*

mented (see Figure 2).

The Gelman-Rubin statistic, R-hat, of 1 was used to determine model convergence. Results show that low C/N ratio material 0-5 have a mean percent nitrogen of 38.53 (CI: 23.27-53.60), next C/N ratio 5-10 had a mean value of 9.82 (CI: 7.51-12.27), middle range C/N 10-15 of 8.07 (CI: 6.27-9.90) and high C/N ratio 15-30 of 1.12 (CI: 0.23-2.03). The model fits for the single pool were generally poor and need further refinements as seen by high sigma values (Figure 2).Laboratory Incubations: Two full factorial 60-day aerobic Laboratory Incubations: Two full factorial 60-day aerobic laboratory incubations have been completed in contrasting soil textural types (clay vs. sand) under two temperature regimes (20°C and 10°C). Figure 3 shows data collected from separate aerobic incubations over 60 days. Our results show that both temperature and soil type have inconsistent impacts on net N release. Kinetic model fitting is currently on going and will aid in quantifying the impact these factors have on net N release.

## TAKE-HOME MESSAGE

At this stage, our project results indicate 1) The commonly used single pool nitrogen mineralization model varies in its ability to characterize organic fertilizers across a wide range of amendment C/N characteristics. 2) High C/N ratio amendments such as compost or aged manure may result in positive plant available N in the long-term, likely due to initial immobilization and subsequent N recycling through the organic pool. Further research will evaluate uncertainty between each study in addition to other factors such as temperature and soil type, using a hierarchical approach. DayCent model projections of mineralized N from selected organic fertilizers will then be compared to selected common N mineralization models. With a better understanding of how accurately biogeochemical models such as DayCent describe N mineralization, future research can work to improve these important agroecosystem impact assessment tools.

## LITERATURE CITED


Cabrera, F., Martín-Olmedo, P., Lopez, R., and Murillo, J. M. (2005). Nitrogen mineralization in soils amended with composted olive mill sludge. Nutrient cycling in agroecosystems 71, 249-258.

Harter, T., and Lund, J. R. (2012). "Addressing Nitrate in California's Drinking Water: With a Focus on Tulare Lake Basin and Salinas Valley Groundwater: Report for the State Water Resources Control Board Report to the Legislature," Center for Watershed Sciences, University of California, Davis.

Joseph, C.A., L. Khiari, J. Gallichand, and S. Bouslama. 2017. Classification and assessment models of first year byproducts nitrogen plant-availability from literature data. Sci. Total Environ. 586: 976–984.

Schomberg, H. H., Wietholter, S., Griffin, T. S., Reeves, D. W., Cabrera, M. L., Fisher, D. S., Endale, D. M., Novak, J. M., Balkcom, K. S., and Raper, R. L. (2009). Assessing indices for predicting potential nitrogen mineralization in soils under different management systems. Soil Science Society of America Journal 73, 1575-1586.

Stanford, G., and Smith, S. (1972). Nitrogen mineralization potentials of soils. Soil Science Society of America Journal 36, 465-472.

Stehfest, E., and Bouwman, L. (2006). N2O and NO emission from agricultural fields and soils under natural vegetation: summarizing available measurement data and modeling of global annual emissions. Nutrient Cycling in Agroecosystems 74, 207-228.

## ACKNOWLEDGEMENTS

We would like to thank True Organics for providing organic fertilizers, Javier Zamora and JSM Organics for providing the field project site.  Also, UC Davis and UCANR staff and student interns for help with laboratory and field projects.

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


## Project Co-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

### Work Plan Year 2 – Bok Choy

**Task 2**: We conducted N and irrigation evaluations of bok choy starting in Fall of 2020 and completed in Winter 2021 in Santa Clara County

### Sub-task 2.1 Conduct N uptake pattern and total N uptake evaluations

1. During the growing season, we conducted above ground biomass, biomass N and soil nitrate evaluations 3 times for bok choy to generate N uptake curve. Each field was 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 were sampled separately.
2. At harvest, samples were collected from 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 po1tion of the crops (expressed in lbs/ton fresh weight).
3. At key stages of crop development, diagnostic sampling of leaves was done for analysis of total N.

### Sub-task 2.2 Conduct crop canopy evaluations and irrigation application evaluations

1. We installed flow meters in the above-mentioned fields.
2. Using an infra-red camera, we took canopy photos of the crop every two weeks.
3. We installed and maintained soil moisture monitoring sensors.

### Sub-task 2.3 Analyze all data and prepare mid-term report to FREP

- Data analysis is currently underway.

### Sub-task 2.4 Reports and extension

In Santa Clara County data was collected for the second year for Bok Choy starting in Fall 2020 and completed in Winter 2021. Each field was divided into three blocks. Separate samples were collected from each block. During the growing season, we collected samples for conducting above ground biomass, biomass N and soil nitrate evaluations 3 times for bok choy to generate N uptake curve. The crop canopy images were also collected, and analysis is currently ongoing. The plant samples and soil moisture data from the second year of bok choy in Santa Clara County are also currently being analyzed.

### Work Plan Year 1 – Water Spinach, Garlic Chives, and Moringa

**Task 1:** N and irrigation evaluations for water spinach, garlic chives (Santa Clara), and moringa (Fresno) were installed in the field in Spring 2021 and data collection is currently ongoing.

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

1. Two high yielding fields of water spinach and garlic chives were selected in Santa Clara.
2. For moringa in Fresno, two plots were selected at the Kearney Agricultural Research and Extension Center (KARE): one with established moringa that was planted in 2019, and one with new moringa transplants that were planted in June 2021. Both plots included a fertilizer treatment and a control.
3. During the current growing season, data collection is underway for above ground biomass, biomass N and soil nitrate evaluations 7 times for water spinach and moringa and 12 times for garlic chives to generate N uptake curve. Each water spinach and garlic chives field was divided into three blocks (replicates). Separate samples are being taken from each block. For water spinach and garlic chives, the crops lack separation of biomass into marketable and unmarketable portions as all harvested biomass is marketable.
4. At harvest, samples will be collected from 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).
5. 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. We installed flow meters in the above-mentioned fields.
2. Using an infra-red camera, we are currently taking canopy photos of the crop every two weeks.
3. We installed and are maintaining 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

In Santa Clara County work began on year 1 of water spinach and garlic chives in January of 2021. Tensiometers and dataloggers were recalibrated and all sensors and dataloggers were installed in two grower fields of water spinach and two grower fields of garlic chives. Each field was divided into three blocks. Separate samples are being collected from each block. Currently we are collecting samples for conducting above ground biomass, biomass N and soil nitrate evaluations 7 times for water spinach and 12 times for garlic chives to generate N uptake curve. We are also collecting soil moisture data, and crop canopy data (Figure 1a and b).

In Fresno County, work began on year 1 of moringa in May/June 2021. Tensiometers required repair and calibration, including replacement of some parts to match the current, improved design by Michael Cahn's program. Dataloggers were set up with network service, and dataloggers, tensiometers, and flow meters were installed in both plots. In each moringa plot (established and new), 4 rows were selected, two of which are receiving NPK fertilizer and two of which are an unfertilized control. We are currently collecting samples for aboveground biomass, biomass N, and soil nitrate, and collecting soil moisture and crop canopy data.

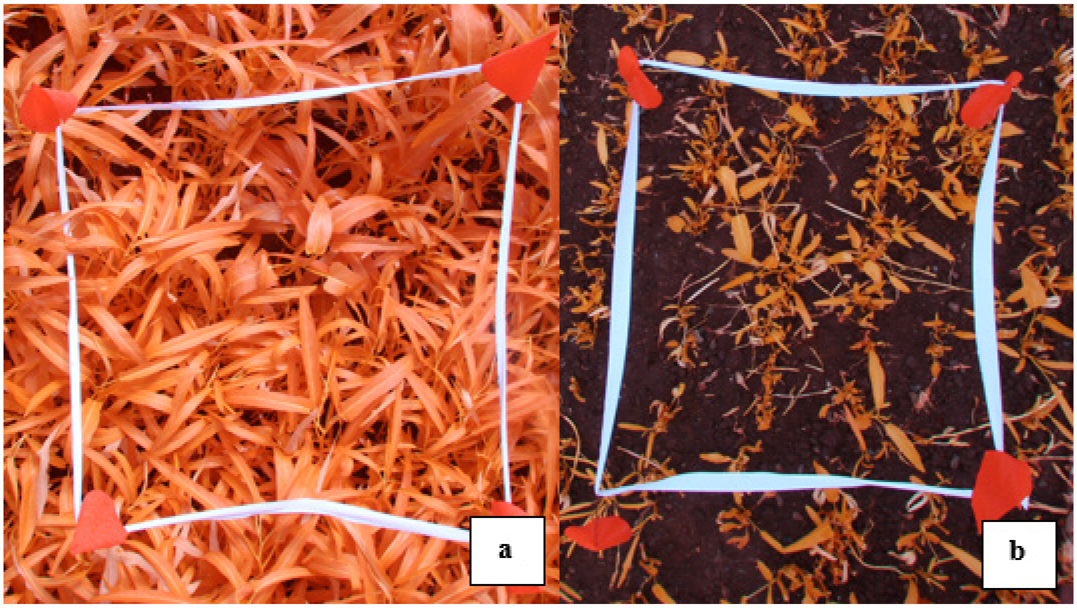



*Figure 1a. Infra-red crop canopy cover image of water spinach at 3 weeks after a harvest. 1b. Infra-red crop canopy cover image of water spinach 1-week after a harvest, the crop is harvested 7-10 times during the growing season.*

We plan to present the initial findings of the bok choy and moringa trials as posters presentations at the 2021 FREP/WPH Nutrient Management Conference to held in San Luis Obispo that will be attended by over 150 people (UCCE Advisors and Specialists, Certified Crop Advisors, and agricultural production consulting personnel).

## 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.*

# Improving nitrate and salinity management strategies for almond grown under micro-irrigation


## Project Leaders

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

## Cooperators

**Francisco Valenzuela**
Postdoctoral Researcher
University of California Davis
Plant Sciences Department
facevedo@ucdavis.edu

**Daniela Reineke**
Graduate Student Researcher
University of California Davis
Plant Sciences Department
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, these values, however, was derived for Lovell rootstock under flood irrigation and are 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 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 (Simunek 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, 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 scenarios (HFS: daily irrigation with saline water and daily fertigation, HFNS: daily irrigation with non-saline water and daily fertigation, and LFS: irrigation every four days with saline water and fertigation every 8 days) are being tested.
2. Soil water content, salt and nitrate concentrations of the soil solution are being measured at different locations in the root zone. Plant performance under the different irrigation treatments is being evaluated using leaf tissue analysis and measurements of stem water potential and tree growth.
3. A computer model that can 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 managements. 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.

## RESULTS AND DISCUSSION

Drip-irrigating with saline water resulted in an increase in soil solution salinity in the saline treatments (HFS and LFS) and in a heterogeneous distribution of soil salinity, with lowest values of near the drip emitter in the center of the wetted area and values of over 10 dS/m near the margins of the wetted zone (Fig. 1). This distribution pattern is typical of drip-irrigation with saline water.

Almonds have a salinity threshold of 1.5 dS/m (Grieve et al., 2012), which means that part of the rootzone experiences salinities that would cause significant yield losses if distributed uniformly across the rootzone. Measured root densities are much higher in the less saline zones however (Fig. 1), which might reduce negative effects of the highly saline zones on the plant.

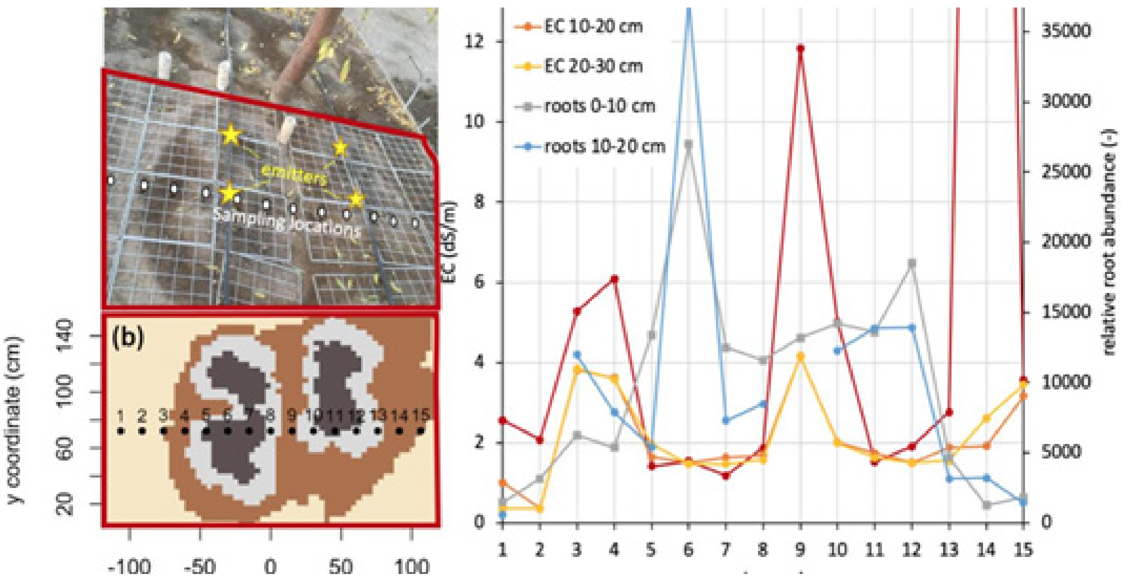



*Figure 1: Example of a distribution of salinity and roots in the saline low-frequency treatment (LFS). (a) picture of the irrigated soil surface, (b) soil color map of the irrigated soil surface with locations of the 15 soil samples, (c) electrical conductivity of the saturated paste (calculated from 2:1 soil extracts) using a calibration equation.*

The higher soil salinity in the treatments HFS and LFS resulted in a significant increase in leaf Cl concentration (Fig. 2). However, a significant difference between HFS and LFS was found only in the Viking rootstock for Cl where the higher Cl concentrations were found in the LFS treatment. Moreover, the LFS treatment resulted in higher Magnesium concentrations and lower zinc concentrations in the Nemaguard. rootstock when compared to HFS.

## ACCOMPLISHMENTS

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 under different irrigation and fertigation management scenarios. 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.

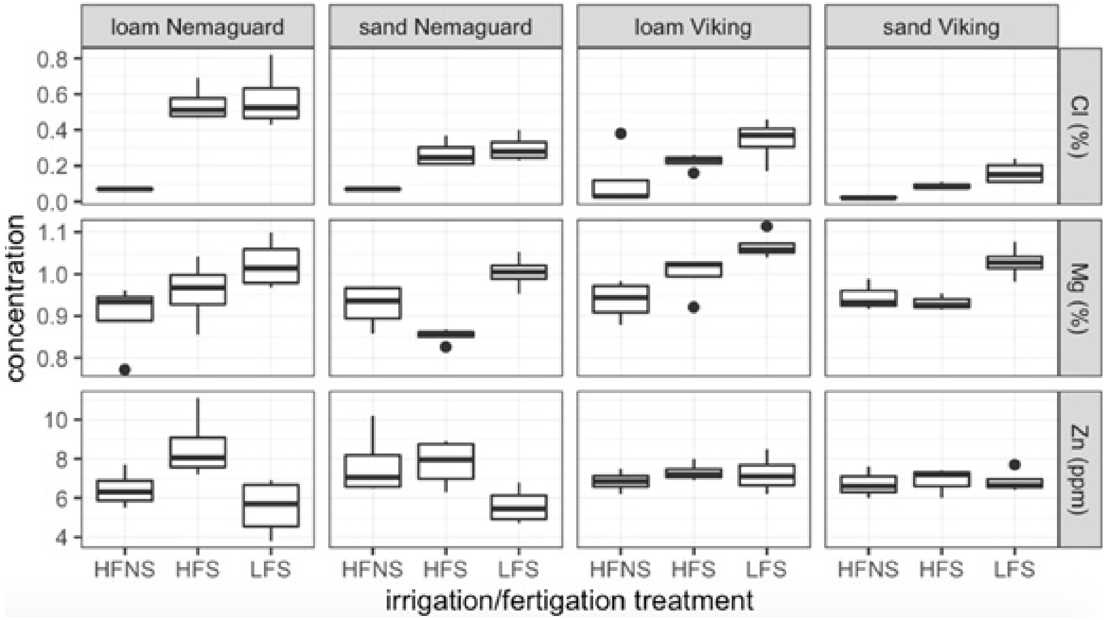



*Figure 2: Leaf concentrations of Cl, Mg, and Zn for the three treatments HFNS (high frequency, no salt added), HFS (high frequency, saline), LFS (low frequency saline), two different soils (loam and sand) and two different rootstocks (Nemaguard and Viking).*

## LITERATURE CITED

Grieve, Catherine M., Stephen R. Grattan, and Eugene V. Maas. "Plant salt tolerance." ASCE manual and reports on engineering practice 71 (2012): 405-459.

Šimůnek, J., M. Th. van Genuchten, and M. Šejna. 2012. HYDRUS: Model use, calibration and validation. Special issue on Standard/Engineering Procedures for Model Calibration and Validation, Transactions of the ASABE, 55(4), 1261-1274.

## ACKNOWLEDGEMENTS

We wish to express our gratitude to the California Department of Food and Agriculture's Fertilizer and Education Program for funding the project.

# Assessing Drip Irrigation and Nitrogen Management of Fresh Onions Produced in California Low Desert


## Project Leaders

**Jairo Diaz**
Director, University of California, Desert Research and Extension Center, 1004 Holton Rd, Holtville, CA 92250, phone: 760-356-3065, email jdiazr@ucanr.edu

**Roberto Soto**
Professor, Universidad Autonoma de Baja California - UABC, Instituto de Ciencias Agrícolas, Carretera a Delta s/n C.P. 21705, Ejido Nuevo León, Baja California, México, phone 52-1-686-121-6934, email roberto_soto@uabc.edu.mx

**Daniel Geisseler**
Cooperative Extension Specialist in Nutrient Management, University of California, Land, Air and Water Resources, One Shields Avenue, Davis, CA 95616, phone 530-754-9637, email djgeisseler@ucdavis.edu



## Supporters

Imperial Valley Vegetable Growers Association, Coastline Family Farms, Horizon Farms, and Imperial Valley College.


## INTRODUCTION

California is the largest onion producer in the nation. The 2017 farm gate value for onions in California was estimated at $359.29 million. In 2017, Imperial County growers harvested close to 13,000 acres of onions that generated over $79 million in farm gate value, equivalent to 22% of total onions produced in California. Onion production value in Imperial County ranked 8th in 2017. Irrigation excesses as well as municipal and industrial discharges from the Imperial, Coachella and Mexicali valleys flow into California's largest lake, the Salton Sea. Currently, the Salton Sea has high nutrient, salinity, and toxic compound concentrations. Adoption of improved irrigation and nutrient management practices by growers is needed in order to reduce water pollution from excess nutrients in California's low desert region. The purpose of this project is to enhance sustainability through evaluation of irrigation and nutrient management strategies that conserve water and minimize nutrient export. The use of irrigation technology based on plant needs along with soil moisture indicators can help create a healthy environment for crops and minimize the risk of nitrate losses to the groundwater. The main goal of this project is to evaluate the effects of irrigation management and nitrogen fertilization rates on yield and quality of fresh onion bulb production in arid regions using saline water.

## OBJECTIVES

1. Evaluate the response of onion to drip irrigation and regimes and compare onion production under different N fertilizer application rates.
2. Communicate findings directly to growers, as well as to crop advisors, academics, regulatory bodies, and agriculture industry.
3. Provide training opportunities to college students.

## DESCRIPTION

A field assessment is performed at the University of California Desert Research and Extension Center - UCDREC, Holtville, CA. The assessment is carried out with four replicates in a split-plot design with drip irrigation treatments in the main plot and four N-fertilization rates at the subplot level. Research plots are 50 ft long and comprise 4 rows on 40-inch beds. Sixty-four plots are established (16 treatments and 4 replicates). Sprinklers are used for germination and establishment in all treatments. Four irrigation levels are established: 40, 70, 100, and 130% of crop evapotranspiration (ETc). Irrigation scheduling is based on weather data from the UCDREC's CIMIS station and stage-specific crop coefficients developed for the region. Soil water tension meters are installed at 6-, 12-, and 24-in. Four in-season nitrogen treatments are assessed: 0, 75, 150, and 225 lbs N per acre. Soil samples are collected (pre-planting, in-season, and post-harvesting) at different depths (from 0 to 36 in depth) and analyzed for NH4 and NO3. Furthermore, bulbs and leaves are analyzed for their N concentration during the growing season to determine N uptake and removal in the different treatments. Onion yield, size, and quality are assessed at harvest.

## RESULTS AND DISCUSSION

This summary shows results from the October 2020 to May 2021 growing season.

Seventeen sprinkler irrigations were scheduled for all treatments from 10/27/2020 to 12/29/2020 with a total water applied of 10.43 in. Irrigation treatments were converted to drip in January 2021. Total applied irrigation water (sprinkler and drip systems) for the growing season ranged from 15.10 in (40% ETc) to 24.63 in (130% ETc). Total rain during the growing season was 1.26 in.

Average hourly soil water tension (SWT) records during germination and establishment periods (10/27/2020 – 2/8/2021) were near field capacity in the top one foot. During the irrigation treatments (2/9/2021-4/25/2021), the 100% and 130% ETc treatments were in the range of plant optimal growth (Table 1). Average records at 6- and 12- in depths from 40% and 70% ETc treatments indicated dryness.

In general, N in biomass increased as irrigation and N fertilization increased (Table 2). The initial residual soil N was high because the previous crop was alfalfa. With one exception, N in the biomass exceeded the amount of N applied with fertilizers. Final residual N in soil tended to increase as N fertilization increased. We believe that nitrogen mineralization during the growing season likely exceeded 100 lb/ac, which contributed to our observation that N output exceeded N input in all treatments.

Onion yields and bulb size distribution responded to irrigation rates (Table 3). The total yield reductions by 40%, 70%, and

*Table 1. Average hourly soil water tension (cb) from 2/9/2021 to 4/25/2021.*

| Depth (in) | 130% ETc | 100% ETc | 70% ETc | 40% ETc |
|---|---|---|---|---|
| 6 | -56.5 | -46.7 | -77.1 | -95.4 |
| 12 | -22.0 | -37.0 | -57.0 | -112.3 |
| 24 | -1.3 | -4.0 | -8.0 | -4.3 |

*Table 2. Nitrogen balance by irrigation and nitrogen treatments.*

| Treatment[1] | Initial residual N (lb/ac in 3 ft) | N fertilization (lb/ac) | Total input (lb/ac) | N in biomass (lb/ac) | Final residual N (lb/ac in 3 ft) | Total output (lb/ac) | Output – Input[2] (lb/ac) |
|---|---|---|---|---|---|---|---|
| I1-N1 | 254 | 0 | 254 | 176 | 114 | 290 | 36 |
| I1-N2 | 254 | 75 | 329 | 220 | 412 | 632 | 303 |
| I1-N3 | 254 | 150 | 404 | 225 | 229 | 454 | 50 |
| I1-N4 | 254 | 225 | 479 | 179 | 577 | 756 | 277 |
| I2-N1 | 254 | 0 | 254 | 195 | 159 | 354 | 100 |
| I2-N2 | 254 | 75 | 329 | 209 | 161 | 370 | 41 |
| I2-N3 | 254 | 150 | 404 | 217 | 287 | 505 | 101 |
| I2-N4 | 254 | 225 | 479 | 273 | 504 | 777 | 297 |
| I3-N1 | 254 | 0 | 254 | 176 | 130 | 306 | 52 |
| I3-N2 | 254 | 75 | 329 | 212 | 240 | 452 | 123 |
| I3-N3 | 254 | 150 | 404 | 236 | 266 | 501 | 97 |
| I3-N4 | 254 | 225 | 479 | 236 | 439 | 675 | 196 |
| I4-N1 | 254 | 0 | 254 | 207 | 144 | 351 | 97 |
| I4-N2 | 254 | 75 | 329 | 215 | 182 | 397 | 68 |
| I4-N3 | 254 | 150 | 404 | 205 | 355 | 560 | 156 |
| I4-N4 | 254 | 225 | 479 | 251 | 379 | 631 | 152 |

[1]Irrigation treatments I1 to I4 correspond to water applications of 40, 70, 100, and 130% of ETc, while N treatments N1 to N4 correspond to in-season N application rates of 0, 75, 150, and 225 lbs per acre; [2]positive values mean that there was some input not included in this budget, negative values indicate that N was lost.

100% ETc compared to 130% ETc were 45%, 24%, and 10%, respectively. High value sizes (jumbo, colossal, and super colossal) were highly affected by irrigation rates counting only 37% of the total yield in 40% ETc treatment and up to 78% of the total yield in 130% ETc irrigation treatment. Onion size distribution and total yield did not respond to nitrogen rates (Table 3). There were no significant irrigation rate x nitrogen rate interactions ($P \leq 0.05$) for bulb size distribution and total yield (Table 3).

Jumbo sizes were used for onion quality analysis. Onion bulb firmness and total soluble concentration (brix) ranged from 13.3 to 15.1 lbs and 7.2 to 8.1%, respectively. There were no statistical differences in measured firmness in response to irrigation and nitrogen rates. Highest firmness value (14.9 lbs) was measured for the two highest irrigations rates (100% and 130% ETc), but there was no difference among the other treatments. There was no significant interaction between N application and water regimes. Brix values responded to irrigation rates. Highest brix values (7.8%-8.1%) were measured in irrigations trials at 70%, 100% and 130% ETc. Brix measures did not respond to nitrogen rates.

## ACCOMPLISHMENTS

Two students from Imperial Valley College

*Table 3. Effect of irrigation and nitrogen rates on fresh market onion size distribution x and total yield.*

| Treatments | Prepack | Medium | Jumbo | Colossal | Super Colossal | Total |
|---|---|---|---|---|---|---|
| | ton/acre | | | | | |
| Irrigation rate (I) | | | | | | |
| 130% ETc | 0.8b[y] | 7.4b | 18.2a | 5.8a | 4.8a | 36.9a |
| 100% ETc | 0.9b | 9.2ab | 12.5b | 6.0a | 4.7a | 33.3b |
| 70% ETc | 1.1b | 8.9ab | 12.6b | 3.1b | 2.5a | 28.2c |
| 40% ETc | 2.0a | 10.8a | 4.8c | 2.0b | 0.8a | 20.4d |
| *P* | 0.000 | 0.002 | 0.000 | 0.001 | 0.000 | 0.000 |
| Nitrogen rate (N) | | | | | | |
| PN + 225 lb/ac | 1.5a | 9.3a | 11.1a | 4.7a | 3.1a | 29.7a |
| PN +150 lb/ac | 1.1a | 9.2a | 12.6a | 4.3a | 3.3a | 30.5a |
| PN + 75 lb/ac | 1.1a | 9.3a | 12.3a | 3.7a | 2.9a | 29.4a |
| PN + 0 lb/ac | 1.1a | 8.7a | 11.2a | 4.0a | 3.3a | 28.3a |
| *P* | 0.326 | 0.893 | 0.628 | 0.856 | 0.979 | 0.568 |
| Interaction (IxN) | | | | | | |
| *P* | 0.658 | 0.239 | 0.228 | 0.656 | 0.126 | 0.722 |

[x]Onion bulbs were categorized as prepack (less than $2^{1/2}$ in), medium ($2^{1/2}$-$3^{1/4}$ in), jumbo ($3^{1/4}$-4 in), colossal (4-$4^{1/4}$ in), and super colossal (greater than $4^{1/4}$ in) based on bulb diameter. [y]Means in a column followed by the same letter are not significantly different at $P \leq 0.05$ according to the Duncan's multiple range test. ETc = crop evapotranspiration. PN = pre-plant nitrogen.

majoring in plant sciences were trained in tasks related to irrigation and nutrient management of onion production. Results from this project were presented in Spanish to 70 participants of the Latino Farmer Conference in January 14, 2021.

## RECOMMENDATIONS

Pre-plant mineral N (PMN) in the top 1 foot can be a significant source of N. Adjust nitrogen applications based on PMN.

## TAKE-HOME MESSAGE

Proper irrigation management (amount, timing, and system) will maximize yields, large size distribution, and quality (total soluble concentration) of onion production in CA low desert region. Growers can take a conservative approach while managing nitrogen fertilization of onions planted after alfalfa or other vegetables in conventional fields.


## ACKNOWLEDGEMENTS

We thank you CDFA FREP for providing funds for this project. We are grateful to the support of DREC staff. We appreciate the comments and discussion provided by Mr. Larry Cox and Mr. John Hawk about commercial onion irrigation and nutrient management.

# Promoting the adoption of CropManage to optimize nitrogen and irrigation use through technical assistance with data loggers and cellular modems for Spanish-speaking growers in Santa Cruz and Monterey Counties


## Project Leader

**Sacha Lozano**
Program Manager
RCD Santa Cruz County
820 Bay Ave, Ste 136
Capitola, CA 95010
slozano@rcdsantacruz.org

## Cooperators

**Dr. Michael Cahn**
Farm Advisor
UCCE Monterey County
1432 Abbott Street
Salinas, CA 93901
mdcahn@ucanr.edu

**Whitney Haraguchi**
District Conservationist
NRCS Capitola Office
820 Bay Ave, Ste 136
Capitola, CA 95010
whitney.haraguchi@usda.gov


## INTRODUCTION

Irrigation and nitrogen management are challenging issues in berry and vegetable production on the California central coast. Many growers irrigate based on a fixed schedule throughout the irrigation season, generally resulting in over-application at the beginning of the crop cycle, and under-irrigations at the end of the cycle. Few growers keep track of the total irrigation water applied per crop cycle or per irrigation season. Under-irrigation results in lowered yields, while over-irrigation results in nitrate leaching, water quality impairment and aquifer overdraft, all of which expose growers to increasingly stringent water resource regulations. Similarly, growers often manage nitrogen application based on a schedule or on previous year's management. Some use pre-plant soil nitrogen testing and/or in-season soil testing, but there are uncertainties among growers on how to interpret the test results to inform fertilizer applications. CropManage is an online decision-support tool developed by the UC Cooperative Extension (https://cropmanage.ucanr.edu/) that assists growers with water and nitrogen management and record keeping (Cahn et al 2011 and 2015). The software has built-in crop water and nitrogen uptake models for various specialty crops (based on years of local research), and it uses customer-defined data inputs including evapotranspiration (ET) data from local weather stations, ranch settings, soil nitrogen tests and water use (flowmeter data), to generate recommendations based on crop demand at any given time. The adoption of CropManage has great potential for improving water and nitrogen application efficiency, particularly in vegetable and berry production, by reducing over-irrigation and thus leaching of nitrogen to the groundwater and by producing nitrogen application recommendations based on soil sampling.

## OBJECTIVES

1. Increase understanding and trust in weather-based irrigation scheduling decision support tools among Spanish-speaking growers and irrigators.
2. Increase adoption of CropManage and implementation of recommendations among Spanish-speaking growers and irrigators.
3. Assess effectiveness and impact of CropManage adoption among participating growers and irrigators.

## DESCRIPTION

The project approach is to promote and facilitate adoption of CropManage among Spanish-speaking berry and vegetable growers. While the CropManage software allows for manual data entry, the most efficient and practical way to optimize its value for irrigation water use tracking and recommendations in real-time is using flowmeters with telemetry (dataloggers and cellular communication) to automate data input. Through this project, RCD staff works with growers to install, manage, and troubleshoot equipment for data collection to be used in CropManage. Commercially available and relatively affordable flowmeters and dataloggers are installed at the fields of participating growers as part of a loaner program allowing them to try this technology and learn how to interpret and use the data it provides. Direct and sustained individual

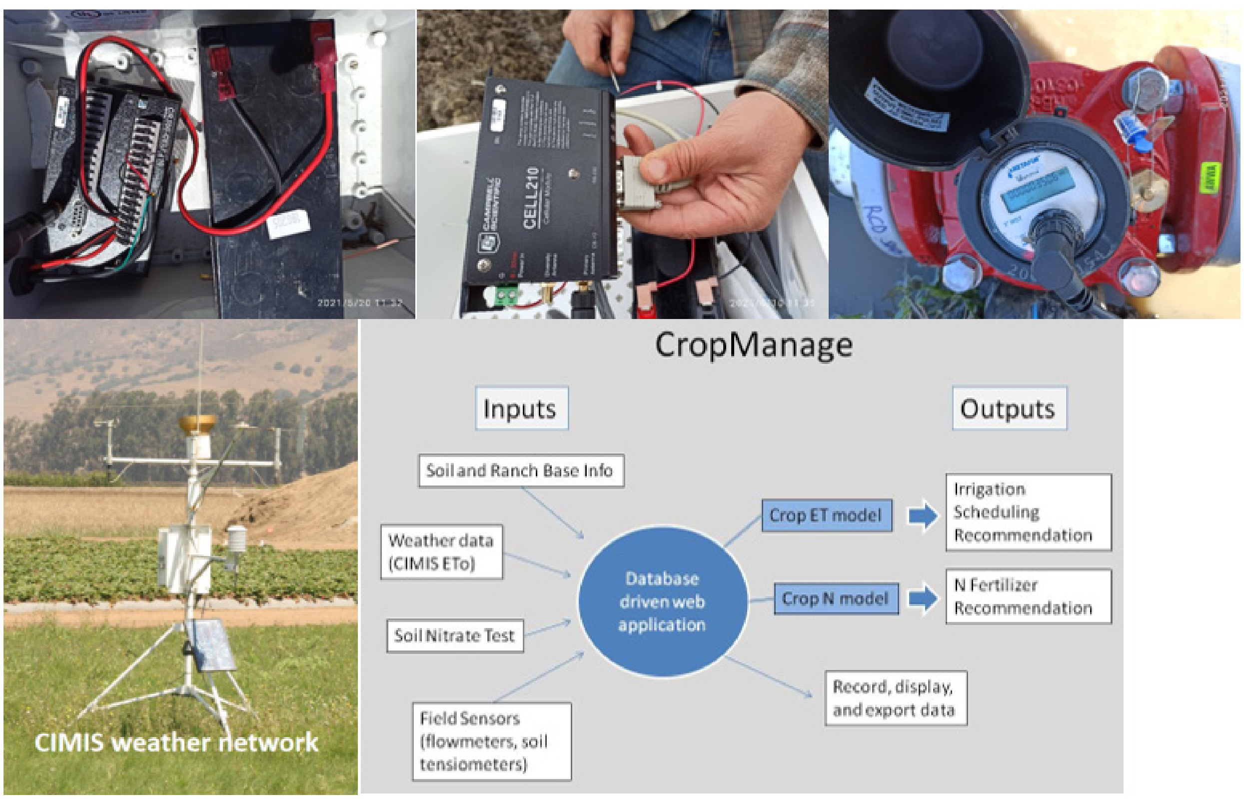



*Figure 1. Irrigation monitoring equipment, weather station and CropManage flowchart.*

assistance in Spanish facilitates adoption and fosters trust in new management ideas and tools to adapt and improve existing cultural practices. Growers and irrigators are trained on how to install irrigation monitoring equipment in the field, how to collect and interpret a soil nitrate quick test, and how to setup an account, ranches and plantings on CropManage to access real-time recommendations for water and nitrogen management through computers or mobile devices. Each participating grower (and/or irrigator) is visited once or twice a month and receives a bi-weekly report comparing their current irrigation management (water use) with weather-based recommendations from CropManage. The irrigation reports include potential savings in water and money throughout the crop cycle. Upon request, growers and irrigators are also trained on how to conduct a soil nitrate quick test and enter the results into CropManage to obtain nitrogen application recommendations.

## RESULTS AND ACCOMPLISHMENTS

Direct individual assistance to growers:

1. Ten (10) Spanish speaking growers and/or irrigators were identified and enrolled to receive technical assistance, monitoring, and individual training on weather-based irrigation scheduling and use of CropManage as a decision support tool.
2. Baseline practices and decision-making tools and processes regarding irrigation scheduling were documented for ten participating growers. Most growers relied on direct observations of plant vigor and soil moisture, and their practical experience to inform their irrigation scheduling. Only one of the ten participating growers had used CropManage before.
3. Irrigation monitoring equipment was installed on ten ranches and ten growers and/or irrigators were introduced to basic concepts and tools related to weather-based irrigation. Nine growers/irrigators were introduced to CropManage for the first time.
4. Participating growers have received monthly visits to review monitoring data and recommendations to improve their irrigation scheduling. Monthly meetings with participating growers have offered insights to evaluate their reaction to CropManage recommendations and feedback on the use of weather-based irrigation scheduling monitoring tools and concepts.
5. RCD staff provided one-on-one training and assistance to growers on conducting and interpreting a soil nitrate quick test and entering the results to CropManage.

### Education and Outreach:

1. UCANR and RCD co-hosted a “CropManage Hands-On Webinar” (“Seminario Practico Sobre CropManage”) for growers and irrigators – RCD staff provided simultaneous Spanish interpretation. The training had 78 attendees (mostly growers), 22 were Spanish speakers.
2. RCD and UCANR co-hosted an irrigator training in Spanish for 10 growers and irrigators at the Triple M ranch in Royal Oaks CA. The training provided an overview of irrigation scheduling concepts and tools.

*Figure 2. Individual assistance to growers to monitor and inform irrigation scheduling and nitrogen management.*

## TAKE-HOME MESSAGE

CropManage is a powerful and relatively easy-to-use decision-support tool that can help growers improve their irrigation and nitrogen management. However, for it to be effective, irrigators and ranch managers must invest time to familiarize with and develop trust for the new tool, and they require sustained individual assistance in a linguistically and culturally appropriate manner to ensure adequate data inputs, and to track, interpret and apply management recommendations from the software.


*Figure 3. Education and outreach events co-hosted by the project lead organization*

## LITERATURE CITED


Cahn, M., Hartz, T., Smith, R., Noel, B., Johnson, L., & Melton, F. 2015. Crop Manage: An online decision support tool for irrigation and nutrient management. In Proc Western Nutrient Manage Conf (pp. 9-14).

Cahn, M., English, M. J., & Hartz, T. 2011. Irrigation and nitrogen management web-based software for lettuce production. In Fertilizer Research and Education Program Conference (p. 19).


## ACKNOWLEDGEMENTS


This project has been possible thanks to generous support from the CDFA-FREP program and technical guidance from UCANR.

# Next Generation N Management Training for Certified Crop Advisors


## Project Leaders

**Doug Parker**
Director
California Institute for Water Resources
University of California Agriculture & Natural Resources
doug.parker@ucop.edu

**Amanda Crump**
Assistant Professor of Teaching
Department of Plant Sciences
University of California Davis
acrump@ucdavis.edu

**Sat Darshan S. Khalsa**
Assistant Professional Researcher
Department of Plant Sciences
University of California Davis
sdskhalsa@ucdavis.edu


## INTRODUCTION

The enactment of the Irrigated Lands Regulatory Program (ILRP) now mandates grower reporting of nitrogen (N) use efficiency (applied N from all sources/N removed in the harvested crop) and legislates a reduction in nitrate leaching to groundwater. This represents a challenge to farming communities as implementation of these rules will require an increase in the efficiency of applied N. Current regulations require growers to develop an annual N management plan in consultation with a certified crop advisor (CCA) at the beginning of the growing season, followed by reporting actual N use the following year. As the mandate of the ILRP widens, our reliance on an educated and informed CCA workforce becomes more important. Our current CCA N management program resulted in 11 workshops and multiple UC ANR publications. However, these efforts have yet to translate into a long-term sustainable solution for training the next generation of CCAs to be proficient in N management. The overall goal of this program is to facilitate the understanding of best N management practices and increase the ability of CCAs to make informed recommendations to growers, thereby improving both environmental quality and crop productivity.

## OBJECTIVES

1. Deliver one in-person CCA workshop
2. Organize key information sources into a study curriculum
3. Curate study materials into online video course
4. Develop exam questions in collaboration with our partners
5. Analyze exam responses and update study and exam materials accordingly

## DESCRIPTION

Our project will consist of distinct phases – 1) CCA workshop; 2) curriculum building; 3) exam questions and video development; and 4) test deployment and feedback. In March

2020, we conducted one CCA N training workshop following the 2-day agenda developed by our project team. In early 2020, we began to build the study curriculum including 1) consolidation of training modules and study materials already developed by our team; 2) drafting of exam question categories and outlining levels of difficulty and; 3) organization of workshop slides to be developed into video content. In mid-to-late 2020, we finalized exam questions for review by our project partners into a standardized specialty exam to be hosted by American Society of Agronomy (ASA) and launched an online course.

## RESULTS AND DISCUSSION

Our CCA workshop was hosted in Fresno, CA during March 3rd and 4th 2020. The number of participants to gain the California N specialty was 65 CCAs. Transition to an internet-based training exam began in April 2020 with the following performance objectives (POs) outlined as educational goals for the new CCA exam:

### Competency Area 1. Environmental Impacts of Nitrogen Loss

**a** Identify the impact of nonpoint source N pollution on human health

**b** Recognize sources of surface runoff and describe the effect on water quality

**c** Describe how N leaching influences groundwater and drinking water quality

**d** Understand the role of certified crop advisors in promoting efficient N use

### Competency Area 2. Nitrogen Cycling - Soil Transformations

**a** Describe mineralization including N sources and products types of microbes, and how moisture, temperature, and C:N ratios affect rates

**b** Describe immobilization including N sources, energy requirements, types of products and impact of C:N ratios

**c** Explain nitrification including the necessary reactants, products and how rates are impacted by temperature

**d** Explain denitrification including reactants, intermediary steps and products, and how soil moisture and soil texture affect rates

**e** Define volatilization and the role of soil pH plays along with what practices create significant losses

### Competency Area 3. Nitrogen Uptake - Plant Utilization

**a** Compare the differences in root N uptake of ammonium and nitrate profile and the consequences of choice of N source on soil pH

**b** Understand the process of assimilation of inorganic N into organic N compounds in plants

**c** Identify important times in the growing season for N uptake and understand the patterns of N allocation and utilization for annual and permanent crops

### Competency Area 4. Nitrogen Sources

**a** Outline the contribution of various N sources to soil by different forms of fertilizers (organic/synthetic/foliar/controlled release/inhibitors)

**b** Identify organic matter amendments and crop residues and how their availability is impacted by C:N ratios

**c** Identify and calculate the availability of nitrate in irrigation water

**d** Describe the residual soil nitrate as a N source during crop rotations

**e** Recognize the contribution of soil organic matter as a source of N via mineralization

### Competency Area 5. Nitrogen Budgeting

**a** Define different terminologies of N requirement, N uptake and N removal

**b** Understand how to account for N credits from irrigation water, residual nitrate and organic matter amendments

**c** Calculate the N sink and source terms to develop a balanced N budget

**d** Express the N removed over input ratio to determine crop N use efficiency using the partial nutrient balance method

### Competency Area 6. Irrigation and Nitrogen Management

**a** Understand how irrigation practices can lead to N leaching below the root zone due to nitrate mobility in soils

**b** Identify efficient fertigation methods by surface and pressurized irrigation systems like split applications

**c** Identify the role of evapotranspiration in irrigation scheduling and how timing irrigation scheduling relative to fertigation can influence nitrate leaching

**d** Understand how the practice of leaching excess salt under saline or sodic conditions may increase the risk of N leaching below the root zone

**e** Determine how distribution uniformity by irrigation systems influences N use efficiency

### Competency Area 7. California Cropping systems

**a** Describe how to minimize N losses during annual crop rotations and what factors to consider like residual soil nitrate, crop residues and rooting depth

**b** Discuss storage and remobilization of stored N in woody biomass of permanent crops and what role N storage plays in early season N demand

Starting in November 2020, and again July 2021 the UC Nitrogen Management Online Course was available to the public at http://ucanr.edu/NitrogenCourse and offers associated Nutrient Management (NM) and Soil and Water Management (SW) CCA CEU units for individual Modules and Discussion sections:

- Module 1: Environmental Impacts of Nitrogen Loss - CEUs: 0.5 SW unit
- Module 2: Nitrogen Cycling Soil Transformations - CEUs: 1.0 SW unit
- Module 3: Nitrogen Cycling Plant Utilization - CEUs: 1.0 NM unit
- Module 4: Nitrogen Sources - CEUs: 1.0 NM unit
- Module 5: Nitrogen Budgeting - CEUs: 1.0 NM unit
- Module 6: Irrigation and Nitrogen Management - CEUs: SW 1.5 unit
- Module 7: California Cropping Systems - CEUs: 2.0 NM unit
- Discussion 1: Nutrient Management I - CEUs: 1.0 NM unit
- Discussion 2: Soil & Water Management I - CEUs: 1.0 SW unit
- Discussion 3: Nutrient Management II - CEUs: 1.0 NM unit
- Discussion 4 Soil & Water Management II - CEUs: 1.0 SW unit

## TAKE-HOME MESSAGE

Preliminary work shows demand for the California CCA N Management Specialty will continue in the years to come with internet-based methods for teaching and testing playing a vital role. The performance objectives were reviewed by twenty professionals and vetted for importance, relevance and frequency of use. We launched our online course in on November 2020, and offered it again in July 2021. Future registration can be found at http://ucanr.edu/NitrogenCourse. Two exam sessions were made available to the public in February and August 2021. To find more information on the California N Management Specialty exam visit http://www.certifiedcropadviser.org/exams/

## ACCOMPLISHMENTS

We wish to thank CDFA FREP for funding this project, and Dawn Gibas from ASA and Grace Perry from UC Davis for their support. We also acknowledge Mallika Nocco, Patrick Brown, Daniel Geisseler, Mae Culumber, Khaled Bali, Sarah Light, Phoebe Gordon, Ben Faber, Nicholas Clark and Michelle Leinfelder-Miles from UC Davis and UCANR as well as Jerome Pier, Carl Bruice and Mark Cady for their contributions to the exam and course.

# Developing a Nitrogen Mineralization Model for Organically Managed Vegetable Farms on the Central Coast


## Project Leaders

**Joji Muramoto**
Assist. Cooperative Extension
Organic Production Specialist
Center for Agroecology and
Sustainable Food Systems
Dept. of Environmental Studies
University of California, Santa Cruz
jmuramoto@ucanr.edu

**Richard Smith**
Vegetable and Weed Science Advisor
University of California, Cooperative
Extension
Monterey County
rifsmith@ucanr.edu

**Michael Cahn**
Irrigation and Water Resources Advisor
University of California, Cooperative
Extension
Monterey County
mdcahn@ucanr.edu

**Daniel Geisseler**
Assoc. Cooperative Extension
Nutrient Management Specialist
Dept of Land, Air, and Water Resources
University of California, Davis
djgeisseler@ucdavis.edu


## INTRODUCTION

Organic production on the Central Coast (Monterey, Santa Cruz, and San Benito Counties) was valued at $766 million in 2019. Organic production continues to expand given the optimal climatic conditions and increasing consumer demand. Science-based information for managing nitrogen (N) is rarely applied to organic fertilizer programs; current fertility practices vary widely among growers, which have both economic and environmental ramifications. Further, growers are now required to estimate mineralization rates to complete the mandatory N management plans submitted to the Regional Water Quality Control Board, but there is insufficient information on N mineralization of organic fertilizers and amendments under local conditions for this to be done in an informed way.

CropManage (CM) is an online irrigation and N management decision support tool that was originally developed under FREP funding in 2011 and now has more than 1700 registered users. In recent years, the online advisory service has provided more than 1000 recommendations per month during the production season to vegetable and berry growers mainly farming in the coastal valleys of California. Though originally developed for lettuce, continued research efforts and funding have expanded CM to include other leafy greens (spinach, mizuna, leaf lettuce), cole crops (broccoli, cabbage, and cauliflower), celery, pepper, raspberry, and strawberry. However, currently, CM cannot simulate N mineralization from organic fertilizers and amendments.

This three-year project aims to integrate a simple N mineralization model with CM so that it can provide fertilizer recommendations for organic vegetable production. Here we describe the outline of the entire project and report the progress made by August 2021.

## OBJECTIVES

1. Create an N mineralization database for organic fertilizers and amendments, crop residues, and soil organic matter (SOM).
2. Develop a simple N mineralization model using the existing data.
3. Evaluate and improve the simple model by field trials and incubation studies.
4. Integrate the model into CropManage (CM).
5. Conduct outreach and a demonstration field demonstration.

## DESCRIPTION

1. Creating N mineralization database. We compiled existing data on N mineralization of organic fertilizers and amendments, crop residues, and soil organic matter from literature and past studies. N-mineralization data of replicated incubation trials conducted under a controlled environment were gathered. Incubation trials are in progress to fill any gaps in database that need to be addressed experimentally. Crop residues of artichoke, Brussels sprout, and strawberries and some liquid and solid organic fertilizers will be examined.
2. Developing a simple N mineralization model. We selected a simple model to calculate net N mineralization rates for soil organic matter and organic amendments (see Results and Discussion). The model can easily be incorporated into CM. In a next step, the model will be calibrated to simulate N mineralization from crop residues and additional organic amendments. The response of N mineralization to temperature and soil moisture will also be expressed with mathematical functions. These equations will then be used to calculate net N mineralization rates in daily time steps for each pool (soil, organic amendments, and residues) separately. The model will assume that net N mineralization rates from these pools are additive and that there are no priming effects, e.g., the addition of residues or organic amendments will not change the N mineralization rates of SOM.
3. Evaluate and validate the model in field trials. To evaluate the model, N mineralization rates of selected dry organic fertilizers and amendments and crop residues will be determined under field conditions on organic farms in Coastal California.
4. Integrate the model into CropManage (CM). The model developed under Objective 2 and evaluated under Objective 3 shall be incorporated into CM.
5. Conduct outreach and a demonstration field demonstration. We reported results at the Annual Salinas Valley Irrigation and Nutrient Management Meeting (2/23/2021. Virtual) and the Practical Training on Nitrogen Management in Organic Production of Vegetables and Strawberries (3/2/2021. Virtual).

## RESULTS AND DISCUSSION

A simple N turnover model adapted from CERES Maize (Jones and Kiniry, 1986; Godwin and Jones, 1991) was used to simulate N mineralization and immobilization from soil organic matter and added organic fertilizers. A total of 113 datasets from the scientific literature were included in the study. The model predicted that 61% of total N in feather meal with an average carbon:N ratio (C:N ratio) of 4 would be in the mineral form after 100 days under optimal conditions (Figure 1). Guano is a similarly readily available N source with 72.5% of the total N being in the mineral form after 100 days. Nitrogen availability from poultry manure and poultry manure compost was lower. On average, 16-17% of total N was present as mineral N in the materials, while at the end of the 100-day simulation, 39.6% and 32.7% of total N from an average poultry manure and its compost, respectively, were in the mineral form. Poultry manure is a heterogeneous fertilizer and literature values vary considerably (Figure 1). Yard waste compost and vermicompost are stable materials, with less than 10% of the total N in an average material being in the mineral form at the end of the 100-day simulation. The results of this study allow estimating the release of N from a variety of organic fertilizers and composts. The results were summarized in a scientific article, which is under review. The equations of the model can be easily incorporated into CropManage and other decision support tools.

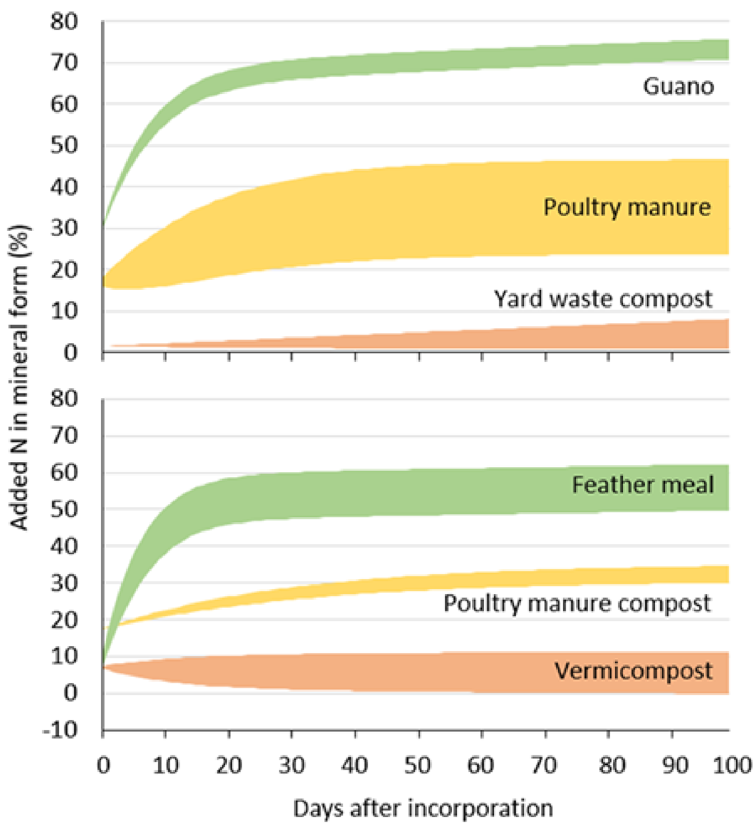



*Figure 1: Availability of N from organic fertilizers and composts. The graph shows modeled values based on literature data of amendments incorporated into soil with a temperature of 25 °C and optimal soil moisture. The range reflects N availability of the materials with the highest and lowest C:N ratio in the dataset.*

## LITERATURE CITED

Godwin, D. C., and Jones, C. A. 1991. Nitrogen dynamics in soil-plant systems. In: Hanks, J., and Ritchie, J. T., editors, Modeling Plant and Soil Systems. Agronomy monograph 31. ASA, CSSA, and SSSA, Madison, WI. p. 287-321.

Jones, C. A., and Kiniry, J. R. 1986. CERES-Maize: A simulation model of maize growth and development. Texas A&M University Press, College Station, Texas.

## ACKNOWLEDGEMENTS

We thank Margherita Zavatta and Sidney Lee of University of California, Santa Cruz for assisting data entry and incubation trials for this project. We appreciate the California Department of Food and Agriculture, Fertilizer Research and Education Program (FREP) for funding this project.

# Achieving Efficient Nitrogen Fertilizer Management in California Wheat


## Project Leaders

**Mark Lundy, Ph.D.**
Assistant CE Specialist
University of California, Davis
Department of Plant Sciences
melundy@ucdavis.edu

**Taylor Nelsen, M.S.**
Assistant Specialist
University of California, Davis
Department of Plant Sciences
tsnelsen@ucdavis.edu

**Nicholas Clark, M.S.**
Assistant CE Advisor
UCCE Kings County
neclark@ucanr.edu

**Giuliano Galdi, M.S.**
Assistant CE Advisor
UCCE Siskiyou County
gcgaldi@ucanr.edu

**Thomas Getts, M.S.**
Assistant CE Advisor
UCCE Lassen County
tjgetts@ucanr.edu

**Michelle Leinfelder-Miles, Ph.D.**
CE Advisor
UCCE San Joaquin County
mmleinfeldermiles@ucanr.edu

**Sarah Light, M.S.**
Assistant CE Advisor
UCCE Sutter-Yuba Counties
selight@ucanr.edu

**Konrad Mathesius, M.S.**
Assistant CE Advisor
UCCE Yolo County
kpmathesius@ucanr.edu

## Cooperators

**Kimberly Gallagher**
Cooperating Grower
Erdman Farms
gallagher.kimberly@gmail.com
Cooperating Grower
D.T. Farming

**Fritz Durst**
Cooperating Grower
Fritz Durst Farms
fritz.durst@gmail.com

**Erik Hansen**
Cooperating Grower
Hansen Ranch

**Darrin Culp**
Principal Superintendent of Agriculture
ANR Intermountain Research and Extension Center
daculp@ucanr.edu
Dennis Lewallen
Cooperating Grower
Crescent Farming Company

**Colin Muller**
Cooperating Grower
Yolo County


## INTRODUCTION

Wheat and other small grains are grown in diverse agricultural environments throughout California. Approximately 90% of the wheat, triticale and barley in California are fall-sown and rely on precipitation that varies dramatically across the state. These conditions result in a wide range of fertilizer use efficiency, which makes it difficult to make robust N fertilizer rate recommendations across seasons and among farms. With increasing regulatory, market and social demands for sustainable N management, Growers and crop consultants need improved N fertilizer management strategies and innovative tools that enable adaptive management and responsive farming. Therefore, the goal of this project is to demonstrate and enable new ways of achieving best N management practices in California wheat.

## OBJECTIVES

1. Demonstrate how to use N-rich reference zones and site-specific measurements of the soil and plant N status on a field-scale to guide real-time N management decisions in wheat and triticale. Demonstration sites are located on diverse California farms and implemented across three growing seasons.
2. Measure crop yield and N uptake resulting from N fertilization management decisions in response to site-specific, real-time information. Compare results in alternative management scenarios within and across demonstration sites.
3. Produce case-studies for each demonstration site that document agronomic conditions, in-season measurements, management responses, final grain yield and N uptake as well as provide an agronomic interpretation of the results.
4. Develop guidelines for implementing N-rich reference zones, taking site-specific measurements, interpreting results, and making responsive farming decisions.
5. Develop, beta-test, and extend dynamic, web-based decision support tools that provide customized information and management recommendations based on site- and time-specific farm management variables, environmental conditions and California-specific models of wheat growth and development.

## DESCRIPTION

Eleven field-scale demonstrations were completed during 2020 and 2021, the first two years of a three-year project. To date there have been 6 fields in the Sacramento Valley, 2 in the San Joaquin Valley, 2 in the Delta region, and 1 in the Tulelake basin. Fields have included highly productive, irrigated locations with yields as high as 9000 lb/ac. They have also included low productivity, rainfed locations with yields as low as 1500 lb/ac. Each site had one to four 90-ft by 180-ft N-rich reference zones that were established in representative areas of the field at or near the time of planting. N fertilizer rates in these zones were 2-3 times the amount of expected crop N uptake from planting until the start of in-season plant and soil monitoring.

From the tillering stage of growth to the heading stage of growth, project leaders recorded measurements of canopy reflectance (i.e. NDVI/NDRE) both within N-rich reference zone(s) and in the broader field and also measured soil nitrate-N in the top foot of soil using quick tests. Measurements were made prior to participating growers' in-season fertilizer management decisions. When crop N deficiency was detected by real-time plant and soil measurements, N fertilizer recommendations were produced using a combination of the site-specific measurements and the expected crop N demand remaining for the field. When no deficiency was detected, monitoring continued until either deficiency was detected or the grower decided whether or not to apply N fertilizer in-season. Where possible, the alternative to the cooperating grower's management action (either applying N fertilizer when the grower applied none or excluding fertilizer when the grower decided to apply) was enacted to measure the effect of the management decision and the accuracy of the modeled, in-season fertilizer recommendation. Alternative N management scenarios were successfully implemented at 7 of the 11 locations to date. When the crops reached maturity, yields and grain N uptake were measured within the main field, the N-rich reference zones, and the alternative management zones (where applicable).

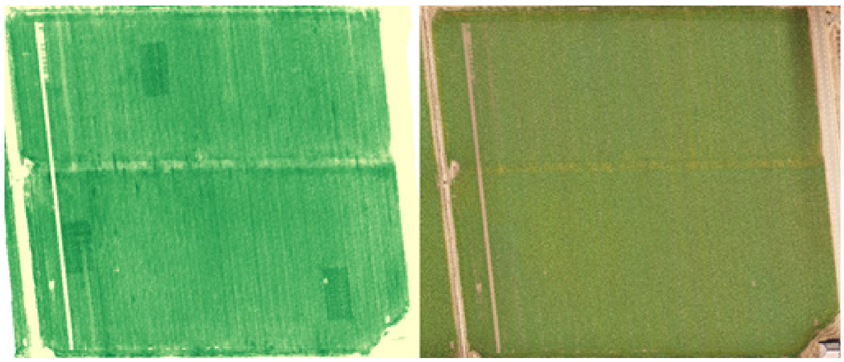


*Figure 1. Demonstration site in Solano County on 2/20/20 showing crop N deficiency signal. The three N-rich reference zones appear in the NDRE measurement (on the left) but are not visible to the naked eye (RGB image on the right).*

## RESULTS AND DISCUSSION

In-season monitoring of the plant and soil resulted in a range of measurements, in-season N applications, and grain yields (Table 1). Monitoring detected crop N deficiency in 7 of the 11 demonstration fields. When deficiency was detected, the decision support tools produced a targeted in-season N fertilizer recommendation. These recommendations resulted in an average yield increase of 28% (1422 lb/ac). In addition, average fertilizer recovery efficiency for the recommended application was 50%, which is the higher end of the typical range for wheat and other grain crops (30-50%). In fields where real-time plant and soil monitoring informed or confirmed a grower's decision not to apply N fertilizer, N budgets were reduced by 41% of the potential budget. This translated to an average savings of 48 lb/ac N and approximately $36/ac in fertilizer costs. Overall, the applied/removed ratio for growers participating in demonstration activities was 72%. This indicates that, on average, crops in the demonstration activities removed more N than was applied as fertilizer. The varied in-season measurements, in-season N fertilizer applications, and grain yield from the sites indicate that plant and soil monitoring can inform in-season N fertilizer applications across a wide range of California small grain agroecosystems.

## ACCOMPLISHMENTS

In addition to the agronomic measurements recorded at the demonstration sites, several outreach products were produced during the past two seasons.

# Development of Nutrient Budget and Nutrient Demand Model for Nitrogen Management in Cherry

## Project Leaders

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

**Douglas Amaral**
Cooperative Extension Advisor
University of California
Agriculture and Natural Resources
amaral@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. Currently, nutrient management decisions in cherries are based on leaf analysis and critical value interpretation which only indicates a deficiency or sufficiency and is performed too late to respond to deficiencies or plan N applications. In other high value crops such as Almond, Pistachio and Walnut, nutrient management is increasingly based on yield and vegetative growth estimated crop demand coupled with an understanding of seasonal nutrient demand dynamics. This approach has not been developed for cherry cultivars in California and hence cherry growers do not have improved fertilizer management decision tools to apply the right rate of fertilizer at right time, to optimize productivity and avoid environmental losses. Current approaches to nutrient management in cherries rely heavily on leaf sampling collected during late summer which is too late to respond to deficiencies or adjust fertilizer regimes. The concept of demand driven nitrogen management is not widely practiced but is essential to meet ILRP guidelines and achieve a high efficiency of N use. Critical data on N export rates, seasonality of N demand and differences between cultivars and practices in N dynamics, is not currently available from California cherry production.

## OBJECTIVES

Our goal is to develop knowledge of the pattern of nutrient uptake and allocation of nutrients in cherry and to provide insight into nutrient allocation patterns, the storage of nutrients in perennial tissue and the role of nutrient remobilization in supplying early season nutrient demand and direct application for the management of nutrients in commercial orchards.

## DESCRIPTION

The study is being conducted in three high yielding commercial cherry cultivars “Bing”, “Coral”, and “Rainier” orchards in the California Central Valley. All varieties were grafted on Mazzard rootstock with an approximate planting density of 202 trees per acre.

We are currently monitoring three replicated blocks of trees (3 trees per block, totaling 9 trees per orchard) for each cherry cultivar (“Bing”, “Coral”, and “Rainier”) for changes in nutrient concentrations 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.

A new nutrient BMP will be developed by integrating the findings from whole tree nutrient curves and early season tissue analysis. The combination of nutrient budget, seasonal changes in tree N content and in-season prediction of tissue nutrient status will help is developing a robust new fertilizer management tools for cherry growers of California.

## RESULTS AND DISCUSSION

### Tree biomass and nutrient content

Total nutrient amounts per tree was obtained by summing the nutrient content of tree organs calculated by multiplying the dry weight of each tree organ by its nutrient concentration. Data refer to the average of six trees excavated in 2020-2021 for each cultivar. Canopy branches and large roots accounted for the majority of the biomass (~40-60%) in all orchards. Canopy branches and large roots also included a notable fraction of nutrients present in below- and aboveground tissues as shown in Figure 1.

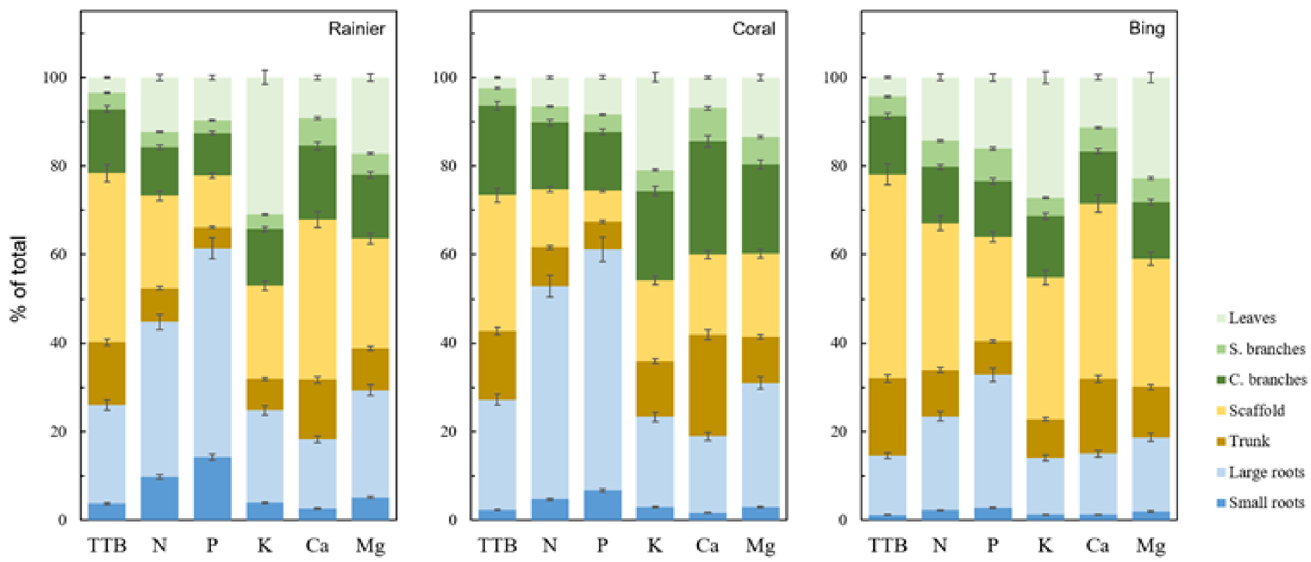



*Figure 1. Tree partitioning (% of total) of total tree biomass (TTB) and macronutrients (N, P, K, Ca, and Mg) content. Data refer to cherry cultivars “Rainier”, “Coral”, and “Bing”. Bars represent standard errors.*

### Dynamics of Nitrogen uptake during the season

Seasonal N content in perennial organs (trunk, scaffold, canopy branches and roots), and leaves of cherry trees are shown in Figure 2. Data refer to the average of 9 trees per orchard for each species.

The seasonal demand of N in cherry is high early in the season from March through September. 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 nutrients should be available in the soil for root to uptake by cherry trees from March to October. In contrast, from November to February, no net increase in nutrient was observed during this period.

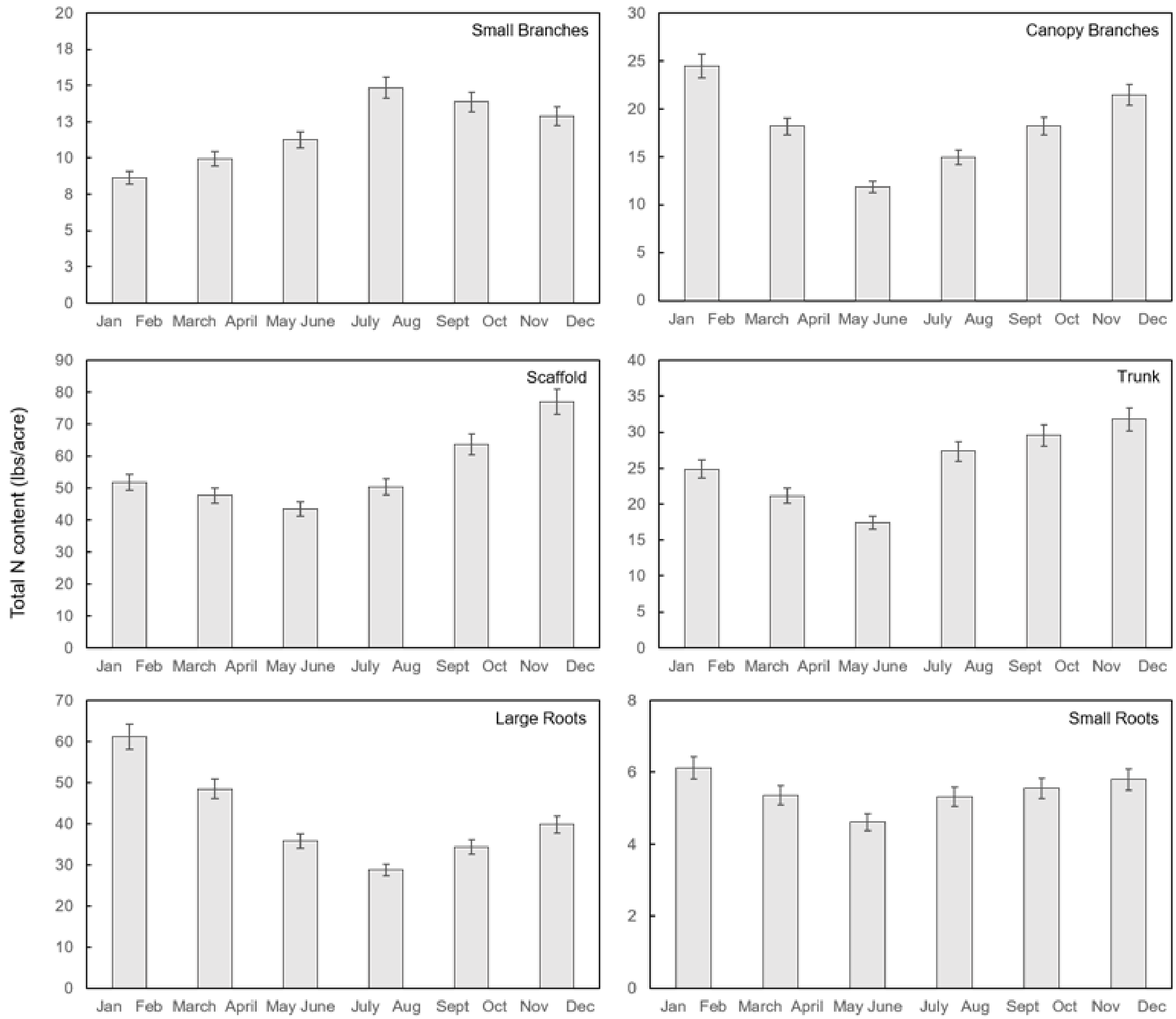



*Figure 2. Seasonal trends in Nitrogen partitioning in perennial organs (trunk, scaffold, canopy branches and roots) of mature cherry trees. The overall average is weighted for the number of observations in all trials (n = 27). Bars represent standard errors.*

## Nitrogen removal during the season

On average, preliminary data suggests that cherry offtake of N was estimated to be 13.4 lb. per 1000 lbs. of fruit. In addition, N requirement for tree development (biomass accumulation) was estimated to be 28.3 lbs. per acre (Table 1). Nitrogen use efficiency can be optimized by adjusting fertilization rate based on realistic, orchard specific yield, accounting for all N inputs and adjusting fertilization in response to spring nutrient status and yield estimates.

*Table 1. Nitrogen removal in cherry cultivars. The overall average is weighted for the number of observations in each trial (n = 9).*

| ***Variety*** | ***Removal at harvest (lbs N/1000 lbs of fruits DW)*** |
|---|---|
| Rainier | 13.99 |
| Coral | 13.96 |
| Bing | 12.13 |
| **Weighted Average** | **13.36** |
| | |
| | ***Tree development (lbs N/acre*)*** |
| Rainier | 28.99 |
| Coral | 28.41 |
| Bing | 27.51 |
| **Weighted Average** | **28.30** |

*Planting density of 202 trees per acre.

It is important to note that the data shown in this report is a preliminary data from year 1 of a 3-year project, then no conclusive data are shown. Our goal is to develop knowledge of the pattern of nutrient uptake and allocation during three seasons (2020-2022) in cherry trees to develop a nutrient prediction model for cherry cultivars “Rainier”, “Coral”, and “Bing” to guide fertilizer application based on crop phenology for the State of California.

## TAKE-HOME MESSAGE

As a best management practice, fertilizer application in a cherry orchard should be based on expected yield estimated at flowering and fruit set followed by analysis of leaves to diagnose any deficiency. The combination of nutrient budget determination, nutrient response information, improved sampling and monitoring strategies, and yield determination provide a theoretically sound and flexible approach to ensure high productivity and good environmental stewardship.

## LITERATURE CITED

Benbi and Biswas. 1999. Nutrient budgeting for phosphorus and potassium in a long-term fertilizer trial. Nutr. Cycling Agroecosyst. 54 (2), 125–132.

Muhammad et al. 2015. Seasonal changes in nutrient content and concentrations in a mature deciduous tree species: Studies in almond (Prunus dulcis (Mill.) D. A. Webb). Europ. J. Agronomy 65 (2015) 52–68.

## ACKNOWLEDGEMENTS

We would like to thank the California Cherry Board (CCB), the California Department of Food and Agriculture(CDFA) and the Fertilizer Research and Education Program (FREP) for funding this research. We also would like to thank growers and the cherry industry for assisting with the project.

# Immobilization of Nitrate in Winter-Fallow Vegetable Production Beds to Reduce Nitrate Leaching


## 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

**Joji Muramoto**
UCCE Organic Specialist, Dept of Environmental Studies, UC Santa Cruz, 1156 High Street, Santa Cruz, CA 95064, 831 247-3804, joji@ucsc.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

In the fall, at the end of the cool-season vegetable production season on the Central Coast of California, crop residues are incorporated into the soil as the soil is tilled and listed into fallow beds for the winter. Cool season vegetable crop residues contain significant quantities of nitrogen (N) which allows rapid decomposition of the tissue. For instance, cole crop residues contain more than 2.5% N, and 60 to 80% of the tissue decomposes in 4-8 weeks following incorporation into moist soil (Hartz, 2020). The resulting pool of residual soil nitrate-N is vulnerable to leaching by rains during the winter fallow (Smith et al, 2016). Winter-grown cover crops can take up and a large portion of this nitrate and maintain it in their biomass and thereby reduce nitrate leaching over the winter. However, cover crops are little used on the coastal due to economic constraints such as high land rents and the risk they pose to winter/early spring planting schedules. As an alternative to the use of cover crops, we are examining the use of high carbon: nitrogen (C:N) ratio composts (e.g. > 40) to immobilize residual soil nitrate. The use of fall applications of compost is a common practice in this region and the goal of this project is to test whether substituting a high C:N soil amendments could successfully immobilize a portion of soil nitrate in winter beds and thereby reduce nitrate leaching during this critical time of the year. In recent studies, we observed that 5 – 10 tons/A of almond shells ground to pass through a 2 mm screen and glycerol at 2.5 tons/A reduced the load of nitrate in the top three feet of soil by 34 to 51% over the untreated control (Smith et al 2019). Although effective, ground almond shells and glycerol are currently cost prohibitive. This project is evaluating lower cost, locally-sourced high C:N ratio green waste compost to sequester residual soil nitrate. If successful, the use of this material would be a practical and economical practice that growers could readily adopt as a best management practice (BMP) to reduce nitrate leaching during the winter fallow period and improve water quality.

## OBJECTIVES

1. Identify and select locally-sourced high C:N ratio green waste materials and conduct laboratory incubations of them at different particle sizes to determine the levels of N immobilization that they provide of cole crop residues.
2. Conduct large scale field trials with cooperating growers in commercial vegetable production fields evaluating the impact of materials identified in objective 1 on nitrate leaching during the winter fallow
3. Evaluate the magnitude and longevity of the impact of the high C:N materials on subsequent crop production, and determine if there is a negative effect of these materials on the yield and N fertilizer requirement of the subsequent vegetable crops
4. Develop algorithms for CropManage that can provide estimates of immobilization based on C:N ratio of the amendment and the quantity added to the soil
5. Conduct economic analysis of the cost of the use of high C:N amendments
6. Conduct grower outreach through blogs, trade journal articles and grower meetings.

## DESCRIPTION

1. Identify and select locally sourced high C:N ratio green waste materials. We worked with a local composting company to identify an affordable high C material that could be used to immobilize residual soil nitrate. A material called "forest mulch" compost which is made from trunks and branches of trees was identified. It is triple screened and contains a good percentage of small fines that can rapidly stimulate soil bacteria to immobilize nitrate-N in a timely fashion. It has a C:N ratio of 186 and costs $25/ton which is equivalent to yard waste compost that is commonly used in vegetable production fields. Further laboratory incubation evaluations of high C composts will be conducted to better understand the efficacy and longevity of the immobilization process.
2. Conduct large scale field trials with cooperating growers in commercial vegetable production fields. A large-scale field trial was conducted in a commercial head lettuce field in which 5, 10, 15 and 20 tons/A of forest mulch compost was applied to 40 inch beds and mulched into the top 3 inches of soil with a spike toothed bed shaper. Soil nitrate samples down to three feet deep were collected each month during the winter fallow period and during the subsequent lettuce crop.
3. Evaluate the magnitude and longevity of the impact of the high C:N materials on subsequent crop production. After seeding the starter fertilizer 6-15-0 was applied to the bed tops at three rates: 7.8, 15.5 and 31.2 lbs N/acre. Soil nitrate and yield evaluations were conducted to determine detrimental effects of the compost on the lettuce crop.
4. Develop algorithms for CropManage that can provide estimates of immobilization based on C:N ratio. Algorithms developed and refined in Objective 1 will be incorporated into CropManage.
5. Conduct economic analysis of the cost of the use of high C:N amendments. Cash costs for the use of high C compost in Objective 2 will be calculated.

6 Conduct grower outreach through blogs, trade journal articles and grower meetings. Results of this project were presented at the 2021 Salinas Valley Irrigation and Nutrient Management Meeting, and an article was included in the UCCE Salinas Valley Agriculture Blog.

## RESULTS AND DISCUSSION

We identified an affordable high carbon compost called "forest mulch" which is made from locally sourced tree trunks and branches. It is triple screened and is composed of a mix of fines and coarser material. The cost is comparable to yard waste compost that is commonly used in the Salinas Valley. We conducted a large-scale field evaluation in the winter of 2020-21 in which we evaluated 0, 5, 10, 15 and 20 tons/A of forest mulch on immobilizing residual soil nitrates left in the soil following a crop of broccoli. There was little effect of the forest mulch compost on levels of soil nitrate over the course of the evaluation (Figure 1). We speculate that there are insufficient fines and labile carbon to effectively stimulate microbial activity to immobilize soil nitrate. It appears that, if forest mulch is to be a viable source of carbon to immobilize soil nitrate, it will need to be further screened to increase the amount of fine materials that it contains to be able to effectively stimulate bacteria to immobilize soil nitrate. This would undoubtedly increase the price of this material which may change the economic assumptions that we were hoping would spur its use in the vegetable production fields. To examine the effect of particle sizes and labile carbon content of this and other high-carbon amendments on N immobilization, an incubation trial will be initiated this fall. Forest mulch was further evaluated to better understand its impact on the yield of the subsequent lettuce crop. There is a trend that indicates lower lettuce yield at higher application rates of forest mulch compost. However, this trend can be reversed by applying a greater amount of starter fertilizer to overcome the effect of immobilization (Table 1).

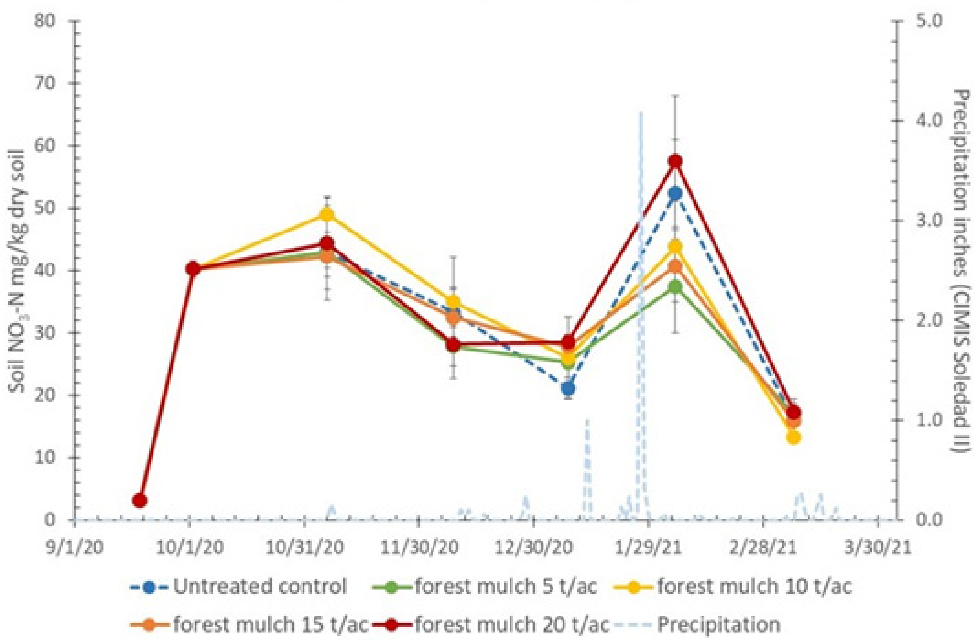



*Figure 1. Nitrate nitrogen in the first foot of soil of high carbon amended treatments*

*Table 1. Soil mineral nitrogen and lettuce crop evaluations in compost treatments (including all fertilizer treatments and fertilizer treatments (including all compost treatments)*

| Compost Tons/A | Starter fertilizer Lbs N/A | Starter fertilizer Gallons/A | February 26 | | May 10 | | |
|---|---|---|---|---|---|---|---|
| | | | NH4-N | NO3-N | Percent N in heads | lbs N/A in lettuce | Mean head weight lbs |
| 0 | --- | --- | 0.7 | 13.4 | 3.1 | 127.8 | 2.6 |
| 5 | --- | --- | 1.3 | 13.3 | 3.0 | 122.6 | 2.6 |
| 10 | --- | --- | 1.2 | 11.9 | 2.9 | 114.9 | 2.6 |
| 15 | --- | --- | 0.9 | 13.8 | 2.9 | 112.5 | 2.4 |
| --- | 0.0 | 0 | 0.6 | 8.8 | 3.0 | 121.1 | 2.5 |
| --- | 7.8 | 15 | 1.4 | 12.1 | 2.9 | 125.2 | 2.5 |
| --- | 15.5 | 30 | 0.8 | 15.3 | 2.9 | 123.6 | 2.5 |
| --- | 31.2 | 60 | 1.3 | 16.2 | 2.9 | 122.9 | 2.6 |

1 – Compost 36.7% moisture (net solids applied: 5 tons/A = 3.2, 10 = 6.3; 15 = 9.5); compost C:N ratio = 186:1

2 – Fertilizer applied post planting 6-16-0 (7.8 lbs N/A = 15 gallons/A; 15.5 = 30 gallons/A; 31.2 = 60 gallons/A)

## LITERATURE CITED

Hartz, TK. 2020. Efficient nutrient management in California Vegetable Production. University of California Agriculture and Natural Resources. Publication 3555.

Smith, R.F., M.D. Cahn, T.K. Hartz, P. Love and B. Farrara. 2016. Nitrogen dynamics of cole crop production: implications for fertility management and environmental protection. HortScience 51(12): 1586-1591.

Smith, R.F., J. Muramoto, L.J. Tourte, A. Haffa, F. Melton and P. Love. 2019. Immobilization of nitrate in fallow winter vegetable production beds. UCCE Blog, Jan. 3.

(https://ucanr.edu/blogs/blogcore/postdetail.cfm?postnum=29071).

# Irrigation and Nitrogen Management, Monitoring, and Assessment to Improve Nut Production While Minimizing Nitrate Leaching to Groundwater


## Project Leaders

**Thomas Harter**
Dept. Land, Air and Water Resources, UC Davis
Email: thharter@ucdavis.edu

**Isaya Kisekka**
Dept. Land, Air and Water Resources/ Biological and Agricultural Engineering, UC Davis
Email: ikisekka@ucdavis.edu

**Patrick Brown**
Dept. Plant Sciences, UC Davis
Email: phbrown@ucdavis.edu

## Cooperators

**Gabriele Ludwig**
Almond Board of California
Garret and Art Bowman
cooperator grower
Modesto, CA
Email: glbowman77@gmail.com

**Hanna Ouaknin**
Dept. Land, Air and Water Resources,
UC Davis
Email: houaknin@ucdavis.edu

**Hanni Haynes Christine "Teena" Armstrong**
Dept. Land, Air and Water Resources,
UC Davis
Email: rehaynes@ucdavis.edu
Staff Research Associate
Department of Plant Sciences
UC Davis
Email: tmarmstrong@ucdavis.edu


## INTRODUCTION

Over 100,000 Central Valley (CV) residents lack safe drinking water because they rely on groundwater wells impacted with nitrate. Agriculture is a regionally significant source of nitrate in groundwater and is associated with leaching of fertilizers and confined animal facilities. During the past decade, millions of acres of croplands in the CV have been converted to orchards. Orchard crops have high nutrient demands; for example, almonds require approximately 170-225 kilograms (kg) nitrogen (N) per hectare (ha) annually and have replaced crops with lower nutrient requirements (i.e. alfalfa). Following this trend, the continued degradation of rural groundwater supplies is likely without intervention. The Irrigated Lands Regulatory Program (IRLP) developed by the Regional Water Boards (RWB) charges growers and their agricultural coalitions with implementing N management plans that are protective of groundwater quality by improving N use efficiency (NUE) and reducing N leaching to groundwater.

Previous research at the plot scale shows that high frequency low concentration (HFLC) fertigation can improve production through higher nitrogen use efficiency, potentially reducing impacts to groundwater.

This project not only provides commercial orchard scale implementation of HFLC but also novel direct measurements of resulting groundwater quality immediately underneath the orchard.

## OBJECTIVES

1. Fine-tune the HFLC approach and demonstrate, in a commercial scale almond orchard, that HFLC fertigation practices increase NUE while successfully producing high yields and reducing groundwater quality impacts.
2. Perform, compare, and assess three independent monitoring approaches to estimate groundwater nitrate contribution from an orchard to guide growers, agricultural coalitions, and regulatory agencies on the compliance process.
3. development of a vadose zone - crop model, a groundwater model, and an integrated groundwater-vadose zone-crop model; apply models to evaluate scaled-up regional application of HFLC as potential new best management practices (BMP) capable of minimizing nitrate leaching to groundwater and improve groundwater quality at the regional scale.
4. Inform and discuss interim and final findings with grower-collaborator, ILRP agricultural coalition representatives, nut and other commodity grower representatives, and orchard growers.

## DESCRIPTION

This project provides the first comprehensive assessment of groundwater nitrate impact from a best management practice (in this case, HFLC) comparing three monitoring approaches to assess nitrate impact to groundwater:

1. monitoring equipment to measure water and nitrogen application rates, ET, and harvest N removal (orchard water and N mass balance as employed by the ILRP);
2. 7 replicate multi-level, vadose zone monitoring sites (water, nitrate, and ammonium fluxes and storage at 0 -3 m depth).
3. 20 groundwater monitoring wells (screened at 7-17 m below ground surface, in first encountered groundwater), a regulatory “gold standard” for monitoring pollution.

The project further investigates the relationship between groundwater nitrate and fluxes through the development of an unsaturated zone model and groundwater model. The modeled results are compared to the collected field measurements.

## RESULTS AND DISCUSSION

Water and N mass balance monitoring. Water mass balance calculations were done on an annual and monthly basis, for each of the blocks in the orchard:

Eq. 1: $R = P - ETa + IR + dS$

where R is the estimated recharge to groundwater, P is the precipitation measured and reported by the Modesto Irrigation District (MID), IR is the total irrigation, measured by the grower using a flow meter, ETa is actual evapotranspiration, and dS is the change in soil moisture storage. ETa data were computed using the Cal-ETa model (3). The 2013-2017 mass balance reported previously showed a negative balance and therefore recharge could occur only during the rainy season. 2019, shows a similar trend (Figure 1). Currently, we have ETa data processed through December 2019, which shows mostly the rainy season of 2020, and therefore the water mass balance for 2020 is still positive on an annual balance. The N mass balance was calculated using Eq.2:

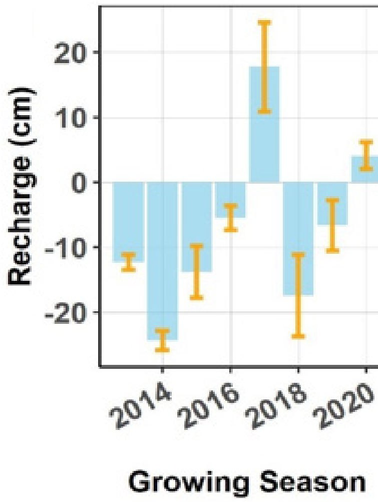



*Figure 1: mean annual water recharge of the blocks based on mass balance eq 1*

N-Losses = (N-applied) +(N-deposition)+(N-mineralization)-(N-uptake)-(N-denitrification)

Applied N, N-applied, follows the HFLC practice. Atmospheric deposition, N-deposition, is set to 20 kg N ha-1 annually (a-1) due to dairies upwind of the orchard. N-uptake is based on the harvested kernel weights as reported by the grower, calculated as (kernel weight)*68/1000, to which 45 kg N ha-1 a-1 are added for tree growth. Denitrification is 5% of N inputs. Resulting N use efficiency is very high and, for 2020, was above 100%.

Root zone monitoring occurs at seven monitoring stations distributed randomly throughout the 56 ha orchard. Each monitoring station is equipped with four tensiometers at depths of 280 and 300 cm and a datalogger collecting data every 15 minutes. Five pore water samplers are located at depths of 30, 60, 90, 180 and 280 cm, and a neutron probe is used for water content measurement. Collection of pore water samples occurred every two weeks, on average, during fertigation season. Soil water tension at depths of 280 and 300 cm (about 9 and 10 feet) were monitored continuously, using tensiometers connected to dataloggers. Measured soil water tension gradient between 280 and 300 cm and measured nitrogen concentrations at that depth are used to compute water and nitrogen flux out of the root zone. During 2019 growing season these fluxes were highly variable and indicate average losses of 50 kg N ha-1 a-1.

Groundwater monitoring demonstrates a high spatial variability in nitrate concentrations across the orchard. The standard deviation of the annual mean concentrations in wells ranged between 12.8 and 23 mg/L N between 2017 and 2020 (Figure 2). Meanwhile the temporal variability is low. Overall mean is 25 mg N/L over the measured years (Figure 3). Development of a groundwater model strives to evaluate potential causes of the N variability. Preliminary results from the groundwater flow model suggests that the source areas for N concentrations measured in the wells span less than 500 m upgradient from the well and may represent a mixture of recharge from at least the past decade. We have also performed multilevel sampling in the wells, for which ongoing analysis may possibly provide additional insight on vertical variability.

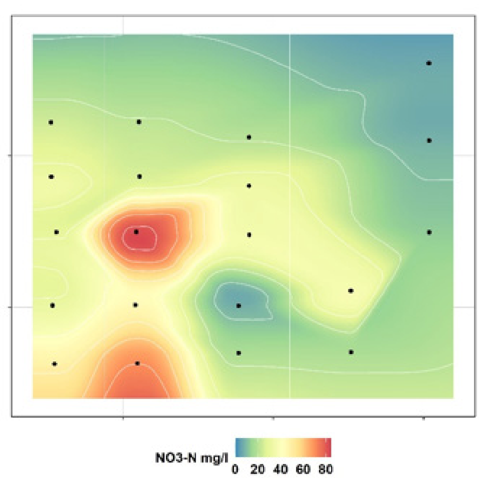



*Figure 2: Spatial concentration of nitrate (March 2021) in the 20 monitoring wells using Kriging interpolation.*

Modeling. A one-dimensional model of the unsaturated zone from the surface to the water table (about 7m) was created for the stratigraphy at each of the 20 soil cores logged during the well construction in 2017. Boundary conditions (precipitation, irrigation) were based on nearest weather station information and on grower information. Modeling results suggest that changes in water and N uptake in trees due to age and irrigation may play a significant role in creating variability in N concentrations.

Model results also indicate that efficient irrigation in mature trees may leads to lower water fluxes and, hence, higher N leaching concentrations; meanwhile, young trees with higher water fluxes due to inefficient irrigation cause N leaching concentrations half that of mature trees, while N applications are also lower (Figure 3). The amount of time for excess N to reach the water table was modeled to be at least 10 years and is longer for mature trees than young trees. The difference in irrigation and nutrient management between mature and young trees was a significantly more affecting factor in the N and water fluxes than the high variability in soil texture between the soil cores as described in (4).

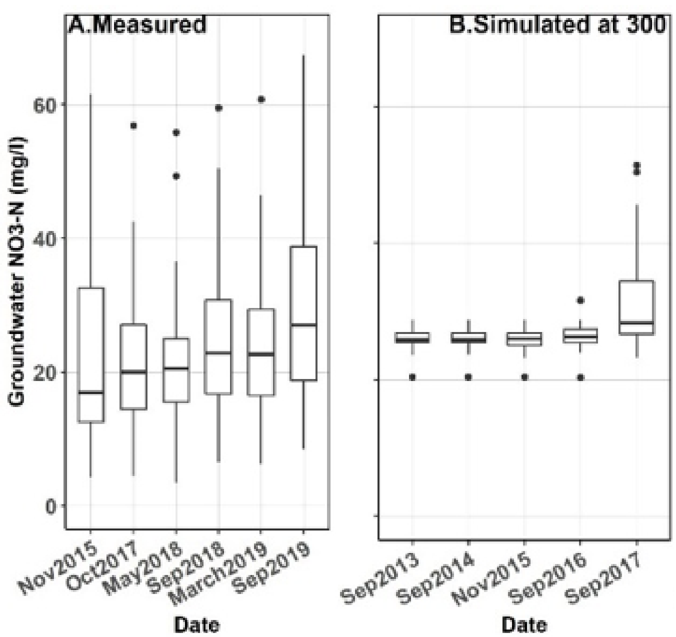



*Figure 3: Temporal variability in groundwater concentrations. A. median and 25th and 75th quantiles of the spatial measurements during the sampling period. B. median and 25th and 75th quantiles of N concentration at depth of 300 cm, assumed to reach groundwater*

## TAKE-HOME MESSAGE

This study is monitoring the effectiveness of HFLC as a management practice and is seeking to determine resulting improvements in N groundwater concentrations. HFLC showed promising results during the first and third year. In year two, spring climate conditions led to lower yields. This will need further observation and refinement as trees may take time to accommodate the HFLC practice and tune it to the amounts needed to get both better yield and reduction in nitrate leaching. The historic mass balance is a straightforward tool, but misleading when used to estimate N losses from agriculture in years with low precipitation. Modeling shows some downward N fluxes even though the N mass balance is zero or slightly negative. Furthermore, the model simulations suggest that grower practices and their resulting effect on N efficiency have a significant impact on the variability of N transport to groundwater.

## LITERATURE CITED

Paul G, Dickey J, Chong CS, Yimam YT, Schmid B, Hawkins T, et al. Remote Sensing Based Statewide Actual Evapotranspiration Mapping Program (CalETa) for Water Resources Management. In 2018.

Gurevich H, Baram S, Harter T. Measuring nitrate leaching across the critical zone at the field to farm scale. Vadose Zo J. 2021;(September 2020):1–16.

## ACKNOWLEDGEMENTS

We thank the grower for allowing us to conduct this research and being supportive and cooperative. This research is funded in part by The Almond Board of California, project number PREC6.HARTER, FREP project number 19-0968 and CDFA project number 19-0001-017-SF.

# Development of Site-Specific Nitrogen Fertilization Recommendations for Annual Crops


## Project Leaders

**Daniel Geisseler**
Cooperative Extension Specialist; UC Davis; Department of Land, Air and Water Resources; One Shields Avenue; Davis, CA 95616; (530) 754-9637; djgeisseler@ucdavis.edu

**Sanjai Parikh**
Associate Professor of Soil Chemistry; UC Davis; Department of Land, Air and Water Resources; One Shields Avenue; Davis, CA 95616; (530) 752-1265; sjparikh@ucdavis.edu

**Nick Clark**
UCCE Farm Advisor, Kings, Tulare, & Fresno Counties, 680 Campus Drive
Suite A, Hanford, CA 93230. 559-852-2788; neclark@ucanr.edu

**Michelle Leinfelder-Miles**
UCCE Farm Advisor, San Joaquin County, 2101 East Earhart Avenue, Suite 200, Stockton, CA 95206. 209-953-6120; mmleinfeldermiles@ucanr.edu;

**Sarah Light**
UCCE Farm Advisor Sutter, Yuba, and Colusa Counties; 142A Garden Highway; Yuba City, CA 95991; (530) 822-7515; selight@ucanr.edu

**Konrad Mathesius**
UCCE Farm Advisor, Yolo, Solano & Sacramento Counties; 70 Cottonwood Street; Woodland, CA 95695; (530) 666-8704; kpmathesius@ucanr.edu

**Rob Wilson**
Intermountain REC Director, UCCE Farm Advisor, ANR Intermountain Research & Extension Center, 2816 Havlina Road, Tulelake, CA, 96134. (530) 667-5117; rgwilson@ucanr.edu


## INTRODUCTION

To minimize nitrate leaching to groundwater while maintaining high yields, growers need reliable tools to determine optimal rates and timing of N applications. These tools should be based on field-specific information, including availability of N from non-fertilizer sources, such as residual soil nitrate, nitrate in the irrigation water and N mineralization from soil organic matter (SOM). With funding from FREP, we recently developed such a tool for processing tomatoes. This online calculator estimates the N fertilizer requirements based on expected yield, residual soil nitrate, nitrate in the irrigation water and in-season N mineralization from SOM. However, the calculator currently estimates in-season N mineralization based on an N budget for Central Valley cropping systems and does not take into account site-specific soil properties and cropping history.

In a recent project, we found that combining measures of soil texture as well as SOM content and quality can provide accurate site-specific N mineralization estimates. In soils with a high SOM content from the Delta and the Tulelake basin, particulate organic matter was a good measure for SOM quality, while in soils from the Central Valley with a low SOM content, fluorescein diacetate (FDA) hydrolysis, a measure for microbial activity, was a better predictor. However, these estimates have not yet been validated in field trials. Furthermore, while both SOM quality methods are relatively simple to use, they may not be attractive to commercial soil test labs, where growers and consultants routinely send their samples. The particulate organic matter analysis requires several steps, which are carried out over a period of three days, while for FDA analysis a strict protocol needs to be followed to reduce user-variability. Fourier transform infrared spectroscopy (FTIR) has been shown to be useful to identify labile SOM fractions that are related to N mineralization. We hypothesize that FTIR can be used to assess soil quality measures such as particulate organic matter and FDA hydrolysis. Infrared spectroscopy is a rapid and cost-effective method and is already commonly used to characterize feed and forage samples. Therefore, the personnel of many analytical labs are already familiar with the principals of infrared spectroscopy, which will greatly facilitate adoption by commercial labs. The results can then be used to generate site-specific recommendations for calculating N mineralization from SOM, improving the precision of annual crop N management plan budgets.

## OBJECTIVES

The goal of the proposed project is to develop robust site-specific estimates of the contribution of N mineralization to the plant-available N pool for different regions in California and incorporate them into user-friendly online N fertilization calculators. Specific objectives are:

1. Validate N mineralization estimates in field trials in the Central Valley, including the Delta, as well as in the Tulelake basin
2. Characterize the chemical composition of SOM using FTIR and correlate it to soil quality
3. Develop user-friendly and site-specific online N fertilization calculators for different crops.

## DESCRIPTION

Field trials will be conducted in commercial fields in the Central Valley, including the Delta, as well as in the Tulelake basin. Two treatments will be included: (i) no N fertilizer applications in plots within the field and (ii) grower's standard N management. Soil samples will be collected pre-plant and analyzed for soil properties and N mineralization potential. Pre-plant and post-harvest soil samples will also be analyzed for residual mineral N content in the top 4 feet of the profile. Multiple times during the season and at harvest, the aboveground biomass of crops from fertilized areas within the field will be harvested to determine dry matter biomass and its N concentration. This information will be used to develop seasonal N uptake curves and N uptake per unit yield. Irrigation water samples will be analyzed to determine the input of N with the irrigation water. At harvest, the aboveground biomass and its N concentration will also be determined in the unfertilized plots. With data collected from the unfertilized plots, we will determine the capacity of the soil to provide plant-available N through mineralization in order to validate the N mineralization estimates.

The FTIR-based method to assess soil quality will be developed using air-dried samples collected in more than 70 fields across northern and central California in previous and ongoing projects. A wide range of analyses has already been performed on these samples to characterize their properties, including N mineralization potential.

Multivariate regression analysis will be used to estimate N mineralization based on soil texture, SOM content and FTIR-based measurements of SOM composition. The estimate will then be validated with the results of the field trials as described above. The online N calculators will be developed by expanding the processing tomato calculator with site-specific features based on the results of the proposed study.

## RESULTS AND DISCUSSION

Field trials were set up in spring 2021 in 12 fields as described above (Figure 1, Table 1). Soil samples, including undisturbed soil cores, were collected pre-plant and analyzed for residual mineral N (ammonium-N and nitrate-N). Undisturbed cores from the top 6 in. were collected and incubated at 25 °C for 10 weeks. The amount of N mineralized ranged from 7.2 to 56.5 mg/kg (Table 2). Other soil analyses are ongoing.

The aboveground biomass of fertilized crops is being harvested in 3-week intervals to determine dry matter biomass and its N concentration. Plant samples have been dried and weighed. They are currently being processed and analyzed for total N.

## ACKNOWLEDGEMENT

We would like to thank Suzette Turner, Makena Savidge, Ben Halleck, Chaitanya Muraka and Darrin Culp for help with laboratory analyses and fieldwork. We also thank our grower collaborators. Funding for this project was provided by the CDFA Fertilizer Research and Education Program.

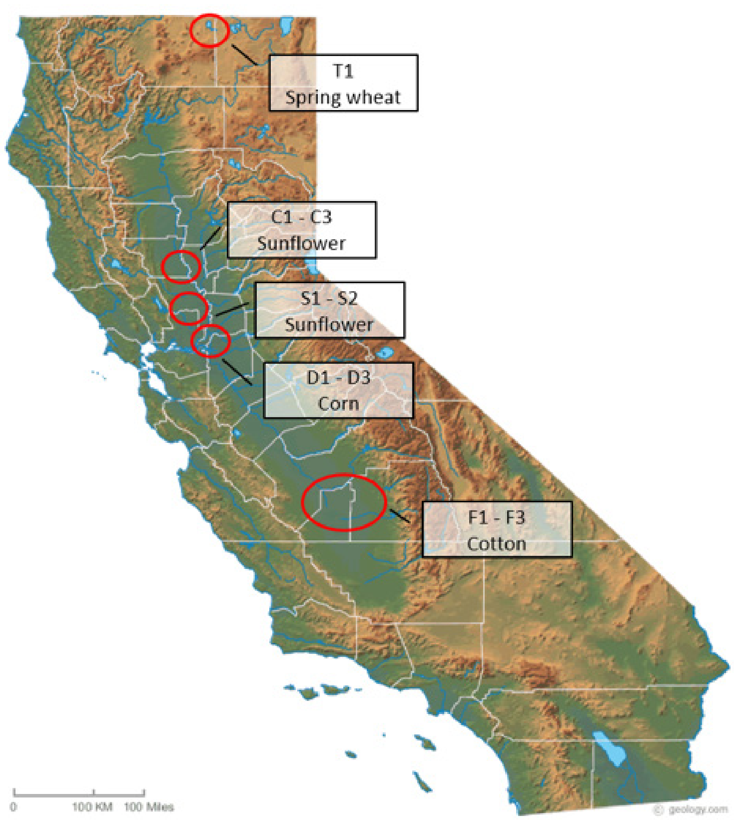



*Figure 1: Location of the field sites*

*Table 1: Background info of the field sites included in 2021. For location, see Figure 1.*

| Site ID | Soil series | Crop 2020 | Crop 2021 | Irrigation |
|---|---|---|---|---|
| C1 | Sacramento clay | Wheat | Sunflower | Furrow |
| C2 | Sycamore silty clay loam | Safflower | Sunflower | Furrow |
| C3 | Sycamore silty clay loam | Tomato | Sunflower | Furrow |
| D1 | Gazwell mucky clay | Corn | Corn | Subsurface |
| D2 | Rindge mucky silt loam | Corn | Corn | Subsurface |
| D3 | Rindge muck | Corn | Corn | Subsurface |
| F1 | Whitewolf coarse sandy loam | Cotton | Cotton | Furrow |
| F2 | Panoche clay loam | Cotton | Cotton | Furrow |
| F3 | Biggriz-Biggriz | Cotton | Cotton | Furrow |
| S1 | Yolo loam | Tomato | Sunflower | Furrow |
| S2 | Reiff fine sandy loam | Tomato | Sunflower | Furrow |
| T1 | Tulebasin mucky silty clay loam | Sudan Grass | Spring Wheat | Solid set sprinklers |

*Table 2: Net nitrogen (N) mineralization, bulk density and moisture content at 60% water holding capacity (WHC) in undisturbed soil cores. For net N mineralization, the cores were incubated at optimal moisture content and 25 °C for 10 weeks. Average values with standard deviations in parentheses (n = 4).*

| Site ID | Net N mineralization | Bulk density | Moisture content at 60% WHC |
|---|---|---|---|
| | (mg/kg) | ($g/cm^3$) | (g/g) |
| C1 | 20.9 (1.28) | 1.15 (0.02) | 0.33 (0.020) |
| C2 | 11.7 (6.61) | 1.23 (0.01) | 0.27 (0.016) |
| C3 | 27.6 (9.49) | 1.20 (0.02) | 0.27 (0.001) |
| D1 | 27.9 (6.23) | 0.85 (0.03) | 0.47 (0.021) |
| D2 | 52.7 (10.55) | 0.69 (0.02) | 0.65 (0.026) |
| D3 | 49.0 (19.34) | 0.63 (0.03) | 0.63 (0.010) |
| F1 | 40.4 (6.61) | 1.42 (0.07) | 0.19 (0.032) |
| F2 | 7.2 (4.38) | 1.33 (0.04) | 0.27 (0.026) |
| F3 | 56.5 (12.13) | 1.13 (0.13) | 0.29 (0.020) |
| S1 | 18.9 (7.55) | 1.32 (0.07) | 0.26 (0.004) |
| S2 | 24.4 (5.46) | 1.28 (0.04) | 0.27 (0.006) |
| T1 | 19.8 (5.35) | 0.88 (0.08) | 0.52 (0.009) |

# Nitrogen Content of the Harvested Portion of Specialty Crops to Estimate Crop Nitrogen Removal and Improve Nitrogen Management in Crops


## 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

**Aparna Gazula**
UCCE Farm Advisor, Santa Clara County, 1553 Berger Drive, Bldg. 1, San Jose, CA 95112, (408) 282-3110, agazula@ucanr.edu

**Andre Biscaro**
UCCE Farm Advisor, Ventura, Los Angeles and San Bernardino Counties, 669 County Square Drive, Suite 100, Ventura, CA 93003, 805-645-1465, asbiscaro@ucanr.edu


## INTRODUCTION

The Irrigated Lands Regulatory Program (ILRP) has issued waste discharge requirements (WDRs) that affect agricultural operations throughout California. The WDRs are intended to improve water quality by affecting grower implementation of more efficient nitrogen (N) management practices. One metric to assess grower progress in improving N management is the difference between applied (A) and removed (R) nitrogen in harvested crop biomass (A-R). The Central Coast Regional Water Quality Control Board (CCRWQCB), Region 3, approved Ag Order 4.0 in April 2021 and uses the A minus R metric to assess nitrogen use. The CCRWQCB requested development of R coefficient values for crops that represent 95% of the acres in Region 3. UC Researchers have developed total crop N uptake (U) to improve N management for a number of commodities grown in Region 3; however, R values were not determined for harvested product for many of these commodities (Bottoms et al. 2012; Breschini and Hartz 2002; Heinrich et al. 2013; Smith et al. 2016a; Smith et al. 2016b). Under Ag Order 4.0 growers will be required to comply with A-R limits and targets according to a schedule. Producers will need to estimate N removed from fields in harvested crop biomass. Depending on the crop, the harvested biomass could include leaves, bulbs, roots, flowers, stems, or a combination of plant parts. Additionally, the same commodity may be harvested into different products. For example, romaine lettuce is harvested as trimmed, cored, and heart products, which likely have different N and dry matter contents.

## OBJECTIVES

1. Assess N removed in harvested product for 35 commodities identified in the special request for proposals over three growing seasons.

2 Develop N removal coefficients that can be multiplied by grower yield data to provide an estimate of N removed (R) in the harvested crop.

3 Expand knowledge and promote appropriate use of N-removal coefficients (as part of routine N-management planning, and evaluation) by growers, advisors and consultants.

## DESCRIPTION

1 1. Assess N removed in harvested product for 35 commodities identified in the special request for proposals over three growing seasons. Significant progress has been made to sample 15 fields of each of the 35 commodities proposed to study. For the lettuces we increased the number of fields to 20. Due to feedback from growers we included new crops to evaluate such as baby kale, baby lettuces and clipped spinach. As a result, a total of 45 commodities are now being evaluated (Table 1).

2 Develop N removal coefficients that can be multiplied by grower yield data to provide an estimate of N removed (R) in the harvested crop. Final coefficients will be calculated once we have sampled all of the fields proposed.

3 Expand knowledge and promote appropriate use of N-removal coefficients (as part of routine N-management planning, and evaluation) by growers, advisors and consultants. A presentation was made at the 2021 Irrigation and Nutrient Management Meeting in February.

## RESULTS AND DISCUSSION

Preliminary coefficients that have been developed for the commodities evaluated in this project show significant variability in moisture and nitrogen contents of the products. For instance, the amount of nitrogen removed in 30,000 lbs of full-sized fresh-market romaine averaged 54 lbs N/A but varied from 44 to 73 lbs N/A (Table 2). Romaine lettuce takes up 120 to 170 lbs nitrogen/A. For a crop like lettuce, a significant portion of the crop biomass is trimmed off and remains in the field and only a portion of applied nitrogen is removed in the harvested product. While A-R may be 47 lbs N/A (120-73) in some cases, the variation in both N uptake and N removed may also result in a totally different A-R value: 126 lbs N/A (170-44). That is a significant difference (79 lbs N/A), especially for a crop that may be grown two to three times a year. The need to apply sufficient nitrogen to satisfy the needs of the growing crop will create a tension in the A minus R metric that is central to Ag Order 4.0 recently approved by the CCRWQCB.

## LITERATURE CITED


Bottoms, T., R. Smith, M. Cahn, and T. Hartz. 2012. Nitrogen requirements and N status determination of lettuce. HortScience 47(12): 1768-1774.

Breschini, S. and T. Hartz. 2002. Drip irrigation management affects celery yield and quality. HortScience 37(6): 894-897.

Heinrich, A., R. Smith and M. Cahn. Nutrient and water use of fresh market spinach. 2013. HortTechnology 23(3): 325-333.

Smith, R., M. Cahn, T. Hartz, P. Love and B. Farrara. 2016a. Nitrogen dynamics of cole crop production: implications for fertility management and environmental protection. HortScience 51(12): 1586-1591.

Smith, R. M. Cahn and T. Hartz. 2016b. Evaluation of N uptake and water use of leafy greens grown in high-density 80-inch bed plantings and demonstration of best management practices – Final Report. https://www.cdfa.ca.gov/is/ffldrs/frep/pdfs/completedprojects/12-0362-SA_Smith.pdf

*Table 1. List of commodities being evaluated*

| Commodity | Product | Pack Type | Commodity | Product | Pack Type |
|---|---|---|---|---|---|
| Baby lettuce, Green | Bulk | bulk | Onion, yellow | Bulk | bulk |
| Baby lettuce, Red | Bulk | bulk | Onion, red | Bulk | bulk |
| Head lettuce | Fresh market | film wrap | Arugula | Bulk | bulk |
| Head lettuce | Fresh market | naked (liner) | Broccolini | Fresh market | carton |
| Head lettuce | Bulk | bulk | Fennel | Fresh market | carton |
| Romaine | Fresh market | naked (liner) | Leek | Bulk | bulk |
| Romaine | Hearts | carton | Parsley | Fresh market | carton |
| Romaine | Bulk | bulk | Beet | Fresh market | carton |
| Green leaf | Fresh market | carton | Red Radish | Fresh market | carton |
| Red leaf | Fresh market | carton | Red Radish | Bulk | carton |
| Butter | Fresh market | carton | Radicchio | Fresh market | carton |
| Cabbage, Red | Fresh market | carton | Spinach, baby | Bulk | carton |
| Cabbage, Red | Bulk | bulk | Endive | Fresh market | carton |
| Cabbage, Green | Fresh market | carton | Escarole | Fresh market | carton |
| Cabbage, Green | Bulk | bulk | Shallot | Bulk | carton |
| Cabbage, Green | Bulk | bulk | Celery | Fresh market | carton |
| Cauliflower | Fresh market | carton | Cilantro | Fresh market | carton |
| Kale, baby | Bulk | bulk | Chinese Celery | Fresh Market | carton |
| Kale, multi pick | Retail | RPC | Gai Choy | Fresh Market | carton |
| Rapini | Fresh market | carton | Tong Ho | Fresh Market | carton |
| Brussels sprouts | Fresh market | carton | Yam Leaf | Fresh Market | carton |
| Edible Pod Pea | Fresh market | RPC | Jalapeno | Fresh Market | carton |
| Annual Artichoke | Fresh market | carton | | | |

*Table 2. Preliminary estimate of removal coefficient for fresh market romaine lettuce*

| | Mean | Maximum | Minimum |
|---|---|---|---|
| Moisture content % | 94.3 | 95.4 | 92.5 |
| Nitrogen content % | 3.15 | 3.97 | 2.33 |
| Removal coefficient | 0.00178 | 0.00243 | 0.00147 |
| Removed in 30,000 lbs fresh product lbs N/A | 54 | 73 | 44 |


## ACKNOWLEDGEMENTS

We thank Margherita Zavatta and Sidney Lee of University of California, Santa Cruz for assisting data entry for this project. We appreciate the California Department of Food and Agriculture, Fertilizer Research and Education Program (PREP) for funding this project.

# Ventura County Nitrogen Management Training Program


## Project Leader

**Jodi Switzer**
Water Program Director
Farm Bureau of Ventura County
5156 McGrath Street, Ventura, CA 93003
Phone: (805) 289-0155
Email: jodi@farmbureauvc.com

## Cooperators

**Dr. Ben Faber**
University of California,
Cooperative Extension Ventura County
669 County Square Drive, #100, Ventura, CA 93003
Phone: (805) 645-1462
Email: bafaber@ucanr.edu

**Andre Biscaro**
University of California,
Cooperative Extension Ventura County
669 County Square Drive, #100, Ventura, CA 93003
Phone: (805) 645-1465
Email: asbiscaro@ucdavis.edu

## Supporters

**Dawn Afman**
Natural Resource Conservation Service
3550 S Harbor Blvd. suite #2-202, Oxnard, CA 93035
Phone: (805) 984-2358 x101
Email: Dawn.Afman@ca.usda.gov

**Jamie Whiteford**
Ventura County Resource Conservation District
3380 Somis Road, Somis, CA 93066
Phone: (805) 764-5132
Email: jamiewhiteford.vcrcd@gmail.com


## INTRODUCTION

The third iteration of the Los Angeles Regional Water Quality Control Board's Conditional Waiver of Waste Discharge Requirements for Discharges from Irrigated Lands within the Los Angeles Region ("Conditional Ag Waiver", Order No. R4-2016-0143) was adopted on April 14, 2016. To address existing water quality issues, the 2016 Conditional Ag Waiver included a requirement that growers located in areas associated with nutrient water quality exceedances or Total Maximum Daily Load (TMDL) specific requirements, develop certified Nutrient Management Plans for their farms. Approximately 70% of the agricultural acreage in Ventura County is located in an area where these requirements currently apply.

The required elements of the plans themselves, as well as the certification options, were modeled after the requirements already in effect for Central Valley growers. To provide local growers with the tools and training needed to implement these requirements, the Ventura County Agricultural Irrigated Lands Group (VCAILG, administered by the Farm Bureau of Ventura County) worked collaboratively with CDFA FREP, the University of California Cooperative Extension, and Fruit Growers Laboratory to expand the Central Valley self-certification training programs in Ventura County. Many more growers will need to complete this training and develop Irrigation and Nutrient Management Plans to comply with the upcoming Conditional Ag

Wavier term, which will include the East San Joaquin River Watershed Waste Discharge Requirements precedential requirements related to nitrogen tracking and reporting.

## OBJECTIVES

1. Provide growers with the information and credentials needed to develop site-specific Nitrogen Management Plans (NMPs) and Irrigation and Nitrogen Management Plans (INMPs) for their farms
2. Improve surface and ground water quality through an education program focused on the principles of crop-specific irrigation and nutrient management
3. Increase awareness of grower resources, including crop-specific nitrogen demand/removal factors
4. Provide training program and resources for Spanish-speaking audiences

## DESCRIPTION

The primary tasks included in this education project include the following:

1. Update current NMP training program to include INMP components and other ESJ precedential requirements.
2. Translate training program and resources for Spanish-speaking audiences.
3. Conduct three training programs per year, one of which will include active Spanish translation.
4. Provide English and Spanish versions of training binders and other resources.

## RESULTS AND DISCUSSION

The planned implementation schedule for this education project has been impacted by both the ongoing COVID-19 public health emergency, as well as the one-year extension of the current Conditional Ag Waiver term, which was originally set to be renewed in April 2021 but will now be renewed in April 2022. Due to the public health restrictions on in-person gathering, the training program was revised and had been conducted in on online format. The timeline for the renewal of the Conditional Ag Waiver is significant in that it will include requirements for the implementation of the East San Joaquin precedential order. Once the renewal is adopted and an implementation program is established for the precedential requirements, the training program will be updated and translated for Spanish-speaking audiences.

In the meantime, this project will continue to implement the current NMP training program through online workshops and exams. An update and translation of the training program is anticipated to be completed by the end of Summer of 2022.

## ACCOMPLISHMENTS

A two-day online training session was conducted on April 6 and 7 of 2021. Attendance included 29 participants, 28 of which went on to successfully pass the certification exam. A second two-day training session will be offered on November 3 and 4, 2021.


## ACKNOWLEDGEMENTS

The implementation of this project has been supported through CDFA FREP grant funding. Additional support and training program collaboration has been provided by Ben Faber and Andre Biscaro with the University of California Cooperative Extension, Ben Waddell and Scott Bucy with Fruit Growers Laboratory, Amy Storm with Larry Walker Associates, and Nichole Nunes with CDFA FREP.

# Assessment of Harvested and Sequestered Nitrogen Content to Improve Nitrogen Management in Perennial Crops, Phase 2


## Project Leaders

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

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

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

## Cooperator

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


## INTRODUCTION

As part of its Irrigated Lands Regulatory Program (ILRP), the Central Valley Regional Water Quality Control Board (Water Board) 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, climates, 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.

Additional data are necessary to improve estimates of coefficients for the remaining 62 crops identified in the N-concentrations Report. To accomplish this, a two-phased project is underway. As part of Phase 1, samples were collected and analyzed for their N content for carrots, silage corn, peaches, pistachios, plums, pomegranates, sunflower, safflower, and processing tomatoes. Furthermore, data on pima and upland cotton as well as walnuts were obtained from other projects and used to update the N-removal coefficients. Data on N requirements for perennial tissues of almond was also obtained from a collaborator. The updated coefficients and perennial tissue data are documented in Geisseler (2021) and have been incorporated into the N removed calculator on the agmpep.com website (http://agmpep.com/calc-y2r/). Phase 2 of the project continues this assessment for additional crops. Sampling and analysis results from Phase 1 and Phase 2 will increase coverage of highly reliable N removal estimates to 99% of Central Valley acreage.

## OBJECTIVES

1. 1. Assess N concentration of harvested material removed from fields (N removed [R]) for approximately 33 crops over several growing seasons, and N sequestration rates for eight perennial crops (which are included among the 33 total crops), by working with grower/packer/shipper partners to obtain samples, and UC Davis to analyze samples and interpret results.
2. 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.
3. 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. This includes the following:
   - **a** Incorporate results in an update of Geisseler (2016, 2021).
   - **b** Update existing online and off-line tools for estimating N removed in crops and incorporate into regional assessments of N balance in irrigated crop lands. Update N accumulation rates in crop models used in the ILRP.

## DESCRIPTION

Phase 2 includes updating conversion factors for approximately 33 crops. By partnering with commodity organizations, growers, processors, packers, and retailers, it is possible to procure hundreds of samples that represent a range of varieties and growing environments for each crop. Currently, samples are planned to be or are being collected and analyzed for apricots, nectarines, cherries, Valencia and Navel oranges, lemons, tangelos, grapefruit, figs, table grapes, raisins, sweet corn, corn grain, sorghum grain, non-alfalfa hay/haylage, cantaloupe, honeydew, watermelon, summer squash, cucumber, onion, garlic, potato, sweet potato, fresh market tomato and bell pepper.

Results will be incorporated into the assessment and planning tools available to growers, grower advisors, and coalitions. This includes updates of the N-concentrations Report (Geisseler 2016, 2021) and the N removed calculator on the agmpep.com website.

## RESULTS AND DISCUSSION

Work completed since the commencement of Phase 1 includes coordination of three years of sampling of nine crops with grower/packer/shipper partners, along with preparation and analysis of the samples obtained. Information on two crops was provided by collaborators already in possession of relevant datasets from other projects. Results from Phase 1 are documented in Geisseler (2021) and have been incorporated into the N removed calculator on the agmpep.com website (http://agmpep.com/calc-y2r/). These results are also presented in Table 1. Results from Phase 2 are not yet available.

*Table 1. Initial (Geisseler 2016) and Updated (Geisseler 2021) N removal Coefficients.*

| **Crop** | Geisseler (2021) | | Geisseler (2016) | | Change |
|---|---|---|---|---|---|
| | Av. Lbs N/ton | CV* (%) | Av. Lbs N/ton | CV* (%) | % |
| Corn Silage | 7.53 | 10.9 | 7.56 | 10.5 | -0.4 |
| Cotton | 43.4 | 16.1 | 43.7 | 29.5 | -0.69 |
| Safflower | 51.7 | 10.2 | 56.8 | 20.0 | -9.0 |
| Sunflower | 63.2 | 11.1 | 54.1 | 14.3 | 17 |
| Carrots | 2.80 | 22.7 | 3.29 | 22.4 | -15 |
| Tomatoes, Processing | 2.92 | 15.0 | 2.73 | 11.1 | 7.0 |
| Peaches | 3.04 | 19.0 | 2.26 | 20.7 | 35 |
| Pistachios** | 20.4 | 21.6 | 56.1 | 3.5 | - |
| Plums | 2.27 | 14.5 | 2.83 | 11.2 | -20 |
| Pomegranates | 3.96 | 15.4 | 15.2 | 15.0 | -74 |
| Walnuts | 31.8 | 10.9 | 31.9 | 11.2 | -0.31 |

*Coefficient of variation.

**N removed for pistachio in Geisseler (2016) was based on tons of dry yield (CPC), while the updated N removal coefficient is based on tons of net green weight. Net green weight was selected because it does not require any assumptions related to moisture content and the weight of dried in-shell nuts produced from fresh fruit removed from the field.

Results from this project improve our understanding of N removed in harvested materials from crops grown within the Central Valley. As shown in Table 1, in some cases (e.g., corn silage, cotton, and walnuts), the N-removal coefficient changed little after integration of new data obtained from this project, while with other crops (e.g., peaches and pomegranates), it changed substantially. Differences in updated conversion factors can be caused by many variables related to how relevant and comprehensive the previously used data were to current Central Valley conditions. Regardless of whether the coefficient changed considerably or not, the collection and integration of current data from the Central Valley that span differing climates, soils, management practices, and years, provides a clearer picture of N removal dynamics within Central Valley agriculture and helps growers, advisors, and coalitions better plan and refine nutrient management into the future.

## TAKE HOME MESSAGES

A sound understanding of N removed in harvested portions of crops is a vital component of any nutrient management plan and helps growers determine fertilizer requirements for a growing season. To use these N removal coefficients, it is paramount to understand what they represent. The Geisseler (2016, 2021) reports provide important information on the coefficients related to their associated yield units, presumed moisture contents, and what plant materials are represented (e.g., the cotton coefficient includes N in lint and seed, and needs to be adjusted if yields only consider lint). Furthermore, the reports contain metrics on the degree of variability of N in harvested materials to show how N concentrations may differ across space and time and potential reasons for that variability. Other considerations for estimating fertilizer requirements should include other sources of N besides fertilizers (e.g., N in irrigation water and crop residues) and N required for non-harvested plant materials such as leaves, stems, roots, and perennial tissues. Proper N application rates, timing, and placement should be tailored to crop growth stage, nutrient demand, and irrigation practices. Local conditions (e.g., soil and climate) should also be factored in to ensure better fertilizer-use efficiency.

As our understanding of crop N-removal coefficients continues to improve, stakeholders can continue to work towards a productive and sustainable future for Central Valley agriculture.

## LITERATURE CITED

Burt, C., et al. 2014. Agricultural Expert Panel. Recommendations to the State Water Resources Control Board.

Geisseler, D. 2016. Nitrogen Concentrations in Harvested Plant Parts – A Literature Overview. http://geisseler.ucdavis.edu/Geisseler_Report_2016_12_02.pdf

Geisseler, D. 2021. Nitrogen Concentrations in Harvested Plant Parts – Update 3/2021. http://geisseler.ucdavis.edu/Geisseler_Report_U1_2021_03_31.pdf

# “Crop Nutrient Minute” Video Series


## Project Leaders

### Parry Klassen
Principal Investigator
Executive Director
Coalition for Urban Rural Environmental Stewardship (CURES)
1480 Drew Ave, Suite 130, Davis, CA
559-288-8125; klassenparry@gmail.com

### Patrick Brown, Ph.D.
Co-PI
Professor of Plant Sciences
University of California, Davis
Department of Plant Sciences
One Shields Ave, Davis, CA
530-752-0929; phbrown@ucdavis.edu

## Cooperators

### Katherine Jarvis-Shean, Ph.D.
Orchard Systems Advisor, University of California Cooperative Extension, 530-377-9528, kjarvisshean@ucanr.edu

### Doug Parker, Ph.D.
Director, UC Agriculture and Natural Resources,
510-987-0036, doug.parker@ucop.edu

### Zheng Wang, Ph.D.
Vegetable Crop Advisor, University of California Cooperative Extension, 209-525-6822, zzwwang@ucanr.edu

### Richard Smith
Vegetable Crops and Weed Science Farm Advisor, University of California Cooperative Extension, 831-759-7357, rifsmith@ucanr.edu

### Gabriele Ludwig, Ph.D.
Director, Almond Board of California, 209-765-0578, gludwig@almondboard.com

### Casey Creamer
President/CEO, California Citrus Mutual, 559-592-3790, casey@cacitrusmutual.com

### Alan Reynolds
Board Chairman, East San Joaquin Water Quality Coalition, 209-394-6200, alan.reynolds@ejgallo.com

### Joseph McGahan
Executive Director, Westside San Joaquin River Watershed Coalition, 559-582-9237, jmcgahan@summerseng.com

### Bruce Houdesheldt
Executive Director, Sacramento Valley Water Quality Coalition, 916-442-8333, bruceh@norcalwater.org

### Michael Wackman
Executive Director, San Joaquin County and Delta Water Quality Coalition, 916-684-9359, michael@wackmanconsulting.org

## Supporters

### Gail Delihant
Director of California Government Affairs, Western Growers, 916-325-4265, gdelihant@WGA.com

### Renee Pinel
President and CEO, Western Plant Health Association, 916-574-9744, reneep@healthyplants.org

### Nicole Bell
Manager, Kern River Watershed Coalition Authority, 661-616-6500, nbell@krwca.org

## INTRODUCTION

The Irrigated Lands Regulatory Program (ILRP) mandates that producers of irrigated crops minimize or eliminate excessive nitrate movement beyond the root zone where it can pose a risk to drinking water sources. While extensive amounts of information have been published on how to accomplish this, many growers and crop advisors lack access to an easy-to-digest information and how-to guides for their specific crop needs in an online video format. The goal of this project is to produce two video series in English and Spanish: 30-minute segments useful for Continuing Education (CE) requirements and succinct 5-minute videos called "Crop Nutrient Minutes" that enable growers on a busy schedule access to succinct presentations on information that has taken years to develop and is currently used in crop production today. The CE segments help address the lack of online resources for growers who have completed the Irrigation and Nitrogen Management Plan (INMP) Self-Certification Program. For maintaining their certification, growers must complete three-hours of Continuing Education Units (CEU) in a three-year period. CE courses are typically in-person meetings, which are always difficult for busy growers. Currently, many live meetings and in-person gatherings are temporarily suspended due to COVID-19. Online CE courses are instrumental in ensuring growers and CCAs are able to fulfill their Continuing Education requirements. This project includes an "INMP Continuing Education" video series, creating seven 30-minute videos that will be posted on the CURES website and linked to other sites for self-certified growers and to use to complete their CEUs. The videos will also supplement the new Certified Crop Adviser (CCA) online training and facilitate CCAs in obtaining CEUs. The videos will cover seven crops including almonds, citrus, pistachios, processing tomatoes, wine grapes (high tonnage), strawberries and romaine lettuce. This CURES educational video series will focus on California's major acreage crops and be accessible to Central Valley and Central Coast growers and crop advisors.

## OBJECTIVES

1. Compile irrigation and nitrogen management information on the seven major acreage crops in the Central Valley and Central Coast.
2. Develop and produce seven, 5-minute videos in English and Spanish for the "Crop Nutrient Minute" video series.
3. Develop and produce seven 30-minute videos in English and Spanish that expand on "Crop Nutrient Minute" video content for Continuing Education uses.
4. Post "Crop Nutrient Minute" videos online and conduct outreach.
5. Apply for CEU credit for "INMP Continuing Education" and CCA trainings, post videos online, fulfill sponsor requirements and conduct outreach.

## DESCRIPTION

Video content will be developed by the Project Leaders, University of California Cooperative Extension (UCCE) specialists and University of California (UC) personnel in each crop category. The foundational information for the videos will be the 4R principles (Right time, Right place, Right amount and Right product) developed by FREP and the UC for California crops. Video content will also include information on soil health, nitrogen processes in the soil, leaf sampling, crop nutrient tracking and efficient irrigation practices, as well as tips gained from crop advisors, UCCE specialists and UC personnel who work with the crops featured in a specific video. Scripts for each of the seven 30-minute videos will then be written by the Project Leaders and Cooperators using information gathered from the CDFA Crop

Nutrient Guidelines and findings from past FREP-funded research. Each draft script will be reviewed by a Review Committee, comprised of Project Leaders, Cooperators and subject matter experts to obtain edits and comments. Once the scripts are approved by the Review Committee, videos will be taped using CURES, UC and PCA/CCAs with crop-specific footage recorded in the field. Animation and art will also be used to illustrate information. Videos will be recorded and produced in English and Spanish, using English- and Spanish-speaking farm advisors and PCAs/CCAs specializing in a specific crop.

After the 30-minute videos are produced and approved by the Review Committee, CURES staff will condense the content to create the 5-minute "Crop Nutrient Minute" series. These more succinct videos will focus briefly on the fundamentals and will cover crop-specific tips and techniques to properly implement the 4Rs. Once approved, the finished 5-minute videos will be posted on the CURES, CDFA and UCCE websites. Outreach will then be conducted to growers, crop advisors, commodity groups, Water Quality Coalitions, and other agricultural education entities to notify them of the series. In addition to CURES presentations and workshops, the crop-specific videos could be shown during Coalition member meetings, CCA trainings, UC agronomy classes, commodity group outreach, and other events targeting growers and crop advisors that focus on a specific crop. These videos are modeled off a FREP-funded 4R video produced for walnuts: https://www.curesworks.org/best-management-practices/

Once approved to offer CEUs, the finished "INMP Continuing Education" videos will be posted on the CURES website and linked to other sites. Self-certified growers and CCAs and PCAs will be notified via email and postcard of the online CE opportunities. CDFA and Water Quality Coalitions will be encouraged to send out email blasts, postcards and/or blog posts informing growers and crop advisors of the online courses. Quiz questions will be developed and included with each video, in compliance with current INMP CE requirements (5 questions per 30 minutes). The mandatory quizzes will be automatically graded, results recorded, and Certificates of Completion sent to growers who pass.

## RESULTS AND DISCUSSION

For the "Crop Nutrient Minute" video series, project success will be measured through view counts and feedback surveys. The total number of video views will be tracked quarterly. If views decrease, CURES will perform analyses on outreach methods to ensure we are reaching growers and crop advisors in the most efficient ways. Optional feedback surveys will also be posted with each video. Survey responses will be recorded and used to determine if viewers find the videos helpful or need improvements. For the "INMP Continuing Education" video series, project success will be measured by grower participation and feedback surveys. Grower quiz results will be used as a metric to track grower participation and understanding of content. Optional feedback questions will be included with the quizzes to determine if growers find the videos helpful or need improvement. In the long-term, project success will be measured by Continuing Education completion and measurable reductions of nitrate in Central Valley and Central Coast groundwater. To date, 3,600 growers have completed their self-certification courses but only a fraction of them have maintained their certification through Continuing Education. These videos will allow more growers to complete their CEUs, which are tracked and recorded through the INMP Self-Certification Program. In addition, project success can be measured by reduced nitrate levels in groundwater over the next few decades. There are many programs and educational efforts being done across the state to minimize groundwater leaching. If nitrate levels decrease over the next few decades, it would mean this project and the many other efforts contributed to the overall success.

## ACCOMPLISHMENTS

The research-based information delivered to growers and crop advisors by this project will help support the reduction of agricultural contributions of nitrate to groundwater in the Central Valley and Central Coast. The management practice recommendations will be vital to the approximately 25,000 landowners/operators in the Central Valley and 2,000 on the Central Coast who are affected by requirements to improve nutrient and irrigation application practices for reducing salt and nitrate discharges to ground and surface water. Giving growers access to a easily accessible, more efficient source of information will advance the knowledge of proper nitrogen stewardship and, over time, may improve overall groundwater quality in California.

Furthermore, this project will serve as a conduit to transfer the latest information on efficient nitrogen fertilizer applications and the practices that can minimize or prevent movement of nitrate to groundwater developed by FREP, UCCE and UC. Some new information is likely to come from interviews with Certified Crop Advisors, agronomists and farm advisors who have crop-specific tips, techniques or other knowledge gained through their work in the field. Much knowledge has already been developed through UC, UCCE and FREP projects to improve nitrogen efficiency and needs to be disseminated to growers and crop advisors who would benefit from the information. This project provides another option of communicating this information using media that is popular with an increasing number of growers and crop advisors.

## ACKNOWLEDGEMENTS

CURES acknowledges these leaders, cooperators, and supporters (see references page 1): Patrick Brown, Richard Smith, Katherine Jarvis-Shean, Phoebe Gordon, Doug Parker, Zheng Wang, Gabriele Ludwig, Casey Creamer, Alan Reynolds Joseph McGahan, Bruce Houdesheldt, Michael Wackman and CURES dedicated staff, Maureen Thompson, Courtney Jall

# Enhancing Nitrogen and Water Use Efficiency in California Carrot Production Through Management Tools and Practices


## Project Leaders

**Ali Montazar**
Principal Investigator
Irrigation and Water Management Advisor
UCCE Imperial County
1050 East Holton Road
Holtville, CA 92250
Phone: (442) 265-7707
Email: amontazar@ucanr.edu.

**Michael Cahn**
Irrigation and Water Resources Advisor
UCCE Monterey County
1432 Abbott Street
Salinas, CA 93901
Phone: (831) 759-7377
Email: mdcahn@ucanr.edu

**Daniel Geisseler**
Nutrient Management Specialist
Dept. of LAWR, UC Davis
One Shields Ave., PES Building
Davis, CA 95616
Phone: (530) 754-9637
Email: djgeisseler@ucdavis.edu

**Jaspreet Sidhu**
Vegetable Crops Farm Advisor
UCCE Kern County
1031 South Mount Vernon Avenue
Bakersfield, CA 93307
Phone: (661) 868-6222
Email: jaksidhu@ucanr.edu


## INTRODUCTION

Nitrogen (N) and water management in carrot production systems is critical for increasing efficiency of crop production and decreasing costs and nitrate leaching losses. There is lack of sufficient information on efficient water and N management practices in carrot production systems, while the industry is being held responsible for determining what the most efficient N fertilization rate is for the crop. This project aims to develop more accurate information on carrot water use and N uptake patterns under different soil types, climate, and irrigation practices which can help producers determine the optimal timing and amount of water and N fertilizer applications.

## OBJECTIVES

1. Develop data and information on crop N uptake curve, net N removal, and recommendations on N applications in California carrot production.
2. Develop data and information on crop water use in California carrot production.
3. Adapt the CropManage tool for water and N management in carrots.
4. Disseminate the project outcomes to growers and stakeholders.

## DESCRIPTION

A three-year project with extensive field measurements is ongoing at the UC Desert Research and Extension Center (DREC) and commercial fields in Imperial and Kern Counties to comprehensively represent various N and water management practices, soil types, climate, and carrot cultivars in California carrot production system (Table 1).

*Table 1. General information for the experimental sites in the low desert in the 2020-2021 season. Plant establishment was performed using sprinkler irrigation at all sites.*

| Experimental site | Seeding date | Harvest date | Irrigation practice | Carrot type |
|---|---|---|---|---|
| DREC | Oct 14, 2020 | Mar 21, 2021 | Sprinkler | Fresh market |
| I | Oct 1, 2020 | Mar 11, 2021 | Furrow | Processing |
| II | Oct 13, 2020 | Mar 26, 2021 | Furrow | Processing |
| III | Oct 2, 2020 | Apr 12, 2021 | Sprinkler | Fresh market |
| IV | Oct 16, 2020 | Apr 7, 2021 | Sprinkler | Processing |

In the DREC trial (Fig. 1a), three N fertilizer strategies (most common N fertilizer amounts used by regional/local growers, N1; 120% N1; and 80% N1) are assessed under two irrigation regimes (100% crop ET and 120% crop ET). In each plot, irrigation regime (as main driver) and N strategy (as secondary driver) are investigated in a Randomized Complete Block Design with Split Plot Arrangement over four replications. In the commercial fields, due to logistical limitations, the experiments are carried out in plots with an area of 400 feet by 400 feet under irrigation and N fertilizer management practices followed by growers (Fig. 1b.)

Soil nitrate content (NO3-N) and total N percentage in tops and roots are determined monthly through laboratory analysis. Preplant and post-harvest soil samples are taken from six depths (0-1, 1-2, 2-3, 3-4, 4-5, and 5-6 ft.). At other sampling dates, soil is collected from the top three depths (0-1, 1-2, and 2-3 ft.). A composite soil sample is analyzed from each layer for NO3-N content. Plant measurements is carried out on 40-plant samples collected randomly (per plot at the DREC trial, and from five sub-areas at the commercial sites) and determinations are made on market-

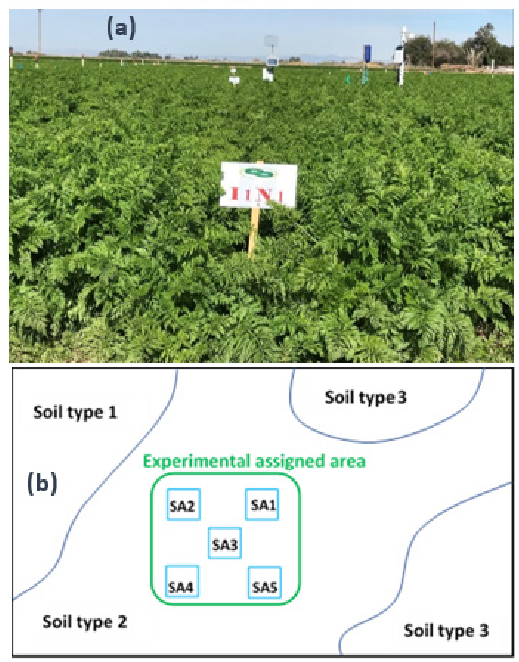



*Figure 1. Monitoring station in one of the treatments at the UC DREC trial (a), and layout of a commercial experimental site (not to scale) (b).*

able yield and biomass accumulation. Fresh weight and dry weight of roots and foliage are measured on a regular basis. The actual consumptive water use (actual crop ET or ETa) was measured using the residual of the energy balance method with a combination of surface renewal and eddy covariance equipment. As an affordable tool to estimate actual crop ET, Tule Technology sensors were also set up at all experimental sites.

## RESULTS AND DISCUSSION

Irrigation management. A comparison between the averages of applied water and actual consumptive water use for a 30-day period after seeding suggested that carrots are typically over-irrigated during plant establishment. An average of 3.8-in was measured as actual consumptive water use or ETa for this period across the experimental sites (Fig. 2), while the applied water varied from two to three times of this amount.

The results clearly demonstrated that the carrot sites had variable actual consumptive water uses depending upon early/late planting, irrigation practice, length of crop season, soil type, and weather conditions. For instance, site III was a sprinkler irrigated field with a dominant soil texture of sandy clay loam where the carrots were harvested very late, 193-day after seeding. The seasonal consumptive water use was 19.2-in at this site (Fig. 2). The results illustrate that the seasonal crop water use of fresh market carrots is nearly 16.0-in for a typical crop season of 160-day with planting in October. Approximately 50% of crop water needs occurred during the first 100 days after seeding and the other 50% during the last 60 days before harvest. Crop canopy model developed in this study demonstrated that fresh market carrots reach 85% canopy coverage by 100 DAS (day after seeding).

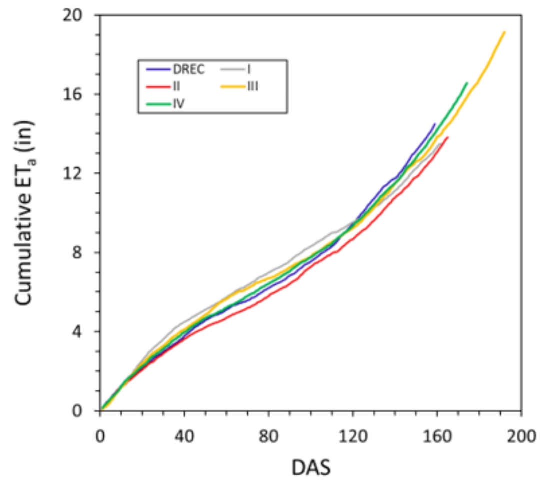



*Figure 2. Cumulative ETa at each of the experimental sites.*

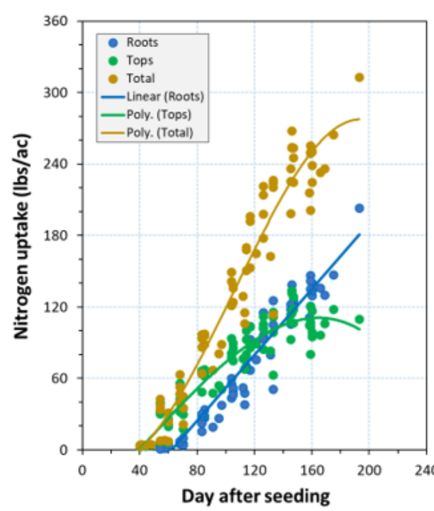



*Figure 3. N accumulation trends in storage roots, tops, and total (plants) over the growing season at the experimental sites. Data from the 2019-2020 and 2020-2021 trials in fresh market carrots were used for this analysis (Montazar et al., 2021b).*

Nitrogen management. The results demonstrated that a wide range of N accumulated both in roots and tops at harvest (Fig. 3). For instance, a total N content of 312.9 lbs. ac-1 was observed in a fresh market carrot field with a long growing season of 193-day, including 202.9 and 110.0 lbs. N ac-1 in roots and tops, respectively. The total N accumulated in plants (roots + tops) was less than 265 lbs. ac-1 in the other sites.

A linear regression model was found for the total N uptake in roots after 60-73 DAS without declining near harvest. Small gradual increases in N contents of roots were observed until about 65 DAS. This suggested that N begins to accumulate at a rapid rate between 65 and 80 DAS, however, the period of rapid increase could vary depending on early (September) or late (November) plantings. N uptake in tops increased gradually following a quadratic regression, and in most sites levelled off or declined slightly late in the season. The findings suggest that a total N accumulation of 260 lbs. ac-1 occurred by 160 DAS, with 145 lbs. ac-1 in roots and 115 lbs. ac-1 in tops.

Across all sites, nearly 28% of seasonal N accumulation occurred by 80 DAS, when the canopy cover reached an average of 67% (Montazar et al., 2021a). The large proportion of N content was taken up during a 30-day period (50 DAS – 80 DAS). The results also suggest that nearly 50% of the total N was taken up during a 50-day period (80 DAS through 130 DAS). This 50-day period appears to be the most critical period for N uptake, particularly in the storage roots, when carrots developed the large canopy and the extensive rooting system. For a 160-day crop season, 22% of N uptake could be accomplished over the last 30-day before harvest.

Recommendations. Careful management of N applications in the low desert carrots is crucial because fertilizers are the main source of N, particularly due to low organic matter content of the soils and very low nitrate level of the Colorado River water. The majority of N is taken up during the months of December to February, and hence, proper N fertility in the effective crop root zone is essential during this period. An integrated optimal N and water management needs to be approached to accomplish greater N and water efficiency, and consequently keeping lower rates beneficial to overall profitability.

## LITERATURE CITED


Montazar, A.; Geisseler, D.; Cahn, M. (2021a). Spatial Variability of Nitrogen Uptake and Net Removal and Actual Evapotranspiration in the California Desert Carrot Production System. Agriculture, 11 (8), 752: https://doi.org/10.3390/agriculture11080752.

Montazar, A.; Geisseler, D.; Cahn, M. (2021b). New Knowledge-Based Information Developed to Enhance Water and Nitrogen Use Efficiency in the Desert Fresh Market Carrots. Progressive Crop Consultant, September/October 2021, 8-13.


## ACKNOWLEDGEMENTS


Funding for this study was provided by the California Department of Food and Agriculture (CDFA) - Fertilizer Research and Education Program (FREP). The research team gratefully acknowledges the farms that are being contributing to this project, the UCCE Imperial County staff, the UC DREC staff, and several student assistants for their help in field-work-related tasks during this study.

# Certification and Distance Learning for Fertigation


## Project leader

**Charles M. Burt**
Chairman
Irrigation Training and Research Center (ITRC)
Cal Poly State University
San Luis Obispo, CA 93407-0740
(805) 748-3863
cburt@calpoly.edu

## Co-Leader

**Franklin Gaudi**
Project Manager
ITRC
(805) 207-7137
fgaudi@calpoly.edu


## INTRODUCTION

Fertigation is the application of fertilizers plus water treatment chemicals such as soluble gypsum, acid, and other related chemicals to crops via irrigation systems. There is a lack of accessible training for irrigators and specialists regarding both simple and complex concepts of the chemistry, fertilizer needs, application hardware, and irrigation system characteristics. This project is intended to address that with both English and Spanish training materials and certifications.

## OBJECTIVES

1. Prepare written material for training.
   a. The recent English second edition of the book Fertigation, sponsored by FREP, was already available for free download
   b. Spanish material would be developed.
2. Prepare approximately 21 training modules would be developed; 11 would be in Spanish.
3. The laboratory exercises would be available on YouTube videos in English and Spanish.
4. ITRC will work with the Irrigation Association and others to develop a certification program in both English and Spanish.

## DESCRIPTION

The videos and training materials are to be improved versions of the Fertigation class that has been taught in the Cal Poly BioResource and Agricultural Engineering Dept. since about 1980. The proposed modules, each with questions and a quiz, are shown in the table below.

*Table 1. The proposed training modules, each with questions and a quiz*

| | Module Topic | Modules in both English and Spanish | | Additional modules only in English | |
|---|---|---|---|---|---|
| | | California Fertigator Certification (interactive) | YouTube (video only) | IA (interactive) | YouTube (video only) |
| 1 | Linkage between irrigation and nitrogen management and the environment. Will include interviews with impacted communities or NGOs. | x | x | | |
| 2 | Nutrient needs of crops – purpose, amounts, timing (general) | x | x | | |
| 3 | Basic soil principles – CEC, AWHC, depletion patterns | x | x | | |
| 4 | Tests to assess nutrient needs – plant, soil, water. Contribution of N in irrigation water. | x | x | | |
| 5 | Converting between fertilizer labels and soil and plant | x | x | | |
| 6 | How nutrients move and are stored in the soil; nitrogen leaching | x | x | | |
| 7 | Nitrogen conversions and types; spoon feeding versus infrequent dosages. | x | x | | |
| 8 | Irrigation system uniformity and efficiency | x | x | | |
| 9 | Safety | x | x | | |
| 10 | Injection duration, chemical travel time, large dosages | x | x | | |
| 11 | Venturi injector operation | x | x | | |
| 12 | Specific fertilizers | | | x | x |
| 13 | Fertigation for soil infiltration problems | | | x | x |
| 14 | Chemigation for drip system maintenance | | | x | x |
| 15 | Solubility and interaction between various nutrients | | | x | x |
| 16 | Misc. fertigation injection hardware | | | x | x |
| 17 | Details of injection with specific irrigation methods | | | x | x |
| 18 | Specific crop requirements for major crops of California | | | x | x |
| | | Video only | | | |
| | | Calif. Fert | YouTube | IA | |
| 19 | Resources (FREP, UC, ITRC, etc.) | x | x | x | |
| 20 | Interviews with agronomists and consultants | x | x | x | |
| 21 | Interviews with farmers | x | x | x | |

## RESULTS AND DISCUSSION

The original proposal did not include the translation of the Fertigation book into Spanish, but it was soon realized that the book represents an essential background document for anyone who wants to go beyond the video modules.  So the book was translated into Spanish.

Because of delays in securing the contracts and subsequent COVID-19 problems, the project has not advances quite as fast as originally intended.  However, the most complex portions of the video learning modules are the laboratory exercises.  Those have all been completed except for some final editing on a few.  Those videos are:

- Compatibility of different fertilizers
- Volatilization of ammonia
- Calibration of various fertilizer injectors
- How to vary venturi injection rates.
- Calibration of injection rates, titration, and irrigation system travel time.
- Leaching of ammonium and nitrate.
- Conversion of urea in the soil.
- Injection devices.
- Sulfur burners.
- Purging sand media tanks and other filters of chemicals prior to backflush.

## TAKE-HOME MESSAGE

Excellent, free training materials are now available via the ITRC web site (www.itrc.org/books/)  that were not there before this program was funded.  They are:

- "Fertigation" in English
- "Fertirrigación" in Spanish
- "Drip and Micro Irrigation Design and Management" in English

Ten (10) YouTube videos of laboratory demonstration should be available by the end of September.

## ACKNOWLEDGEMENTS

This work has been entirely supported by FREP.

# Outreach and Revenue Generation for Sustaining CropManage Irrigation and Nutrient Management Decision Support Tool


## Project leader

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

## Cooperators

**Aliasghar (Ali) Montazar**
Irrigation and Water Resources Advisor
UC Cooperative Extension, Imperial & Riverside Counties
1050 East Holton Road
Holtville, CA 92250-9615
(442) 265-7707
amontazar@ucanr.edu

**Daniele Zaccaria**
Irrigation Water Management Specialist
LAWR/Hoagland
One Shields Avenue
Davis, CA 95616
(530) 219-7502
dzaccaria@ucdavis.edu

**Brenna Aegerter**
Vegetable Crop Advisor
UC Cooperative Extension, San Joaquin County
2101 East Earhart Ave, Suite 200
Stockton, CA, CA 95206-3924
(209) 953-6114
bjaegerter@ucanr.edu

**Khaled M. Bali**
Irrigation Water Management Specialist
Kearney Agricultural Research & Extension Center
9240 S. Riverbend Ave.
Parlier, CA 93648
559-646-6541
kmbali@ucanr.edu

**Gabriel Youtsey**
Chief Innovation Officer
UCANR
2801 Second Street
Davis, CA 95618
530-750-1314
gdyoutsey@ucanr.edu

**Gerry Spinell**
Production Horticulture Advisor
Cooperative Extension
9335 Hazard Way
Suite 201
San Diego, CA 92123
530-304-3738
gspinelli@ucanr.edu

**Mae Culumber**
Nut Crops Farm Advisor
UC Cooperative Extension Fresno County
550 E. Shaw Avenue, Suite 210-B
Fresno, CA 93710
559-241-7526
cmculumber@ucanr.edu

**Michelle Leinfelder-Miles**
Delta Crops Resource Management Advisor
2101 E. Earhart Ave., Ste 200
Stockton, CA 95206 (209) 953-6100 office
(209) 953-6128 fax mmleinfeldermiles@ucanr.edu

## INTRODUCTION

California farmers are under regulatory pressure to use fertilizer nitrogen efficiently and demonstrate that they are following best management practices. Because nitrate can readily leach in soil, 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 and water needs and resulted in several spreadsheet and on-line tools that growers can use to determine appropriate amounts of fertilizer and water to apply to their crops.

CropManage (CM) is an online decision support tool developed by UCANR for assisting growers with efficiently managing water and nitrogen fertilizer to match the site-specific needs of their crops. 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. With financial support of CDFA-FREP, CM was originally developed in 2011 to help farmers estimate irrigation schedules in lettuce using CIMIS ETo data and determine fertilizer N needs using the soil nitrate quick test and models of N uptake. Later CM was expanded to include other coastal crops, including baby salad greens, broccoli, cabbage, cauliflower, celery, spinach, strawberry, and raspberry. Funding from CDFA-FREP and DWR facilitated adapting CM for central valley crops including alfalfa, almond, walnut, pistachio, and processing tomato.

CM is used by growers, farm managers, consultants, governmental and nonprofit agencies. With the addition of new crops and features grower adoption of CM has steadily increased during the past 5 years, often providing more than 2000 recommendations per month during the growing season (March – November). Nevertheless, more outreach in the form of dedicated user support, hands-on workshops, and presentations at industry meetings could potentially boost grower adoption of the decision support tool, especially for regions such as the central valley and the southern desert where growers are less familiar with CM, or with the new features and commodities that have been recently added to the software. Also training of technical support providers such as consultants, resource conservation staff, and extension advisors on CropManage is needed in these regions to facilitate grower adoption.

Although CM has always been free for users, fixed costs of maintaining and updating the software have become an increasing concern. Hosting CropManage on a professional cloud server and storing user data has fixed costs. UC Farm Advisors have relied on grants to pay these expenses as well as the salary of a full-time professional software engineer who keeps CropManage running smoothly and adds new capabilities and features to the decision support tool.

This project addresses both increasing outreach and training on CM to growers, consultants, technical support providers, and UC farm advisors as well as explore and implement a strategy to continue funding software development.

## OBJECTIVES

The proposed project would accomplish two goals that would increase the impact of CropManage on improving irrigation and nutrient management in California:

1. Target outreach on irrigation and nitrogen management using the CropManage decision support tool for growers

and industry groups producing commodities recently added to the software or are unfamiliar with the decision support tool.

2. Develop and implement a plan that would generate funding to sustain CropManage software into the future.

## DESCRIPTION

Outreach on CropManage will be accomplished through introductions at industry and grower meetings and through hands-on trainings taught virtually or through in-person meetings. Additionally, help resources for CropManage will be developed including adding tutorial articles to the CropManage help (help.cropmanage.ucanr.edu), a quarterly newsletter to introduce new features that will be delivered electronically to CM users, Spanish language translation of terms and labels, and Spanish language how-to videos. One-on-one help will be offered to users through contacts from the CropManage hotline or the CropManage "feedback" link. Revenue generation for sustaining CropManage will be explored through an oversight committee that will evaluate options such as subscription and donation-based models, as well as sponsorship from for-profit, and non-profit organizations, as well as commodity groups, and governmental agencies. Existing CM users will be invited to participate in a survey to explore revenue generation options.

Automated reporting capabilities will be augmented in CropManage which may also increase the user-base as well as lead to revenue generation. These reports include summaries to assist growers with regulatory compliance such as calculating the applied nitrogen from fertilizer and water sources and for determining N removal in harvested products, and monthly reports to assist Farm advisors and consultants to tabulate the acres and number of recommendations made by CropManage users by commodity and county.

Finally, another update that will be explored that may lead to a larger user-base and revenue generation is to add task management capabilities to CropManage. This may be accomplished by interfacing CropManage with existing software used by growers and/or developing a simple native app that can be used on a smartphone. Adding task management capabilities would greatly simplify data entry for farming operations that want to adopt CropManage on a large scale.

## ACCOMPLISHMENTS

### Outreach

Although the current COVID pandemic has reduced the ability to hold in person trainings, a virtual hands-on workshop was held in May 2021 with more than 60 participants. Additional presentations on CropManage were made at four grower educational meetings for clientele in the Southern Desert, Central Coast, and Central Valley regions. Further workshops and presentations are planned for the upcoming fall and winter. The help section of CropManage was expanded with additional articles and Frequently Asked Question answers, and six Spanish language how-to-videos.

### Revenue Generation

A committee within UC Division of Agriculture and Natural Resources (UCANR) was established for overseeing revenue generation strategies for sustaining CropManage. A business plan is currently under development for adding subscription services and will be reviewed in the upcoming months. A donation link was added to the CropManage website and has received funding directly from CropManage users. Software development costs and support have been significantly reduced through the recruitment of an inhouse software engineer dedicated to CM.  Collaboration has also begun with two private companies to add task management capabilities to CM.  In addition to exploring avenues to generate funding from CropManage users, several research grants were awarded to add new capabilities and crop types to the software platform that will expand the user-base.


## ACKNOWLEDGEMENTS

We thank the California Tomato Research Institute, Almond Board of California, and Central Coast Grower Shipper Association for their assistant and support of this project as well as funding from CDFA Fertilizer Research and Education Program.

# University of California Nursery and Floriculture Alliance Fertilizers and Plant Nutrition Workshops for Greenhouse and Nursery Growers


## Project Leaders

**Lorence R. Oki, Ph.D.**
Cooperative Extension (CE) Specialist and Co-Director UC Nursery and Floriculture Alliance (UCNFA)
University of California, Davis
Department of Plant Sciences, MS6
One Shields Avenue
Room 1110 Environmental Horticulture
Davis, CA 95616-8780
(530) 754-4135
lroki@ucdavis.edu

**Dave Fujino, Ph.D.**
Executive Director
California Center for Urban Horticulture and Co-Director UCNFA
University of California, Davis
College of Agriculture and Environmental Sciences
One Shields Avenue
Room 1108 Environmental Horticulture
Davis, CA 95616-8570
(530) 754-7739
dwfujino@ucdavis.edu

**Don Merhaut, Ph.D.**
Associate CE Specialist, Nursery and Floriculture Crops
University of California, Riverside
Department of Botany and Plant Sciences
4118 Batchelor Hall Extension
Riverside, CA 92521
(909) 560-0038
donald.merhaut@ucr.edu

**Maria de la Fuente, Ph.D.**
Director UC CE Monterey County and CE Advisor Monterey, San Benito, and Santa Cruz Counties
1432 Abbott Street
Salinas, CA 93901
(831) 759-7358
medelafuente@ucanr.edu


## INTRODUCTION

Fertilizers are an essential part of greenhouse and nursery plant production. Crops in these systems are grown in substrates that are “synthetic” in that they contain little to no natural mineral soils. Due to the limited fertility provided by these substrates, nutrition must be provided, mostly with fertilizers, for healthy and productive growth.

Another challenge to greenhouse and nursery production in California is that the majority of these crops are grown in containers, although there is some field production of specific nursery and floriculture crops. In either case, since these crops are grown in highly intensive systems, high plant densities and shortened crop times, there is also a high demand for resources including water, energy, labor, and nutrients.

Improper management of plant nutrition can affect crop health. Both under- and over-applying fertilizers can result in poor crop quality, which not only has negative economic impacts, but also can result in polluting surface and groundwater.

This project will utilize workshop programs and materials developed under Agreement Number 16-0678-000-SA. The previous project presented 8 workshops in English and Spanish and this proposal would provide 8 additional short courses (4 in English, 4 in Spanish) to respond to the requests we have received for this workshop.

## OBJECTIVES

Objective 1: Review and improve the workshops that were provided by the previous CDFA FREP grant (Agreement Number 16-0678-000-SA). Workshops will be modified from half-day events to full-day events to allow for grower schedule accommodation, more content and demonstrations, greater discussion amongst attendees, and minimization of travel for project staff. Improvements will be made based on grower-attendee feedback from previous post-workshop surveys and instructor insight. Content will be expanded and may include demonstrations of how to monitor irrigation water and media conditions.

Objective 2: Provide 8 new workshops (4 in English, 4 in Spanish) for growers on plant nutrition and fertilizer management. Workshop locations may include areas with high concentrations of nursery and greenhouse production such as San Diego, Ventura, the San Joaquin Valley, and Salinas/Watsonville. At each location, day 1 will be the English workshop and day 2 will be the Spanish workshop. Workshop attendees will be surveyed to determine if workshops on additional topics regarding managing plant nutrition and the use of fertilizers would be helpful to growers for efficiently using fertilizers to optimize crop growth and minimize environmental impacts.

Objective 3: Continue to monitor the plant nutrition YouTube videos produced under the previous grant (Agreement Number 16-0678-000-SA). These videos were announced at the UCNFA website (http://ucnfa.ucanr.edu/), included a link to the list of the videos (http://ucnfa.ucanr.edu/Fertilizers_and_Plant_Nutrition_Videos), and posted on the UCNFA YouTube channel (https://www.youtube.com/channel/UC7OYtL9PEKN4CzcJLBYoFdg) for easy access by growers and their personnel. Viewership totals and video comments will be monitored. Videos will be assessed and improvements to the existing videos may be proposed. Additional topics for future videos may also be proposed.

## DESCRIPTION

This project builds upon prior work by the University of California Nursery and Floriculture Alliance (UCNFA) and a previously awarded CDFA FREP grant (Agreement Number 16-0678-000-SA).

As part of a long-term project, the UCNFA team has been providing half-day English and Spanish workshops on plant nutrition and fertilizer management since 2011. Over the years, these workshops have been revised, expanded, and offered to growers throughout California. A listing of previous workshops can be found at http://UCNFA.UCANR.edu.

In the previously awarded CDFA FREP grant titled "University of California Nursery and Floriculture Alliance Fertilizers and Plant Nutrition Education Program," 8 half-day workshops (4 in English and 4 in Spanish) were offered during the 2017-2018 project period. These workshops included new topics and demonstrations incorporated by the UCNFA team in response to feedback from attendees on previous events. This grant also provided funding for the production of educational nutrient management YouTube videos.

The success of the workshops led to numerous requests for more events. This project will provide 8 additional workshops (4 in English, 4 in Spanish) to meet grower demand. Workshops will be held throughout California in locations of high concentrations of nursery and greenhouse growers such as San Diego, Ventura, the San Joaquin Valley, and Salinas/Watsonville. The workshops will be modified from half-day events to full-day events. This will accommodate the incorporation of more content and demonstrations and greater discussion amongst attendees. Post-workshop surveys will provide feedback for continuous workshop improvement and insight on grower likelihood of implementing efficient fertilizer management practices.

The earlier workshops delivered content in 2 half-day sessions.  On the first day, Part 1 of the workshop series described the roles of plant nutrients. Content was provided in English in the morning and to a different audience in Spanish in the afternoon. About 1 month later, Part 2 of the series discussed operational topics related to fertilizer use and management, again in English in the morning and Spanish in the afternoon. This format was used based on surveys of attendees of the pilot workshop conducted in the previous project. However, we found that the audiences of Parts 1 and 2 were different, so few attendees received the entirety of the information presented by the program. This project proposes to provide all of the content in a single day so that attendees will receive all of the relevant information on plant nutrition and fertilizer management. This format also reduces travel costs since the transportation costs per workshop are reduced.

## ACCOMPLISHMENTS

As this is an outreach and extension project of in-person workshops, no events took place due to COVID restrictions.  Plans are in progress to proceed with in-person events for 2022 with contingencies to transition to web-based events should COVID restriction remain in place during the summer of 2022. The project team will meet to discuss and adjust the workshop program for web-based delivery.  Changes that will be considered may include breaking the program up into shorter sessions and adapting demonstrations for online presentations.  There will also be considerations for synchronous (live) delivery to allow for questions and recording the session for later play back.

## ACKNOWLEDGEMENTS

We would like to acknowledge the funding support from CDFA FREP for this project under agreement 20-0963-000-SA and for the funding for the earlier project that initiated and developed this extension program under agreement 16-0678-000-SA.

# Nitrogen Response of Industrial Hemp Cultivars Grown for CBD, Essential Oils


## Project Leaders

**Robert Hutmacher**
Univ. CA Cooperative Extension Specialist
UC Davis Plant Sciences Dept., UC West Side Research and Extension Center
PO Box 158, Five Points, CA 93624; (559) 260-8957; rbhutmacher@ucdavis.edu

**Daniel Putnam**
Univ. CA Cooperative Extension Specialist
UC Davis Plant Sciences Dept,
One Shields Avenue, Davis, CA 95616;
(530) 752-8982; dhputnam@ucdavis.edu

## Cooperators

**Sarah Light**
Univ. CA Coop. Extension Farm Advisor, Yuba and Sutter Counties
Yuba City, CA; selight@ucanr.edu

**Nicholas Clark**
Univ. CA Coop. Extension Farm Advisor, Fresno, Kings, Tulare Counties
Hanford, CA; neclark@ucanr.edu

**Daniel Geisseler**
UC Cooperative Extension Specialist
UC Davis Land, Air and Water Resources Dept, Davis, CA; djgeisseler@ucdavis.edu

**Geoffrey Koch**
PhD Graduate Assistant
UC Davis Land, Air and Water Resources Dept., Davis, CA; gmkoch@ucdavis.edu

Kayagene Corporation, Phylos Biosciences Corporation, Alkemist Laboratories


## OBJECTIVES

1. Evaluate for two biotypes of industrial hemp (autoflower/shorter-season types, full-season photoperiod-sensitive types) grown for essential oils such as cannabidiol (CBD) the impacts of N application amount and variety/growth habit/plant type on plant N uptake, harvest removal, yield responses.
2. Assess impacts of N management approach on THC and CBD tissue content, including partitioning to harvested portions of plants.

## DESCRIPTION

Two first year trial sites were prepared at the UC West Side REC (WSREC) in Fresno County with a Panoche clay loam soil, and at the UC Davis Campus Farm (UCD) in Yolo County with a Yolo fine sandy loam soil. Preliminary soil samples were collected and analyzed for N, P, K at field sites, and samples analyzed for use in N, P, K fertilization decisions. Based on analyses, supplemental P fertilizer (100 lbs 1-52-0) was applied prior to planting at the WSREC site based on analyses.

Sites were prepared, subsurface drip irrigation lines were installed (8-10 inches deep, two lines per bed 30 inches apart on 60 inch wide beds). For the 2021 growing season, seeds were provided by two seed companies (Phylos and Kayagene for autoflower varieties N study), and transplants were provided by one company (Cultivaris for full season varieties in the nitrogen studies). Full-season, photoperiod-sensitive cultivars selected were “Scarlett” and “The Wife”, while “Maverick” and “Alpha Nebula” were chosen for the Autoflower, short season types. We requested and received assistance from seed company(s) to identify varieties targeted for CBD production potential. Seed companies provided certificates of analysis to certify that their varieties are bred for low THC content and we have notified County Agricultural Commissioners for the respective sites of plantings, and will follow all state and federal laws, and University policy regarding reporting, including harvests.

Transplants of the full-season types were planted the third week of June at the UCD site, and early in the fourth week of June at the WSREC site. The initial plantings of the direct-seeded autoflower cultivars were done within a week of the timing of the full season types, but the plantings were not successful in producing an acceptable stand of plants at either location due to variability in planting depths and related problems impacting emergence. Different types of planters were used for a second round of direct seed plantings of the autoflower cultivars, with the second plantings occurring the second week of July at the UCD site and the end of the third week of July at WSREC. Good stands of plants were achieved in this second planting at both sites. Plants were established (through essentially complete seedling emergence) using sprinkler irrigation (WSREC) or surface drip irrigation (UCD), after which the irrigations were applied using the subsurface drip systems,

Drip-injection units used to establish five fertilizer levels for each study, with a different range of applied N for the autoflower cultivars (five treatments ranging from approximately 20-30 lbs N/acre to 120 lbs N/acre) versus 30 to 220 lbs N/ac in the full season cultivars. In past trials, time to harvest will differ markedly between autoflower types (estimated 70-85 days emergence to harvest for CBD) versus approximately full-season types (100-130 days for the photoperiod-sensitive (PPS) types). Since the autoflower types will be established from seed plantings, and the full season types from transplants, actual duration of time between plantings and harvest will be very different from the time periods shown above. Based on differences in ultimate size of plants, growth duration, and optimal planting densities, we are running the nitrogen management experiments on these two very different types of hemp cultivars (autoflower versus full-season) as completely separate field trials, with the different ranges of applied nitrogen described above, and with different irrigation water applications based on plant size and duration of growth. Planting densities for the trials were adjusted from original plans based on analysis of experiences during the prior two years in other hemp experiments. Plant densities used were approximately 17,000-20,000 plants/ac for autoflower varieties (typically smaller plants) and 6,000-7,000 plants/ac for larger, longer growing season photoperiod- sensitive cultivars. Plots used are 25-30 feet in length (depending on location/field site), 3-4 beds in width, with two planted rows per bed approximately 2.5 feet apart.

## RESULTS AND DISCUSSION

The autoflower varieties have been observed to produce far fewer branches that the full season types, and the timing of the beginning of first cola (flower buds) development is about 2 to 3 weeks earlier in the autoflower cultivars. For the purposes of running a nitrogen fertilizer response trial, we have attempted to also adjust the irrigation water application amounts to also reflect the difference in plant size and canopy cover between the smaller autoflower cultivars versus the full season cultivars. This has meant about 30 to 40 percent lower water applications for the autoflower cultivars, and our neutron probe and soil sampling to date has backed up this idea of reduced irrigation water amounts per week and for a shorter duration of weeks in the autoflower cultivars. These measurements have indicated that we are not markedly over-irrigating or under-irrigating the autoflower cultivars in this nitrogen fertilization trial.

Preliminary observations from the first year of the field trials (which have not been harvested yet at the time of this report) are that there are significant differences in plant width and height of both autoflower and full-season cultivars to increasing nitrogen applications, as might be expected when beginning stored soil nitrogen is low to moderate. Harvests to be done in September and October will provide information on total plant dry weight and cola dry weight responses across treatments.


*Figure 1. Shorter-season autoflower plants (left photo) and full-season plants (right) during the first week of September, 2021 at the UC West Side REC location.*

At the WSREC location, autoflower plants will likely be ready for harvest within 2 weeks of the timing of the Figure 1 photos, while harvest will probably be late-September in the full-season cultivars at the WSREC site in 2021 even though the full-season types were grown from transplants and the auto-flower types were direct-seeded. Harvests will be 7-10 days earlier at the UCD location due to the slightly earlier planting dates. Plant total dry weights will be measured along with cola fresh and dry weights to determine yield responses, and cola versus stem plus leaf total nitrogen content will be determined on select plants to assess peak above-ground nitrogen uptake in these trial sites.

## TAKE-HOME MESSAGE

Research on best management practices for industrial hemp is made more complicated by the fact that there are a wide range of available cultivars of hemp with widely different plant characteristics including plant size, duration of growth and required growing season length for commercial harvests, final product of interest (earlier harvests of colas (flower buds) for essential oils, versus later harvests of mature plants when grown for fiber or seed).

This current nitrogen study includes both full season and autoflower cultivars, but this trial is evaluating nitrogen management practices of industrial hemp is only for hemp cultivars grown for essential oils such as CBD, so it also is of importance that we will be testing for harvest timing concentrations of THC and CBD across cultivars and treatments. Differences in the prevailing growth habit of autoflower cultivars versus full-season photoperiod-responsive cultivars are large in the tested varieties, and the basis for the decision to use a lower range of N fertilizer application treatments in the shorter-season smaller autoflower cultivars than with the much larger plants in the longer growing season full-season cultivars.

## ACKNOWLEDGEMENTS

This industrial hemp multi-year nitrogen management trial is supported by the California Department of Food and Agriculture Fertilizer Research Education Program (CDFA-FREP) as project #20-0964, and that support is gratefully acknowledged. Donations of hemp transplants/clones and seed for conducting the trials were received from Cultivaris Hemp of Encinitas, Cal., Kayagene, LLC, of Hollister, Cal., Phylos Biosciences of Portland, Oregon. The project will also include THC and CBD analyses, with donation of analytical services by Alkemist Labs of Garden Grove, CA. These are incredibly valuable donations from each of these companies to assist with this project, and we wouldn't be able to do the study without this additional assistance.

# Techniques to Minimize Nitrate Loss from the Root Zone During Managed Aquifer Recharge


## Project Leaders

**Toby O'Geen**
Professor and Cooperative Extension Specialist
atogeen@ucdavis.edu

**Helen Dahlke**
Associate Professor
hdahlke@ucdavis.edu

**Scott Devine**
Post-Doctoral Researcher
smdevine@ucdavis.edu

**Isaya Kisekka**
Associate Professor
ikisekka@ucdavis.edu

**Thomas Harter**
Professor and Cooperative Extension Specialist
thharter@ucdavis.edu

**Majdi Abou Najm**
Associate Professor
mabounajm@ucdavis.edu

Department of Land, Air and Water Resources, University of California, Davis
One Shields Avenue, Davis CA 95616


## INTRODUCTION

The managed application of floodwaters on agricultural fields (Ag-MAR) is gaining a great deal of interest in California as a technique to offset groundwater overdraft (DWR, 2018). Despite its promising possibilities, there are significant challenges that need to be addressed before this practice can be widely implemented. One concern is the potential for groundwater contamination by nitrate (NO3-). While floodwaters are generally considered to be relatively low in nitrogen, it is likely that soils of many cropping systems have residual nitrogen after harvest in autumn that could be readily transported to groundwater during Ag-MAR, which happens in winter. Cost-effective strategies are needed to maximize groundwater recharge while minimizing groundwater contamination through NO3- leaching. During Ag-MAR, NO3- can follow several pathways, some of which include leaching, uptake, denitrification (conversion of NO3- to NOx, N2O, and N2 gases under anaerobic conditions) and/or immobilization of NO3- (soil microbes consume and immobilize NO3-). Occurrence and rates of these N-cycle processes is dependent on soil environmental conditions, and soil physical and chemical properties. For example, some fine-textured soils have drainage characteristics where anaerobic conditions can promote N losses by denitrification during Ag-MAR, whereas coarse textured soils may leach NO3- before it can be denitrified or immobilized (Waterhouse et al. 2021). Place-based guidance is needed to optimize Ag-MAR strategies to limit NO3- leaching.

## OBJECTIVES

The main research objective is to simulate Ag-MAR scenarios through a physically based hydrologic model to quantify aspects of the nitrogen cycle including leaching, mineralization, and denitrification during winter flooding of agricultural fields.

The specific objectives are as follows:

1. “Optimizing Denitrification” Identify anaerobic conditions created and maintained in a prewetting event to maximize denitrification while minimizing water and NO3- leaching
2. “Pulsed Applications” Identify scenarios of water-pulse intervals that maximize anaerobic conditions to promote denitrification and minimize aerobic conditions between events to limit N mineralization and subsequent nitrification and leaching
3. “Late Season Irrigation” Evaluate late season irrigations applied after harvest but prior to leaf drop that maximize residual N uptake

## DESCRIPTION

General Summary: We are developing and testing a modeling process where the effect of amount, timing, and duration of Ag-MAR on nitrogen transformations and translocations are evaluated over a range of soil types and different residual NO3- levels. We chose the Root Zone Water Quality Model (RZWQM). This tool is being used to evaluate how Ag-MAR can be optimized to influence the water budget and nitrogen cycle. It will evaluate potential differences relative to variation in soils and climate. We are simulating low, medium and high residual NO3- levels in soil. This modeling effort is informed by field data collected at six sites. The field sites used in this research project represent a range in suitability based on SAGBI Ratings (O’Geen et al., 2015), ultimately allowing us to tailor best management Ag-MAR strategies for agriculture in the Central Valley.

Rationale for modeling tool: Preliminary RZWQM trials suggest RZWQM can be used to further explore simulations of different combinations of Ag-MAR management, soil, climate, and crop factors in influencing NO3- leaching into groundwater. The RZWQM can be used to test a full array of soil-crop-climate combinations. Specifically, it has been demonstrated capable of accurately simulating NO3- leaching from agroecosystems. It also has built-in crop parameter datasets and models, making crop management scenarios (such as cover crop timing and growth) realistic to evaluate.

Modeling Approach: We created initial comparisons of Ag-MAR in the RZWQM. We compared a high and moderate residual NO3- concentration in soil. We also compared fallow and cover cropped soil conditions (Figures 1 and 2). Ag-MAR was simulated with either a cover crop (CC) planted in early November or fallow conditions with varying frequencies and timing of water application. Low frequency (LF) Ag-MAR began in mid-January with four 15-cm events spaced three weeks apart. High frequency (HF) Ag-MAR began in mid-January with four 15-cm events spaced one week apart. Very high frequency (VHF) Ag-MAR began in in either mid-January, mid-February, or mid-Mar with four 15-cm events spaced three days apart. Control runs included only background precipitation. All runs used climate data from the Parlier CIMIS station during a relatively wet winter (October 1, 2016, to April 30, 2017).

## RESULTS AND DISCUSSION

Preliminary Modeling: Across all scenarios initially tested (Figures 1-2), denitrification has barely figured in the RZWQM N mass balance, even though recent research suggests its importance in California Ag-MAR management (Waterhouse et al. 2021). Seasonal denitrification was just 0-1 kg ha-1 across all scenarios. Frequent irrigation in the Fall also did not increase denitrification in initial testing. Our plan is to next test the sensitivity of the denitrification rate constant and to develop appropriate denitrification rate assumptions for different soil types to address objectives 1 and 2.

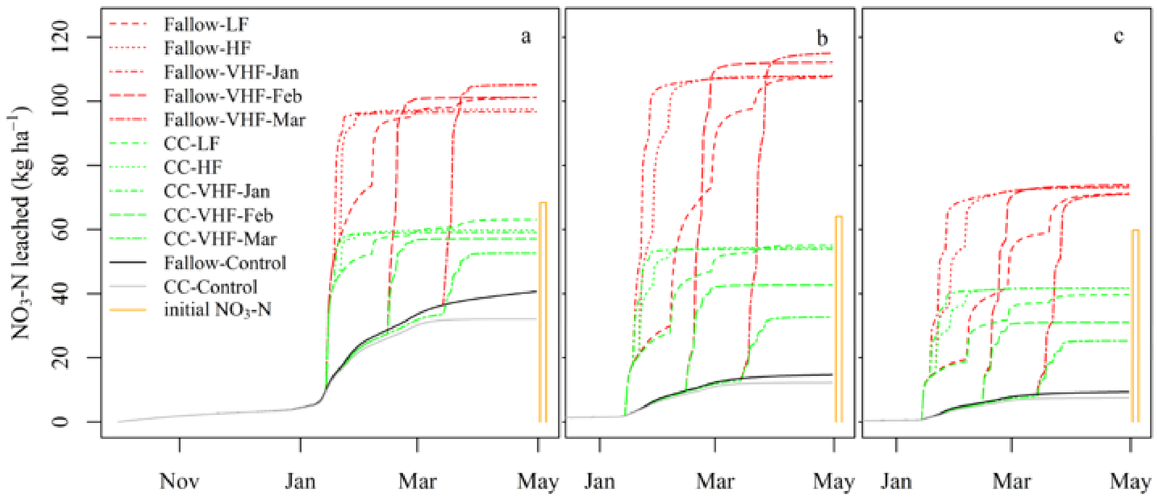



*Figure 1. Nitrate (NO3) leaching from an initial residual content of 60-68 kg NO¬3-N ha-1 (orange bar) comparing Root Zone Water Quality Model simulations of agricultural managed aquifer recharge (Ag-MAR) under a typical (a) coarse textured soil profile; (b) loamy textured soil profile; or (c) fine textured soil profile. Each profile was derived from a conceptual soil health region (Devine et al. 2021) using the region's median properties from the Soil Survey Geographic Database. Ag-MAR was simulated with either a cover crop (CC) planted in early November or fallow conditions with varying frequencies and timing of water application. Low frequency (LF) Ag-MAR began in mid-January with four 15-cm events spaced three weeks apart. High frequency (HF) Ag-MAR began in mid-January with four 15-cm events spaced one week apart. Very high frequency (VHF) Ag-MAR began in in either mid-January, mid-February, or mid-Mar with four 15-cm events spaced three days apart. Controls included only background precipitation. All runs used climate data from the Parlier CIMIS station during a relatively wet winter (October 1, 2016, to April 30, 2017).*

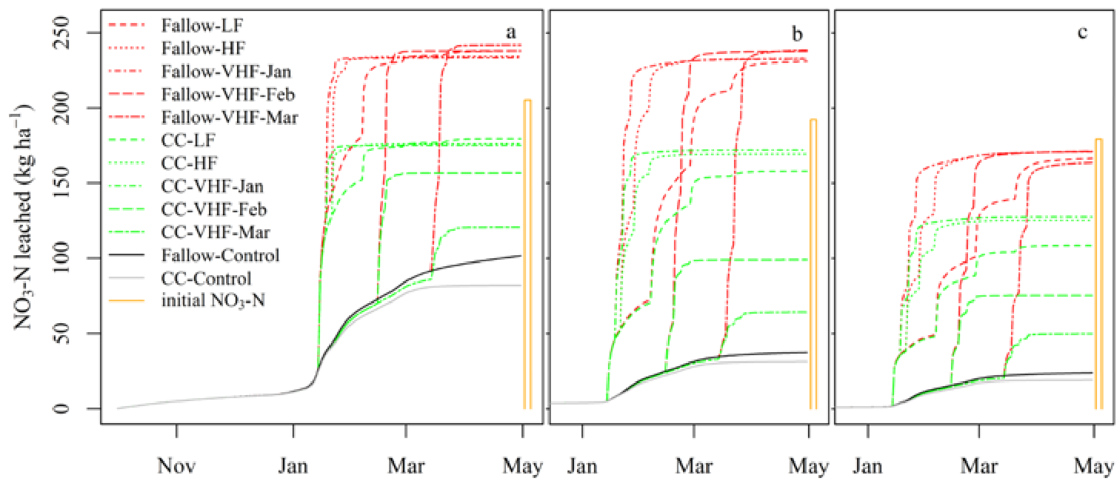



*Figure 2. Nitrate (NO3) leaching from an initial residual content of 179-205 kg NO¬3-N ha-1 (orange bar) comparing Root Zone Water Quality Model simulations of agricultural managed aquifer recharge (Ag-MAR) under a typical (a) coarse textured soil profile; (b) loamy textured soil profile; or (c) fine textured soil profile. Each profile was derived from a conceptual soil health region (Devine et al. 2021) using the region's median properties from the Soil Survey Geographic Database. Ag-MAR was simulated with either a cover crop (CC) planted in early November or fallow conditions with varying frequencies and timing of water application. Low frequency (LF) Ag-MAR began in mid-January with four 15-cm events spaced three weeks apart. High frequency (HF) Ag-MAR began in mid-January with four 15-cm events spaced one week apart. Very high frequency (VHF) Ag-MAR began in in either mid-January, mid-February, or mid-Mar with four 15-cm events spaced three days apart. Control runs included only background precipitation. All runs used climate data from the Parlier CIMIS station during a relatively wet winter (October 1, 2016, to April 30, 2017).*

Preliminary modeling demonstrates the combined benefits of cover cropping and later season water applications to minimize NO3- leaching during Ag-MAR. Allowing winter cover crops time to grow and uptake NO3- before practicing Ag-MAR is a promising strategy to improve the quality of recharge water. Generally, the fallow treatments had a larger cumulative flux of NO3- out of the rootzone that exceeded the initial residual NO3- present due to soil N mineralization and no NO3- uptake (Figures 1 and 2). NO3- leaching from fallow treatments were also insensitive to Ag-MAR timing. This particular finding may change as a result of future work to tune denitrification rate assumptions. Higher initial residual NO3- concentration was associated with more NO3- leached across all scenarios (Figure 2). Finally, soil texture appears to be an important controlling factor, as NO3- leached from fine textured soils tended to be less than both coarse and loamy textured soils. Cover cropping and later season water applications also had less of an effect on NO3- leached from coarse soils compared to finer textured soils (Figures 1a-c and 2a-c).

## LITERATURE CITED

O'Geen, A.T., M.B.B. Saal, H. Dahlke, D. Doll, R. Elkins, A. Fulton, G. Fogg, T. Harter, J.W. Hopmans, C. Ingels, F. Niederholzer, S. Sandovol Solis, P. Verdegaal and M. Walkinshaw. 2015. Soil suitability index identifies potential areas for groundwater banking on agricultural lands. California Agriculture 69:75-84.

Waterhouse, H., N. Bhavna Arora, N.F. Spycher, P.S. Nico, C. Ulrich, H. Dahlke, W. Horwath, 2021. Influence of agricultural managed aquifer recharge (AGMAR) and stratigraphic heterogeneities on nitrate reduction in the deep subsurface. Water Resources Research. https://doi.org/10.1029/2020WR029148

## ACKNOWLEDGEMENTS

This research is being supported by

CDFA-FREP.

# 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.

---

Promoting the adoption of soil nitrogen quick tests by Spanish-speaking operators on strawberry ranches in Santa Cruz and Monterey Counties, • *Gerry Spinelli*, 18-0535

Developing a Review Process for Continuing Education Courses for Growers who Complete the Nitrogen Management Plan Training Course, • *Parry Klassen,* 16-0703

University of California Nursery and Floriculture Alliance Fertilizers and Plant Nutrition Education Program • *Lorence Oki*, 16-0678

Develop Nutrient Budget and Early Spring Nutrient Prediction Model for Nutrient Management in Citrus • *Patrick Brown*, 16-0707

Online Decision Support Tools for Irrigation and Nitrogen Management of Central Valley Crops • *Michael Cahn,* 16-0710

Demonstration of a combined new leaf sampling technique for nitrogen analysis and nitrogen applications approach in almonds • *Patrick Brown*, 16-0708

Understanding Influences on Grower Decision-Making and Adoption of Improved Nitrogen Management Practices • *Mark Lubell*, 16-0620

N and P management in organic leafy greens • *Richard Smith*, 15-0522

Developing a decision support tool for processing tomato irrigation and fertilization in the Central Valley based on CropManage • *Daniel Geisseler,* 15-0410

New Fertigation Book • *Charles Burt,* 15-0393

Evaluation of the Multiple Benefits of Nitrogen Management Practices in Walnuts • *Parry Klassen*, 15-0360

Prediction of Summer Leaf Nitrogen Concentration from Early Season Samples to Better Manage Nitrogen Inputs at the Right Time in Walnuts, Prunes, and Pears • *Patrick Brown*, 15-0492

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

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

Improving Nitrate and Salinity Management Strategies for Almond Grown under Micro-irrigation • *Patrick Brown*, 15-0523

Prediction of Summer Leaf Nitrogen Concentration from Early Season Samples to Better Manage Nitrogen Inputs at the Right Time in Walnuts, Prunes, and Pears • *Patrick Brown*, 15-0492

Train the Trainer: A Nitrogen Management Training Program for Growers • *Terry Prichard and Parry Klassen*, 15-0392

Quantifying N2O Emissions under Different On-farm Irrigation and Nutrient Management BMPs that Reduce Groundwater Nitrate Loading and Applied Water • *Arlene Haffa and WIlliam Horwath, 15-0356*

Online Fertilization Guidelines for Agricultural Crops in California • *Daniel Geisseler, 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*

Field Evaluation and Demonstration of Controlled Resease N Fertilizers in the Western United States • *Charles Sanchez and Richard Smith, 14-0508*

A Data Driven Nitrate Leaching Hazard Index and BMP Assessment Tool • *Toby O'Geen, 14-0452*

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*

Chemistry, Fertilizer and the Environment – A Comprehensive Unit • *Judy Culbertson, Shaney Emerson, and Lyn Hyatt, 10-0010*

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*

California Certified Crop Adviser FREP Educational Project • *Dan Putnam, 08-0627*

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*

Optimizing Nitrogen Availability in Cherry Growth to Obtain High Yield and Fruit Quality • *Kitren Glozer, 07-0666*

Development of Certified Crop Adviser Specialty Certification and Continuing Education in Manure Nutrient Management • *Stuart Pettygrove, 07-0405*

California Certified Crop Adviser FREP Educational Project • *Dan Putnam, 07-0352*

Development and Implementation of Online, Accredited Continuing Education Classes on Proper Sampling and Application of Nitrogen/ Crop Nutrients • *Renee Pinel, 07-0223*

Evaluation of Humic Substances Used in Commercial Fertilizer Formulations • *T.K. Hartz, 07-0174*

Fertilizer Education Equals Clean Water • *Kay Mercer, 07-0120*

Can a Better Tool for Assessing 'Hass' Avocado Tree Nutrient Status be Developed? A Feasibility Study • *Carol Lovatt, 07-0002*

Development of Practical Fertility Monitoring Tools for Drip-Irrigated Vegetable Production • *Timothy K. Hartz, 06-0626*

Updating Our Knowledge and Planning for Future Research, Education and Outreach Activities to Optimize the Management of Nutrition in Almond and Pistachio Production • *Patrick Brown, 06-0625*

Development of a Model System for Testing Foliar Fertilizers, Adjuvants and Growth Stimulants • *Patrick Brown, 06-0624*

Site-specific Fertilizer Application in Orchards, Nurseriesand Landscapes • *Michael Delwiche, 06-0600*

Fertilization Techniques for Conservation Tillage Production Systems in California • *J Mitchell, 04-0808*

Exploring Agrotechnical and Genetic Approaches to Increase the Efficiency of Zinc Recovery in Peach and Pistachio Orchards• *R. Scott Johnson, Steven A. Weinbaum and Robert H. Beede, 04-0770*

Improving Water-Run Nitrogen Fertilizer Practices in Furrow and Border Check–Irrigated Field Crops • *Stuart Pettygrove, 04-0747*

Fertility Management in Rice • *Chris Van Kessel, 04-0704*

Detecting and Correcting Calcium Limitations • *Timothy K. Hartz, 04-0701*

Soil-Solution Partitioning of Trace Elements in Cropland Soils of California: Estimating the Plant Uptake Factors of As, Cd, and Pb • *Chang, 03-0088*

Potassium Fertility Management for Optimum Tomato Yield and Fruit Color • *Tim Hartz, 03-0661*

Precision Fertigation in Orchards: Development of a Spatially Variable Microsprinkler System • *Michael Delwiche et al., 03-0655*

Increasing Yield of the 'Hass' Avocado by Adding P and K to Properly Timed Soil N Applications • *Carol J. Lovatt, 03-0653*

Improving the Procedure for Nutrient Sampling in Stone Fruit Trees • *R. Scott Johnson, 03-0652*

Reevaluating Tissue Analysis as a Management Tool for Lettuce and Cauliflower • *Timothy K. Hartz, 03-0650*

Environmental Compliance and Best Management Practice Education for Fertilizer Distributors • *Renee Pinel, 03-0005*

Evaluation of Polyacrylamide (Pam) for Reducing Sediment and Nutrient Concentration in Tailwater from Central Coast Vegetable Fields • *Michael Cahn, 02-0781*

Practical Soil Test Methods for Predicting Net N Mineralization• *William Horwath, 02-0653*

Determination of Nursery Crops Yields, Nutrient Content, and Water Use for Improvement of Water and Fertilizer Use Efficiency • *Crum/Stark, 02-0651*

California Certified Crop Advisor • *Evans, 02-0331*

California State Fair Farm Upgrade Project • *Michael Bradley, Joe Brengle, and Teresa Winovitch, 01-0640*

Evaluating the Impact of Nutrient Management on Groundwater Quality in the Presence of Deep Unsaturated Alluvial Sediment• *Thomas Harter, 01-0584*

Crop Nitrate Availability and Nitrate Leaching under Micro-Irrigation for Different Fertigation Strategies • *Blaine Hanson and Jan W. Hopmans, 01-0545*

Development of Lime Recommendations for California Soils • *Miller, 01-0511*

Development of a Leaf Color Chart for California Rice • *Randal Mutters, 01-0510*

Efficient Phosphorus Management in Coastal Vegetable Production • *Timothy K. Hartz, 01-0509*

Development of BMPs for Fertilizing Lawns to Optimize Plant Performance and Nitrogen Uptake While Reducing the Potential for Nitrate Leaching • *Robert Green et al., 01-0508*

Site-Specific Fertilizer Application in Cotton • *Richard Plant, 01-0507*

Effects of Cover Cropping and Conservation Tillage on Sediment and Nutrient Losses to Runoff in Conventional and Alternative Farming Systems • *William R. Horwath et al., 01-0473*

Fertilization Technologies for Conservation Tillage Production Systems in California • *Jeffrey Mitchell, 01-0123*

Long Term Rice Straw Incorporation: Does It Impact Maximum Yield? • *Chris Van Kessel & William Horwath, 00-0651*

Seasonal Patterns of Nutrient Uptake and Partitioning as a Function of Crop Load of the 'Hass' Avocado• *Rosencrance, 00-0621*

Field Evaluations and Refinement of New Nitrogen Management Guidelines for Upland Cotton: Plant Mapping, Soil and Plant Tissue Tests • *Robert Hutmacher, 00-0604*

California Certified Crop Advisor Management Project • *Hank Giclas, 00-0516*

Improving the Diagnostic Capabilities for Detecting Molybdenum Deficiency in Alfalfa and Avoiding Toxic Concentrations for Animals• *Meyer, 00-516*

Ammonia Emission from Nitrogen Fertilizer Application • *Charles Krauter, 00-0515*

Reducing Fertilizer Needs of Potato with New Varieties and New Clonal Strains of Existing Varieties • *Ronald Voss, 00-0514*

Minimizing Nitrogen Runoff and improving Use Efficiency in Containerized Woody Ornamentals through Management of Nitrate and Ammonium • *Donald J. Merhaut, 00-0509*

Location of Potassium-Fixing Soils in the San Joaquin Valley and a New, Practical Soil K Test Procedure • *Stuart Pettygrove, 00-0508*

Effect of Different Rates of N and K on Drip-Irrigated Beauregard Sweet Potatoes • *Bill Weir, 00-0507*

Evaluation of Controlled-Release Fertilizers for Cool Season Vegetable Production in the Salinas Valley • *Richard Smith, 00-0506*

Site-Specific Variable Rate Fertilizer Application in Rice and Sugar Beets • *Plant, 00-0505*

Precision Horticulture: Technology Development and Research and Management Applications • *Patrick Brown, 00-0497*

From the Ground Up: A Step-By-Step Guide to Growing a School Garden • *Jennifer Lombardi, 00-0072*

On-Farm Monitoring and Management Practice Tracking for Central Coast Watershed Working Groups • *Kelly Huff, 00-0071*

Teach the Teachers: Garden-Based Education about Fertility and Fertilizers • *Peggy S. McLaughlin, 00-0070*

Pajaro Valley Nutrient Management Education & Outreach Project• *Win, 99-0764*

Nitrogen Budgeting Workshops • *Jim Tischer, 99-0757*

The Role of Inorganic Chemical Fertilizers and Soil Amendments on Trace Element Contents of Cropland Soils in California • *Chang, 99-0533*

Air Quality and Fertilization Practices: Establishing a Calendar of Nitrogen Fertilizer Application Timing Practices for Major Crops in the San Joaquin Valley • *King, 98-0471*

Evaluating and Demonstrating the Effectiveness of In-Field Nitrate Testing in Drip- and Sprinkler-Irrigated Vegetables • *Marc Buchanan, 99-0756*

Demonstration of Pre-Sidedress Soil Nitrate Testing as a Nitrogen Management Tool • *Timothy K. Hartz, 98-0513*

Efficient Irrigation for Reduced Non-Point Source Pollution from Low Desert Vegetables • *Charles Sanchez, Dawit Zerrihun, and Khaled Bali, 98-0423*

Effect of Cover Crop or Compost on Potassium Deficiency and Uptake, and on Yield and Quality in French Prunes • *Rosencrance, 98-0422*

Winter Cover Crops Before Late-Season Processing Tomatoes for Soil Quality and Production Benefits • *Gene Miyao & Paul Robins, 97-0365 M99-11*

Nitrogen Mineralization Rate of Biosolids and Biosolids Compost • *Tim Hartz, 97-0365 M99-10*

Precision Agriculture in California: Developing Analytical Methods to Assess Underlying Cause and Effect within Field Yield Variability • *Chris Van Kessel, 97-0365 M99-08*

Development of an Educational Handbook on Fertigation for Grape Growers • *Glenn T. McGourty, 97-0365 M99-07*

Relationship between Fertilization and Pistachio Diseases • *Themis J. Michailides, 97-0365 M99-06*

The Effect of Nutrient Deficiencies on Stone Fruit Production and Quality - Part II • *Scott Johnson, 97-0365 M99-05*

Nitrogen Fertilization and Grain Protein Content in California Wheat • *Lee Jackson, 97-0365 M99-04*

Development of Fertilization and Irrigation Practices for Commercial Nurseries • *Richard Evans, 97-0365 M99-03*

Irrigation and Nutrient Management Conference and Trade Fair • *Sonya Varea Hammond, 97-0365 M99-02*

Agricultural Baseline Monitoring and BMP Implementation: Steps Towards Meeting TMDL Compliance Deadlines within the Newport Bay/San Diego Creek Watershed • *Laosheg Wu & John Kabashima, 97-0365 M99-01*

Interaction of Nitrogen Fertility Practices and Cotton Aphid Population Dynamics in California Cotton • *Larry Godfrey & Robert Hutmacher, 97-0365 M98-04*

Potassium Responses in California Rice Fields as Affected by Straw Management Practices • *Chris Van Kessel, 97-0365 M98 03*

Development and Demonstration of Nitrogen Best Management Practices for Sweet Corn in the Low Desert • *Jose Aguiar, 97-0365 M98-02*

Development of Nitrogen Best Management Practices for the “Hass” Avocado • *Carol Lovatt, 97-0365 M98-01*

Nitrogen Budget in California Cotton Cropping Systems • *William Rains, Robert Travis, and Robert Hutmacher, 97-0365 M97-09*

Uniformity of Chemigation in Micro-irrigated Permanent Crops •*Larry Schwankl and Terry Prichard, 97-0365 M97-08B*

Development of Irrigation and Nitrogen Fertilization Programs on Tall Fescue to Facilitate Irrigation Water Savings and Fertilizer-Use Efficiency • *Robert Green and Victor Gibeault, 97-0365 M97-07*

Development and Testing of Application Systems for Precision Variable Rate Fertilization • *Ken Giles, 97-0365 M97-06A*

Site-Specific Farming Information Systems in a Tomato-Based Rotation in the Sacramento Valley • *Stuart Pettygrove, 97-0365 M97-05 2002*

Long-Term Nitrate Leaching Below the Root Zone in California Tree Fruit Orchards • *Thomas Harter, 97-0365 M97-04*

Soil Testing to Optimize Nitrogen Management for Processing Tomatoes • *Jeffrey Mitchell, Don May, and Henry Krusekopf, 97-0365 M97-03*

Drip Irrigation and Fertigation Scheduling for Celery Production • *Timothy K. Hartz, 97-0365 M97-02*

Agriculture and Fertilizer Education for K-12 • *Pamela Emery & Richard Engel, 97-0365*

Integrating Agriculture and Fertilizer Education into California's Science Framework Curriculum • *Mark Linder & Pamela Emery, 97-0361*

Water and Fertilizer Management for Garlic: Productivity, Nutrient and Water Use Efficiency and Postharvest Quality • *Marita Cantwell, Ron Voss, and Blaine Hansen, 97-0207*

Improving the Fertilization Practices of Southeast Asians in Fresno and Tulare Counties • *Richard Molinar and Manuel Jimenez, 96-0405*

Management of Nitrogen Fertilization in Sudangrass for Optimum Production, Forage Quality and Environmental Protection • *Dan Putnam, 96-0400*

Fertilizer Use Efficiency and Influence of Rootstocks on Uptake and Nutrient Accumulation in Winegrapes • *Larry Williams, 96-0399*

Survey of Changes in Irrigation Methods and Fertilizer Management Practices in California • *John Letey, Jr., 96-0371*

Development of a Nitrogen Fertilizer Recommendation Model to Improve N-Use Efficiency and Alleviate Nitrate Pollution to Groundwater from Almond Orchards• *Patrick Brown, 96-0367*

On-Farm Demonstration and Education to Improve Fertilizer Management • *Danyal Kasapligil, Eric Overeem, and Dale Handley, 96-0312*

Nitrogen Management in Citrus under Low Volume Irrigation • *Arpaia, 96-0280*

Evaluation of Pre-Sidedress Soil Nitrate Testing to Determine N Requirements of Cool Season Vegetables • *Timothy Hartz, 95-0583*

Development and Promotion of Nitrogen Quick Tests for Determining Nitrogen Fertilizer Needs of Vegetables • *Kurt Schulbach and Richard Smith, 95-0582*

Guide to Nitrogen Quick-Tests for Vegetables with the 'Cardy' Nitrate Meter •*Kurt Schulbach and Richard Smith, 95-0582b*

Western States Agricultural Laboratory Proficiency Testing Program • *Janice Kotuby-Amacher and Robert O Miller, 95-0568*

Avocado Growers Can Reduce Soil Nitrate Groundwater Pollution and Increase Yield and Profit • *Carol Lovatt, 95-0525*

Determining Nitrogen Best Management Practices for Broccoli Production in the San Joaquin Valley • *Michelle Lestrange, Jeffrey Mitchell, and Louise Jackson, 95-0520*

Effects of Irrigation Non-Uniformity on Nitrogen and Water Use Efficiencies in Shallow-Rooted Vegetable Cropping Systems • *Blake Sanden, Jeffrey Mitchell, and Laosheng Wu, 95-0519*

Developing Site-Specific Farming Information for Cropping Systems in California • *G. Stuart Pettygrove, et.al., 95-0518*

Relationship Between Nitrogen Fertilization and Bacterial Canker Disease in French Prune • *Steven Southwick, Bruce Kirkpatrick, and Becky Westerdahl, 95-0478*

Best Management Practices (BMPs) for Nitrogen and Water Use in Irrigated Agriculture: A Video• *Danyal Kasapligil, Charles Burt, and Klaas, 95-0463*

Practical Irrigation Management and Equipment Maintenance Workshops • *Danyal Kasapligil, Charles Burt, & Eric Zilbert, 95-0419*

Evaluation of Controlled Release Fertilizers and Fertigation in Strawberries and Vegetables • *Warren Bendixen, 95-0418*

Diagnostic Tools for Efficient Nitrogen Management of Vegetables Produced in the Low Desert • *Charles Sanchez, 95-0222*

Using High Rates of Foliar Urea to Replace Soil-Applied Fertilizers in Early Maturing Peaches • *R. Scott Johnson & Richard Rosecrance, 95-0214*

Education through Radio • *Patrick Cavanaugh, 94-0517*

Effects of Four Levels of Applied Nitrogen on Three Fungal Diseases of Almond Trees • *Beth Teviotdale, 94-0513*

Use of Ion Exchange Resin Bags to Monitor Soil Nitrate in Tomato Cropping Systems • *Robert Miller, 94-0512*

Nutrient Recommendation Training in Urban Markets: A Video• *Jenks, 94-0463b*

Best Management Practices for Tree Fruit and Nut Production: A Video • *Doerge, 94-0463*

Effects of Various Phosphorus Placements on No-Till Barley Production • *Michael J. Smith, 94-0450*

Nitrogen Management through Intensive on-Farm Monitoring • *Timothy K. Hartz, 94-0362*

Establishing Updated Guidelines for Cotton Nutrition • *Bill Weir and Robert Travis, 94-0193*

Development of Nitrogen Fertilizer Recommendation Model for CaliforniAlmond Orchards • *Patrick Brown and Steven A. Weinbaum, 3-0613*

Extending Information on Fertilizer Best Management Practices and Recent Research Findings for Crops in Tulare County • *Carol Frate, 93-0570*

Western States Agricultural Laboratory Sample Exchange Program• *Miller, 93-0568*

Nitrogen Efficiency in Drip-Irrigated Almonds • *Robert J. Zasoski, 93-0551*

Citrus Growers Can Reduce Nitrate Groundwater Pollution and Increase Profits by Using Foliar Urea Fertilization • *Carol J. Lovatt, 93-0530*

Drip Irrigation and Nitrogen Fertigation Management for California Vegetable Growers: Videotape • *Timothy Hartz, 93-Hartz*

Educating California's Small and Ethnic Minority Farmers: Ways to Improve Fertilizer Use Efficiency through the Use of Best Management Practices (BMPs) • *Ronald Voss, 1993*

Development of Diagnostic Measures of Tree Nitrogen Status to Optimize Nitrogen Fertilizer Use • *Patrick Brown, 92-0668*

Impact of Microbial Processes on Crop Use of Fertilizers from Organic and Mineral Sources • *Kate M. Scow, 92-0639*

Potential Nitrate Movement Below the Root Zone in Drip-Irrigated Almonds • *Roland D. Meyer, 92-0631*

Optimizing Drip Irrigation Management for Improved Water and Nitrogen Use Efficiency • *Timothy K. Hartz, 92-0629*

The Use of Composts to Increase Nutrient Utilization Efficiency in Agricultural Systems and Reduce Pollution from Agricultural Activities • *Mark Van Horn, 92-0628*

Crop Management for Efficient Potassium Use and Optimum Winegrape Quality • *Mark A. Matthews, 92-0627*

Determination of Soil Nitrogen Content In-Situ • *Shrini K. Updahyaya, 92-0575*

Demonstration Program for Reducing Nitrate Leaching through Improvements to Irrigation Efficiency and Fertilizer/Cover Crop Management • *Stuart Pettygrove, 91-0654*

Influence of Irrigation Management on Nitrogen Use Efficiency, Nitrate Movement, and Groundwater Quality in a Peach Orchard • *R. Scott Johnson, 91-0646*

Improvement of Nitrogen Management in Vegetable Cropping Systems in the Salinas Valley and Adjacent Areas • *Stuart Pettygrove, 91-0645*

Field Evaluation of Water and Nitrate Flux through the Root Zone in a Drip/Trickle-Irrigated Vineyard • *Donald W. Grimes, 91-0556*

Nitrogen Management for Improved Wheat Yields, Grain Protein and the Reduction of Excess Nitrogen • *Bonnie Fernandez, 91-0485*

Nitrogen Fertilizer Management to Reduce Groundwater Degradation • *Weinbaum, 91-Weinbaum*