FERTILIZER RESEARCH AND EDUCATION PROGRAM

FREP

2025

FREP WPH

wph Western Plant Health

Nutrient Management Conference

PROCEEDINGS

October 29-30, 2025 • Fresno, California

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

Editors:
Karen Adler
Maria Tenorio Alfred
Natalie Jacuzzi
Jennifer Harmon
Emad Jahanzad, Ph.D.

Image Credit:
Adobe Stock Images

Publication design:
Jennifer Harmon

California Department of Food and Agriculture
Fertilizer Research and Education Program
1220 "N" Street
Sacramento, California 95814
(916) 900-5022
frep@cdfa.ca.gov
www.cdfa.ca.gov/go/frep

Credits

Special Thanks:
Renee Pinel, *President/CEO, Western Plant Health*
Karen Ross, *Secretary, California Department of Food and Agriculture (CDFA)*

Faciliators:
Karl Wyant, *Director of Agronomy, Nutrien*
Chuck Moran, *Senior Agronomist, Buttonwillow Warehouse Co.*

Speakers:
Hannah Waterhouse, *Assistant Professor, UC Santa Cruz*
Martin Burger, *Project Scientist, UC Davis and CDFA (retired)*
Ali Montazar, *Irrigation and Water Management Advisor, UCCE*
Oli Bachie, *Agronomy and Weed Management Advisor, UCCE*
Stavros Vougioukas, *Professor, UC Davis*
Chris Malek, *Senior Agronomist, Deerpoint Group Inc.*
Jagdeep Singh, *Agronomy Advisor, UCCE*
Deanne Meyer, *Extension Specialist, UC Davis*
Bruno Pitton, *Environmental Horticulture Advisor, UCCE Placer and Nevada Counties*
Charlotte Decock, *Associate Professor, CalPoly SLO*
Harol Gonzalez, California Agricultural Specialist, *American Farmland Trust*
Anel Trujillo*, California Outreach Specialist, American Farmland Trust*
Karl Wyant, *Director of Agronomy, Nutrien*

Panels:
Benefits and Economics of Improved Management Systems
Moderator: Franklin Gaudi, *VP of Business Development and Engineered Solutions, Laurel Ag and Water*
Panelists: Sam Ford, *Owner/Operator, Ford Ranches LLC*
Joel Leonard, *Agronomic Operations Director, Sun Pacific Farming*
Guillermo Velenzuela, *VP of Sales and Marketing, WiseConn Engineering*
Roy Levinson, *Commerical Lead & Sr. Product Manager, Netafim USA*

Effective Outreach for Agricultural Professionals
Moderator: Sat Darshan Khalsa, *Associate Project Scientist, UC Davis*
Panelists: Mae Culumber, *Nut Crops Farm Advisor, UCCE Fresno*
Kevin Greer, *Project Manager, Tehama County Resource Conservation District*
Jeff Mitchell, *Cropping Systems Specialist, UC Davis*
Eryn Wingate, *Agronomist, Independent Consultant*

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INTRODUCTION

33rd Annual FREP/WPH Nutrient Management Conference

Welcome to the Fertilizer Research and Education Program (FREP) and Western Plant Health (WPH) Annual Nutrient Management Conference. Over the last 33 years, this conference has provided a forum for FREP grant recipients to report their project findings and industry representatives to both share and learn valuable nutrient and irrigation management information with an audience of crop consultants, students, growers, researchers, and agricultural professionals. Since 1991, FREP has supported farming operations and California agricultural communities by funding research, demonstration, and outreach projects to increase the efficiency and adoption of best nutrient and irrigation management practices.

During the conference this year, we will hear from researchers, extension specialists, technical assistance providers, and industry representatives from across the state on the latest nutrient and irrigation management developments and research findings. The agenda includes presentations showcasing the results from seven FREP-funded projects; six research projects and one outreach-focused project. In addition, the conference will host two panels focused on the economics of improved management systems and providing effective outreach on irrigation and nutrient management to growers, respectively. There are also talks on emerging issues affecting the agricultural industry such as NOx and improving nutrient use efficiency through automation, as well as presentations on manure nutrient management, phosphorus and potassium, and a tour of a green waste composting facility.

Overview of Funded Research

Since 1991, FREP has invested more than $32 million in over 280 projects dedicated to research, outreach, and demonstration related to nutrient and irrigation management. These projects tackle key management challenges and opportunities across various commodities and agricultural regions throughout California (Figure 1).

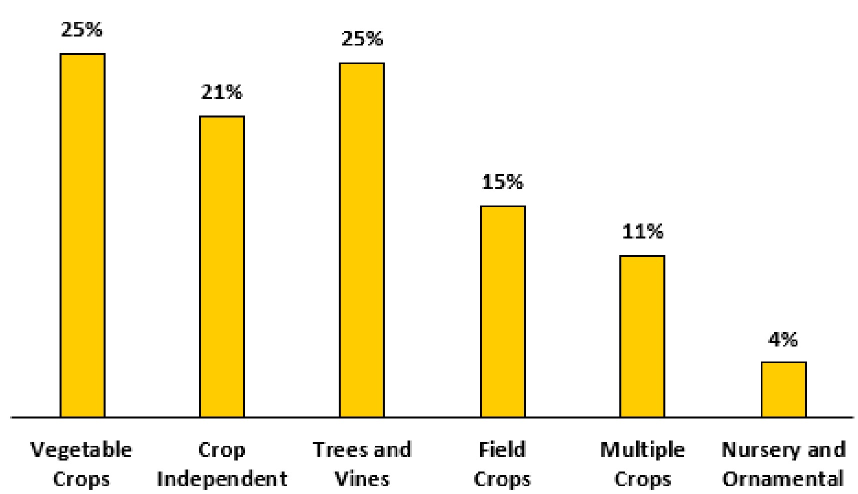


Figure 1. Distribution of commodities (%) represented in FREP-funded projects.

FREP is currently supporting 24 innovative projects aimed at promoting the agronomically sound and environmentally responsible use of fertilizing materials. These projects enhance our understanding of grower decision making, offer valuable technical training, and contribute to a deeper knowledge of nutrient and irrigation management in California crops.

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

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

Future FREP Projects

Beginning in January 2026, FREP will fund six new projects: five focused on research in nutrient and irrigation management, and one dedicated to outreach and education.

In the Central Valley, Dr. Thomas Harter (UC Davis will evaluate strategies to reduce orchard nitrate leaching to groundwater and guide the Irrigated Lands Regulatory Program's (ILRP Soil and Water Assessment Tool (SWAT. This project will provide valuable data to understand better irrigation and nitrogen distribution uniformity in micro-irrigated orchards, examine alternative agricultural managed aquifer recharge (AgMAR) practices (timing, placement, amount) for potential risks and benefits to groundwater quality, and help to develop data for improved management and modeling of young orchards on recycled orchard soils. In addition, this project will assess and validate grower water and nitrogen mass balance estimates and nitrate leaching with the Central Valley SWAT tools at the site and provide critical data, information, and assessment tools to the Central Valley ILRP thus supporting regulatory compliance of the orchard industry in California.

In the Central Coast, Paul Zerbe (Soil Health Lab LLC will develop diagnostic tools to support site-specific nitrogen management decisions in organic cropping systems. The project will assess management history and grower perceptions of nitrogen management challenges and a suite of soil properties for 120 organic vegetable fields in the Salinas Valley to evaluate relationships between these factors in order to develop a preliminary diagnostic tool and interpretation guide to support nitrogen management decisions in organic production systems. In this project, field trials will be used to compare the effect of different fertility programs on yield and plant quality metrics.

In Riverside, Orange, Ventura and San Diego counties, Dr. Ali Montazar (UC Cooperative Extension will develop tools and information to enhance water and nitrogen use efficiencies and sustainability of avocado production systems. This project will assess the impact of grower practices in avocado trees' growth and fruit quality, nitrogen removal, nitrogen soil availability and leaching and will develop nitrogen-removal crop coefficient values in California avocados. Furthermore, this project will evaluate the usefulness and economic feasibility of soil solution access tubes, soil nitrate quick testing, and leaf analysis as tools for nitrogen management in avocados orchards. This study will be conducted in two research sites as well as 15 grower fields.

Dr. Verdi (UC Riverside will study ways to improve irrigation and nitrogen management of cantaloupe in Southern California using field experiments and remote sensing. This project will evaluate the response of cantaloupe to different irrigation and nitrogen rates grown on heavy and coarse soil types in Holtville and Riverside, respectively. The results will provide recommendations for irrigation and nitrogen management of cantaloupe and develop statistical yield predicting remote sensing-based models using drone and satellite data.

In San Diego County, Dr. Valerie Mellano, San Diego Region Irrigated Lands Group, will lead a collaborative approach effort with agricultural and regulatory programs in the San Diego Region to provide nutrient management outreach and education to growers, who produce predominantly orchard, vine and nursery crops. Dr. Mellano will establish and extend best management practices (BMPs that will assist growers in meeting regulatory requirements particularly for surface water contamination (groundwater is sparse and provide access to all growers through a variety of outreach methods to ensure the outreach is accessible to all impacted growers. In addition, this project will create a resource collection available to members of the San Diego Region Irrigated Lands Group and others that can assist them in learning about and implementing BMPs for nitrogen management on their farms.

Finally, in Los Angeles County, Dr. Chris Shogren (UCCE will study nitrogen fate in nursery production systems. This study will measure and compare nitrogen losses for plants grown with a single fertilizer and irrigation method from soilless substrates of different carbon: nitrogen ratios; measure the percentage of nitrogen lost through leaching and runoff for both controlled-release and water-soluble fertilizer applications throughout the production cycle; and measure and compare nitrogen losses for overhead and drip irrigation methods with controlled-release and water-soluble fertilizer applied.

Acknowledgements

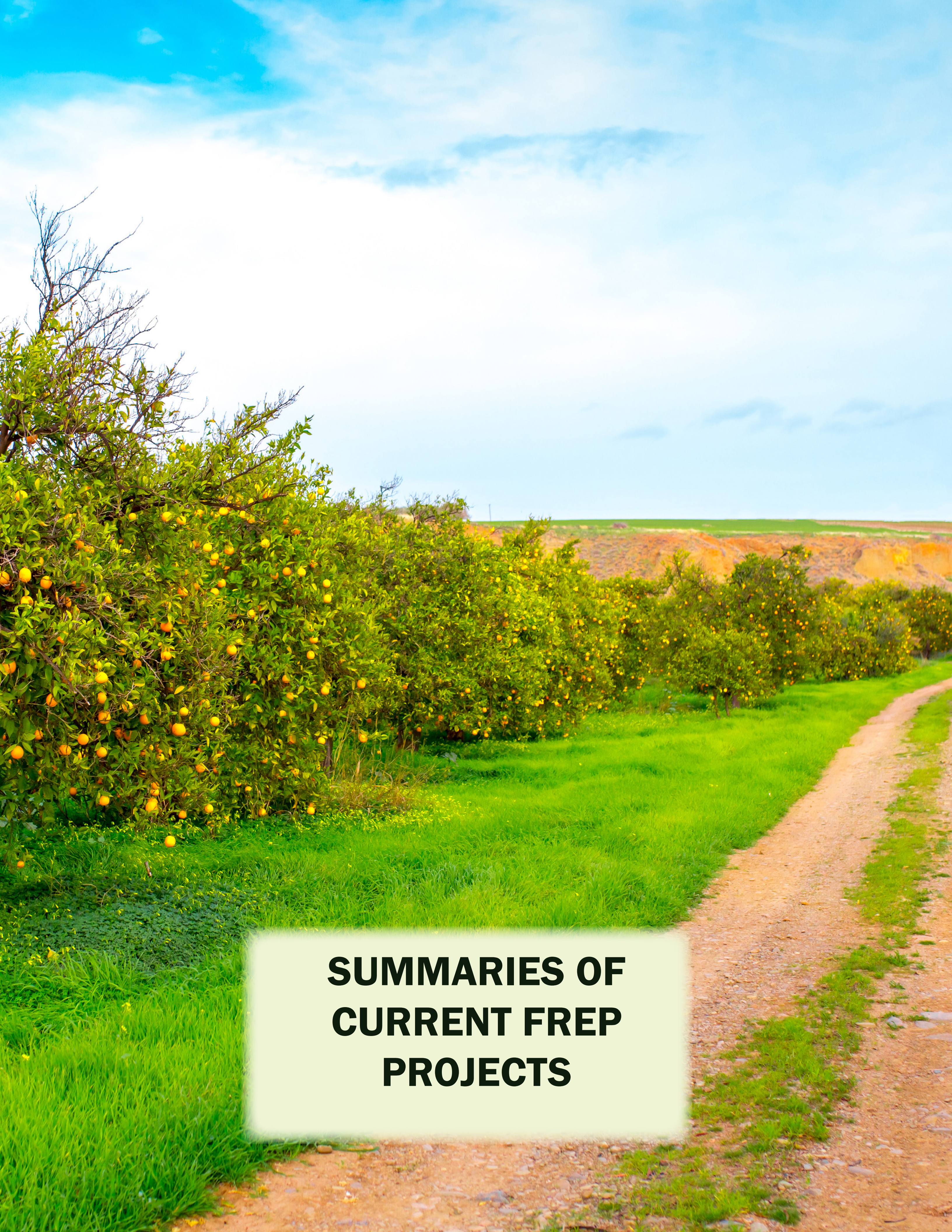
We are grateful to members of the fertilizer industry for their support in providing funds for FREP research and education efforts. Their foresight in creating FREP and their long-term commitment and dedication have been instrumental in the program's success.

We recognize the members of the Fertilizer Inspection Advisory Board's Technical Advisory Subcommittee who review and recommend projects for funding: Dr. Tom Bottoms (Chair), Dr. Mike Almasri (Vice -Chair), Dan Cook, Dr. Charlotte Decock, Dr. Jairo Diaz, Dr. Franklin Gaudi, David McEuen, Dr. Chris Shogren, Daniel Rodrigues, Dr. Sebastian Saa and Dr. Ehsan Toosi.

In addition, we thank the members of the Fertilizer Inspection Advisory Board for their continued support of the FREP program: Gary Silveria (Chair), Christopher Gallo (Vice Chair), Greg Cunningham, Jake Evans, David McEuen, Melissa McQueen, Andrew Larson, William Oglesby, and Tucker Salles.

We also thank Western Plant Health President and CEO Renee Pinel, who has been a longstanding supporter and valued partner in bringing the FREP conference to fruition.

Special thanks go to the leadership at CDFA and the Inspection Services Division for their continued support. We also extend our sincere appreciation to the recently retired supervisor of FREP, Mark Cady, for his years of dedication and contributions to strengthening the FREP team and its mission. Additionally, we thank FFLDRS Branch Chief Jenna Leal for her valuable support and contributions to FREP.



SUMMARIES OF CURRENT FREP PROJECTS

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

Project Leaders

Joji Muramoto
Assoc. Cooperative Extension
Organic Agriculture Specialist
Center for Agroecology
Dept. of Environmental Studies
University of California, Santa Cruz
jmuramoto@ucanr.edu

Richard Smith
Emeritus 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
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 $919 million in 2020. 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 4200 registered users. In recent years, the online advisory service has provided more than 1500 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 2024.

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.
5. Conduct outreach and a demonstration field demonstration.

Description

- 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 from replicated incubation trials conducted under controlled environmental conditions were collected. Incubation trials are underway to address any gaps in the database that require experimental verification. N mineralization from strawberries, Brussels sprouts, and artichoke residues, as well as some new organic fertilizers, was examined, and the results of artichoke residues are presented below.
- Developing a simple N mineralization model. We selected a simple model to calculate net N mineralization rates for soil organic matter and organic amendments. In the next step, the model will be calibrated to simulate N mineralization from crop residues, including cover crops. The response of N mineralization to temperature was also expressed with a mathematical function. These equations will be used to calculate net N mineralization rates in daily time steps for each pool (SOM, organic fertilizers and amendments, and crop 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 would not change the N mineralization rates of SOM.
- 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 were determined under field conditions on organic farms in Coastal California. Two trials were completed.
- Integrate the model into CropManage (CM). The model developed under Objective 2 is incorporated into CM. This process is ongoing.

- Conduct outreach and a field demonstration. We reported results at the Annual Salinas Valley Irrigation and Nutrient Management Meetings (2/23/2021, 2/23/2022. Virtual), FREP Conference (10/26/22), Practical Training on Nitrogen Management in Organic Production of Vegetables and Strawberries (3/2/2021, 11/29/22, 12/05/22, 12/12/22, Virtual), Organic Agriculture workshop In San Diego County (12/08/2022) and Imperial Couty (4/13/2023), Practical Training on Nitrogen Management in Organic Production of Annual Crops (11/27/23, 12/4/23, 12/11/23 virtual), Organic Production Workshop in Mendocino County (4/24/24), Lake County (4/25/24), Sonoma County (4/26/24), Santa Clara Master Gardener seminar (6/20/24), and 2024 Organic Nitrogen Management Workshop (11/18/24, 11/25/24, 12/02/24).

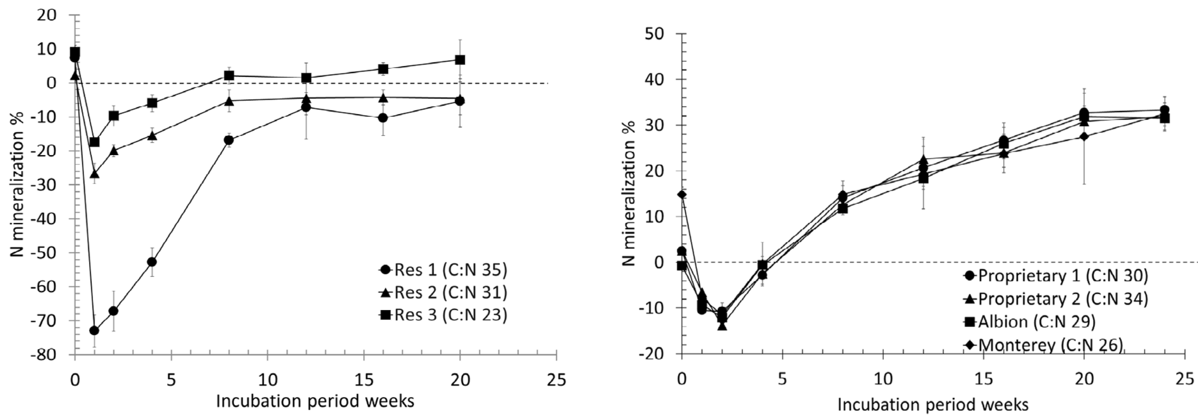
Results and Discussion

Three artichoke residues sampled had different biomass and C:N ratios (Table 1). All three residues immobilized inorganic N in the soil (= negative N mineralization) for the first 4 weeks in a varying degree according to their C:N ratios (Fig. 1A). The lowest N mineralization rate was -73%, -27%, and -17% for Residue 1 (C:N 35), 2 (C:N 31), and 3 (C:N 23), respectively, all at week 1. After 20 weeks, Residue 3, the lowest C:N ratio among three samples, was the only one that had positive net N mineralization of 6.9%, and the other two residues had negative net N mineralization of - 4.5% (Fig. 1A). Strawberry residues examined before had similar C:N ratios with artichoke residues (Fig. 1B). Yet, they showed significantly different N mineralization patterns, probably due to the difference in their carbon compound compositions (i.e., compositions of lignin, cellulose, and non-structural carbohydrates).

Additionally, when Residue 1 was incubated in a soil with higher inorganic N content (~100 mg/kg. Fig. 2A), it showed a much greater N immobilization rate (Fig. 2B). This suggests the N immobilization rate of this residue changes depending on the amount of inorganic N in the soil at the time of incorporation.

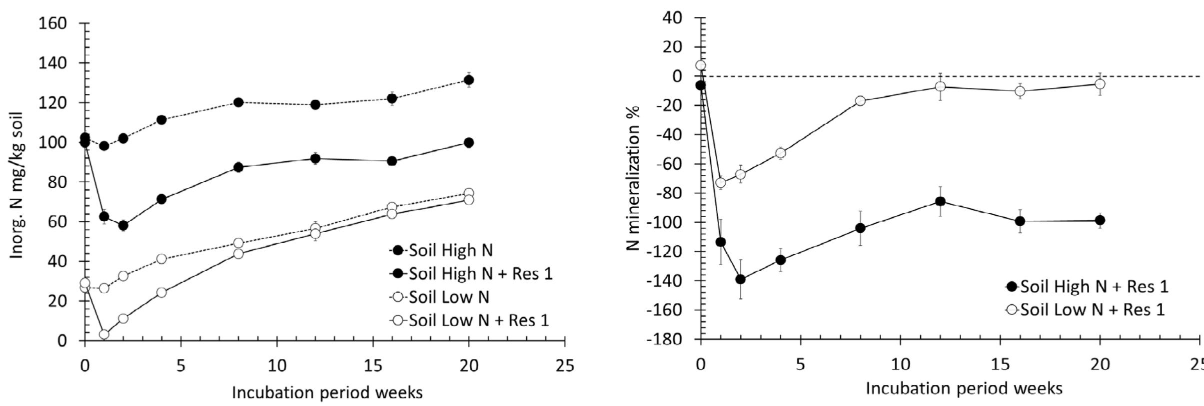
Table 1. Biomass N in artichoke residues collected for the incubation trial.

#	Cultivar	Org. /Conv.	Growing period	Marketable yield Tons/A	Plant density #/A	Dry biomass T/A	C:N ratio	Total N lb-N/A	Mineralized N in 20 weeks lb-N/A (% of total N in residues)
1	Green Queen	Conv.	Dec. 2023 - July 2024	6.6	2,623	2.44	35	56	-3 (-5.4)
2	Green Queen	Org.	May 2024 - Oct. 2024	7.0	2,921	1.45	31	37	-2 (-4.5)
3	F1-3713	Conv.	June 2024 - Nov. 2024	4.9	2,538	1.44	23	51	3 (6.9)



A: Artichoke residues *B: Strawberry residues*

Figure 1: N mineralization patterns of artichoke residues (A) and strawberry residues (B). N mineralization % means the percent of total residue N mineralized.



A: Inorganic N *B: N mineralization*

Figure 2: Changes in inorganic N amount (mg-N/kg. A) and N mineralization rate (%. B) during the incubation trials of artichoke residues using two different soils with different levels of inorganic N content. N mineralization % means the percent of total residue N mineralized.

This can have important implications for N management in a successive crop after incorporating high-carbon crop residues, including mature cover crops. Additional incubation trials are underway to understand this phenomenon further.

Acknowledgements

We thank the staff and student workers of the University of California, Santa Cruz, as well as the staff of the University of California Cooperative Extension, Monterey County, for their assistance with incubation and field trials for this project. We also appreciate the anonymous collaborative growers who allowed us to collect crop residues and provided production information, as well as the California Department of Food and Agriculture's Fertilizer Research and Education Program (FREP) for funding this project.

"Crop Nutrient Minute" Video Series

Project Leader

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

Co-PI
Patrick Brown, Ph.D.
Professor
Dept. of Plant Sciences, UC Davis

Introduction

The Irrigated Lands Program (ILP) 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 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. Online CE courses are instrumental in ensuring growers and CCAs can 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 seven major acreage crops in the Central Valley and Central Coast.
2. Develop and produce seven, 5-minute videos in both English and Spanish for the "Crop Nutrient Minute" video series.

3 Develop and produce seven 30-minute videos in both 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 is being developed by the Project Leaders, University of California Cooperative Extension (UCCE) specialists and University of California (UC) personnel in each of seven crop categories. The foundational information for the videos is the 4R principles (Right time, Right place, Right amount, and Right product) developed by FREP and the UC for California crops. Video content also includes 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 are written by the Project Leaders and Cooperators using information gathered from the CDFA Crop Nutrient Guidelines and findings from past FREP-funded research. The videos are modeled off a FREP-funded 4R video produced for walnuts. Each draft script is 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 are filmed using CURES, UC and PCA/CCAs with crop-specific footage recorded in the field. Animation and art are used to illustrate technical information. Videos are 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 condenses the content to create the 5-minute "Crop Nutrient Minute" series. Both sets of videos can be viewed on the CURES Nitrogen Management webpage (www.curesworks.org/nitrogen-management/, see Fig 1 above) or streamed from the CURES Crop Nutrient Minute 4Rs Series YouTube video playlist: www.youtube.com/playlist?list=PLx4qPv3N7x-ZqF_nqqbw5jXWCi8LYsWMRE. The more succinct videos focus briefly on the fundamentals and cover crop-specific tips and techniques to properly implement the 4Rs. They are designed to be quick and easily accessible references for crop information while in the field.

Outreach is being 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 are available to show 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.

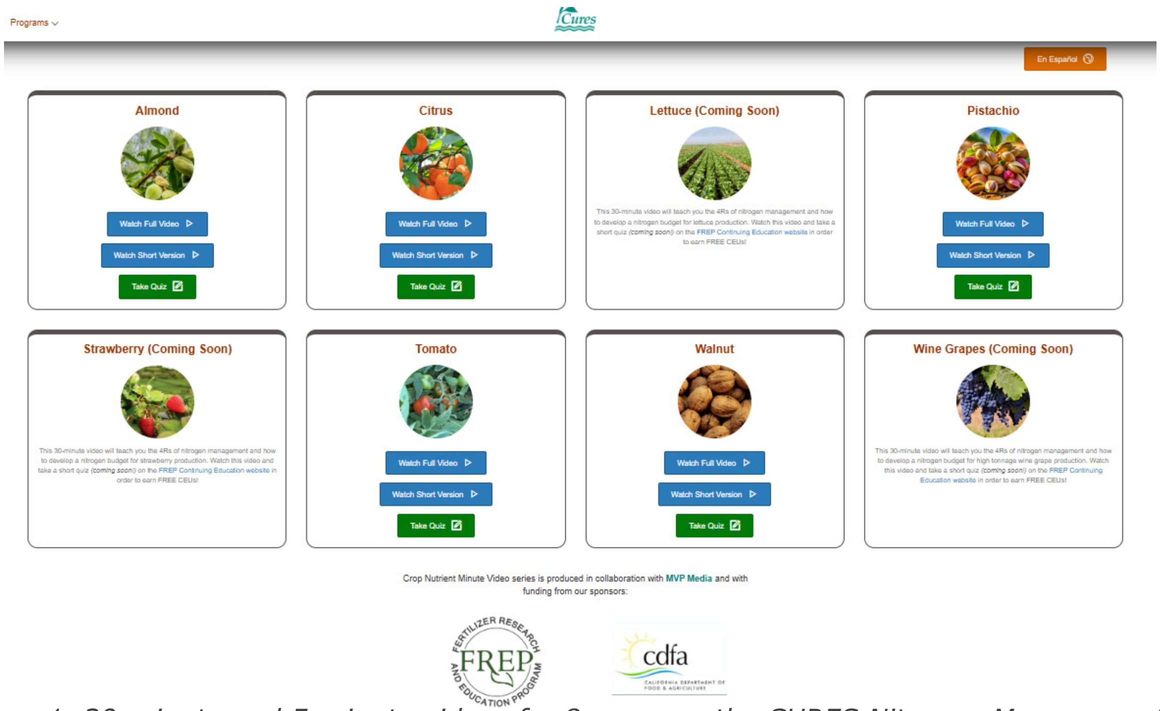


Figure 1. 30-minute and 5-minute videos for 8 crops on the CURES Nitrogen Management webpage.

Flyers are distributed at crop field days, conferences and events (see Figure 2 example).

Once approved to offer CEUs, the finished "INMP Continuing Education" 30-minute videos are posted on the CURES website (www.curesworks.org/nitrogen-management/) and linked to CFDA's Continuing Education webpage (www.cdfa.ca.gov/is/ffldrs/frep/continuing_education.html).

CDFA, crop industry organizations and water quality coalitions are encouraged to send out email blasts, postcards and/or blog posts informing growers and crop advisors of the online courses. Quiz questions are developed and included with each video, in compliance with current INMP CE requirements (5 questions per 30 minutes). The mandatory quizzes are automatically graded, results recorded, and Certificates of Completion sent to growers who pass.

Results and Discussion

Project success is being measured through view counts and feedback surveys. The total number of video views are tracked quarterly. If views decrease, CURES performs analyses on outreach methods to ensure we are reaching growers and crop advisors in the most efficient ways. For the "INMP Continuing Education" video series, project success is being measured by grower participation and feedback surveys. Grower quiz results are used as a metric to track grower participation and understanding of content.

Optional feedback questions may 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.

Figure 2. Flyer advertising the Crop Nutrient Minute video series and opportunity to earn free CE credits

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 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 made 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.

Conclusion

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 an 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 serves 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 thanks CDFA FREP for supporting this project and on behalf of growers statewide. CURES acknowledges the project leaders and thanks cooperators for their time reviewing scripts and filming videos: Katherine Jarvis-Shean, Ph.D. (UCCE), Phoebe Gordon, Ph.D. (UCCE), Jacqueline Vasquez Mendoza (UCCE), Franz Niederholzer, Ph.D. (UCCE), Zheng Wang, Ph.D. (UCCE), Michael Cahn, Ph.D. (UCCE), Andre Biscaro, M.S. (UCCE), Doug Amaral, Ph.D. (UCCE), George Zhuang, M.S. (UCCE), Richard Smith (UCCE), Gabriele Ludwig, Ph.D. (Almond Board of California), Casey Creamer (California Citrus Mutual), Orvil McKinnis (Westside San Joaquin River Watershed Coalition), Michael Wackman (San Joaquin County and Delta Water Quality Coalition), Bruce Houdesheldt (Sacramento Valley Water Quality Coalition), and Caitie Diemel (East San Joaquin Water Quality Coalition). Additional thanks to CURES dedicated staff: Courtney Jallo, Maureen Thompson, Eva Dwyer, Monica Quezada, Alany Valle; and also, to Matt Martin with MVP Media.

Ventura County Nitrogen Management Training Program

Project Leader

Jodi Switzer
Water Program Director
Farm Bureau of Ventura County
jodi@farmbureauvc.com

Introduction

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), adopted in April 2016, requires growers in nutrient-impaired watersheds or under applicable TMDLs to develop certified Irrigation and Nutrient Management Plans (INMPs). Approximately 70% of Ventura County's irrigated acreage falls within these requirements.

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, requiring growers to complete training and pass an exam to self-certify INMPs. To support Ventura County growers, the Ventura County Agricultural Irrigated Lands Group (VCAILG), Farm Bureau of Ventura County, CDFA FREP, UC Cooperative Extension, and Fruit Growers Laboratory collaborated to adapt the Central Valley training for local crops, practices, and local Irrigated Lands Regulatory Program (ILRP) requirements.

The Los Angeles Region's most recent ILRP Order ("Ag Order", Order No. R4-2023-0353) was adopted on September 28, 2023, incorporated precedential requirements from the East San Joaquin River Watershed WDRs, including nitrogen reporting and tracking. This milestone allowed the Ventura County training program to fully launch in 2024, after several years of delay.

Objectives

The project objectives include the following:

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 groundwater 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

This project updates and delivers the CDFA FREP INMP training curriculum for Ventura County growers. Core activities include:

- Revise the training program developed by FREP for the Central Valley to include management practices, crop examples, and Ag Order requirements specific to Ventura County agriculture.
- Translate training program and resources for Spanish-speaking audiences.
- Following the adoption of the Ag Order, conduct three training programs per year, one of which will include active Spanish translation.
- Provide English and Spanish versions of training workbook and other resources.

Results and Discussion

The planned implementation schedule for this education project has been impacted by the delayed incorporation of the East San Joaquin precedential requirements into the LARWQCB's Irrigated Lands Regulatory Program order. These requirements were anticipated to take effect in the Los Angeles Region in April 2021, coinciding with the expiration of the existing Conditional Waiver and the expected adoption of a new order. However, three consecutive extensions of the existing Conditional Waiver resulted in the delayed development and adoption of a subsequent regulatory order. Without the Region 4-specific requirements being adopted, the update and implementation of a training program could not be conducted.

With the September 28, 2023, adoption of an Ag Order now complete, VCAILG began working to develop the INMP and INMR program components needed to implement the program. These efforts included developing INMP and INMR templates, conducting a literature review to compile a list of proposed N removal coefficients for Ventura County crops, and working with Regional Board staff to develop guidance and make determinations for scenarios where the Ag Order was silent. This program development effort was largely completed by late Spring 2024, with approval of the N removal coefficients being one of the few remaining tasks.

With these tasks completed, the focus of this project shifted to updating the training materials to align with the Region 4-specific requirements in early summer 2024 and then to conducting training sessions for Ventura County growers. To accommodate this revised timeline, this project has requested and been approved for a no cost extension through December 31, 2025.

Details on completed training sessions and remaining project objectives are listed below:

Training sessions delivered:

Since August 2024, three training sessions were conducted (August 29–30, 2024; January 29–30, 2025; and February 25–26, 2025), all offered both in-person and via Zoom.

- Exam takers: August 2024 (21 in-person, 63 Zoom), January 2025 (42 in-person, 55 Zoom), February 2025 (44 in-person, 27 Zoom; 19 Spanish-speaking).
- Non-exam participants: August 2024 (20), January 2025 (28), February 2025 (15).

Across the three trainings, total growers served = 297 (exam takers and non-exam participants combined).

Exam outcomes:

- First-attempt passing rate: 87%.
- Of 32 who did not pass initially, 8 retook the exam; 7 passed on the second attempt.

Spanish-language access:

- February 2025 training featured live Spanish interpretation and fully translated presentation slides, workbooks, handouts, and exams.
- A Spanish version of the training workbook is complete, and work is underway to produce a Spanish version of the online self-certification training.

Program development milestones:

- Migrated Ventura County training materials to the CDFA FREP INMPT online portal (https://www.cdfa.ca.gov/is/ffldrs/frep/training.html).
- Achieved formal approval of VCAILG's nitrogen removal coefficients list from the Los Angeles Regional Water Quality Control Board on August 13, 2025.

Remaining 2025 activities:

- One additional in-person and Zoom training is planned for late 2025.
- Completion of the Spanish-language online training module for expanded access.

Conclusions

This project successfully transitioned from development to delivery, training nearly 300 Ventura County growers between August 2024 and February 2025, with almost 220 participants taking and passing the self-certification exam. Combined with NMP Self-Certification trainings conducted from 2018 to 2021, Ventura County now has 510 self-certified growers.

The program achieved strong participation, with the majority of attendees passing on their first attempt. Spanish-speaking growers were supported through live interpretation and translation, with additional online resources in development to further expand access.

The approval of locally derived nitrogen removal coefficients and the migration of Ventura County training into CDFA FREP's online portal represent additional major milestones. Together, these efforts ensure Ventura County growers are equipped with the tools, knowledge, and certification needed to meet Ag Order requirements while improving nitrogen management and protecting water quality.

Acknowledgements

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

Project Leaders

Charlotte Gallock, P.E.
Manager of Water Resources
Kings River Conservation District
cgallock@krcd.org

Ken Cassman
Senior Agronomic and Soils Advisor
kgc1consulting@gmail.com

Ken Miller
Technical Program Manager SSJV
MPEP Program
Formation Environmental
kmiller@formationenv.com

Introduction

Through the 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 information on field 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). 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.

With the participation of several cooperating coalitions, the Southern San Joaquin Valey Management Practices Evaluation Program (SSJV MPEP) Committee contracted and worked with Dr. Daniel Geisseler of UC Davis to complete and publish usable, literature-based yield-to-N-removed conversion factors for 72 crops, representing more than 98% of Central Valley irrigated lands. The report, Nitrogen Concentrations in Harvested Plant Parts - A Literature Overview (N-concentrations Report), was prepared by Dr. Geisseler (2016). The N-concentrations Report noted that some of the conversion factors are based on datasets that were small, more than 20 years old, or from outside the Central Valley, and/or reflected cultivars, yields, cropping systems, and soil types other than those common under contemporary Central Valley conditions. The N-concentrations Report showed that well-established coefficients were available for only 10 of the 72 crops, accounting for approximately 12 percent of irrigated lands in the Central Valley.

Further, there are even fewer data on the amount of N sequestered into perennial crop biomass, which growers need to know when planning N fertilizer programs for younger orchards, groves, and vineyards during rapid early growth of perennial tissues. To refine currently available coefficients, additional data needs to be obtained from analysis of recent crop samples over several years.

In Phase 1 of this project, updated conversion factors for 11 crops were incorporated into a 2021 N-Concentrations Report and the Yield to N-Removed Calculator (https://agmpep.com/tools/calc-y2r/). As a part of Phase 2 (this project), updated conversion factors will be developed for an additional approximately 33 additional crops.

Objectives

The overall objective of this project is to assess harvested and sequestered N content for priority crops. Specific objectives include the following:

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 offline tools for estimating N removed in crops and incorporate into regional assessments of N balance in irrigated crop lands, and c) update N accumulation rates in crop models used in the ILRP.

Description

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, pear, figs, raisin grapes, oil olive, grain corn, barley, non-alfalfa hay/haylage, pumpkin, processing onion and garlic, and sweet potato. 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, 2024, 2025) and the N removed calculator on the agmpep.com website.

Table 1. Initial (Geisseler 2016) and Updated (Geisseler 2016, 2021, 2024, 2025) N Removal Coefficients.

	Crop	Current Study Lbs N/ton	Current Study CV* (%)	2016 Lit Review Av. Lbs N/ton	2016 Lit Review CV* (%)	Change %
Phase 1 of Project (Geisseler, 2021)	Corn Silage	7.53	10.9	7.56	10.5	-0.4
	Cotton	43.4	16.1	43.7	29.5	-0.7
	Safflower	51.7	10.2	56.8	20.0	-9.0
	Sunflower	63.2	11.1	54.1	14.3	16.8
	Carrots	2.80	22.7	3.29	22.4	-14.9
	Tomatoes, Processing	2.92	15.0	2.73	11.1	7.0
	Peaches	3.04	19.0	2.26	20.7	34.5
	Pistachios**	20.4	21.6	56.1	3.5	-
	Plums	2.27	14.5	2.83	11.2	-19.8
	Pomegranates	3.96	15.4	15.2	15.0	-73.9
	Walnuts	31.8	10.9	31.9	11.2	-0.3
Phase 2 of Project (Geisseler, 2024)	Cotton – Acala***	49.9	18.1	43.7	16.1	14.2
	Cotton – Pima	51.7	8.0	43.7	16.1	18.3
	Sorghum grain	35.2	14.2	33	29.7	6.7
	Kiwi	3.57	15.0	-	-	-
	Lemon	3.49	10.4	2.58	10	35.3
	Mandarin	4.31	10.9	2.54	29.2	69.7
	Nectarine	3.83	24.4	3.64	27.1	5.2
	Navel Orange	3.61	15.1	2.96	10.9	22.0
	Valencia Orange***	4.66	20.1	2.96	10.9	57.4
Phase 2 of Project (Geisseler, 2025)	Cherry	5.97	37.7	4.42	19.8	35.1
	Corn, sweet	7.43	15.8	7.17	13.1	3.6
	Garlic, fresh market***	16.42	20.4	15.1	19.5	8.7
	Grapes, Table	2.28	25	2.26	5.8	0.9
	Grapes, Wine	3.43	30.8	3.6	13	-4.7
	Melons, Cantaloupe	4.07	28.1	4.87	15.5	-16.4
	Melons, Honeydew	2.72	21.6	2.95	22.1	-7.8
	Melons, Water	2.25	24.1	1.39	23.9	61.9
	Olives, Table***	7.12	12.2	6.28	22.8	13.4
	Onion, fresh market***	2.43	23	3.94	19.7	-38.3
	Pepper, bell	3.32	23	3.31	7.9	0.3
	Potato, Irish	6.48	27.4	6.24	13.6	3.8
	Squash	4.17	30.2	3.67	22.4	13.6
	Tomato, fresh market	2.77	18.8	2.61	16.5	6.1

*Coefficient of variation.
**Yield units used to express N removed changed from dry yield (CPC) in Geisseler 2016 to net green weight in Geisseler 2021.
***Previous N removal coefficient was not specific to varietal or market.

Results and Discussion

Work completed since the commencement of Phase 1 includes coordination of eight years of sampling with grower/packer/shipper partners, along with preparation and analysis of the samples obtained. Results from Phase 1 and part of Phase 2 are documented in Geisseler (2021, 2024, 2025) and have been incorporated into the N removed calculator on the agmpep.com website. These results are also presented in Table 1. The remaining results from Phase 2 will be available in early 2026 upon project completion.

Conclusions

A sound understanding of N removed in harvested crops or stored in perennial tissues is vital for any nutrient management plan and helps determine fertilizer requirements and evaluate N use efficiency. The Geisseler (2016, 2021, 2024, 2025) reports provide key information including N removal coefficients and their associated yield units and how variable the coefficients were across samples. It is important to consider that crop N requirements often exceed what is removed from the field with harvest and that other sources of N besides fertilizers (e.g., irrigation water, crop residues) can contribute to this demand. Following fertilizing guidelines https://www.cdfa.ca.gov/is/ffldrs/frep/FertilizationGuidelines/ will help ensure that needed fertilizer N is delivered in a way that maximizes its recovery by crops.

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We would also like to aknowledge our cooperator:

Daniel Geisseler
Cooperative Extension Specialist Nutrient Management UC Davis
djgeisseler@ucdavis.edu

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
mdcahn@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 online 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 farm 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 vegetable and berry crops, and more recently central valley crops including alfalfa, almond, walnut, pistachio, processing tomato, and vineyards.

CM is used by growers, farm managers, consultants, governmental and non-profit agencies. With the addition of new crops and features grower adoption of CM has steadily increased during the past 14 years. Nevertheless, more outreach in the form of dedicated user support, hands-on workshops, and presentations at industry meetings is needed to 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 CM 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 explores and implements strategies to continue funding software development.

Objectives

The goal of this project is to 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 is accomplished through introductions at industry and grower meetings and through hands-on trainings taught virtually or through in-person meetings. Additionally, help resources for CM continue to be developed including adding tutorial articles to the CM knowledge base (help.cropmanage.ucanr.edu), an e-newsletter that introduces new features and announces training opportunities to CM users, One-on-one help is offered to users through contacts from the CM hotline or the CM "feedback" link and an online discussion group (Discord).

Revenue generation for sustaining CM continues to be explored at UCANR including subscription and donation-based models. Improving reporting capabilities may also increase the user-base as well as lead eventually 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.

Finally, adding task management capabilities to CropManage may lead to a larger user-base and potential revenue generation.

This may be accomplished by interfacing CM with existing software used by growers and/or developing a simple native app that can be used on a smartphone. Adding task management capabilities greatly simplifies data entry for farming operations that want to adopt CM on a large scale.

Accomplishments

Software updates

Updates were made to CM to accommodate additional crops, improve accuracy of algorithms, and facilitate onboarding of new plantings. These updates were based on feedback from CM users. Users are now guided step-by-step through the set-up process when creating new plantings. Additionally, the user interface was updated to allow tree and vineyard crop users to easily impose deficit irrigation strategies during specific periods during the season. These and other updates help simplify the user experience so that growers can quickly learn to use and implement the CM decision support tool on their farms.

Outreach

A major effort was made to provide increased hands-on training and introductions to CropManage in 2025. More than 12 in-depth hands-on workshops were conducted on the Central and Southern Coast and in the Central Valley. Workshops were conducted in Bakersfield (2), Manteca, Merced, Parlier, Salinas, San Martin, Stockton, Tulare, Watsonville (2), Woodland, and Ventura. Participants at the workshops learned how to set up CM for their farms and use the software as a decision support tool for irrigation scheduling and N fertilizer management. One-on-one assistance on CM was provided to growers and their staff as well as consultants and technical service providers throughout the season (approximately 2 to 4 consultations per week). Assistance included responding to queries on how to use software features, setting up plantings, or interpreting recommendations. An e-newsletter was distributed to CM users at the beginning of 2025 announced training opportunities.

As a result of these outreach efforts CM use has steadily increased (Fig. 1). After a decline in use during the COVID pandemic, CM use rebounded in 2023. CropManage use continued to grow during 2025, providing 10472 irrigation recommendations, 1413 Nitrogen fertilizer recommendations, and recording 600 soil samples events between January 1 and July 31.

An additional 4800 irrigation recommendations were provided through the CM web API from January 1 through July 2025. The number of registered users also increased to more than 5000.

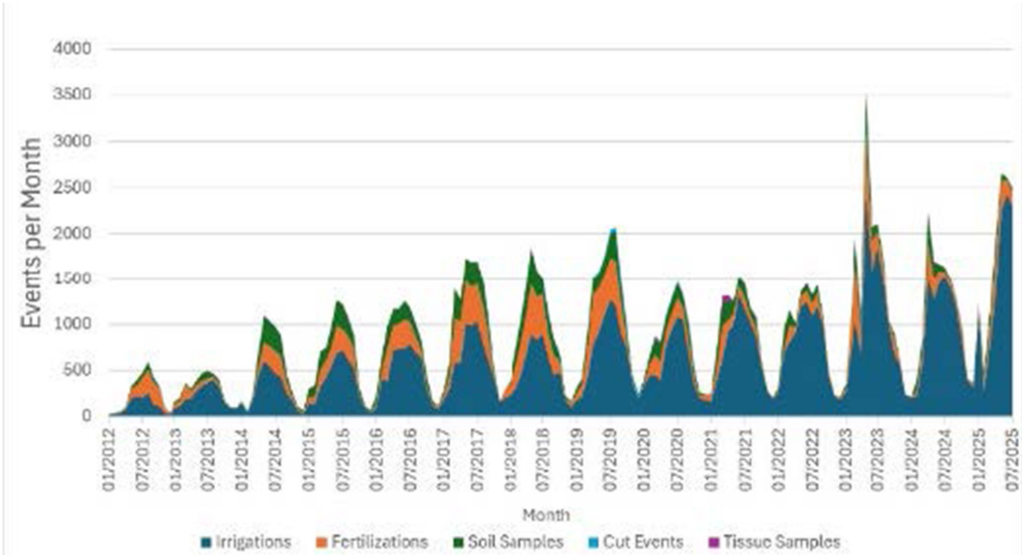

Figure 1. CropManage events recorded between 2012 and 2025.

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Nitrogen Responses Industrial Hemp for CBD, Essential Oils, Fiber

Project Leaders

Bob Hutmacher
Univ. CA Cooperative Extension Specialist, Emeritus; Univ. CA Davis Plant Sciences Dept.
rbhutmacher@ucdavis.edu

Daniel Putnam
Univ. CA Cooperative Extension Specialist, Emeritus; Univ, CA Davis Plant Sciences Dept.
dhputnam@ucdavis.edu

Objectives

1. Evaluate for two biotypes of industrial hemp (autoflower/short-season, full-season photoperiod-sensitive types) grown for essential oils (CBD, others) the impacts of fertilizer N application amount on N uptake and removal, yield under SDI irrigation.
2. Assess impacts of N management practices on THC, CBD in harvested products.
3. Evaluate the impacts of three fertilizer N application rates on N uptake and yield responses in long-season fiber-type industrial hemp cultivars at one location.

Description

Field trials were conducted in 2021 through 2025 at University of CA West Side REC (WSREC) in Fresno County (Panoche clay loam), and in 2021-2022 at the UC Davis Farm (UCD) in Yolo County (Yolo fine sandy loam). The 2021 and 2022 projects were the 2nd year of two-year field projects to evaluate fertilizer nitrogen (N) rate responses for two biotypes of industrial hemp grown for CBD/essential oils, autoflower (non-photoperiodic), shorter season (AF) types, and full-season photoperiod-sensitive (PPS) types. In 2023 through 2025, we added an additional objective, namely limited N response studies of longer-season, larger industrial hemp grown for fiber/construction materials. Even though our original FREP project was designed as a two-year study (2021-2022) at two sites (WSREC, UCD), our grower contacts and research contacts with Oregon State University all expressed interest in more research on industrial hemp for fiber and building construction-type hemp products. The fiber hemp cultivars we evaluated in 2023 through 2025 are photoperiod-responsive plants that initiate reproductive development in response to shortening day lengths relatively late in summer months (late July and August), so growing season length (and plant size/yields) are dependent upon planting date as well as harvest timing.

CBD-Type Nitrogen Responses. Short-season autoflower (AF) varieties begin first cola development about 3-4 weeks earlier than photoperiod-sensitive full season (PPS) types at planting dates evaluated. In this N fertilizer rate trial, we adjusted irrigation amounts and applied N amounts to reflect differences between AF and PPS cultivars in relative plant size and ground cover, with about 50-plus percent lower water and N applications for AF versus PPS cultivars. In 2021, yield levels in AF cultivars were more responsive to increasing N application levels at the WSREC than at UCD (Table 1), with increases in cola yields at WSREC from the T1 to T3 level of N application (about 60 lbs N/acre), with less response to increasing N beyond 60 or 90 lbs N/acre rate. Similar patterns were seen in 2022 cola yield responses to N at WSREC site (Table 1), with cola yields increasing through middle N treatment levels. Cola yields (Table 1) for AF cultivars at UCD site showed little response to applied N either year.

Table 1. Cola (flower bud) yields (in lbs/acre) as a function of applied N treatments for AF cultivars at UCD and WSREC in 2021 and 2022. Mean separation analyses were conducted for each site and cultivar type, different letters indicating differences at the 5% level.

Year-Site	Cultivar name	Cola dry wt yields (all colas larger than 3" length) (lbs/acre)				
21-UCD		**T1 (0 lbs/ac)**	**T2 (15lbs/ac)**	**T3 (50 lbs/ac)**	**T4 (75 lbs/ac)**	**T5 (110 lbs/ac)**
	Maverick	1399 b	1395 b	1595 a	1561 a	1507 ab
	Alpha Neb.	1166 a	1144 a	1099 ab	954 b	1137 a
21-WSREC		**T1 (0 lbs/ac)**	**T2 (30lbs/ac)**	**T3 (60 lbs/ac)**	**T4 (90 lbs/ac)**	**T5 (120 lbs/ac)**
	Maverick	1676 b	1899 ab	2186 a	2344 a	2407 a
	Alpha Neb.	1532 b	1682 b	1971 ab	2126 a	2034 a
22-UCD		**T1 (0 lbs/ac)**	**T2 (30lbs/ac)**	**T3 (60 lbs/ac)**	**T4 (90 lbs/ac)**	**T5 (120 lbs/ac)**
	Rincon	1747 b	1778 b	1887 ab	1962 a	2001 a
	Alpha Neb.	1902 ab	1808 b	1992 a	1728 b	1855 ab
22-WSREC		**T1 (0 lbs/ac)**	**T2 (30lbs/ac)**	**T3 (60 lbs/ac)**	**T4 (90 lbs/ac)**	**T5 (120 lbs/ac)**
	Maverick	1007 c	1528 b	1828 ab	1976 a	2102 a
	Rincon	913 c	1205 b	1663 a	1704 a	1675 a
	Alpha Neb.	937 c	1364 b	1629 ab	1645 a	1699 a

22-UCD		**T1 (0 lbs/ac)**	**T2 (30lbs/ac)**	**T3 (60 lbs/ac)**	**T4 (90 lbs/ac)**	**T5 (120 lbs/ac)**
	Rincon	1747 b	1778 b	1887 ab	1962 a	2001 a
	Alpha Neb.	1902 ab	1808 b	1992 a	1728 b	1855 ab
22-WSREC		**T1 (0 lbs/ac)**	**T2 (30lbs/ac)**	**T3 (60 lbs/ac)**	**T4 (90 lbs/ac)**	**T5 (120 lbs/ac)**
	Maverick	1007 c	1528 b	1828 ab	1976 a	2102 a
	Rincon	913 c	1205 b	1663 a	1704 a	1675 a
	Alpha Neb.	937 c	1364 b	1629 ab	1645 a	1699 a

Table 2. 2021-2022 cola (flower bud) yields (in lbs/acre) as a function of applied N treatments for Full-Season (PPS) cultivars. Mean separation analyses were done by site and cultivar type, different letters indicating differences at the 5% level.

Year-Site	Cultivar name	Cola dry wt yields (all colas larger than 3" length on main stem and branches) (lbs/acre)				
21-UCD		T1 (0 lbs/ac)	T2 (45 lbs/ac)	T3 (85 lbs/ac)	T4 (135 lbs/ac)	T5 (170 lbs/ac)
	The Wife	975 c	1192 b	1469 ab	1818 a	1896 a
	Scarlett	1536 b	2102 a	2018 a	2104 a	2142 a
21-WSREC		T1 (12lbs/ac)	T2 (55 lbs/ac)	T3 (110lbs/ac)	T4 (165 lbs/ac)	T5 (220 lbs/ac)
	The Wife	885 c	1230 b	1589 ab	1812 a	1762 a
	Scarlett	712 b	860 b	1075 ab	1179 a	1269 a
22-UCD		T1 (0 lbs/ac)	T2 (50 lbs/ac)	T3 (100 lbs/ac)	T4 (150 lbs/ac)	T5 (200 lbs/ac)
	Cookie Crush	1698 bc	1576 c	1846 ab	1990 a	1542 c
	Early Wu	1919 b	2003 b	2610 a	2536 a	1984 b
22-WSREC		T1 (0 lbs/ac)	T2 (50 lbs/ac)	T3 (100 lbs/ac)	T4 (150 lbs/ac)	T5 (200 lbs/ac)
	Cookie Crush	1426 c	2013 b	2365 b	2448 ab	2929 a
	Early Wu	1456 c	1823 b	2208 ab	2246 a	2451 a

Nitrogen Uptake. Analysis of N content of CBD plants at harvest at WSREC is shown in table 3. Increases in cola N with increasing N at WSREC in AF and PPS types reflected both increases in cola dry weights through T3/T4 levels and increases in cola N% with increasing N. For both PPS and AF cultivars at WSREC, leaf+stem and cola N content increased significantly through T3 N levels, and in "Cookie Crush" (PPS) and "Maverick"(AF), continued increase in cola+leaf N were seen through T4, T5 levels. Cola yields peaked at T3, indicating excess N uptake unrelated to cola yields. At UC Davis (not shown), N content of plants continued to increase at T3 through T5 in both PPS and AF types, but cola yields did not respond to N rates beyond the N2 level.

Table 3. Average N Content at harvest of plant parts (Leaf + Stem, all Colas) across applied N treatments for AF and PPS cultivars in 2022 at WSREC. Plants were direct-seeded.

Cultivar	Plant Part	Nitrogen Content at Harvest (lbs N / acre)				
PPS Types		T1 (0 lbs/ac)	T2 (55 lbs/ac)	T3 (110 lbs/ac)	T4 (165 lbs/ac)	T5 (210 lbs/ac)
Early Wu	Leaf + Stem	41.4	58.2	97.2	118.7	112.5
	All Colas	45.4	64.0	76.6	84.0	99.0
Cookie Crush	Leaf + Stem	54.6	87.9	123.0	132.8	148.0
	All Colas	45.9	66.7	77.3	85.4	107.5
AF Types		T1 (0 lbs/ac)	T2 (30 lbs/ac)	T3 (60 lbs/ac)	T4 (90 lbs/ac)	T5 (120 lbs/ac)
Maverick	Leaf + Stem	18.7	28.5	46.7	64.8	57.4
	All Colas	33.5	48.7	71.1	76.1	86.6
Rincon	Leaf + Stem	18.9	25.3	44.2	44.3	51.1
	All Colas	30.1	40.6	63.0	63.9	71.7
Alpha Neb	Leaf + Stem	19.1	33.8	53.6	56.0	57.2
	All Colas	29.2	47.6	65.5	64.7	69.0

Cannabinoid (THC/CBD) Analyses. Data analyzed from CBD-type cultivars at WSREC in 2021-2022 have not shown any response to applied N rates in THC or CBD levels, however, in several N treatment/cultivar combinations (CBD and fiber types), unacceptable THC levels (>0.3%) occurred at harvest. In these analyses, where THC levels in excess of >0.3% occurred, it appeared to be a cultivar-specific response mostly related to cola maturity, and not significantly influenced by nitrogen treatments.

Fiber Hemp Studies – 2023-2025. Fiber hemp test sites at WSREC all had low soil nitrate-N (<35 lbs NO_3-N/ac) in upper 3 feet of soil pre-plant, and received 100 lbs/ac 10-52-0 fertilizer pre-plant. The N response evaluations for fiber hemp cultivars were done for April, May and July planting dates (2023, 2024) at this site for limited cultivars, and results showed significant biomass (dry weight) responses to applied N up to 165-170 lbs applied N/ac for April and May plantings, and up to 110 lbs N/ac rate for July planting. Greatly reduced dry matter yields occurred with July planting when compared with mid-April or May in both 2023 and 2024 (data not shown), but a significant N response was observed at the N-2 application level (110 lbs/ac) even with the July planting since the residual soil nitrate levels were low. For 2024, studies continued with the China-origin cultivar “Han NE”, plus an earlier maturing China-origin cultivar “Han J6”, and an even earlier maturing US-origin cultivar from New West Genetics (Fort Collins, CO), “NWG 2463”. For the 2024 study, total plant dry weight comparisons across planting dates for each cultivar are shown in figure 1. Samples to analyze nitrogen uptake in colas, stems and leaves are underway using harvest samples from 2023, 2024 studies, and 2025 samples will also be tested as resources allow.

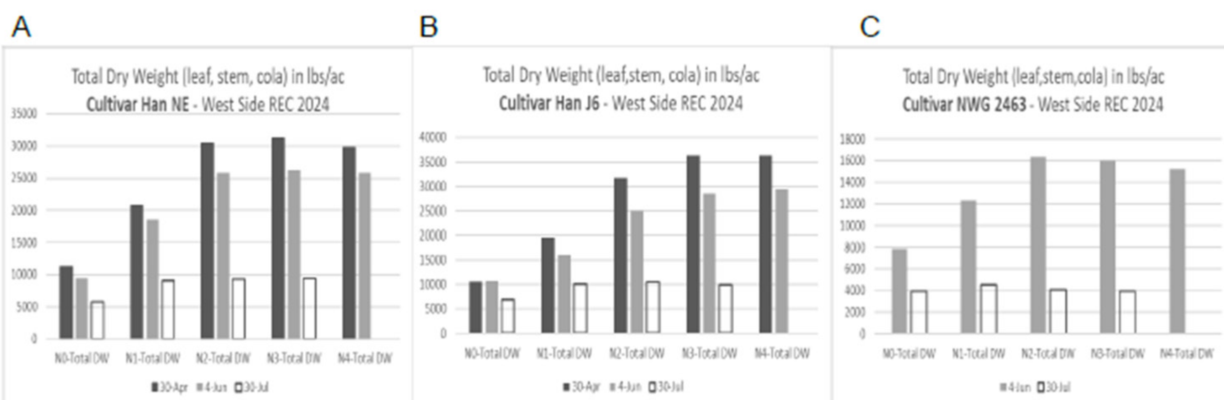

Figure 1.   Industrial hemp cultivars (A) “HAN NE”, (B) “HAN J6” and (C) “NWG 2463” total dry weight yields (stem, leaf, cola) at fall harvest time as a function of planting date (April 30 except NWG 2463, June 4 or July 30) and applied nitrogen fertilizer treatments in study done in 2024 in a Panoche clay loam soil at Univ CA West Side REC. N fertilization treatments were: N0 = no supplemental in-season N fertilizer; N1 = 60 lbs N fertilizer/acre; N2 = 120 lbs N/acre; N3 = 180 lbs N/acre; and N4 = 240 lbs N/acre

Acknowledgements

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

Project Leaders

Toby O'Geen
Professor and Cooperative Extension Specialist, Dept. of Land, Air and Water Resources, UC Davis,
atogeen@ucdavis.edu

Scott Devine
Post-Doctoral Researcher, Dept. of Land, Air and Water Resources, UC Davis
scottmdevine@outlook.com

Helen Dahlke
Professor, Dept. of Land, Air and Water Resources, UC Davis,
hdahlke@ucdavis.edu

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

Thomas Harter
Professor and Cooperative Extension Specialist, Dept. Land, Air and Water Resources, UC Davis
thharter@ucdavis.edu

Majdi Abou Najm
Associate Professor, Dept. of Land, Air and Water Resources, UC Davis,
mabounajm@ucdavis.edu

Claire Kisliuk
Jr. Specialist, Dept. of Land, Air and Water Resources, UC Davis
cakisliuk@ucdavis.edu

Introduction

Agricultural management of floodwaters (Flood-MAR) is of broad interest in California as a tool to recharge aquifers. There are concerns to be analyzed before this practice can be safely implemented, such as contamination of groundwater by leaching soil nitrate (NO_3). This modeling exercise hypothesized: 1. Flood-MAR will enhance NO_3 leaching vs. no Flood-MAR (business-as-usual); 2. Early Flood-MAR timing will leach less NO_3 than late Flood-MAR timing, due to lower rates of mineralization when soils are cooler; 3. Frequency of Flood-MAR pulses (shorter interval between water applications) may leach less NO_3, due to less time for mineralization between Flood-MAR applications; and, 4. NO_3 leaching risk is offset partially by denitrification in finer textured soils with longer periods of saturation and anaerobic conditions.

Objectives

This research evaluated contrasting seasonal timing and frequency of Flood-MAR as strategies to minimize NO3 leaching by leveraging the Root Zone Water Quality Model (RZWQM) to evaluate interaction of Flood-MAR with the N-cycle and inherent soil properties.

Description

RZWQM modeling included 33 Central Valley soils representing distinct particle-size classes (termed here Coarse, Loamy and Fine) and five different 37-year climate records obtained from CIMIS, spanning a precipitation gradient from relatively wet-to-dry in space and time (n=990 unique scenarios). The climatic gradient summarized by town from wettest to driest is: Durham, Davis, Parlier, Five Points, and Shafter. Simulations of maize extended to a depth of 150 cm. Biogeochemical and physical parameters were established using end-of-run values from a preliminary 37-year business-as-usual run of each unique soil x climate modeling combination (n=165). This produced unique initial biogeochemical conditions for each of the soil x climate combinations to test again under another 37-year business-as-usual run and contrasting Flood-MAR strategies. Flood-MAR was practiced during the 10-wettest water years of each 37-year climate record, applying 600-cm additional water via Flood-MAR through four 15-cm water applications in either January or March, using a frequency of either 3- or 7-day intervals. A fifth scenario tested a 21-day Flood-MAR interval January-March. To test the model, NO3 was measured from multiple cores collected from fields (almonds) before and after Flood-MAR across this climatic gradient

Results and Discussion

Multi-decadal RZWQM simulations suggest Flood-MAR can be used with near negligible risk of additional NO_3 leaching in relatively wet Central Valley locations (Durham and Davis, median annual precipitation > 400 mm yr-1) across a range of soil textures. Steady-state residual NO_3 in the wetter climates (Durham and Davis) were typically 60-100 kg N ha^{-1} after 37-years of the business-as-usual scenario (Fig. 1).

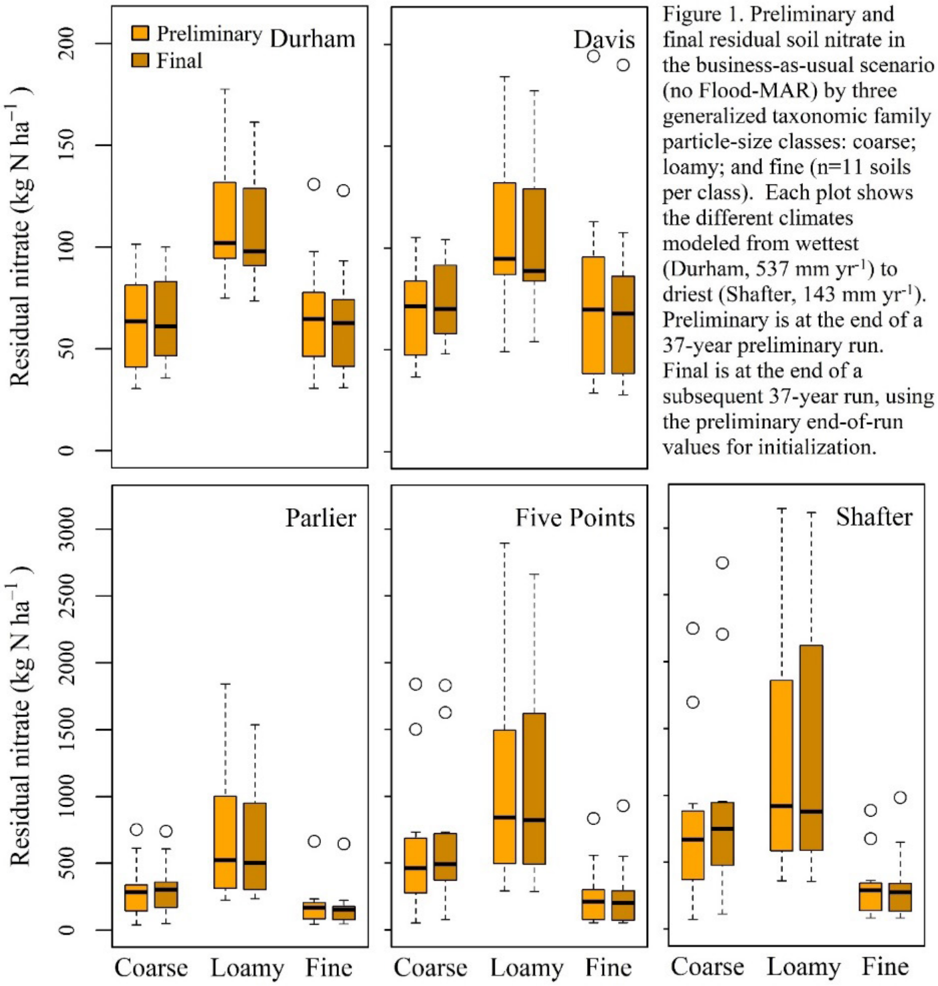

Figure 1. Preliminary and final residual soil nitrate in the business-as-usual scenario (no Flood-MAR) by three generalized taxonomic family particle-size classes: coarse; loamy; and fine (n=11 soils per class). Each plot shows the different climates modeled from wettest (Durham, 537 mm yr^{-1}) to driest (Shafter, 143 mm yr^{-1}). Preliminary is at the end of a 37-year preliminary run. Final is at the end of a subsequent 37-year run, using the preliminary end-of-run values for initialization.

This is because in-situ precipitation during the wet years, when Flood-MAR is expected to be practiced, removed most residual NO_3 through deep percolation. This is true even in the finest textured soils, which are most difficult to leach due to high microporosity. As precipitation declines, the Flood-MAR NO_3 leaching risk increased most clearly in loamy soils, even though the central tendency did not differ substantially across textural groups (Fig. 1 & 2). Additional nitrate leaching risk increased in dry climates, because lack of precipitation allowed for residual NO_3 accumulation across growing seasons.

Loamy soils tended to present the greatest possibility of risk of additional NO_3 leaching with Flood-MAR in drier climates (Figure 2). In the driest climate (Shafter), 4 of 11 loamy soils leached >3000 kg additional NO_3-N ha^{-1} using 21-day frequency Flood-MAR with median fluxes of 1,270 kg additional NO_3-N ha^{-1}. In fine soils, NO_3 leaching risk was mitigated by denitrification, preventing build-up of residual NO_3.

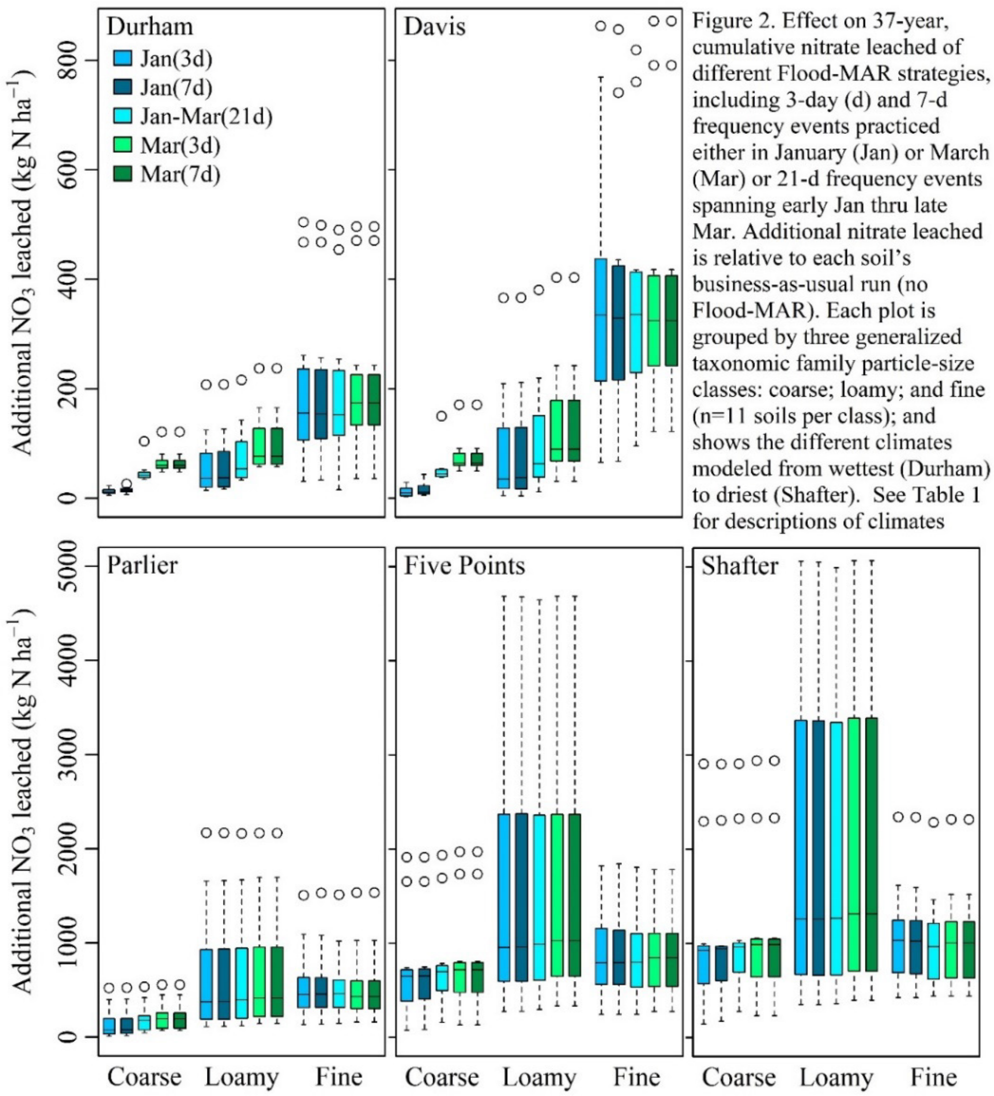

Figure 2. Effect on 37-year, cumulative nitrate leached of different Flood-MAR strategies, including 3-day (d) and 7-d frequency events practiced either in January (Jan) or March (Mar) or 21-d frequency events spanning early Jan thru late Mar. Additional nitrate leached is relative to each soil's business-as-usual run (no Flood-MAR). Each plot is grouped by three generalized taxonomic family particle-size classes: coarse; loamy; and fine (n=11 soils per class); and shows the different climates modeled from wettest (Durham) to driest (Shafter). See Table 1 for descriptions of climates

Flood-MAR timing strategies (January Flood-MAR vs. March Flood-MAR, combined with variable pauses among applications (3 vs. 7 vs. 21-day intervals, the latter January-March Flood-MAR) had only a negligible effect on NO_3 leaching risk. In fact, the effect of Flood-MAR timing strategies was only noticeable in wet climates where additional NO_3 leaching risk was comparably very low. While results demonstrated that Flood-MAR practices would be expected to increase net NO_3 flux to groundwater across all climates and soils, consistent Flood-MAR practices would also be expected to improve groundwater quality compared to business-as-usual irrigated agriculture. This is due to sustained provision of higher quality deep percolation water, which is especially limited in dry climates.

Thus, climates with median precipitation > 400 mm yr^{-1} were sufficient to leach rootzones in this simulated, fertilized agroecosystem, suggesting that Flood-MAR practiced in wetter climates is of low additional NO_3 leaching risk (Fig. 2).

The most direct mechanistic explanation for additional nitrate leaching risk in loamy soils from drier climates is due to their high capacity to retain water and NO_3. Loamy soils require more percolating water to leach effectively compared to coarse soils, explaining their conduciveness to residual NO_3 accumulation. Although coarse soils typically present the greatest risk to NO_3 leaching in agriculture, this truism did not hold up to evaluations of the effect of Flood-MAR on additional NO_3 leaching risk. Except in the driest climates, precipitation is sufficient to leach residual NO_3, such that the additional NO_3 leaching risk from Flood-MAR is typically lower in coarse compared to loamy soils.

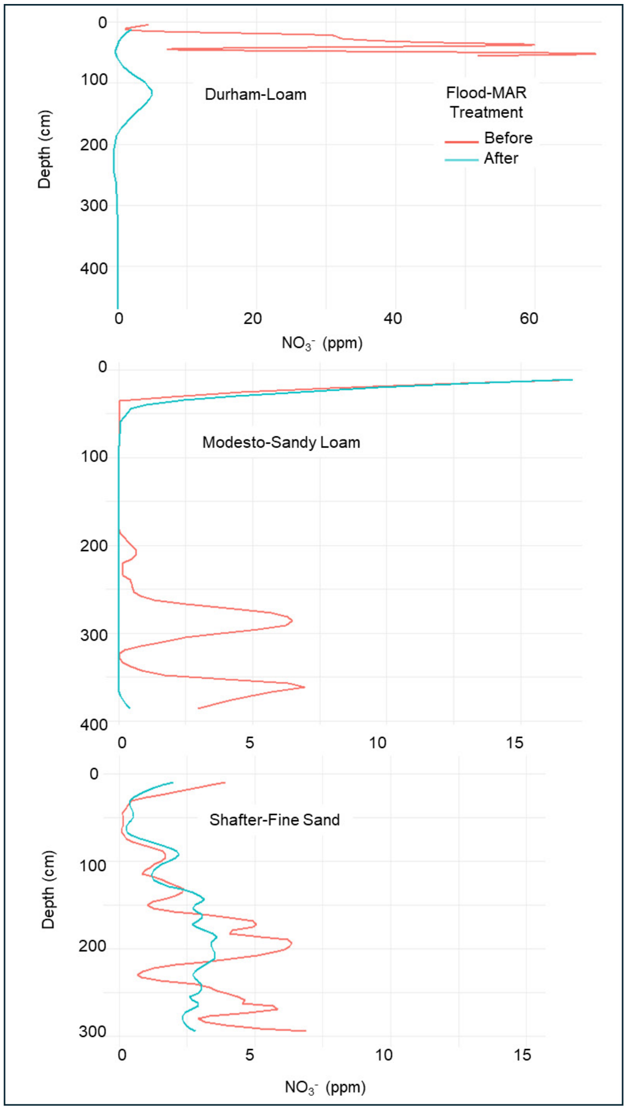

Figure 3. Mean nitrate concentration before and after Flood-MAR in soils nar Modesto and Shafter.

Field Flood-MAR trials partially support modeled outcomes. Deep cores at all sites showed lower NO_3 concentration after Flood-MAR (Fig. 3). However, residual NO_3 in the root zone did not correspond to modeled results because cores were collected from different crops and irrigation systems. The driest site (Shafter-Fine Sand) showed evidence of mineralization and subsequent release of NO_3 after Flood-MAR.

Results indicate the need to be aware of and manage for residual NO_3 levels when practicing Flood-MAR.

Acknowledgements

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Nitrogen Fertilizer and Irrigation Best Management Practices for the Low Desert Sudan Grass Production Systems

Project Leader

Oli Bachie
University of California Cooperative Extension (UCCE) Imperial County Director and Agronomy and Weed Management Advisor for Imperial, San Diego, and Riverside Counties
obachie@ucanr.edu

Introduction

Sudan grass is one of the primary forage crops of the low desert, particularly in the Imperial Valley. Sudan grass is a C4 plant, making it a relatively drought-resistant crop (Beybit et al., 2021) that thrives well in the low desert, where maximum summer daily temperatures often exceed 115°F. Most low-desert growers apply excessive amounts of nitrogen to maximize Sudan grass crop yield. Many growers also apply excessive irrigation water to flush out excess salt accumulation from the root zone. Being a heavy feeder, Sudan grass may take up and accumulate excess nitrate in its tissue, making it toxic to livestock. Higher levels of NO_3-N in the soil may also leach or erode out of crop fields, causing environmental pollution. NO_3 leaching or erosion can be exacerbated with the use of high volumes of irrigation water. There is limited guidance for growers on determining the optimal nitrogen (N) fertilizer and irrigation levels for optimal and safe Sudan grass hay production. This project was designed to develop optimal and sustainable nitrogen (N) fertilizer and irrigation management for efficient resource use, achieving optimal yield and livestock-safe Sudan grass hay, while ensuring ecological safety. The study is being conducted at the UCANR Desert Research and Extension Center (DREC) in Holtville, California. This report consists of findings from two crop harvests of an ongoing 2025 project. It is worth noting that not all project objectives were implemented during this reporting period.

Objectives

1. Develop the best N fertilization and irrigation management that enhances yield and improves the efficiency of crop fertilizer use (NUE) and water use (WUE).
2. Layout strategies that reduce N loss from Sudan grass crop fields and maintain Sudan grass of higher export quality and less risk of livestock poisoning.

3. Develop fertilization practices that will improve the marketability of hay and maximize the grower's economic benefit while reducing the loss of fertilizer into the ecosystem.

Description

The project has been conducted for multiple years. Three irrigation water levels, (1) 80% ET, (2) 100% ET, and (3) 120% ET, delivering 3,000, 3,500, and 4,000 gallons of water per field irrigation, respectively (laid out as main plots), and three fertilizer rates (subplots) were used as a two-way factor treatment. Fertilizer treatments were (N1) 50 lbs of fertilizer N/acre (lower rate) after each harvest/cutting, (N2) conventional N fertilizer rates of 80 lbs of fertilizer N/acre (higher rate), and (N3) N fertilizer based on crop fertilizer needs. A 100-lb N/acre fertilizer was applied to all plots as a pre-plant fertilizer for crop establishment. The trial was laid out in a split-plot design with four replications.

Sprinkler irrigation was used during crop establishment and converted to furrow irrigation controlled by gated pipes. Moisture sensors were used to measure crop water availability. Irrigation water potential and soil conditions of the research project area are reported in the previous interpretive summary. The watermark data for the irrigation levels indicate potential water stress in the 80% ET treatment, but not in the other two irrigation treatments. Nitrate concentration in irrigation tailwaters was measured to detect the erodibility of fertilizers. The biomass productivity and NO_3-N concentration in irrigation tailwaters data of Sudan grass were analyzed using the SAS 9.4 statistical package.

Results and Discussion

Sudan grass is typically harvested 3 to 4 times in its cropping cycle in the low desert when planted in early Spring (March-April). Our findings in this report are from the first and second crop harvest of the 2025 (third year) project. The first cutting (June) was from the pre-plant fertilizer application only and is used to determine the baseline biomass productivity with irrigation treatment as the only variable. The mean baseline fresh biomass (averaged over 12 sample sites) was 10.62 (80%ET), 10.47 (100%ET), and 10.43 (120%ET) tons/ac (Table 1). The findings show that there are no significant differences in Sudan grass biomass among the three irrigation treatments ($P = 0.9643$).

There is no increase in biomass when applying higher amounts of irrigation water; hence, water use efficiency (WUE) is reduced per unit of added water above the 80%ET. With similar biomass productivity (Table 1) among all irrigation treatments, the lower irrigation (80%ET) provided a higher WUE, depicting higher biomass per unit of irrigation water volume.

Table 1: Sudan grass biomass for June 2025 harvest. All treatment plots (12 plots for each irrigation treatment were harvested from the pre-plant fertilizer application only.

Irrigation levels	N observation	Mean biomass (t/ac)
80%ET	12	10.62a
100%ET	12	10.47a
120%ET	12	10.43a
		p = 0.9643 at α 0.05

Similarly, the biomass productivity of Sudan grass for the second harvest (July 2025) did not show significant differences among irrigation treatments (p = 0.2486) or fertilizer treatments (p = 0.8437) (Table 2). The two-way interaction (harvest date*ET*fertilizer) was also insignificant (p = 0.7049). Since biomass productivity is the same under all irrigation and fertilizer treatments, our findings suggest a higher WUE and NUE from the lower (deficit) irrigation and the 50lb N/ac (a once or split application) than the higher fertilizer amount (80 lb N/ac), indicating higher biomass per unit of irrigation water and per unit of added fertilizer amount.

Table 2: Sudan grass biomass for July 2025 harvest. Biomass yield within the columns of each treatment followed by the same letter is not significantly different.

Irrigation treatment	# of observations	Biomass (t/ac)		Fertilizer treatment	# of observations	Biomass (t/ac)
80%ET	12	10.30a		N1	12	11.45a
100	12	10.62a		N2	12	10.90a
120	12	12.29a		N3	12	10.87a
		P =0.2486				P =0.8437

Reduced biomass production under higher fertilizer levels may indicate a diminishing return, suggesting that higher fertilizer rates do not necessarily increase yield. Bachie et al., 2024b also showed that higher irrigation and fertilizer do not necessarily produce higher Sudan grass yield. The similarity in crop yield under low and high fertilizer levels indicates higher productivity (yield) per pound of fertilizer, suggesting a higher NUE.

In other words, Sudan grass can be grown under slight water stress (80%ET and reduced fertilizer supply 50 lbs N/ac applied at once or in split applications than at the highest (80 lbs N/ac) after every cutting, without compromising productivity.

The potential erodibility of nitrogenous fertilizers was assessed by measuring the nitrate (NO_3-) concentration in the tailwaters of an irrigated experimental Sudan grass field. Nitrate-N was detected in tailwaters under all irrigation and fertilizer treatments (Figure 1).

There was no significant difference (p=0.9438) in the amount of NO_3-N in tailwaters between the irrigation treatments (p=0.9438), indicating that even a slightly deficient irrigation (80%ET) can carry NO_3-N to the tail of an irrigated field. Nitrate concentrations in tailwaters were significantly different between the tested fertilizer inputs (p<0.0001) (Figure 2). The 80 lbs N/acre (N2) fertilizer had higher nitrate levels than the 50 (N1) or split 50 (25 lbs/N/acre twice) (N3) (Figure 2) in the respective treatment tailwaters. There were no significant differences in tailwater NO_3 concentration between the 50 and split (25 and another 25 lbs N/ac) fertilizer applications, although tailwater NO_3 concentration from the split application was slightly lower than the one-time 50 lb N/ac application. All fertilizer treatments, even as low as 25 lbs N/acre, resulted in their NO_3-N moving (eroding) into tailwater (Figure 2). The findings suggest that higher rates of fertilizer inputs, exceeding 50 lbs N/acre, result in a greater amount of NO_3-N that can move to the tailwater and ultimately into the drainage water.

The higher the fertilizer levels, the higher the NO_3-N detected in the tailwaters. There was no interaction between irrigation levels and the amount of fertilizer inputs (p = 0.7872) on NO_3-N in tailwaters. Various factors, including the size of the field, the steepness of the field, the slope length, crop cover, soil aggregate composition, water and soil conservation practices, crop types, and other agricultural management practices, can influence soil and nitrate erosion. Soils with faster infiltration rates, higher levels of organic matter, and improved soil structure may have a greater resistance to erosion.

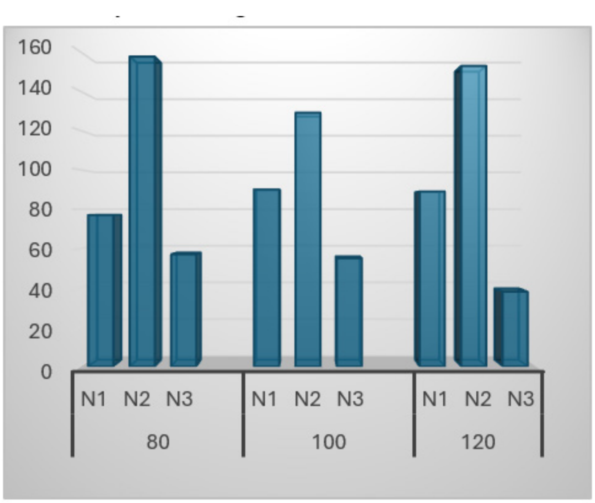

Figure 1: Mean NO_3 concentration in tail waters of fields treated with 3 irrigation (80, 100 and 120% ET) and 3 fertilizer levels (25, 80 and 25 lbs N/ac)

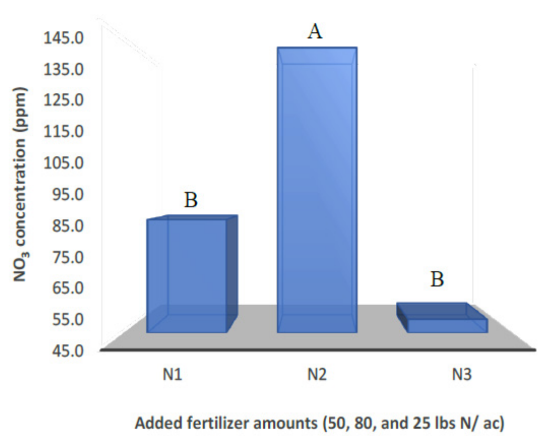

Figure 2: Concentration of NO_3-N in tailwaters of plots fertilized with 50, 80, and 25 lbs N/acre (split application). Bars with different letters indicate significant differences

Although our findings are from a small research field that does not necessarily reflect what might happen in a large commercial field, it can be used as a benchmark to warn of high fertilizer input, erodibility, and potential hazards on ecological systems. These findings were published in the local Imperial AgBrief newsletter (Bachie and Montazar, 2025). Our findings suggest that fertilized agricultural fields, combined with irrigation water, can lead to the movement or erosion of a significant portion of the fertilizer nitrates into tailwater. The higher amount of NO_3-N in tailwater from the higher fertilizer application suggests that excess nitrogen is susceptible to runoff and the amount eroded is related to the amounts applied. The findings, in general, can serve as a guide for providing farmers with information on best management practices to prevent pollution and resource loss associated with the use of fertilizers and irrigation. Growers must be aware of the amount of fertilizer they apply to crop fields.

In some cases, split applications of fertilizers can be beneficial over a single application (Cassman et al., 2002). Strip or minimum tillage, which causes minimal disturbance to the soil surface (Wolkowski et al., 2009) or applying fertilizers when efficient crop nutrient uptake occurs (Scharf & Lory, 2006) can reduce the amount of nitrogen entering the hydrological system. Applying fertilizers with a split schedule is another way to reduce nitrogen loss.

In summary, supplemental fertilizer levels and irrigation water may have limited effects on biomass accumulation within the tested irrigation and fertilizer levels. Contrary to the growers' perception that high irrigation and fertilizer inputs are necessary for increased Sudan grass productivity, we observed that Sudan grass can be stressed to 80% of its evapotranspiration (ET) without significantly reducing biomass productivity. Optimum Sudan grass biomass can also be yielded with lower fertilizer, 50 lbs N/acre after every cutting, or even by splitting the 50 lbs N/acre fertilizer application. Similar yields from lower irrigation water and fertilization indicate higher WUE and NUE, respectively. Growers can make significant economic returns by reducing unnecessary irrigation and fertilizer-level inputs. In the meantime, growers can increase the marketability of their Sudan grass by producing hay with desirable NO_3 levels in the hay. Reduced resource input (fertilizer and irrigation) conserves resource, optimizes economic return, and reduces potential environmental pollution. Nitrogen leaching and erosion studies will be the focus of the upcoming project cycle.

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Ali Montazar
Irrigation and Water Management Advisor
UCCE Imperial County.
amontazar@ucanr.edu

Brooke Latack
Livestock advisor
UCCE Imperial County
bclatack@ucanr.edu

Quantify and Model Overlooked Pathways of Nitrogen Loss from Organic Inputs Across Contrasting Soil Types

Project Leaders

Timothy Bowles, PhD
Assistant Professor
UC Berkeley Department of Environmental Science, Policy and Management
timothy.bowles@berkeley.edu

Bhavna Arora, PhD
Research Scientist, Energy Geosciences Division
Lawrence Berkeley National Lab
barora@lbl.gov

Eric Brennan, PhD
Research Horticulturist
USDA Agricultural Research Service (Salinas)
eric.brennan@usda.gov

Hannah Waterhouse, PhD
Postdoctoral Scholar
UC Berkeley Department of Environmental Science, Policy and Management
hawaterh@ucsc.edu

Introduction

The Agricultural Order 4.0 regulation in the Central Coast region allows for compost and other organic amendments to be included in nutrient management plans, with a discount factor for nitrogen (N) depending on the expected timing of N mineralization. Increased use of organic inputs makes paramount the need for site specific recommendations to reduce unintended externalities, such as N loss to groundwater. Scientific confidence is still lacking in the ways in which the amount, type, and timing of compost application interact with soil properties to improve N use efficiency (NUE) and reduce N loss. While, on average nitrate (NO_3^-) leaching is reduced in systems using organic inputs, the variability in N loading is high, highlighting the need to account for the heterogeneity across systems and landscapes. For instance, long-term N balance research by Collaborator Brennan showed that compost use in an organic vegetable rotation led to >100 kg N/ha/yr that was either lost or stored in the soil below 30cm[2]. This makes the wide scale adoption of compost use challenging. First, our understanding of whether adding compost supports crop N demands at the right time so as to minimize potential for groundwater contamination is growing but still incomplete. Second, there is emerging evidence that leaching of dissolved organic N (DON) from organic inputs could be a considerable, but overlooked, N loss pathway.

DON could act as a source of NO_3^- in groundwater as it is mineralized and on its own can be harmful to human consumption due to the formation of disinfection byproducts. This project proposes to understand how compost application at varying rates interacts with soil edaphic properties to influence both inorganic and organic N retention and loss dynamics in agricultural landscapes within California's Central Coast.

Objectives

This project addresses how compost can be managed to support productivity while protecting water quality. We will leverage a long-term experiment and sampling from 28 farms in prior related projects. Our specific objectives are:

1. Conduct a greenhouse experiment to understand how increasing rates of compost application influence leaching of different N species (inorganic and organic N).
2. Generate and analyze data on N availability, losses and retention across a diversity of farms to inform model development.
3. Calibrate and validate a crop-ecosystem model, Ecosys, for lettuce production in the Central Coast of California.
4. Develop and test scenarios of compost application rates and timing across contrasting soil types to quantify N dynamics and losses in order to develop guidance on how to apply compost to support both productivity and N losses.
5. Conduct outreach to vegetable growers across the study region (Santa Cruz, San Benito, and Monterey Counties), as well as to the Central Coast Water Quality Control Board, and professional agricultural extension and support.

Description

We have now completed the greenhouse column experiments testing the effect of compost additions on leaching of DON and inorganic N from contrasting soil types, a sandy loam (>40% sand) and a clay loam (<20% sand) (Obj. 1), analyzed ammonium (NH_4^+), nitrate (NO_3^-), and DON from 28 fields across the central coast across three time points, transplant, mid-season, and harvest (Obj. 2), and the deep coring from the long term site and the subsequent analyses including total C, N, texture, pH, and CEC in 30cm increments to calibrate and validate our model with and have begun running and calibrating the model (Obj. 3 & 4). During the grant we have presented our preliminary findings at many farmer outreach and workshop events.

For the column experiments, soils were packed into 40cm high columns with small marbles on the bottom to allow for free drainage of leachate to be collected. Soils were packed to approximate field bulk density values. Soils were analyzed for initial inorganic N and DON and subsamples were kept and stored for total soil carbon and N, and soil texture.

We used an experimental regression design where linearly increasing rates of compost additions were applied across 15 columns. This allows for quantifying non-linear/threshold effects of compost addition. Compost rates were 0, 1.9, 3.8, 5.7, 7.6, 11.4, 15.2, 19, 22.8 Mg/ha and compost was added on a per dry weight basis. Lettuce transplants were planted in the columns. Irrigations occurred once a week and columns were brought to 10% above field capacity each irrigation event.

Leachate was collected after each irrigation event and analyzed for NH_4^+, NO_3^-, DON, and DOC. After 8 weeks the experiment was concluded and lettuce was harvested, dried, ground and plant C & N content determined. In addition, total C and N, pH of the compost and soils, and soil texture, as well as CEC were determined.

Deep coring (0-1m) from the USDA long term trial was conducted in late August, 2022 and have been analyzed for total C and N, texture, CEC, and pH. This helped shed light on whether N surpluses documented in Brennan's work were leached or stored deeper in the soil profile and will be used to validate the Ecosys model.

Inorganic nitrogen and DON have been analyzed down to 60cm from 28 fields and three different time points: transplant, mid-season, and harvest (1120 samples total). We also collected management data from the past 5 years and analyzed for texture. This allowed for determination of how management and soil variability can modulate DON loss from organic amendment applications and will help validate the Ecosys model to see if it is performing adequately on varying soil types.

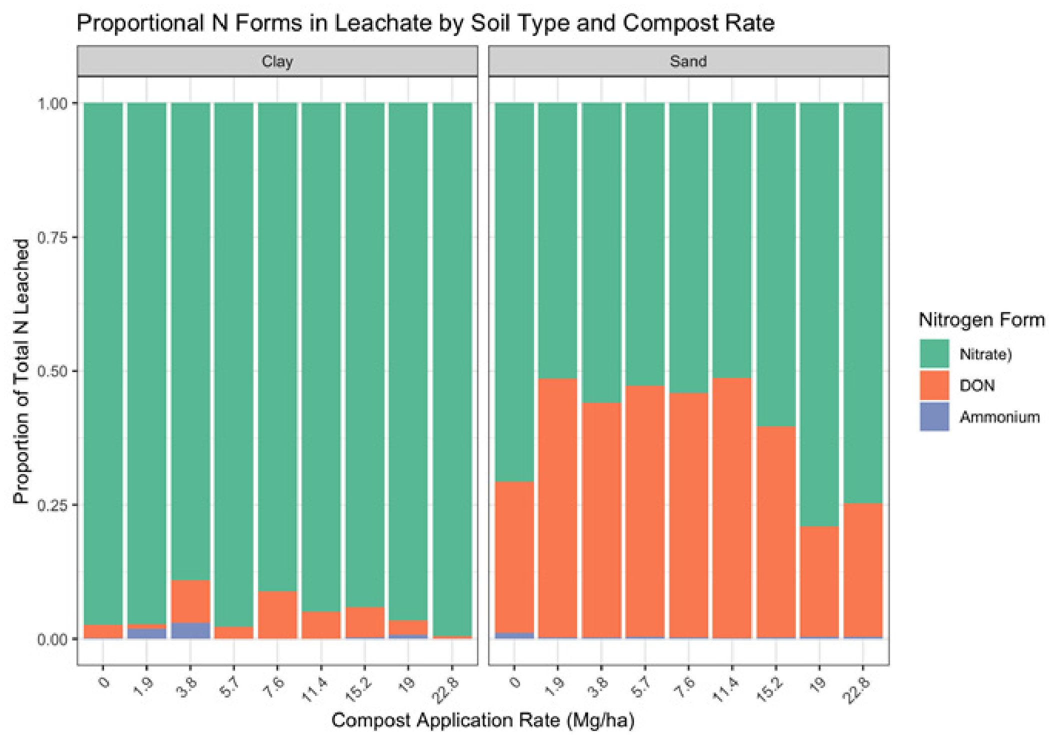


Figure 1: Proportional N Forms in Leachate by Soil Type and Compost Rate

Results from the column experiments suggest that, when management is kept the same across soil types, pathways of N loss differ between soil textures. DON was found to be a major loss pathway in the sandy loam with it making up 20.8% - 53.8% of total N leached, while in the clay loam DON only made up 0.42%-8.9%% of total N leached, with the majority being lost as NO_3^- (Fig. 1). Interestingly, in the sandy loam soil, increasing compost rates led to decreasing DON loss, with the main N loss pathway occurring as NO_3^- (Fig. 2). In the clay loam soil, there was no relationship between increasing compost rates and DON loss (Fig. 2). Overall, total N leaching was higher in the clay loam compared to the sandy loam, likely due to higher initial background levels of NO_3^- and artificial preferential flow pathways due to errors in repacking the columns to field bulk density with a shrink-swell clay.

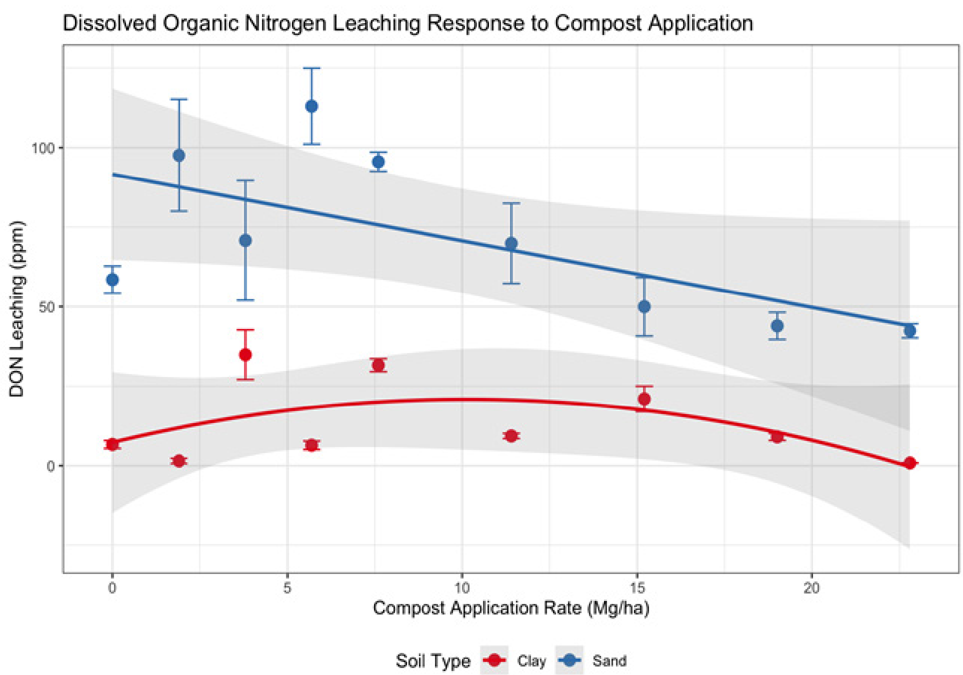
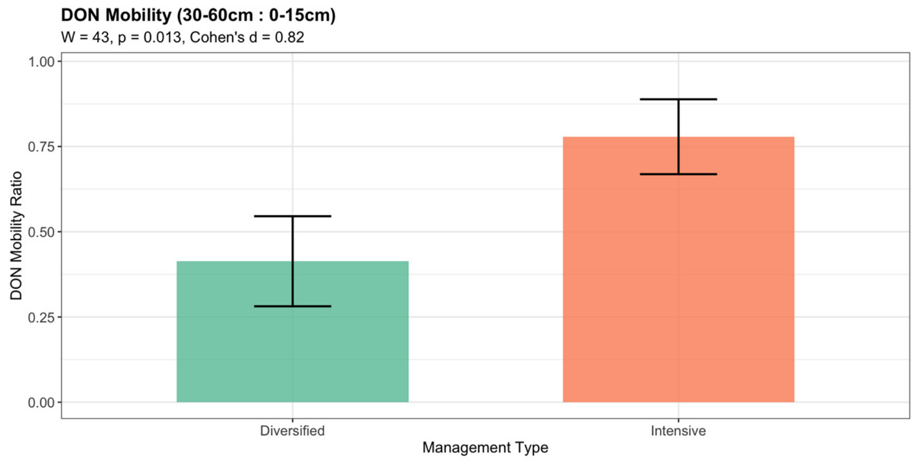


Figure 2: Total DON Leaching by Compost Application Rate and Soil Type

The majority of N leached occurred after a disturbance event (packing of columns) and the first subsequent irrigation event. While NO_3- values in the leachate after the first irrigation were above the 10ppm maximum contaminant limit (MCL), subsequent irrigations led to NO_3- loads below the MCL. Further, in the lowest application rates (1.9 Mg/ha and 3.8 Mg/ha), more N was leached than was applied, suggesting that mineralization of soil organic matter (i.e. the priming effect) was occurring and leading to N losses, whereas higher application rates reduced the percentage of N applied that was leached.

Coring in the long term trial down to 90cm resulted in no statistically significant difference in total N or C contents between treatments, however, total N was elevated at 0-30 cm and 30-60 cm depths in the treatments where cover crops and compost applications were implemented compared to treatments where only compost was added with no cover crops, or where no compost or cover crops were added, demonstrating that there is a legacy effect on N storage down to 60cm even after a decade since the experiment ended.



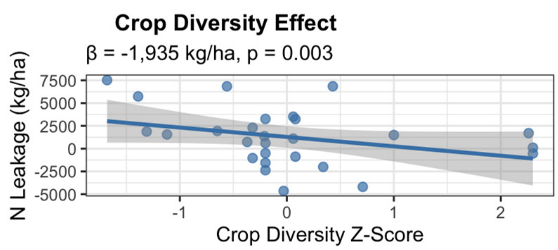


Figure 3: (top) Ratio of DON in 30 to 60 cm layer vs DON in 0-15 cm layer between diversified and intensively managed fields. (bottom) Influence of crop diversification on potential N lost to leaching at the end of the cash crop season.

Sampling across 28 fields, we found that management practices significantly control DON mobility. Comparing soil health practices including crop diversification, carbon additions, cover cropping, and tillage, only crop diversification was significantly correlated with DON and NO_3^- loads after harvest, with increased diversification decreasing N loads. Classifying fields into diversified vs intensive systems based on their implementation of soil health practices, with diversified systems implementing crop diversification and cover cropping at higher rates compared to intensive, we found that intensive systems had significantly higher DON at the end of the season compared to diversified systems.

Accomplishments

We have finished all objectives except for analysis of the modeling results. We expect to finish these by end of the summer and will write multiple publications from this grant.

Acknowledgements

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Optimizing Nitrogen Fertilizer Concentration in Vegetable Transplant Production

Project Leaders

Emma Volk
Production Horticulture Advisor
University of California Cooperative Extension
evolk@ucanr.edu

Bruno Pitton
Environmental Horticulture Advisor
University of California Cooperative Extension
bjpitton@ucanr.edu

Introduction

California's $7.68 billion vegetable crop industry (CDFA 2021) is dependent on the use of vegetable transplants for efficient plant establishment. To produce high quality transplants, nutrients are supplied as water soluble fertilizer through irrigation systems. Fertilizer is a low-cost input for vegetable transplant production, allowing growers to over-apply nutrients without large financial losses. Over-application of nutrients can cause poor shoot growth, decreased root growth, or disease susceptibility in vegetable transplants. In addition, excessive fertilizer application can have negative environmental impacts.

Currently, nitrogen (N) fertilizer application recommendations for vegetable transplant production are extremely broad (ex. 60-600 ppm N), and they do not have specific guidelines for the diverse range of vegetable transplants produced in California. For example, extension publications have general recommendations, such as providing more N for solanaceous crops, and less for cucurbit crops.

Therefore, we evaluated N uptake of the top five vegetable transplant crops produced in California to provide clear nutrient application recommendations for specific crops.

Objectives

1. Determine nitrogen requirements for the top five California vegetable transplant crops
2. Convey results from this research to transplant growers through publications and presentations

Description

Trial 1 for leaf lettuce, broccoli, processing tomato, celery, and romaine lettuce were completed in 2023. Trial 2 was completed for broccoli, celery, and romaine lettuce in 2024 and 2025.

Trial 2 was also conducted for leaf lettuce, but it will have to be repeated, due to technical issues with a lysimeter. Crops were studied in Trial 2 when the daily light integral (DLI) was > 15 mol*m-2*day-1 different, compared to when the same crop was studied in Trial 1. This was done to determine if DLI impacts transpiration and nutrient demands.

Seedlings of each crop were germinated in plug trays on a mist bench before being placed on individual ebb and flood trays for nutrient solution application. Nitrogen, phosphorus (P), and potassium (K) composition of nutrient solution treatments are in table 1. Each ebb and flood tray were built on a weighing lysimeter to record daily evapotranspiration for trial 1. During trial 2, plug trays were weighed by hand right before irrigation, and again 1.5 hours after irrigation. Growing media was refilled to container capacity daily and daily water use was recorded. Plants were harvested after reaching commercial size. Dried shoot biomass for each plug tray was recorded and analyzed for NPK content. The nutrient concentration in plant tissue was multiplied by the total biomass harvested from each plug tray to get the total nutrient mass per plug tray. Optimal nutrient concentration for each vegetable transplant crop was calculated as the total nutrient mass in all plant tissue in a plug tray (mg), divided by the total plug tray transpiration (L).

We will share the study's results through the UC Nursery and Floriculture Alliance newsletter, and through the annual Vegetable Transplant Nursery Association meeting. The results of this study could potentially minimize nitrogen use in vegetable transplant nurseries. This could have a positive impact on agricultural water pollution and minimize input costs for vegetable transplant nurseries.

Results and Discussion

In trials 1 and 2, the 200 and 400 ppm treatments had similar dry weights for the broccoli, romaine lettuce, and celery trials. In trial 1, leaf lettuce and processing tomato also showed statistically similar dry weights between the 200 and 400 ppm treatments. Dry weights were significantly lower in the 50 ppm treatment, compared to the 200 and 400 ppm treatments in all crops and trials, except for Trial 1 leaf lettuce and Trial 2 romaine lettuce.

In Trial 1, the optimal NPK fertilizer concentration for broccoli was calculated as 437, 52, and 232 ppm, respectively. In Trial 2, the optimal NPK fertilizer concentration was calculated as 446, 31, and 124, respectively (Table 1). The N concentrations (Table 1) are in agreement with previous research that found that broccoli transplant dry shoot biomass was maximized at 350 (Tremblay and Senecal, 1988) or 400 ppm N (Masson et al., 1991a; Masson et al., 1991b). Tremblay and Senecal (1988) identified that 200 ppm K was optimal for broccoli transplants and that agrees with our calculated fertilizer concentration of 232 ppm K in Trial 1, but not with the calculated fertilizer concentration of 124 ppm K in Trial 2 (Table 1).

In Trial 1, the optimal NPK fertilizer concentration for leaf lettuce was calculated as 246, 33, and 169 ppm, respectively (Table 1). The N concentration we calculated is 150 ppm N lower than the N concentration Masson et al. (Masson et al., 1991a; Masson et al., 1991b) identified in their research. They determined that 400 ppm N increased lettuce yield in the field by 16% and increased shoot biomass by 38% as compared to 100 ppm N and it is not clear if 246 ppm N will increase field yield. Previous research recommended >15 ppm P and >24 ppm K for nutrient solutions growing lettuce transplants (Soundy et al., 2001a; Soundy et al., 2001b) which agrees with our recommended P and K concentrations (Table 1).

The optimal NPK fertilizer concentration for processing tomatoes was calculated as 304, 44, and 151 ppm, respectively (Table 1). The optimal N concentration we calculated was within the range reported by other researchers (Garton and Widders, 1990; Liptay and Nicholls, 1993; Masson et al., 1991a; Masson et al., 1991b; Melton and Dufault, 1991; Vavrina et al., 1998; Weston and Zandstra, 1989). Greater concentrations resulted in increased shoot mass (Masson et al., 1991b), greatest early yields (Masson et al., 1991a) and total yields (Weston and Zandstra, 1989) than lower concentrations.

In trial 1, the optimal NPK fertilizer concentration for romaine lettuce was calculated as 232, 37, and 280 ppm, respectively. In trial 2, the optimal NPK concentration was calculated as 232, 22, and 189, respectively (Table 1). There are no results in the literature to compare this to because no researchers have reported nutrient concentrations of romaine lettuce specifically.

In trial 1, the optimal NPK fertilizer concentration for celery was calculated as 262, 45, and 242 ppm, respectively. The optimal NPK fertilizer concentration trial 2 was 273, 23, and 131 ppm, respectively (Table 1). The mean transpiration from the 50 and 200 ppm N treatments (Table 1) was used to calculate the nutrient concentration for the 400 ppm N treatment in trial 1. The N concentration (Table 1) agrees with previous research that found that celery transplant dry shoot biomass was maximized at 350 (Tremblay and Senecal, 1988) or 400 ppm N (Masson et al., 1991a; Masson et al., 1991b).

Conclusions

Further analysis to compare the recommended fertilizer concentrations from trials 1 and 2 will have to take place to determine our NPK fertilizer concentration recommendations. That said, the 200-ppm treatment had similar dry weights to the 400 ppm treatments in trials 1 and 2, across all crops. This indicates that the recommended fertilizer concentrations will be derived from the 200-ppm treatment.

Crop	Applied Nitrogen Concentration (ppm)	Shoot Dry Weight (g)		Transpiration (L)		Calculated Fertilizer Concentration					
						Nitrogen		*Phosphorus*		*Potassium*	
		trial 1	*trial 2*	*trial 1*	*trial 2*	*trial 1*	*trial 2*	*trial 1*	*trial 2*	*trial 1*	*trial 2*
Grazion Leaf Lettuce	50	1.66a		10.0a		69a		12a		109a	
	200	2.77a		13.7b		223b		33b		173b	
	400	2a		10.8b		269b		33b		164ab	
Green Magic F1' Broccoli	50	1.44a	0.46a	6.2a	1.9a	118a	102a	17a	7a	96a	49a
	200	3.3b	1.09b	9.4b	1.64a	437b	446b	52b	31a	232b	124ab
	400	3.47b	1.08b	8.9b	1.16a	732c	762b	47b	67b	277b	179b
N 6428' Processing Tomato	50	0.77a		7.1a		48a		8a		48a	
	200	1.77b		8.1a		265b		44b		121ab	
	400	1.83b		9.3a		343c		44b		180b	
Blue Rock' Romaine Lettuce	50	0.42a	0.31a	1.7a	1.17a	216a	90a	38a	5a	383a	102a
	200	0.6b	0.64ab	3.0a	1.57a	232a	232ab	37a	22ab	280a	189ab
	400	0.7b	0.832b	2.5a	1.02a	427b	490b	73b	50b	384a	342b
Kelvin F1 OG' Celery	50	0.37a	0.63a	4.39	1.9a	50a	134a	11a	7a	62a	73a
	200	1.03b	1.71b	4.41	3.3a	262b	273b	45b	23ab	242ab	131ab
	400	0.95b	1.78b	3.01	2.7a	420c	384c	61b	57b	358b	211b

Table 1. Mean values for vegetable transplant crop experiments for trials 1 and 2. Different letters within the same column and for individual crops indicate significant differences ($p<0.05$) in the mean values of different fertilizer treatments. Calculated fertilizer concentration is calculated by multiplying shoot concentration by shoot dry weight and dividing by transpiration.

Acknowledgements

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Developing Tools and Information on Irrigation and Nitrogen Best Management Practices in California's Low Desert Lettuce Production Systems

Project Leader

Ali Montazar
Irrigation and Water Management Advisor
UCCE Imperial County
amontazar@ucanr.edu

Introduction

Effective irrigation and N management are crucial to maximizing lettuce yield while reducing environmental impact, especially in light of growing water quality regulations and water conservation demands in California's low desert. The overall purpose of this study is to understand the viability and applicability of current N and irrigation management practices in the desert lettuce production systems. It aims to develop tools and information on improving and promoting adaptation of management practices that optimize N and water use efficiency in desert lettuce.

Objectives

1. Provide data and information on crop water use and crop N uptake in desert lettuce.
2. Develop recommendations on best N and water management practices in desert lettuce.
3. Adapt the CropManage (CM) decision support tool for water and N management in desert lettuce.

Description

The field experiments were conducted at the University of California Desert Research and Education Center (DREC) over three crop seasons. In the first two seasons, iceberg lettuce was grown, and in the final season, romaine lettuce, all on 2-m-wide raised beds with six crop rows and three drip lines per bed. Three N fertilizer scenarios of (1) 100% of the N amount recommended by CM (N2), (2) approximately 80% of N2 (N1), and (3) approximately 120% of N2 (N3) were assessed under two irrigation strategies (100% crop ET and 125% crop evapotranspiration (ET)). CropManage was used to determine 100% crop ET. Two irrigation strategies were implemented, namely 100% ET (I1) and 125% ET (I2).

In each trial, irrigation strategy (as the primary factor) and N scenario (as the secondary factor) were evaluated in a randomized complete block design with a split-plot arrangement and four replications. Comprehensive yield quality evaluation was conducted at harvest including plant population, head weight, biomass, and marketable yield.

Canopy cover images were collected using an infrared digital camera, modified to take NDVI photographs on a weekly basis beginning at 25 DAP to quantify crop canopy coverage over the crop season. Canopy coverage data was used as input for the CM to verify and, if necessary, adjust the canopy coverage curve developed. In addition, NO_3-N data from laboratory analyses and the Soil Nitrogen Quick Test in early and within the season were incorporated into the CM to improve the accuracy of N recommendations.

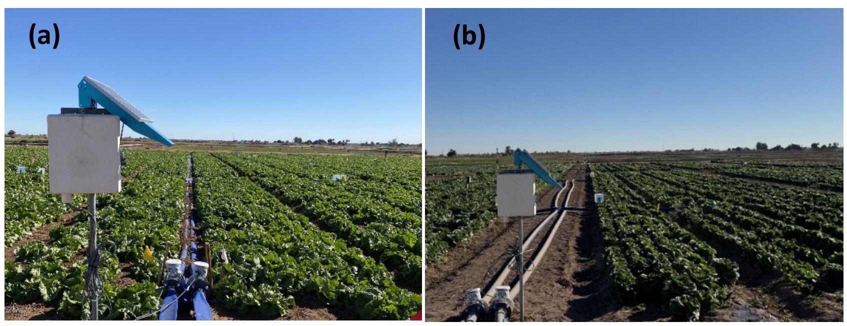

Figure 1. A demonstration of trials in the 2023-24 season (a), iceberg lettuce, and the 2024-25 season (b), romaine lettuce. The water applied was measured using magnetic flowmeters attached to datalogger. The data of water applied was automatically imported and analyzed by the CM tool.

Results and Discussion

Water and N applied. Total applied water across treatments ranged from 230-288 mm in the 2022-23 season, 198-254 mm (plus 26 mm rainfall) in the 2023-24 season, and 244-305 mm in the 2024-25 season.

These values include total applied water during plant establishment and post-establishment, while excluding the water applied for leaching salts in summer, a common practice to sustain soil productivity and control salinity in the desert cropping systems. The N application rates ranged from 101-150 kg ha^{-1}, 98-144 kg ha^{-1}, and 96-146 kg ha^{-1} during the respective seasons, respectively.

Effects of irrigation and nitrogen management on yields. The statistical analysis suggested insignificant impacts of applied water, N application rates, and interaction between irrigation and N rates on aboveground fresh biomass yields (p values ≥ 0.076 in the study seasons) and marketable yields (p values ≥ 0.084 in the study seasons) (Figs. 2a-c). No consistent statistical effect of irrigation and N applications were found on dry biomass yield across the study seasons (Fig. 2d-f). For instance, insignificant impacts from irrigation treatment and N application rates were obtained on dry biomass yield in the 2023-24 season (p values ≥ 0.064), however, the effects of both irrigation strategy and N application scenario were statistically significant in the 2024-25 season (p values ≤ 0.022).

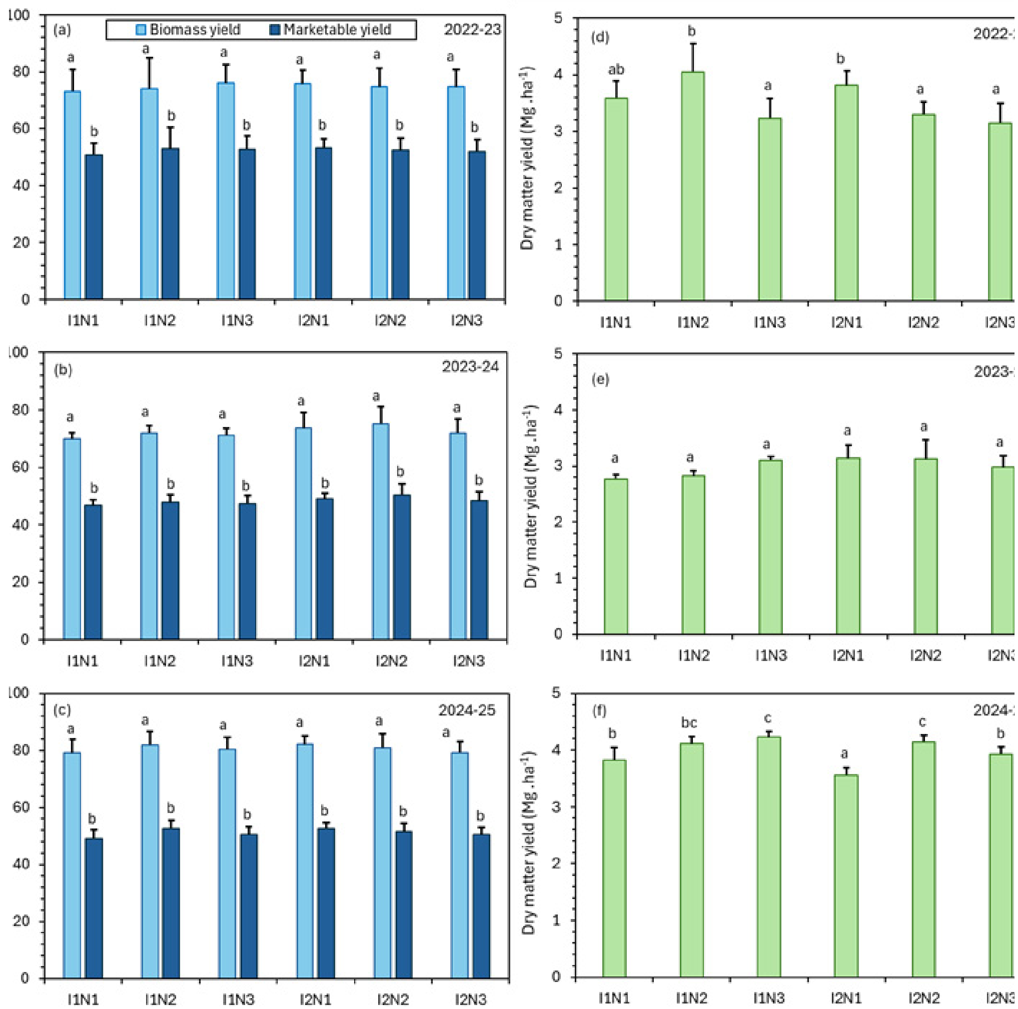

Figure 2. Mean fresh biomass, marketable, and dry matter biomass yields across treatments over the study seasons. Means followed by different letters in the bars with similar color differ from each other by Tukey's HSD test at 0.05 significance level. Error bars represent standard deviations of treatment means.

Effects of irrigation and nitrogen management on N uptake. The results showed that N application rates had a significant effect on N uptake at harvest across all three seasons ($p < 0.05$) (Table 1). Irrigation strategy also had a significant effect in the 2023–24 and 2024–25 seasons ($p < 0.05$); however, the interaction between N application and irrigation strategy was not significant across treatments over the seasons. The findings illustrated a relatively wide range of N accumulated in lettuce plants across treatments and seasons, varying from 109 kg ha^{-1}, treatment I1N1 in the 2023–24 season, to 155 kg ha^{-1}, treatment I1N3 in the 2024–25 season.

Effect of irrigation and nitrogen management on water use efficiency (WUE). The analysis showed significant effects of irrigation treatments on WUE values, greater values in irrigation strategy I1 than irrigation strategy I2 ($p < 0.01$) with respect to biomass and marketable yields (Table 2). On average, the WUE values were 24%, 20%, and 22% higher in irrigation strategy I1 than irrigation strategy I2 for marketable yields across the growing seasons.

Table 1. Mean N uptake (kg ha^{-1}) across the treatments over the study seasons. Means with different letters at the same column are statistically different from each other by Tukey's HSD test at 0.05 significance level. A summary of p-values from ANOVA for effects of I, N, and I×N is presented.

Treatment	2022-23	2023-24	2024-25
I1N1	126a	109a	121a
I1N2	146b	123b	137b
I1N3	132a	137b	155c
I2N1	127a	123b	128a
I2N2	131a	133b	148c
I2N3	141b	149c	150c
	p values of significance test		
Irrigation (I)	0.712	0.0002	0.022
Nitrogen (N)	0.047	<0.0001	<0.0001
I × N	0.057	0.738	0.006

Table 2. Mean WUE value (kg ha^{-1} mm^{-1}) across the treatments with respect to biomass and marketable yields. Means with different letters at the same column differ from each other by Tukey's HSD test at 0.05 significance level. A summary of p-values from ANOVA for effects of I, N, and I×N is presented.

Treatment	2022-23		2023-24		2024-25	
	Biomass	Marketable	Biomass	Marketable	Biomass	Marketable
I1N1	318b	221b	312b	209b	324b	201b
I1N2	322b	230b	321b	213b	336b	215b
I1N3	331b	229b	318b	212b	329b	207b
I2N1	263a	184a	263a	175a	269a	173a
I2N2	260a	182a	269a	180a	265a	169a
I2N3	261a	181a	257a	172a	260a	166a
	p values of significance test					
Irrigation (I)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Nitrogen (N)	0.94	0.51	0.66	0.57	0.62	0.41
I × N	0.86	0.95	0.82	0.36	0.43	0.50

The impacts of N treatments and interaction of irrigation and N application on WUE were statistically insignificant.

Conclusions

This study offers more accurate estimates of N uptake, contributing to the refinement of in-season split N fertilizer strategies in desert lettuce. The findings underscore opportunities to improve water and N management within standard drip-irrigated lettuce practices in the region, positioning the CropManage tool and study results as a practical decision-making framework.

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We would also like to thank our cooperators:

Daniel Geisseler
Nutrient Management Specialist
Dept. of LAWR, UC Davis
djgeisseler@ucdavis.edu

Michael Cahn
Irrigation and Water Resources Advisor
UCCE Monterey County
mdcahn@ucanr.edu

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The Role of Irrigation Rate, Irrigation N, and Deep Soil Testing in Broccoli Nitrogen Management

Project Leaders

Charlotte Decock, Ph.D.
Associate Professor
Cal Poly San Luis Obispo
cdecock@calpoly.edu

Michael Cahn, Ph.D.
Irrigation and Water Resources Advisor
UC Cooperative Extension (UCCE)
Monterey County
mdcahn@ucdavis.edu

Introduction

To reduce nitrogen (N) pollution, regulations increasingly encourage growers to account for all N inputs, including nitrate in irrigation water ("pump-and-fertilize," PAF). Previous research has demonstrated that nitrate-N contained in irrigation water is an effective source of crop nutrition (Cahn et al., 2017). However, attempts by commercial broccoli growers to produce broccoli with high N irrigation water alone have led to low yield, even though water N exceeded crop demand.

For N to benefit crops, irrigation water must remain in the root zone, making irrigation management central to N use efficiency. Moreover, the fate of N in irrigation water may be affected by factors such as soil texture and differ between conventional and organic cropping systems. As a result, the extent to which irrigation water N can offset fertilizer requirements in commercial broccoli production remains unclear.

Objectives

The overall goal of this project is to support growers to reduce N inputs and losses by quantifying the N credit from irrigation water in broccoli production under contrasting irrigation management on organic and conventional ranches with varying soil textures.

Specifically, we aim to:

1. Evaluate if yield will maximize at a lower N rate under ET-based irrigation scheduling compared to the grower standard practice.
2. Assess the effect of irrigation management and N rate on aboveground N uptake, soil N dynamics and partial N budgets on ranches with varying N loadings in irrigation water

Description

We conducted eight controlled on-farm field trials in California's coastal valleys to study the effects of N rate and irrigation management on N dynamics and yield in broccoli production. The experiments took place on commercial ranches between Spring 2022 and July 2025. Fertilizer rates targeted 0 to 150% of the grower's rate, ranged from 0 to 300 lbs N ac^{-1} and were applied by hand mimicking grower practice. Irrigation was managed as grower standard (GS) or ET-based scheduling (ETI) using CropManage (Cahn et al., 2015), a free online decision support tool calibrated for local crops and growing conditions. Flow meters tracked water inputs, and measurements included yield, plant N uptake, and preplant, midseason and postharvest soil N concentrations. In trial 1 and 2, soil N concentrations were measured in the 0-12" and 12-24" depth increments, while the other six trials included the 0-6", 6-12", 12-24" and 24-36" depth increments. In trial 4 and 8, the irrigation treatment was lost due to logistical issues.

Table 1: Key characteristics of trials 1-8. (S = Spring, F = Fall, W = Winter, Conv. = conventional, Org. = organic)

	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Trial 6	Trial 7	Trial 8
Season	S '22	F '22	W '23	S '24	F '24	F '24	S'25	S '25
Management	Conv.	Conv.	Conv.	Org.	Conv.	Org.	Conv.	Org.
Topsoil texture	Sandy loam	Sandy loam	Sandy loam	Clay loam	Sandy loam	Sandy Loam	Clay loam	Fine gravelly sandy loam

Results and Discussion

Across trials, ET-based irrigation (ETI) reduced water use by 4–26% compared to grower standard (GS), with no yield loss (Table 1, Fig. 1). In fact, yields and N uptake were higher with ETI in trials 1 and 2.

Table 2. Percent irrigation water saved in ET-based irrigation (ETI) vs. the grower standard practice (GS), preplant soil nitrate-N concentrations in the 0-12" and 12-24" depth increments in mg N kg^{-1} soil or ppm, and irrigation N inputs (N_{irr}) in lbs N ac^{-1} for trials 1-8.

	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Trial 6	Trial 7	Trial 8
Water saved (%)	26	15	13	NA	4	14	18	NA
Preplant 0-12" soil N (ppm)	24	38	34	7.6	39.9	32	111.9	4
Preplant 12-24" soil N (ppm)	13	18	23	7.1	33	12.1	44.6	13.4
GS N_{irr} (lbs N ac^{-1})	10	7	27	26	46	28	257	274
ETI N_{irr} (lbs N ac^{-1})	8	6	24	26	44	24	211	274

Yield responses to N rates varied drastically between trials (Fig. 1). In trial 1 and 4, yield increased steadily with increasing N rate, likely because pre-plant soil N concentrations and irrigation N inputs were relatively low (Table 1). In these trials, N rates above 250 lbs N ac^{-1} may have been necessary to achieve maximum yield. In trial 8, yields increased with N rate even though soils and irrigation already had high N. Since irrigation applied was 80% above ET-based recommendations, much of that N was probably lost below the root zone.

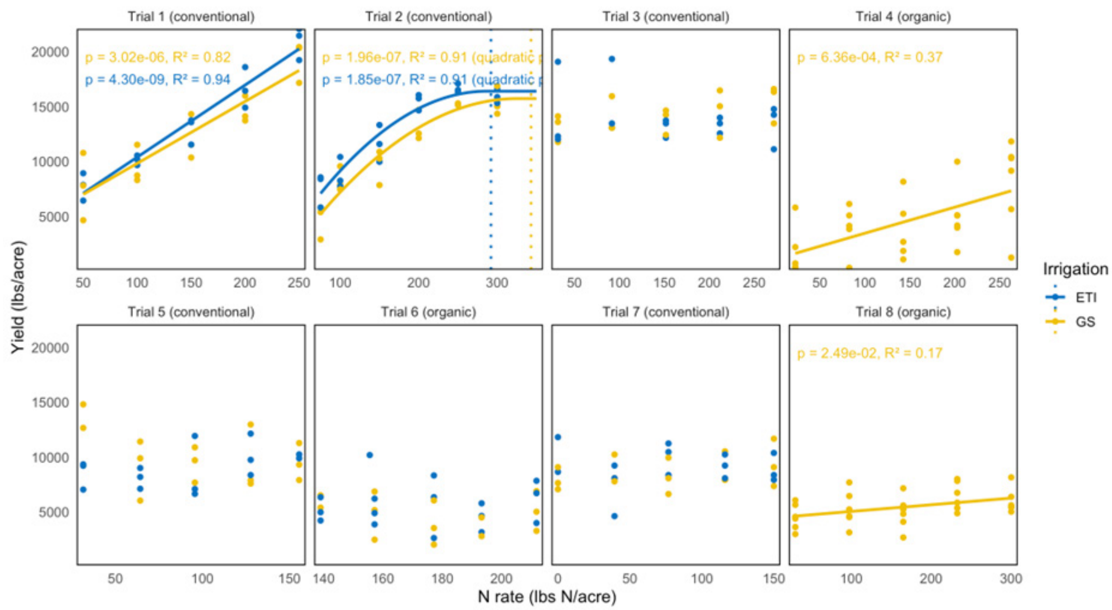

Figure 1. Response broccoli yield (lbs ac^{-1}) to N fertilizer rate (lbs N ac^{-1}) for the grower standard (GS) and evapotranspiration-based irrigation (ETI) practice for eight broccoli trials. In trial 1, 4 and 8, broccoli yield increased linearly with N rate. In trial 2, the relationship between broccoli yield and N rate followed a quadratric plateau model. In trial 3, 5, 6 and 7, there was no effect of irrigation or N rate on broccoli yield. Vertical lines in Trial 2 indicate the N rate at which yield was maximized in ETI vs. GS.

In trial 2, the highest yields occurred with 50 lbs N/acre less under ETI compared to GS. This shows that better irrigation management can cut fertilizer needs. In trials 3, 5, 6 and 7, there was no effect of N rate on yield, suggesting that preplant soil N and irrigation water N provided sufficient N to support plant production.

Overall, soil N content at harvest demonstrated that ETI helps retain N in the root zone (data not shown). This benefits the current crop and can also leave more N available for the next crop in rotation.

Conclusions

Our study highlights several factors that can inform nitrogen management decisions in the context of increasing regulatory scrutiny. ET-based irrigation reduced water use without reducing yields, and in some cases improved nitrogen uptake and yield. Accounting for both preplant soil nitrate and nitrogen in irrigation water can reduce the need for additional fertilizer. Measuring soil nitrogen to greater depths (2–3 feet) was especially important for broccoli, a deep-rooted crop, in explaining whether additional fertilizer N was needed. Efficient irrigation management helped retain nitrogen in the root zone, supporting crop nutrition for both the current and future crops. The contribution of nitrogen from irrigation water, however, depended on avoiding over-irrigation, which otherwise flushed N below the root zone. Together, these results demonstrate pathways to maintain yields while improving nitrogen efficiency and supporting compliance with water quality regulations.

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Acknowledgements

We thank participating growers for support in the management of the trials and are grateful for financial support from CDFA-FREP.

Development of Precision Yield Monitor for Almond and Pistachio

Project Leader

Patrick Brown
Professor
UC Davis
phbrown@ucdavis.edu

Co-PI

Stavros Vougioukas
Professor
UC Davis

Introduction

Providing uniform water and nutrients to an entire orchard is standard practice, but this approach can be inefficient because not all parts of the field produce the same amount of yield. For example, research by Noble et al. (2018) showed that the best 30% of a subfield could produce more than double what the poorest 30% does. In almond orchards, this variation in yield is especially notable. This project is working on a new system to monitor yields that can measure the output of individual almond trees during the commercial harvesting process. This system could also be used for other similar crops, like pistachios. This advanced monitoring tool will not only help manage and optimize water and nutrient use down to the level of individual trees or parts of the orchard but also revolutionize research by providing precise data. This data will enhance the effectiveness of remote sensors that monitor soil and plant conditions by correlating them with actual field variations.

Objectives

1. Measure yield using optical laser-scanning
2. Measure yield using optical and gravimetric methods
3. Develop and integrate a real-time quality control vision system

Description

This project aims to enable single-tree yield monitoring and identification at full commercial harvest speeds. To accomplish this, a laser scanner was mounted above the terminal section of a conventional off-ground harvester (Objective 1). Designed for continuous operation, the setup eliminates the need to stop the harvester during crop collection. Additionally, the harvester is equipped with precise GPS and a vibration sensor on the shaker head, allowing accurate yield estimation for each tree. The weighing conveyor used during the 2023 harvest (Objective 2) made it difficult to maneuver the machine, and the measurements were susceptible to excessive vibration, so it was removed for the following seasons.

Sensing system

The main components and characteristics of the developed system are:

- Tol harvester conveyor belt.
- Laser Gocator 2690 to read the profile of the almonds with a sub-millimeter resolution.
- Wheel encoder to read the belt speed.
- GPS for tree localization.
- Vibration sensor to identify when a tree is shaken.

Volume estimation

The laser is used to estimate the volume of almonds passing under it on the conveyor belt. The laser records the profiles of the almonds; the green points in Figure 1 (left) represent the profile data. An encoder is used to record the belt's speed, which enables the displacement for each profile to be known. The volume can be estimated by combining the laser profile with the encoder readings. Figure 1 (below) provides an example of the resulting point cloud where the volume is calculated.

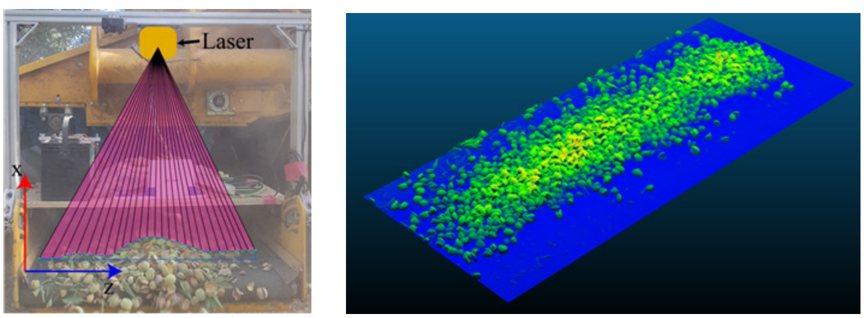

Figure 1. Almond profile reading with a laser (left); result of combining the laser profile and encoder readings (right).

Weight validation

The almonds from a sample of trees scattered throughout the orchard ("ground truth trees") are collected onto a tarp, placed in a bucket, and weighed using a scale to gather data on the trees for mass or volume estimation. The height of the almonds in the bucket is also recorded.

Yield mixing and deconvolving

When a tree is shaken, its almonds fall onto the conveyor belt next to or on top of almonds from previous trees that are still traveling on the belt. The laser measures the "sum" of nut flows from several trees, which depends on the harvester, belt speed, and shake duration (Fig. 2).

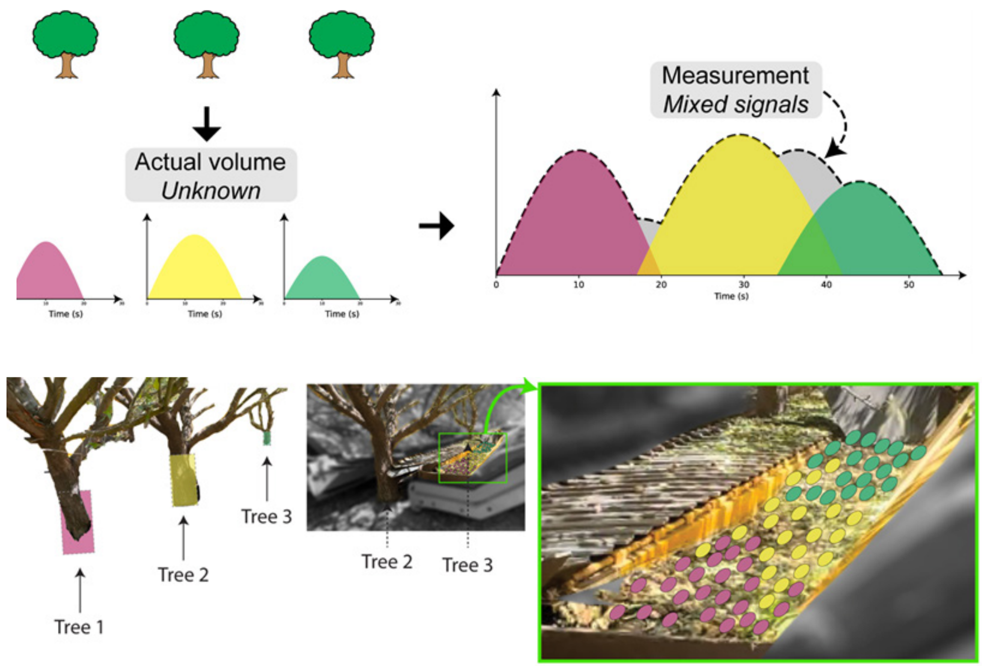

Figure 2. Nuts from consecutive trees mix on the belt, creating a continuous almond flow.

To estimate single-tree yield, we used a mathematical model, specifically a Polynomially Modified Gaussian (PMG2), to describe the volume flow of individual trees. Next, that model was used to deconvolve the continuous composite flow into the contributions of single trees (Fig. 3).

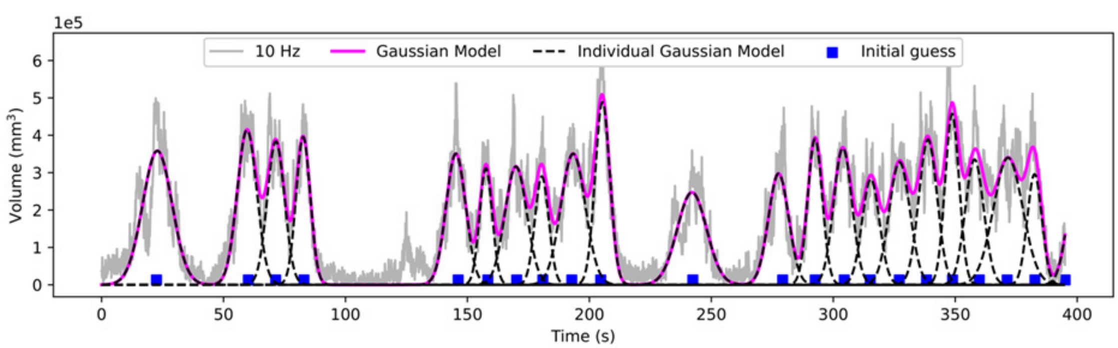

Figure 3. Estimation of individual volume flow (black dashed line) based on a continuous volume flow (grey line).

This method was first tested on ground-truth trees and then applied to all the trees in the orchard.

Detection and Rejection of Data from Debris

The laser measures almond flow on the conveyor belt, but it also detects leaves, branches, and other debris. This can affect volume estimates. To improve this, we are developing an AI model to filter out the unwanted materials from the high-resolution laser data (Objective 3).

Results and Discussion

Harvesting with the yield monitor took place on August 6–9, 2024, at Westwind Farm in Woodland, CA, and on August 19–22, 2024, at KG-Ranch in Madera, CA. The harvester was a Twin D T4 by TOL. 94 ground-truth (GT) trees were evaluated at Westwind Farm, and 59 GT trees at KG-Ranch. Fig. 4 shows the achieved errors in the yield estimation and the yield distribution of the ground truth trees.

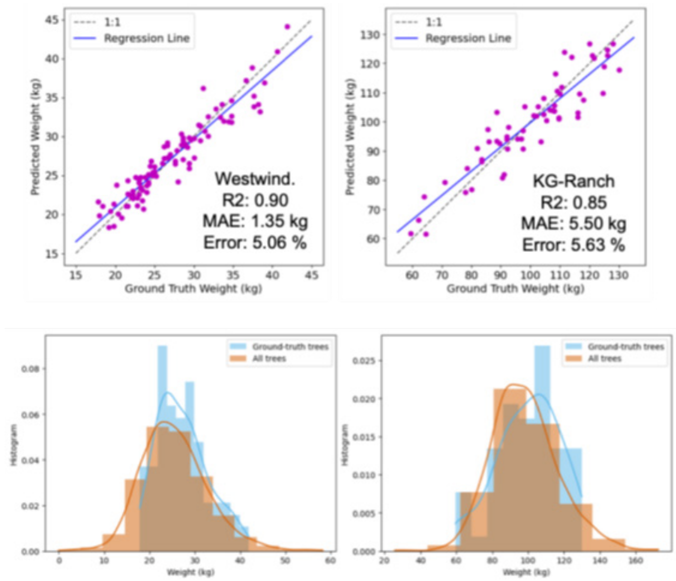

Figure 4. Left: Westwind – Yield variation in GT and Non-GT trees. Right: KG-Ranch – Yield variation in GT and Non-GT trees.

Figure 5. Westwind Yield Map.

Our novel deconvolution method was applied to obtain the volume of each tree's yield from the tree-row data. The GPS data fused with the vibration sensor provided accurate individual tree localization. Almond bulk density was measured and used to convert yield volume into mass.

The next step will involve using artificial intelligence to remove the effect of debris from the laser data.

Conclusions

High-resolution laser technology enables quick and precise yield estimations in high-value crops like almonds. Our method for individual tree yield estimation can be applied to harvesters operating at commercial speeds, balancing accuracy and speed. This system can be integrated into existing commercial machinery with minimal modifications and is versatile enough to be applied to other similar crops, such as pistachios.

Acknowledgments

We acknowledge the funding from CDFA-FREP.

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Facilitating Grower Adoption of Cover Crop Nitrogen Scavenging to Minimize Residual Nitrogen Loss and Comply with the Irrigated Lands Water Quality Protection Program (Ag Order 4.0) on the Central Coast of CA

Project Leader

Sacha Lozano
Program Manager
RCD Santa Cruz County
slozano@rcdsantacruz.org

Introduction

Intensive specialty crop rotations in the central coast region depend on recurrent nitrogen inputs and often leave a considerable amount of residual nitrogen in the soil, which is highly susceptible to leaching below the root zone, especially during winter rains. Losing residual nitrogen is a missed cost-savings opportunity and can also cause water quality impairment, affecting environmental and human health. With good management, residual nitrogen can be reused for subsequent crops, lowering input costs and avoiding water contamination. Cover cropping is one of several soil management practices that can help to recover and recycle nitrogen from crop residue mineralization and excessive fertilizer application through 'nitrogen scavenging'. This practice has been incorporated as a valid 'removal' strategy in the context of balancing 'applied (A)' and 'removed (R)' nitrogen within the Central Coast Regional Water Quality Control Board's Irrigated Lands Regulatory Program (Ag Order 4.0).

The latest version of this regulation (approved in 2021 but now being remanded), which applies to most growers in the central coast region (540,000 acres of irrigated land), proposed a credit for 'nitrogen scavenging' by certain winter-grown cover crops. The credit allows for up to 97% of the cover crop shoot N uptake to be counted as 'nitrogen removed' in the annual A-R metric, providing a major incentive for cover crop adoption to help growers achieve regulatory compliance. However, to qualify the cover crop must 1) be a non-legume that produces at least 4,500 lb/acre of oven-dry shoot biomass, 2) be grown for ≥90 days from October to April, and 3) have a carbon to nitrogen (C:N) ratio ≥ 20:1. To help growers meet these requirements, USDA-ARS, UCANR, CLGRB and the RCDs of Monterey and Santa Cruz Counties partnered to conduct research trials and develop simple methods to quantify the cover crop shoot biomass production and its associated %N (N uptake) and C:N ratio (Brennan and Smith 2023, Brennan 2022).

This project is facilitating grower adoption of such methods through education, outreach, one to one technical assistance and cost-share for cover crop implementation.

Objectives

1. Educate central coast growers on the practical application of a validated method to estimate the biomass and C:N ratio of a winter cereal cover crop, based on simple field-based measurements and observations, to demonstrate residual nitrogen recovery (scavenging) by winter cover crops, in the context of a regional water quality regulation (Ag Order 4.0)
2. Facilitate and guide grower adoption of winter cover cropping (with cereal cover crops) and the proposed nitrogen scavenging verification method to reduce residual nitrogen loss and receive full credit for 'nitrogen removal' in the context of Ag Order 4.0's Applied (A) minus Removed (R) nitrogen limits and targets
3. Demonstrate and disseminate the proposed methodology and lessons learned to a broader community of growers and certified crop advisors (CCAs) through outreach events and print materials in multiple languages

Description

The project goal is to facilitate grower adoption of winter cover cropping and demonstrate research-validated methods to easily and confidently estimate cover crop biomass, C:N ratio, and associated N uptake, helping growers to receive the cover crop N scavenging credit to meet the Applied (A) minus Removed (R) limits and targets in Ag Order 4.0 as approved by the Central Coast RWQCB in April 2021 (anticipating that these credits, limits and targets will still be applicable after the conclusion of a remand process currently in progress). The project is using outreach, education, and technical assistance to demonstrate and support grower adoption of winter cover cropping for N scavenging on the central coast.

Multiple field–scale demonstrations were implemented on commercial fields during winter in year one and will continue to be implemented in the second and third years of the project. Merced Rye cereal grass cover crops were planted on 36 fields after the end of the last 2024 crop cycle and prior to winter. Participating growers have received cost-share for cover crop seed. Soil N concentrations are measured on all fields using the soil nitrate quick test before and after each cover crop cycle. Participating growers are being trained on how to collect simple measurements of a cover crop 3-4 months after planting to demonstrate that the shoot biomass and C:N ratio meet the criteria to receive full credit for cover crop N scavenging under Ag Order 4.0.

Findings and lessons learned from field trials are being shared with other growers and certified crop advisors (CCAs) in the region through outreach events (field days) at different locations in the Salinas and Pajaro valleys, and guidance documents (accessible in print and electronic formats) that illustrate the protocol and benefits of this practice in the context of Ag Order 4.0.

Field days are tailored to growers of different scales, crops and cropping systems, and focus on general education about the Ag Order, practical demonstration of cover crop N scavenging credit quantification and reporting, and broader benefits associated with the use of cover crops for nitrogen management. Guidance documents will provide a reference on methods for reporting a cover crop N credit under Ag Order 4.0, and considerations for effective management of winter cover crops. These documents will be available in English, Spanish and simplified Chinese script (the written language for Cantonese speakers) to support a wide range of growers on the Central Coast.

Results and Accomplishments

Direct individual assistance to growers (18 months):

- Since the beginning of the project 32 participating farming operations have signed up to implement cover cropping (receiving cost-share for seed) and participated in education events and 1:1 training on simple field-based quantification methods to estimate nitrogen scavenging.
- 32 farming operations completed winter cover crop plantings (Merced Rye cereal grass) on 36 different fields in 2024 and engaged in nitrogen scavenging quantification training and practice in early 2025.
- The project team conducted soil nitrate quick tests to estimate the soil nitrogen levels before and after each cover crop planting and documented the duration (number of days) of each planting and measured shoot length and Feekes stage to estimate cover crop biomass, C:N ratio and amount of nitrogen scavenged.

Table 1. Soil nitrate quick tests to estimate the soil nitrogen levels before and after each cover crop planting and documented the duration (number of days) of each planting and measured shoot length and Feekes stage to estimate cover crop biomass, C:N ratio and amount of nitrogen scavenged.

n=36	Cover Crop duration (# days)	Cover Crop shoot length (in)	Cover Crop biomass (lb/ac)	Cover Crop C:N ratio (based on Feekes stage)	Soil N before CC (ppm NO3-N)	Soil N at termination of CC (ppm NO3-N)	N Scavenged (lb N/ac)
MIN	74	14.5	1,525	10:1	3.2	0	58
MAX	159	65.1	11,020	33:1	74	15	179
AVG	105.6	38.4	6,276	26:1	19.3	1.2	102.6

Conclusions

During the past 18 months the project team has:

- Collaborated with staff from agricultural industry groups, grower and shipping companies and academic researchers working on the central coast region to identify and coordinate opportunities for cover crop and nitrogen management education and outreach events under this project.
- Presented a general overview of multiple benefits from the use of cover crops emphasizing nitrogen recovery and management in the context of Ag Order 4.0 during the 2024 Latino Farmer Conference.
- Hosted a series of educational field days focusing on the use of cover crops for nitrogen management with a group of 7 Spanish-speaking growers who are co-managing and organically farming an 88-ac ranch in Watsonville.
- Presented an update on the scope and progress of this project at the 2024 California Marine Sanctuary Foundation’s event “Unlocking the Power of Cover Crops: Benefits, Risks and Ag Order Updates”. The audience included growers, farm companies, and certified crop advisors.
- Co-hosted and presented at a cover crop workshop in March of 2025 for Spanish-speaking growers (discussing water conservation, water quality protection and nutrient management aspects of cover cropping) with a total attendance of 54 farming operations, most of which are limited resource and diversified organic farms.
- Collaborated with technical advisor Dr. Eric Brennan from USDA-ARS to inform and develop a practical guide to conduct and interpret simple field measurements that can quantify nitrogen recovery from the use of cover crops.

Figure 1. Photos taken from field days and presentations in support of this project.

Conclusions

Using winter cover crops to recover and recycle end-of-year residual nitrogen for crop production during the following growing season is an advisable practice for several reasons, including, but not limited to input cost savings, water quality protection, soil fertility enhancement and maintaining an active and diverse soil microbiome. Using relatively simple measurements and observations of a cover crop stand 90 or more days after planting it is possible to confidently estimate the total amount of recovered (scavenged) nitrogen in a field and claim it as a "Removed N" credit in the context of Ag Order 4.0 regulatory compliance. This project provides training and one-on-one technical assistance for growers to adopt this practice and quantify its benefits.

Acknowledgements

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Kasey Butler
Ag Projects Manager
RCD Monterey County

Elliot Grant
Project Manager

Sustainable Conservation

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Estimating Mineralization and N Utilization from Banded Compost Applications in Drip Irrigated Sweetpotatoes and Processing Tomatoes

Project Leader

Daniel Geisseler
Cooperative Extension Specialist
UC Davis
djgeisseler@ucdavis.edu

Co-PI

C. Scott Stoddard
County Director and Farm Advisor
UC Cooperative Extension Merced County

Introduction

Composts are important sources of nutrients for crops and are increasingly popular to maintain or improve soil health. The contribution of compost to crop-available nitrogen (N) depends on net N mineralization, which is affected by temperature, moisture, soil texture, composition of the composts, and management practices. In Merced County, the application of poultry and dairy manure compost to supply part of the N required by crops is commonly used in sweetpotatoes and processing tomatoes.

California is a major producer of sweetpotatoes, with annual production around 700 million pounds from 18,500 acres. Most of this production occurs on the sandy soils in Merced and Stanislaus Counties. Both organic and conventional growers frequently apply a band of composted poultry manure under the surface drip tape, then supplement fertilizer N through the drip tape during the growing season. Merced County is also a major producer of processing tomatoes, with over 1 million tons annually on about 25,000 acres. Production generally occurs on clay loam soils using subsurface drip irrigation. Compost may be band applied, then pre-plant incorporated (PPI) in the fall into the bed above the buried drip tape. As with sweetpotatoes, additional N is supplied through the drip system during the growing season.

Based on previous research projects, less than 30% of the total N applied with poultry manure compost is mineralized within six months when incorporated in early April under typical climatic conditions of the San Joaquin Valley. Observations in sweetpotato fields, however, suggest that very high decomposition and N mineralization rates occur, as the compost is no longer visible by the end of the 120-day season. Therefore, we may underestimate N availability from the compost. Consequently, application rates may need further refinement.

Objectives

The objective of the project is to develop N budgets for sweetpotatoes and processing tomatoes in Merced County where the crop nutrient sources include both compost and mineral fertilizers as fertilizer sources. Specific objectives are:

1. Determine N release of commonly used manure composts in field trials.
2. Investigate the effects of soil texture on N mineralization.
3. Determine the accumulation of N in the vines and storage roots of sweet-potato plants throughout the growing season.
4. Conduct outreach and develop user-friendly tools for growers and consultants.

Description

The 2025 season marks the second year for this project. The sweetpotato trials were located in commercial fields near Ballico (project site 4) and Turlock (project site 5). At both sites, the texture in the top foot of the profile is a loamy sand and the soil organic matter content is less than 1% (Table 1). A third site in a processing tomato field near Los Banos, CA, was added in fall 2024. The texture in the top foot of the profile is sandy clay loam and the soil organic matter content is 2.7% (Table 1).

Table 1: Soil properties at the three trial sites. Samples were collected in spring and fall 2024 from the top foot of the profile. Total nitrogen (N) was determined by dry combustion. Soil organic matter (SOM) content was calculated based on measured soil carbon, assuming that carbon makes up 50% of SOM. pH and electrical conductivity (EC) were measured on a soil water slurry. Values for EC would be approximately three times higher in a soil paste extract.

Site	SOM (%)	Total N (%)	pH	EC (dS/m)	Sand (%)	Clay (%)	Texture
3	2.69	0.11	7.77	1.56	48	34	sandy clay loam
4	0.70	0.04	6.94	0.16	84	3	loamy sand
5	0.99	0.05	6.69	0.16	78	5	loamy sand

At the two sweetpotato sites, a compost made from poultry manure, steer manure, and almond hulls was applied prior to transplanting. The compost was machine applied in a band in the center of the bed. At site 4, the trial consists of four treatments: (i) no compost, no in-season fertilizer N, (ii) compost plus in-season fertilizer N, (iii) compost but no in-season fertilizer N, and (iv) in-season fertilizer N but no compost. At site 5, the trial consists of only treatments (ii) and (iv). Plots are 3 beds wide (20 ft) and 50 ft long with four replications. Sweetpotatoes were transplanted on May 1st and May 16, 2025, at sites 4 and 5, respectively.

At transplanting, soil samples were collected from the control plots to a depth of 4 ft in 1-ft increments. The samples were analyzed for ammonium-N and nitrate-N. At the same time, litter bags containing compost were buried at a depth of 4-6 in and soil moisture and temperature sensors were installed at depths of 3 and 6 in.

Every three weeks during the growing season, soil samples from the center of the bed were collected from the top 2 ft of the profile from all treatments. These samples were analyzed for ammonium-N and nitrate-N. At the same time, litter bags were removed and analyzed for total dry matter, carbon, and N content.

On the same dates, above and belowground plant biomass were collected from beds surrounding the trial in areas where compost was applied. The plant biomass was dried and analyzed for dry matter and total N content. The results will be used to determine the seasonal N uptake pattern of sweetpotatoes (Objective 3). Irrigation water samples were also collected and analyzed for nitrate-N.

At harvest, plant dry matter, yield and N concentration in the biomass will be determined in all plots. At the same time, soil samples from the top 4 ft will be collected and analyzed for ammonium-N and nitrate-N. The data will be used to calculate plant-available N in all treatments.

At the processing tomato site (site 3), a compost made predominantly from poultry manure was applied on October 21, 2024. The compost was machine applied in a band in the center of the bed, then incorporated. The trial consists of three treatments with four replicates: (i) control plots without compost (0 t/ac), (ii) plots with grower's standard application rate of 2.1 t/ac, and (iii) plots with an application rate of 4.8 t/ac. Plot size is 3 beds wide (19 ft) and 75 ft long. After compost application, soil sampling of the top 4 ft of the soil profile was performed and soil samples were analyzed as described above. At the same time, litter bags were buried at a depth of 4-6 in and soil moisture and temperature sensors were installed at depths of 3 and 6 in. Repeat soil samples were taken again in April 2025. Processing tomatoes were transplanted April 24, 2025.

To address Objective 2, an 18-wk laboratory incubation was set up in February 2025 using three compost treatments with C to N ratios ranging from 6.4 to 15.4 in two different soil textures (i.e., clay and sandy). This experiment utilized the same composts applied at each of the three sites for the 2024 season and soils from the first and third sites to represent different soil textures. Treated samples were incubated at 25 °C and ideal moisture content for N mineralization (i.e., 60% of the soil's water holding capacity). At weeks 1, 3, 6, 12, and 18, soil samples were analyzed for ammonium-N and nitrate-N. Net N mineralization of compost N was calculated as the difference between the unamended control and the treated sample at each time step.

Results and Discussion

The composts had C to N ratios of 6.35, 11.37, and 12.01 at sites 3, 4, and 5, respectively (Table 2). Preliminary analyses of the soil samples taken from the center of the bed in 3-week intervals at the sweetpotato sites suggest minimal impact of compost application on plant-available N in the soil, while fertilizer N had a greater impact at site 4. The small effect of compost on N availability confirms our results from the 2024 season: yields were not significantly improved at Site 1 and decreased at site 2. Sampling and data collection will continue throughout the season, including total plant biomass and root yield. At the processing tomato site, no statistically significant differences in total mineral N were found between compost-treated and control plots throughout the 4 ft soil profile in spring. Approximately 75% of the compost remained at transplanting, and there was no compost rate effect observed. Soil temperatures continue to be monitored over the growing season, and end of season plant yield and total plant biomass measurements are planned.

Table 2: Properties of the composts used at the three field sites for the 2025 season. Total carbon (C) and nitrogen (N) are shown in percent of dry matter (DM) while the application is the measured fresh weight.

Site	Total C (% in DM)	Total N (% in DM)	C to N ratio	DM (%)	Application rate (t/ac as is)	Application date
3	23.0	3.6	6.4	82	2.1 and 4.8	10/21/2024
4	13.1	1.2	11.4	49	6.9	04/29/2025
5	12.0	1.0	12.0	54	5.9	05/15/2025

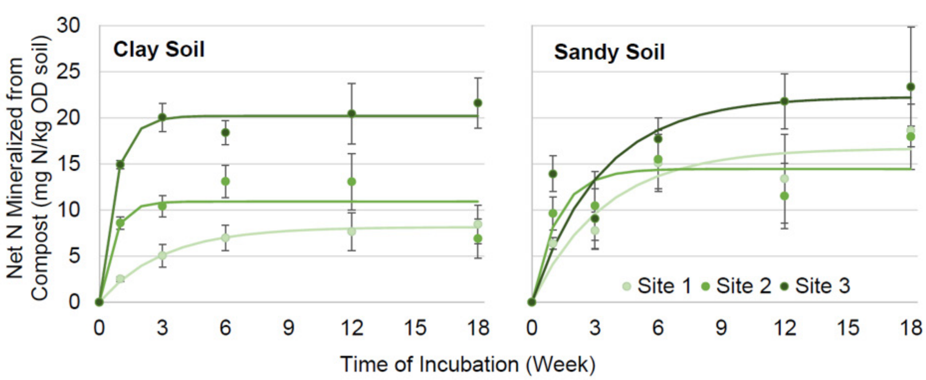

Figure 1: Results of a laboratory incubation of three composts in clay (left) and sandy (right) soil. Data points show an average of observed values at every time point, while a trend line was modeled. Standard error bars are shown.

The incubated composts had C to N ratios of 15.44, 13.82, and 6.35 from sites 1, 2, and 3, respectively. As expected, the compost with the lowest C to N ratio from site 3 had the highest final net N mineralized, while the compost with higher C to N ratios from sites 1 and 2 had less mineralized N by the end of the incubation period (Figure 1). Soil texture did appear to influence final N mineralized from the compost in the higher C to N ratio treatments, with more final N release observed in sandy soil.

Acknowledgments

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Nitrogen Movement Out of Root-Zones in Central Valley Irrigated Lands: A Multi-Scale Management, Monitoring, Modeling, and Outreach Project

Project Leader

Isaya Kisekka
Professor of Agricultural Water Management and Irrigation
UC Davis
ikisekka@ucdavis.edu

Co-PI

Thomas Harter
Professor and Specialist in Cooperative Extension for Groundwater Hydrology
UC Davis

Introduction

To comply with the Central Valley (CV) Irrigated Lands Regulatory Program (ILRP) to reduce nitrate leaching, growers use advanced irrigation and fertigation methods, often guided by decision-support tools like CropManage (CM). ILRP Coalitions assess the efficacy of these practices on 5.2 million acres using specialized models (CV-SWAT and CV-NPSAT) that track water and nitrate movement through soil and groundwater, under the condition that they be continually refined. CV-NPSAT's refinement is funded and ongoing; however, CV-SWAT requires validation against new, more detailed field data. Project leaders have created an extensive Cal Vadose Zone Monitoring Network to study nitrate leaching in key crops, including almonds, oranges, and processing tomatoes. This project will leverage existing and new data from this monitoring network to ultimately improve the performance of CV-SWAT and encourage the use of decision-support tools like CM.

Objectives

1. Evaluate and enhance the performance of CV-SWAT in quantifying the effects of irrigation and nutrient management practices on nitrate leaching
2. Evaluate uncertainty in predicted nitrate leaching through inter-model comparisons (CV-SWAT, APEX, and HYDRUS) and comparisons with field measurements
3. Expand the application of CM by adding data and algorithms for orange, lemon, and mandarin crop types
4. Integrate results from monitoring, management, and modeling efforts to inform outreach to water quality stakeholders at multiple in-person and/or virtual events

Description

This project workflow (Figure 1) involves integrating data from three study sites, evaluating grower-implemented practices relative to CM's recommendations, validating process-based models, and quantifying the effects of management practices on nitrate leaching.

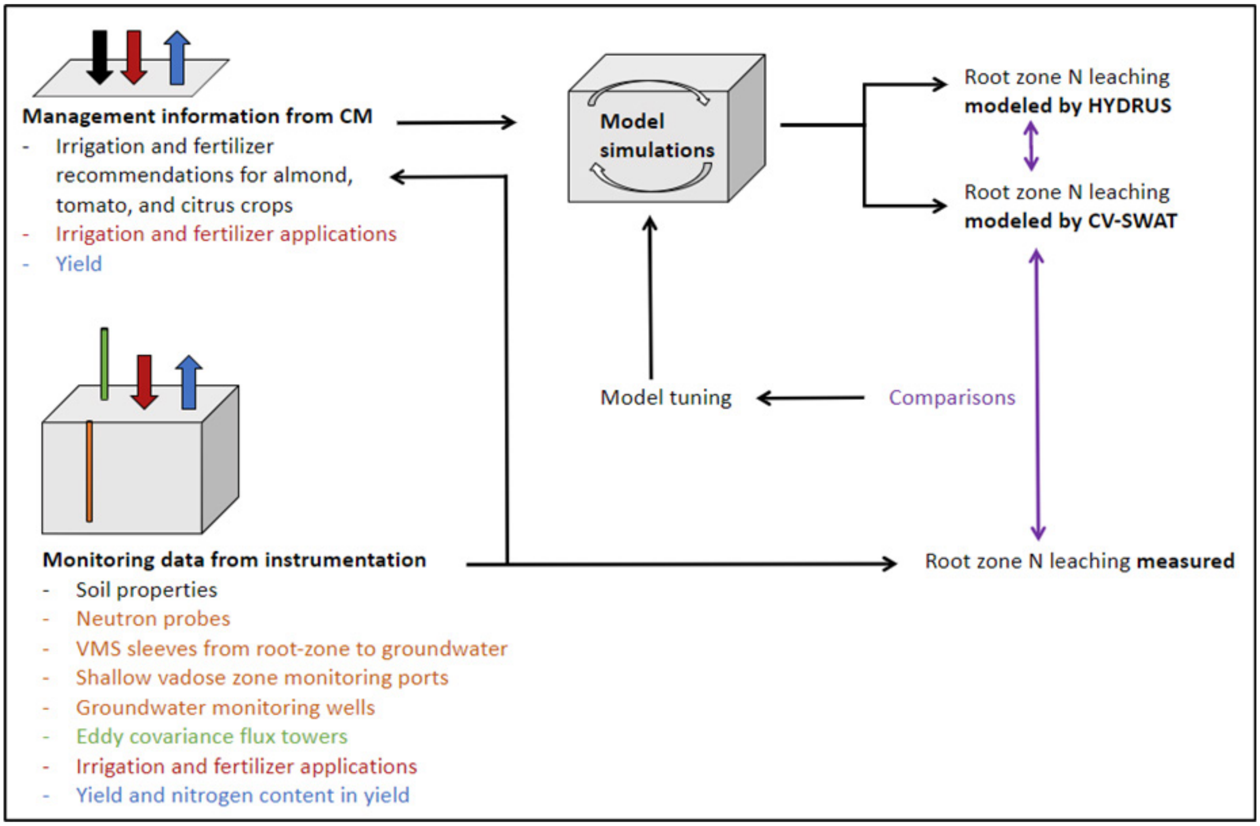

Figure 1. Project schematic integrating management data, monitoring data, and modeling simulations.

This project leverages three existing, funded, intensively monitored research sites that are uniquely suited to quantifying nitrate leaching using field-scale mass balance, vadose zone monitoring, and groundwater monitoring. Data collection includes: nitrate leaching collected using vadose zone monitoring, evapotranspiration collected using eddy covariance flux towers, irrigation and fertilizer applications, groundwater observation, well networks for water levels, neutron probes for soil moisture, soil sampling, and yield (Raij-Hoffman et al., 2024). Using this data, the project is evaluating and verifying CM efficacy in minimizing nitrate leaching while maintaining or improving production. Monitoring and management data is being integrated into CM to derive recommendations that are compared against actual practices. This data is also used to create CV-SWAT modeling scenarios for each site. First, we are comparing measured leaching against modeled leaching estimates using the "Root-Zone Library" of existing, calibrated model scenarios.

Second, we are comparing measured and modeled water and nitrogen balances using detailed CV-SWAT simulations, which are customized to reflect on-farm management practices. Third, CV-SWAT output is being compared to other calibrated root-zone models (e.g., APEX).

Results and Discussion

Monitoring Data Collection.

Intensive monitoring of nitrate leaching from annual crop rotation cropping systems, almonds, and citrus is ongoing. Key findings to date include 1) limited nitrate leaching was observed in vadose zone samples during the growing season as the irrigation at these sites has been managed efficiently, 2) Nitrate leaching occurred during heavy winter rainfall following dry summers, and 3) in the annual cropping system, rotating in a deep-rooted sunflower crop helped capture residual nitrate and led to lower monitored nitrate leaching in the winter of 2024 compared to winter 2023.

CropManage Evaluations.

Utilization of CM at the three study sites is ongoing. The grower managing the almond site uses decision-support technology to automate site-specific irrigation scheduling based on ET, soil moisture, and to deficit irrigate when appropriate, as well as high-frequency low-volume fertigation practices. As a result, irrigation water is currently applied very efficiently and below the current CM recommendation, though drought stress has not been historically observed. To better align CM with grower practices, canopy cover measurements will be conducted to locally refine crop coefficients, and the CM deficit irrigation functionality will be employed. The tomato grower's applied water was comparable to CM recommendations throughout the growing season, and seasonal totals of actual and recommended were within 10.6% and 8.0% for both monitored blocks. N use efficiency is relatively high in both of these systems and consistent with yield-based N requirement estimates in CM. For the citrus site, an experimental model has been set up for use, while a complementary FREP project aims to improve CM citrus modules.

Root-Zone Modeling.

Local CV-SWAT models delineated to represent each site have been set up to simulate historical management and crop productivity for the annual cropping system and almonds (citrus is forthcoming). To date, existing crop model parameters used to develop the Root-Zone Library have been employed, but field-scale calibration of growth, N uptake, crop ET, and yield is planned to finalize validation. Compared to monitoring data, seasonal CV-SWAT ET matched closely with eddy covariance measurements in the annual cropping system under both tomato and vine seed. For the almond site, CV-SWAT currently underestimates crop ET compared to OpenET estimates, but comparisons to eddy covariance data are forthcoming, and uncertainty in ET at this site has been investigated due to water balance anomalies (Jordan et al., 2024).

Regarding crop growth, N uptake, yield, and N removed, CV-SWAT aligns with average conditions for the almond fields, though it does not capture the year-to-year variability since a single set of crop model parameters is used. For the annual cropping system, CV-SWAT aligns more closely from year to year; however, additional site-specific calibration is still required. When comparing nitrate leaching estimates from the custom CV-SWAT models and the "Root-Zone Library" approach, there tends to be good agreement (see Figure 4b), particularly over multiple growing seasons, highlighting the rigor of the ILRP approach applied to the landscape.

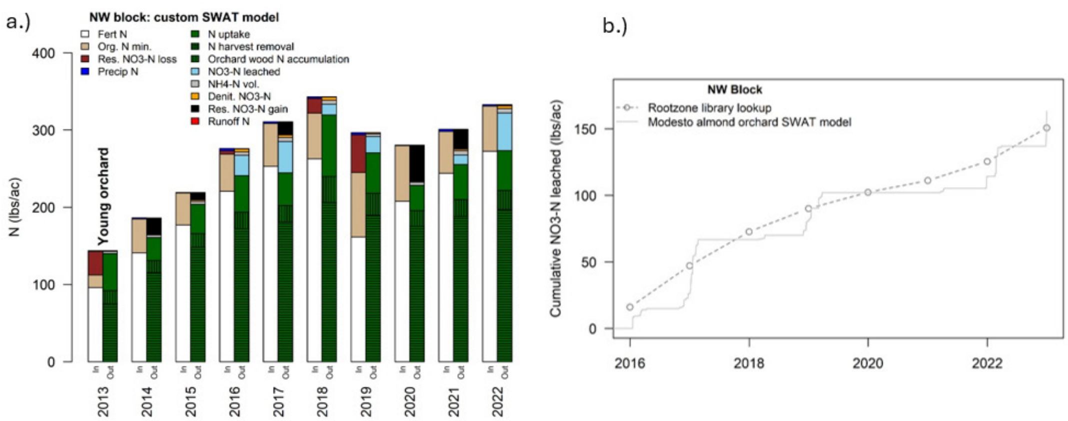

Figure 2. Example of output from a customized CV-SWAT model for an almond block showing a) nitrogen mass balance over 10 years of production and b) comparison of cumulative nitrate leaching using the "Root-Zone Library" lookup approach.

Conclusions

- Monitoring data confirms that stacking conservation practices (e.g., cover crops, irrigation nitrogen credit) reduces residual soil N at the end of the crop season that could leach in the winter.
- Decision support tools for irrigation and N management can help optimize N management.
- Nitrate leaching from agricultural lands is measurable using mass balance, vadose zone, or groundwater monitoring approaches, but uncertainty varies between approaches, with the highest uncertainty in field mass balance.
- Deep vadose zone monitoring is a very useful tool to continuously monitor the fate and transport of nitrates between the root zone and the groundwater table.
- Root-zone models integrating crop x soil x climate x management information can produce robust estimates of nitrate leaching that can be difficult to measure.

- Preliminary results illustrate consistency in nitrate leaching estimates between the ILRP modeling approach and more data and labor-intensive site-specific modeling.

Acknowledgements

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No-Till Planting of Rice to Conserve Water and Ensure the Sustainability of Rice Systems

Project Leader

Bruce Linquist
Professor of Cooperative Extension
University of California, Davis
balinquist@ucdavis.edu

Introduction

The sustainability of California rice systems is being threatened by ongoing droughts with significant reductions in rice area due to them. This has both economic and environmental impacts. Rice systems use a significant amount of water, but there are limited options for reducing water use in rice systems in California while maintaining an economically viable crop. California rice farmers water-seed rice and evaporation losses are high during the first month of the season. Dry-seeding is the practice of planting rice (broadcasting or drilling) into a dry seedbed (similar to corn or wheat). Since there is no reliable rain, fields are flush irrigated two or three times during the first month, after which fields are permanently flooded. However, water use between these two systems is similar (Linquist et al., 2015). One option is to dry-seed into a field that has not been tilled (no-till, NT). One of the purposes of tillage is to dry the soil in order to prepare a good seedbed. With NT, soil moisture in the soil is conserved and can be used to support plant growth early in the season. In fact, water conservation is one of the big benefits of NT in other cropping systems (Busari et al., 2015). In rice systems, NT is not widely practiced; but given the promise of the NT system for water conservation, it is an important area to investigate. We estimate that NT systems can conserve up to 0.5 feet of water which is 15 to 20% of the consumptive water use of CA conventional rice systems. If successful, such a practice will help ensure continued rice production and still provide the other valuable ecosystem services that the rice system provides.

There are many challenges to developing NT systems. Complicating the challenge are a wide range of potential field conditions before planting, which relates to how fields were managed the previous year. This includes where fields were fallowed in the previous year and tilled (common following drought years) or, where rice was grown, straw may have been left on surface, removed for off-site use or burned. Our goal is to develop the agronomic information required to make these systems viable and sustainable.

Objectives

1. Develop robust fertility practices (examining different rates and timings of fertilizer applications).
2. Test options to optimize stand establishment (i.e. settings on no-till drills)
3. Quantify water inputs to develop a water budget and estimate evapotranspiration losses.
4. Monitor weed populations and develop weed control methods.

In the first year of the study, the research occurred at the Rice Experiment Station (RES), where we have better control and management. In the second and third years, research is continuing on-station but will include on-farm trials. Throughout this whole process, we will be engaging with farmers, CCAs and PCAs through field-days, winter grower meetings and informal meetings.

Description

In 2025, we conducted a replicated field experiment at the RES to evaluate three NT drill seeded systems. The treatments were identical to 2024. In brief, we NT drill seeded into three different seed beds: (1) a seedbed that was fallowed and worked the previous year, (2) a seedbed that had rice in the previous year and the straw was removed, and (3) a seedbed that had rice in the previous year and the straw was chopped and left on the surface. The fields were planted on April 21, flushed on April 22 and drained on April 27. Averaged across treatments, 50% of the rice emerged by May 4-9. No further irrigation was applied until May 21 and 22 when the fields were permanently flooded. Just before the permanent flood (May 21), we applied N fertilizer (urea) and herbicides (Clincher and Loyant). Within these plots we had (1) N management trails (N source, timing and rates), (2) herbicide trails and (3) water use. Also, we have an on-farm trial (Colusa County) where an N trail (similar to RES) was set up. However, the crop did not establish well, and we will likely have to abandon the trial.

Results and Discussion

The 2025 crop will not be harvested until Sept./Oct., so 2024 results are discussed.

Stand establishment:

We tested the use of gibberellic acid (GA) as a seed treatment to accelerate emergence. Among the three treatments, seedling emergence was slowest in the Chopped (Figure 1-left). These differences were likely due to differences in soil temperature which averaged 74.6, 70.8 and 67.9 oF for Fallow, Removed, and Chopped, respectively. GA had a small effect on emergence and resulted in emergence occurring about a day earlier. Based on these findings, GA does not appear to be necessary.

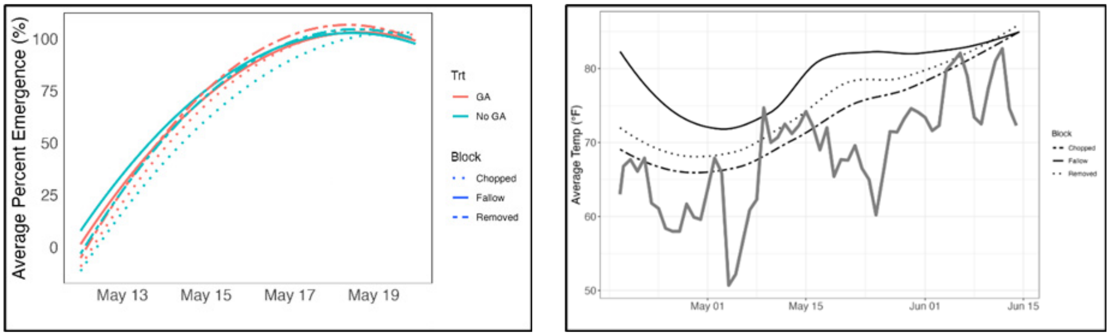

Figure 1. Effect of gibberellic acid (GA) on seedling emergence (left) and soil temperature at 5 cm below soil surface (right).

Water savings:

These systems conserve water in two ways. First, they use water that is available in the soil. Secondly, in the NT system there is no flood water on the field for the first month, which minimizes evaporation losses. Compared to conventional water seeded rice, evaporative losses were 4.8 inches less. Consumptive water use (evapo-transpiration-ET) is roughly 36 inches for a full crop season. Thus, these savings of 7 inches represent a potential water savings of 15 to 20%.

Table 1. Soil moisture in the top 15 cm (+/- standard deviation) just before planting (in NT) or before flooding field in preparation for planting (in WS).

Treatment	Soil moisture (mm)
NT-DS Fallow	58.6 +/- 11.6
NT-DS Removed	52.1 +/- 2.8
NT-DS Chopped	50.9 +/- 3.7
CT-WS	8.8 +/- 1.2

Table 2. Consumptive water use (ET) (+/- standard deviation) during the initial period from seeding until permanent flood (in NT) or from flooding for a comparable time period in a water seeded systems (value calculated from Montazar et al., 2017).

Treatment	ET (mm)
NT-DS Fallow	60 +/- 13.4
NT-DS Removed	53 +/- 4.8
NT-DS Chopped	53 +/- 4.9
CT-WS	179

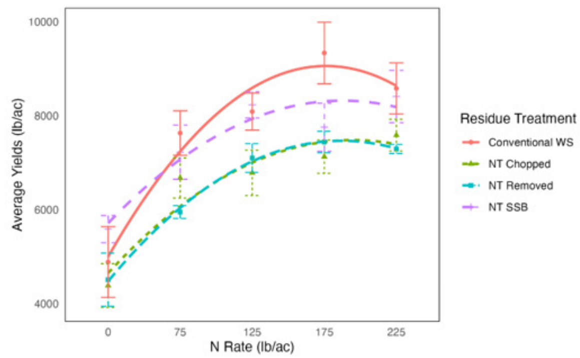

Figure 2. Yield response to varying rates of N fertilizer. NT-SSB is the fallow treatment.

Yields across N rates:

There were significant differences (P<0.05) in yield as a result of both system and N rate. However, there was no interaction between these two factors indicating that the N response was similar for all systems. Across systems, the N rate required for maximum yields was 175 lb/ac (Figure 2). At optimal N rates, yields were highest in the WS treatment (9333 lb/ac), followed by the NT-SSB (8413 lb/ac) and the other two NT treatments (about 7500 lb/ac). The lower yields in the NT-SSB treatment compared to the WS treatment contrasts with what we observed in a pilot study in 2023 where yields were similar between these two treatments. This may be due to the high July temperatures (hottest on record). The NT treatments were all flowering in July which can cause sterility and reduced yields (Espe et al., 2017). The WS treatment, which was planted 3 weeks later, flowered in mid-August.

Response to varying N sources:

We evaluated four different N sources (urea, Anvol, Super U and manure) all applied at permanent flood, and a split application of urea (permanent flood and panicle initiation). The recommended control is the single application of urea at permanent flood. All N sources were applied at 125 lb N/ac which is below the optimal rate (Figure 2); thus, differences in N use efficiency should be evidenced in grain yield. There were significant differences in yield as a result of both system and N source/management. However, there was no interaction between these two factors indicating that the sources and management options were similar across systems. All N sources/management significantly increased yields compared to not adding any N fertilizer (Figure 3). When N was applied, yields were lowest when the N source was applied as manure. Applying N as urea (single or split applications), Anvol or Super U had no significant effect on yields. This finding is similar to what was found by Cornelio and Linquist (2023) in water seeded systems. Interestingly, in all the NT systems, the split N application had the highest yields. Although not significant, it will be something we keep an eye on as research progresses.

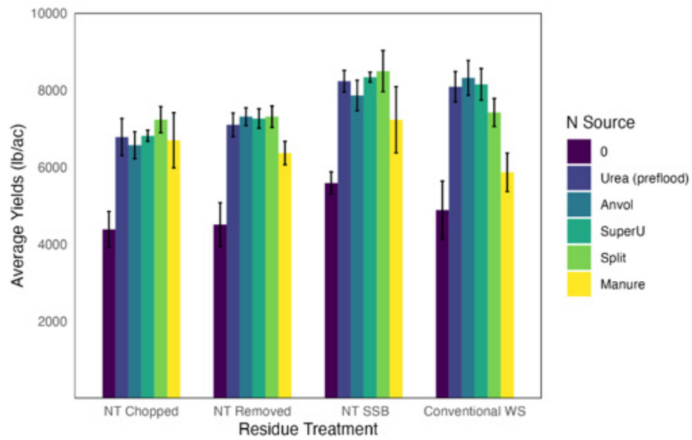

Figure 3. Yield response to varying treatments and management practices. All N was applied at a rate of 125 lb N/ac. NT-SSB is the fallow treatment.

Conclusions

These systems do have the potential to conserve water and allow farmers to plant earlier as we had suspected. Our results suggest that a GA seed treatment is not required. Yield potential was higher in Conventional water seeded rice than in the other treatments. The NT-SSB (fallow) treatment had higher yields than the strict NT treatment. Low yields in the strict NT treatments are similar to what we saw in the 2023 pilot study. These early findings suggest that strict NT may not be economically viable but the NT following the fallow (NT-SSB) has promise.

Acknowledgements

The authors would like to acknowledge FREP for supporting this research.

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Improving Nitrogen and Potassium Management in Almond Orchards with Hulls and Shells as a Soil Amendment and Off-Ground Harvest

Project Leader

Sat Darshan S. Khalsa
Assistant Professional Researcher
UC Davis
sdskhalsa@ucdavis.edu

Co-PIs

Ranjith Karunakaran
Postdoc Researcher
UC Davis

Patrick H. Brown
Professor
UC Davis

Introduction

Almond production plays a crucial role in California's Central Valley agricultural economy but poses significant environmental challenges. Intensive nitrogen (N) use, combined with harvest practices such as nut sweeping and hull/shell removal, depletes soil organic matter, reduces N retention, and increases leaching into groundwater. Traditionally, these byproducts have been used in other industries, primarily dairy farms, but with almond production surpassing dairy growth, new strategies are needed to sustain soil health. This project investigates recycling hulls and shells within almond orchards to enhance N, potassium (K), and carbon (C) cycling. While hull and shell amendments can meet up to 80% of orchard's K requirements, N release dynamics remain poorly understood. A field trial was set up to evaluate three approaches: unamended control, hull/shell amendments with conventional on-ground harvest, and hull/shell amendments with off-ground harvest. The project aims to optimize hull/shell management, improve nutrient use efficiency, and assess economic feasibility, while stakeholder engagement ensures practical, scalable adoption across California orchards.

Objectives

1. Characterize N release/absorption dynamics from amended hulls and shells and evaluate the tradeoffs between K release and its impacts on calcium, magnesium, and sodium in plants and soil
2. Integrate hulls and shells with off-ground harvest to explore benefits
3. Assess the effects of hull and shell application on tree growth, physiology, and yield
4. Promote adoption of improved orchard management

Description

We conducted experiments at Westwind Farms, established in 2008 with Nonpareil as the main cultivar. The study used a random complete block design (RCBD) with three treatments: 1) unamended tree berm; 2) tree berm amended with hulls and shells with on-ground harvesting; and 3) tree berm amended with hulls and shells with off-ground harvesting. Each treatment was replicated four times, resulting in 12 plots, each with 40 trees.

- Conducted initial soil sampling to determine nutrient availability and hull/shell composition before applying a 70:30 hull/shell mix at 3 tons/acre.
- Sampled soil and hull/shell from March to July to assess N release and absorption; leaf sampling to evaluate plant nutrient status and interactions with other nutrients.
- Evaluated changes in soil N and hull/shell nutrient composition to understand N release dynamics and compare treatments.
- Compared nutrient release and water use in hull/shell amended trees with off-ground versus traditional on-ground harvesting.
- Determined vegetative growth and yield relationship corresponding to treatments.
- A cost-benefit analysis will be completed by December 2025 to compare the nutrient value of hulls versus synthetic fertilizers, including transportation and logistics costs.
- Engagement with growers through outreach events to identify adoption barriers and opportunities will be continued.

Results and Discussion

Soil and amended hull/shell samples were analyzed at a 0–10 cm depth, with nitrogen (N) fertigation applied within 24 hours. Across three assessments from March to May, soil nitrate-nitrogen (NO_3-N) and ammonia-nitrogen (NH_4-N) levels were roughly 50% higher in hull/shell-amended plots compared to unamended plots. Additionally, the N concentration in the amendments rose from an initial 0.8% to approximately 1.2%.

Despite the amendments retaining substantial N from fertigation, soil N retention increased by up to 50%, suggesting that the mulch layer effectively minimized nitrogen leaching. The higher organic matter (OM) and moisture content in amended plots likely enhanced nutrient retention and microbial activity, helping to maintain nitrogen in the root zone for longer.

Exchangeable K concentrations in the soil were nearly double in the amended plots compared to the control throughout the assessments. The increase in exchangeable K following hull/shell application was calculated by subtracting the March (0–10 cm) measurements from the pre-treatment K levels (ΔK). ΔK was highest in amended plots with on-ground harvesting (175 ppm), followed by amended plots with off-ground harvesting (123 ppm), and lowest in the control plots (48 ppm). This increase was reflected in plant K status as well, with amended blocks averaging ~2.0% leaf K compared to ~1.6% in unamended controls. Conversely, calcium (Ca) and magnesium (Mg) concentrations were slightly lower in the amended plots relative to the control.

Despite potential benefits such as improved moisture and N retention, 2024 yields declined by ~6% in amended off-ground (A-OFF) harvested plots and ~30% in amended on-ground (A-ON) harvested amended plots compared to the unamended off-ground (UA-OFF) harvested plots (Fig. 1A). The 30% drop cannot be attributed solely to treatment effects, as factors like prior-year yields, bloom overlap, and pollinizer cultivar distribution also influence production. For instance, on-ground harvested amended plots produced 8.33 kg dry kernel/tree in 2023 (~10% higher than other treatments), possibly contributing to the 2024 decline. Over a three-year period, cumulative yields decreased by 6% in off-ground and 9% in on-ground harvested amended plots (Fig. 1B). These results suggest that improved tree K status did not enhance yields and may have had a negative impact on productivity.

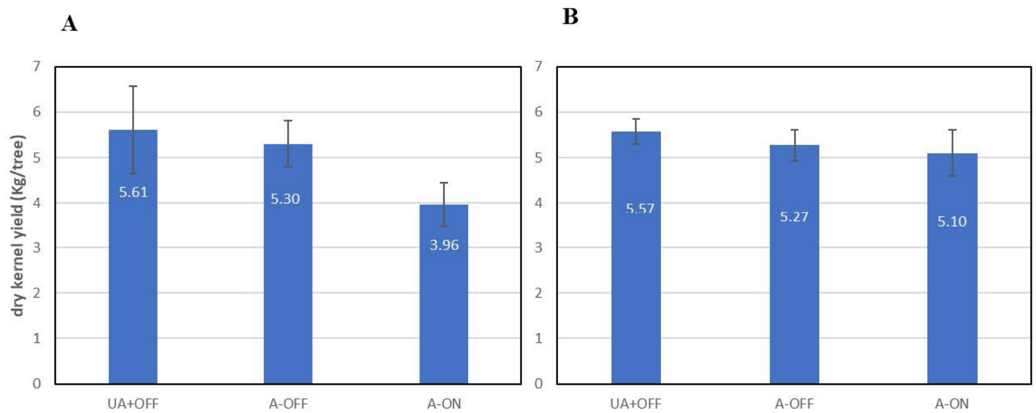

Figure 1: Average tree yield in almond trees under hull/shell amended and unamended treatments with different harvesting methods. A) Average yield of almond trees under different treatments in 2024. B). Average yield of almond trees under different treatments for the period of 3 years (2022 to 2024). Vertical bars represent the mean ± standard deviation of four replicates. Each replicate consists of 3 trees in the year 2024 and 40 trees in 2022 and 2023. The total yield was divided by the number of trees in the block to determine the average tree yield.

Notably, trunk circumference was higher in the amended blocks by approximately 15% compared to the unamended plots (Fig. 2). Similarly, the higher leaf K observed in the amended plots was associated with a greater leaf area index (Fig. 3), which in turn correlated with reduced yield (Fig. 4). Increased trunk and leaf growth may indicate the potential for improved fall carbohydrate recharge; however, the reduced yields suggest that elevated K might limit carbohydrate utilization essential for bloom vitality, thereby reducing fruit set and subsequent yield. Under these conditions, unutilized resources for fruit production may be diverted toward vegetative growth. This pattern aligns with prior studies linking higher trunk growth to lower almond yields (Karunakaran et al., 2023; Karunakaran et al., 2024).

Further research is required to better understand this phenomenon.

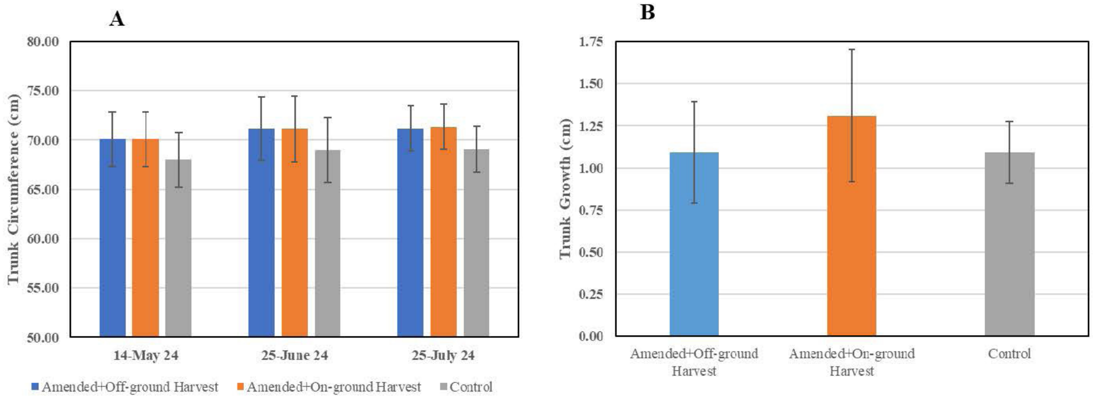

Figure 2. Trunk circumference and growth of almond trees under hull/shell amended and unamended treatments with different harvesting methods over time. A. Trunk circumference of trees from May through July 2024. B. Trunk growth of trees between May and July 2024. Vertical bars represent the mean ± standard deviation (SD) of four replicates. Each replicate consists of 3 trees.

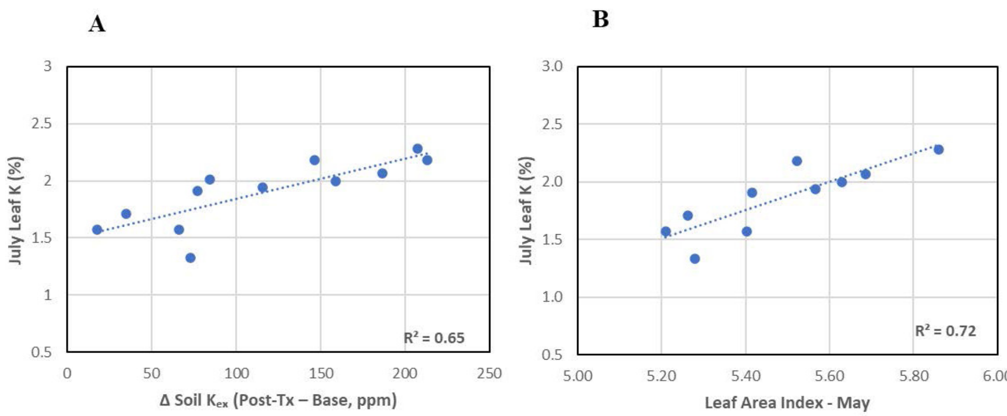

Figure 3. Effect of soil K addition on plant K levels and its impact on leaf growth. A. Correlation between soil K addition by hull/shell amendments and leaf K levels. (Soil K addition (Δ Soil K) was calculated by subtracting the exchangeable K assessed (0-10 cm) in March from the pre-treatment K levels. B. Correlation between leaf area index and July leaf K. Each data point represents each replicate, and each replicate is the average of 3 technical replicates in all the assessments. Dotted lines represent linear regression fits.

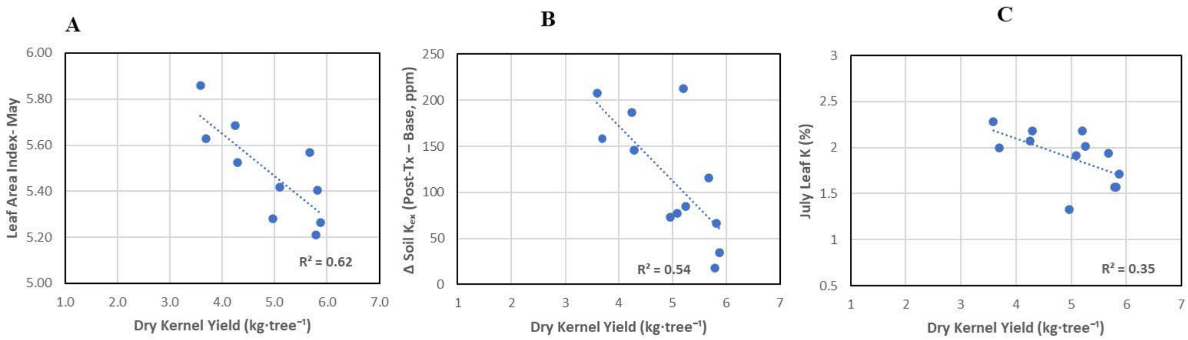

Figure 4. Effects of soil K addition, plant K levels, and vegetative growth on yield of almond trees. A. Correlation between LAI and yield. B. Correlation between soil K addition and yield. C. Correlation between plant K status and yield. Each data point represents each replicate, and each replicate is the average of 3 technical replicates in all the assessments. Dotted lines represent linear regression fits.

Recommendations

Excessive tree K levels (>2%) do not appear to improve yield, so K application rates should be determined based on both K removal rates and orchard K status to balance vegetative and reproductive growth. Additionally, when using hull/shell amendments, supplemental K fertilization should be adjusted according to the K contribution from these materials.

Acknowledgements

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Optimizing Potassium (K) Fertilization Management in Almond Orchards

Project Leader

Brown, Patrick H.
Distinguished Professor
University of California, Davis
phbrown@ucdavis.edu

Co-PIs

Jin, Yufang
Professor
University of California, Davis

Scudiero, Elia
Research Agronomist
University of California, Riverside
Department of Environmental Sciences

Introduction

Potassium (K) is one of the most important nutrients for almonds and is an abundant element in the topsoil; however, only 0.02-2% of the total K is available to plants. The availability to plants of soil K is affected by a multitude of different factors and variability in the spatial distribution of soil available K is often detected (Blanchet et al, 2017; Gao et al, 2019). Incomplete understanding of K dynamics compromises sampling technologies and limits our ability to manage orchard K effectively. Almonds have a high K demand, with a total of 248-388 kg K/ha allocated to fruits in high-yielding crops (Muhammad et al, 2015). Given our lack of understanding of K dynamics, and absence of reliable diagnostic tools, growers apply uniformly high rates of K applications to avoid deficiency of K. However, with the recent dramatic increases in K fertilizer prices, excessive applications are wasteful and not economically viable.

This research aims to improve our understanding of the complex dynamics of K in the soil and in the plant with the ultimate objective of improving K management and K use efficiency.

Objectives

The objective of the research is to:

1. Characterize the extent of spatial and temporal K within-the-orchard variability
2. Identify the main factors affecting soil K distribution and plant availability and their interaction with each other
3. Incorporate the use of sensing technologies into sampling protocols to improve the precision of the measurement

4 Describe leaf K distribution within the plant canopy and remobilization patterns during the day
5 Identify the factors affecting K mobilization within the canopy
6 Develop novel leaf testing protocols that accurately reflect plant K status
7 Develop online training resources and extend outcomes through talks and publications

Description

Our approach:

- Collect repeated soil, leaf and yield data at the tree level, and georeference the data.
- Map the soil using a multi-coil/depth Gamma Ray Spectroscopy and Electro Magnetic Interference (EMI) Detector.
- Interpret the results and analyze the causes and the extent of spatial and temporal K variability.
- Formulate guidelines for improving monitoring of soil plant-available K.
- Collect leaf samples from 7 trees in both of the orchards at three different heights (160-190 cm, 200-250 cm and >270 cm) and at three different times of the day (7 am, 1 pm and 7 pm, and in July 2023 4 am) to detect the variability of K within the canopy and daily fluctuations of K during the day.
- Take measurements of photosynthesis rates, individual leaf area, stomata conductance, stem water potential, relative water content, osmotic potential, mineral fresh juice composition, leaf sugar and starch concentration.

Results and Discussion

Large variability in the distribution of both forms of plant-available K was detected, varying from areas of surplus K to areas of lower K supply in both orchards in all the sampling dates (Fig.1). In both sites, soil solution K displayed more variability over the different soil samplings.

An explanatory model for both sites was found for soil solution K and included exchangeable K, soil solution Mg, and cation exchange capacity with a R^2 of 0.64.

The model explaining exchangeable K included soil solution K, cation exchange capacity and Mg, Ca, Na in the exchangeable pool, with a R^2 of 0.97. A multivariate clustering analysis was performed using sensor data to detect hidden soil property patterns and our data suggests that high sand levels may also play a role in the dynamics of release and adsorption of soil K on the soil colloids.

		Exchangeable K (ppm)			Soil Solution K (meq/L)		
Site 1	Date	October 2022	Winter 2024	November 2024	October 2022	Winter 2024	November 2024
	n	88	44	56	88	44	56
	Mean	228	240	274	0.26	0.09	0.32
	SD	74	92	99	0.12	0.05	0.38
	CV	32%	38%	36%	47%	59%	120%

		Exchangeable K (ppm)		Soil Solution K (meq/L)	
Site 2	Date	January 2024	October 2024	January 2024	October 2024
	n	37	57	37	57
	Mean	197	257	0.10	0.27
	SD	102	211	0.08	0.60
	CV	52%	82%	88%	221%

Figure 1 Summary statistics of soil Exchangeable K (ppm) (left) and Soil Solution K (meq/L) (right) concentrations at Site 1 (upper table) and Site 2 (lower table) across all sampling dates. Sample size (n), mean, standard deviation (SD), and Coefficient of Variation (CV) are reported for each date.

The leaf experiment showed consistent results in both orchards, with the bottom leaves having the highest levels of leaf K, and the top having the lowest levels (Fig. 2). In some cases, the time of day influenced leaf K, with higher levels observed in the morning.

There was no strong correlation between leaf K and stomata conductance, leaf water potential and transpiration, suggesting that photosynthesis is not responsible for the heterogeneity of leaf K levels across the canopy or across time. Relative water content was uniform across the canopy, and it was lower in the afternoon (Fig. 2). However, the bottom leaves decrease their relative water content more than the rest of the canopy. Leaf osmotic potential and leaf K were positively correlated (as leaf K increased, also osmotic potential increased), which was unexpected as, generally, an increase in solutes generally determines a more negative osmotic potential. However, there was no correlation between leaf K and leaf soluble sugars, but a weakly negative correlation between leaf K and leaf starches was detected (Fig.2). This suggests that leaf K heterogeneity pattern may be explained by plant water relations and osmotic regulation.

Accomplishments

We participated in the following conferences:

- Poster presentation at the Almond Board Conference in Sacramento in December 2024.
- Oral presentation at 2025 UCCE Yolo-Solano-Sacramento Almond Meeting in March 2025.
- Oral presentation at the International Plant Nutrition Colloquium in Porto, Portugal, in July 2025.

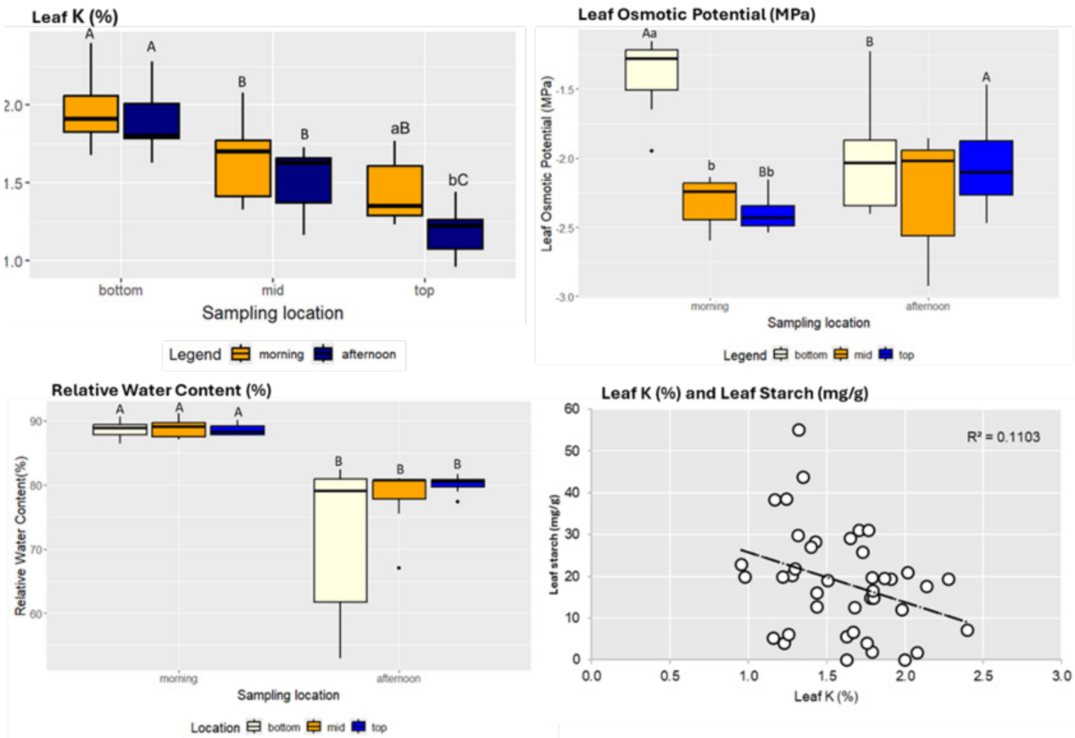

Figure 2: Leaf K (%), Leaf Osmotic Potential (MPa), Relative Water Content (%) and relation between Leaf K and Leaf starch (mg/g) in August 2024 in Site 1.

Acknowledgements

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A Science-Based and Interactive Website for Nutrient Management in Organic Crop Production

Project Leader

Daniel Geisseler
Cooperative Extension Specialist
UC Davis
djgeisseler@ucdavis.edu

Introduction

Nutrient management in organic systems is complex and can be challenging because organic growers predominantly apply nutrients with organic inputs, such as composts, organic fertilizers, and cover crops. Most of the nitrogen (N) in these materials is not directly crop-available and needs to be mineralized first by soil microorganisms. How much is mineralized and when N is mineralized depends strongly on the properties of the material, especially its carbon (C) to N ratio, but also on environmental conditions such as soil temperature and moisture. Many fertilizers, composts and amendments are available for organic agriculture. The availability of the N applied with these materials can range from zero to up to 90%. Some plant-based composts may even immobilize N, which means that crop-available N in soil solution is tied up temporarily. Accurate data to estimate N availability is crucial to achieving high N use efficiency, decrease losses with potentially harmful environmental effects and make organic production economically viable. Furthermore, composts and most organic amendments contain many different macro- and micronutrients. Finding amendments or combinations of materials that match the crops' demand for different nutrients is more challenging than using single-nutrient fertilizers.

Since their creation some ten years ago, the online California Fertilization Guidelines (https://www.cdfa.ca.gov/is/ffldrs/frep/FertilizationGuidelines/) have become an important source of information for growers and crop consultants in California.

The guidelines are a summary of the research done in California and other regions with comparable conditions. The focus of the guidelines is on nutrient management in conventional agriculture.

In the current project we aim to make relevant information about nutrient management in organic systems available online.

The website will complement the California Fertilization Guidelines and include webpages that summarize the available literature on nutrient availability from different sources in organic systems and an interactive N, phosphorus (P) and potassium (K) budget calculator for major annual crops grown organically in California. The website will contribute to the efficient use of nutrients in organic crop production by helping growers and consultants find relevant information and supporting their decisions when planning nutrient management for their crops.

Objectives

The objective of the proposed project is to develop webpages and an online interactive nutrient calculator for organic growers and consultants where they can access science-based information on organic nutrient management and develop nutrient budgets for organically grown annual crops. Specific objectives are:

1. Summarize the available literature with a focus on studies from California and create webpages for organic nutrient management.
2. Develop an interactive tool to calculate field-specific N, P and K budgets.
3. Fill knowledge gaps and validate the estimates of the calculator in field trials.
4. Conduct outreach to growers, consultants, and other stakeholders.

Description

The project started in January 2025. During the first year we are focusing on reviewing the available literature and developing a first version of the online calculator for N. This will allow us to identify knowledge gaps which will be closed in years 2 and 3.

Results and Discussion

The calculator has a modular design (Figure 1). Each module can be used independently. The modules for N availability from different sources include residues from the previous crop, cover crop residues, residual soil nitrate, N mineralization from soil organic matter, organic amendments and composts, irrigation water, and liquid amendments fertigated during the growing season. Furthermore, the temporal N uptake of different crops can be determined based on the expected yield.

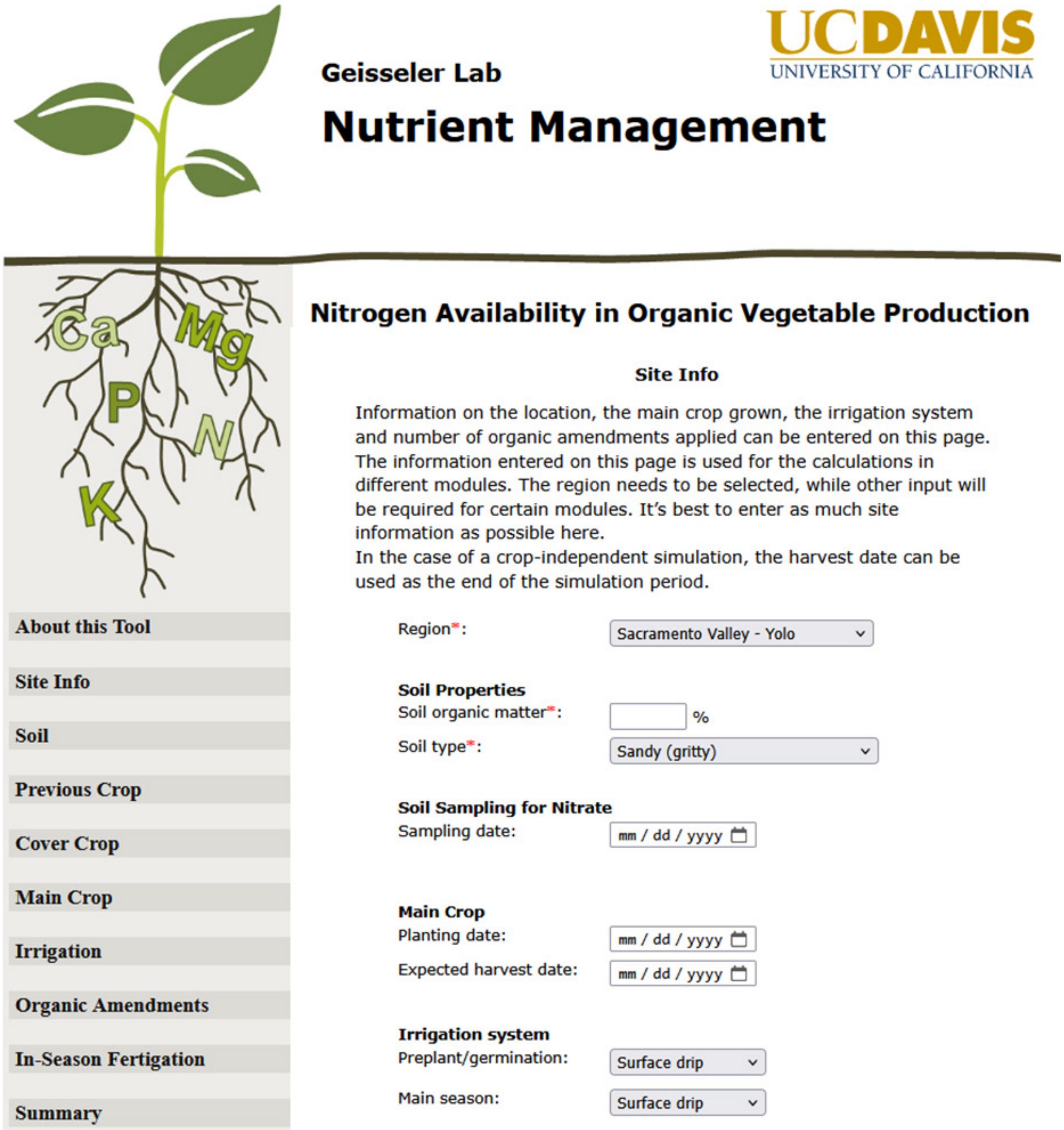

Figure 1: Screenshot of the page where users enter general information about the field. The panel on the left shows the different modules of the calculator. The website is currently under development.

Acknowledgement

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Determination of Crop N-Removal Coefficient Values for the Imperial and Coachella Valleys Cropping Systems

Project Leader

Ali Montazar
Irrigation and Water Management Advisor
UCCE Imperial County
amontazar@ucanr.edu

Introduction

Nitrogen (N) balances in agricultural fields are an important component of the Irrigated Lands Regulatory Program (ILRP) in California. Accurate crop N-removal coefficient values for different crops are crucial for estimating the amount of N removed in harvested product. The crop coefficient values have been updated for several commodities in the Central Valley and the Central Coast regions while the lack of this information for the desert region has caused big concern for growers and the local Irrigated Land Coalitions. This study intends to develop crop N-removal coefficient values for several major commodities in the Imperial and Coachella Valleys.

Objectives

The specific objectives of this study are:

1. Develop N-removal values in harvested products for 10 commodities identified in the Imperial and Coachella Valleys.
2. Disseminate knowledge and information developed by the project to the Imperial Valley Irrigated Land Coalition (IVILC) and the Coachella Valley Irrigated Land Coalition (CVILC) and local growers in the region.

Description

Over the past seven months since the project's initiation, extensive field sampling, processing, and analysis have been carried out on alfalfa, bermudagrass, kleingrass, dehydrator onions, broccoli, bell peppers, cauliflower, romaine lettuce, head lettuce, green leaf lettuce, and wheat from 114 individual sites across the Imperial and Coachella Valleys.

For the hay crops—alfalfa, bermudagrass, and kleingrass—data were collected from five separate harvests during this period. Samples were collected from five locations within each field at the time of commercial harvest following grower standards.

A composite sample was used to determine the N percentage of the harvested plant parts at a moisture content typical for each commodity. Plant samples were first oven-dried at 60°C to a constant weight, then ground using a Wiley mill to pass through a 1 mm screen. Initial and final weights were recorded during drying to calculate dry matter content, allowing for the determination of N concentration on a fresh weight basis. Samples were thoroughly mixed prior to subsampling to ensure representativeness. Total N content of product was determined through laboratory analysis.

Results and Discussion

N removal coefficients developed for various commodities during this period are presented in Table 1. For each commodity, the table includes the mean, minimum, and maximum N-removal coefficients. As expected, there is variability in these estimates, which can be attributed to differences in percent N and percent solids in crop tissue (mean and the range also shown in Table 1). These differences arise from variations in growing conditions, soil type, irrigation method, and crop variety.

Mean N-removal coefficients ranged from as low as 0.001384 for head lettuce to 0.033293 for alfalfa hay. These coefficients generally reflect the type of crop. For example, forages such as alfalfa, bermudagrass, kleingrass, wheat straw and seeds tend to have higher removal coefficients (e.g., >0.012) compared to vegetables (e.g., <0.005). Higher N concentrations and greater solids content in plant tissue contribute to higher removal coefficients. For both hay and seed crops, the harvested product is considered to represent nearly 100% of the plant tissue solids, which contributes to higher N-removal values.

The values presented in Table 1 will be updated to include additional commodities—such as date palm, lemons, alfalfa seeds, and table grapes—along with more comprehensive dataset for those already reported.

To estimate total N removal from an individual field using the mean N-removal coefficients presented in Table 1, the coefficients should be multiplied by the actual harvested yield (in pounds).

Table 1. Mean and range of crop N-removal coefficients, and associated factors used in their development: percent solids and percent N.

Commodity	# Fields sampled	mean N-Coeff.	min N-Coeff.	max N-Coeff.	mean % solids	min % solids	max % solids	mean %N	min %N	max %N
Alfalfa hay	12	0.033293	0.01780	0.04520	-	-	-	3.33	1.78	4.52
Bermuda grass hay	5	0.018361	0.01220	0.0240	-	-	-	1.84	1.22	2.40
Bell pepper (Red)	6	0.001919	0.001710	0.002075	8.15	4.91	9.54	2.42	2.03	3.48
Bell pepper (Green)	5	0.002105	0.001982	0.002382	6.77	5.92	7.34	3.13	2.85	3.66
Broccoli	9	0.005405	0.003749	0.007342	10.15	8.96	11.42	5.31	3.72	6.73
Cauliflower	10	0.002180	0.001591	0.002609	6.59	4.99	8.54	3.35	2.44	4.49
Dehydrator onion	5	0.002555	0.002253	0.002884	22.93	20.61	26.21	1.12	0.98	1.29
Klein grass hay	8	0.022197	0.01120	0.03360	-	-	-	2.22	1.12	3.36
Romain lettuce	19	0.001851	0.001062	0.002774	5.54	3.32	8.48	3.42	2.16	4.02
Head lettuce	20	0.001384	0.001043	0.002093	4.35	2.66	5.63	3.18	2.88	3.71
Green leaf lettuce	11	0.002219	0.001494	0.003382	6.30	4.18	9.11	3.61	2.71	4.18
Wheat - seeds	4	0.029573	0.02740	0.0310	-	-	-	2.95	2.74	3.10
Wheat - straw	4	0.012973	0.00860	0.01780	-	-	-	1.29	0.86	1.78

Conclusions

This ongoing study aims to develop crop N-removal coefficients for several major commodities in California's low desert region. This report summarizes the mean and range of crop N-removal coefficients developed during the first year of the study. Considering the diversity of commodities and cultural production practices, a wide range of mean N-removal coefficients was observed from as low as 0.001384 for head lettuce to 0.033293 for alfalfa hay. These values will be updated to include additional commodities, along with a more comprehensive dataset for those already reported.

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 cooperating farmers in the low desert region. We would also like to acknowledge our cooperators:

Daniel Geisseler
Nutrient Management Specialist
Dept. of LAWR, UC Davis
djgeisseler@ucdavis.edu

Richard Smith
Vegetable Crops and Weed Science Advisor (Emeritus)
UCCE Monterey County
rsmith@ucanr.edu

AI-Driven Assessment of Nutrient Status Variability in Almond Orchards Using Remote Sensing

Project Leader

Yufang Jin
Professor
UC Davis
yujin@ucdavis.edu

Co-PIs

Patrick H Brown
Distinguished Professor
UC Davis

Alireza Pourreza
Associate Professor of CE
UC Davis

Introduction

Nutrient management in almond orchards is essential for maximizing yield, reducing costs, and protecting the environment. Current monitoring methods rely on limited leaf sampling, which cannot capture fine-scale variability or rapid changes in nutrient status. This knowledge gap limits timely, site-specific decisions. Hyperspectral imagery, combined with artificial intelligence, offers a new opportunity to monitor nutrient status remotely, accurately, and at scale. While hyperspectral sensing has shown promise in crop monitoring, its operational use for almond nutrient management remains undeveloped. This project will develop an integrated remote sensing–AI approach using proximal, airborne, and spaceborne hyperspectral sensing to assess spatial and temporal nutrient variability, link it to soil and yield patterns, and guide efficient sampling strategies. The outcomes will improve the efficiency of fertilizer use, enhance productivity, reduce environmental impacts, and support sustainable orchard management across California.

Objectives

To achieve the overall objectives of the project, the specific objectives for this phase are:

1. Collect comprehensive ground-truth data by sampling almond leaves for chemical analysis across multiple canopy heights, varieties, and orchard locations, and over different time periods to capture maximum variability in nutrient status
2. Obtain hyperspectral measurements from leaves to establish direct relationships between leaf-level spectral signatures, drone and satellite-based imagery, and laboratory-derived nutrient concentrations
3. Acquire and process aerial imagery from drone-based multispectral and thermal sensors to generate high-resolution spatial information

4 Integrate multi-source datasets (leaf chemical analysis, drone imagery, hyperspectral leaf data, and satellite imagery) to develop and validate an AI-driven framework for large-scale monitoring of nutrient status in almond orchards

Description

In the first phase, nine randomly selected almond trees were designated as target trees for intensive monitoring. Four data collection campaigns were conducted during the growing season (May, June, July, and August) to capture seasonal variability. For each tree, leaf samples were taken from three canopy heights and four cardinal directions with four replicates (3x4x4), ensuring comprehensive coverage of spatial variability.

All leaves were scanned in the field using a hyperspectral point scanner (SVC). Combined leaf samples from each canopy height were then processed to record fresh weight, scanned with an RGB system for leaf area estimation, and dried under controlled conditions to measure dry weight, producing three data points per tree. These samples were subsequently submitted for laboratory chemical analysis to determine nutrient concentrations.

Additionally, aerial flight campaigns were conducted in parallel with leaf sampling events. RGB and multispectral imagery were collected during all flights, while thermal imagery was captured only in August, just prior to harvest. These aerial datasets will be linked with satellite imagery to establish multi-scale relationships between ground measurements and remote sensing observations.

Preliminary analysis of the leaf spectral data was conducted to assess differences in spectral signatures across canopy positions, among trees, and throughout the growing season. Additionally, a pre-trained AI model was used to interpret spectral patterns and predict leaf nutrient concentrations from the spectral data.

Building on these initial findings, the project integrates detailed leaf-level hyperspectral data, aerial imagery, and satellite observations within a unified RTM–AI framework to create an accurate, scalable method for nutrient monitoring in almond orchards. This integrated approach is designed to support earlier detection of nutrient imbalances, improve fertilizer use efficiency, enhance yield stability, and reduce environmental losses. The resulting tools and insights will be shared through field demonstrations, grower workshops, extension publications, and online platforms, with stakeholder feedback guiding further refinement to ensure practical adoption across the industry.

The next phases of this research will focus on scaling these models from tree-level to orchard and regional levels by linking leaf measurements with drone- and satellite-based imagery across larger grower blocks, along with continuous data collection.

Extending data collection across multiple seasons will allow calibration of models under different weather, soil, and management conditions, improving robustness and transferability.

Results and Discussion

Getting nitrogen right is pivotal for photosynthesis, shoot growth, and nut fill; adopting height-aware sampling improves diagnostic accuracy and translates directly into better fertigation timing and rates, lower input costs, and reduced environmental losses. Preliminary analyses revealed clear variation in spectral signatures and derived traits across canopy positions, among individual trees, and over the course of the season. Canopy height had a consistent effect, with leaves from the upper canopy generally exhibiting higher nitrogen and chlorophyll contents, reflecting greater light exposure, while lower canopy leaves showed reduced pigment levels. While some gradual change is evident across the season, leaf nitrogen expressed per area is relatively stable from May to August (ranging from 0.25–0.33 mg/cm² across trees). Chlorophyll concentrations peaked in June and July, then declined by August as trees approached harvest.

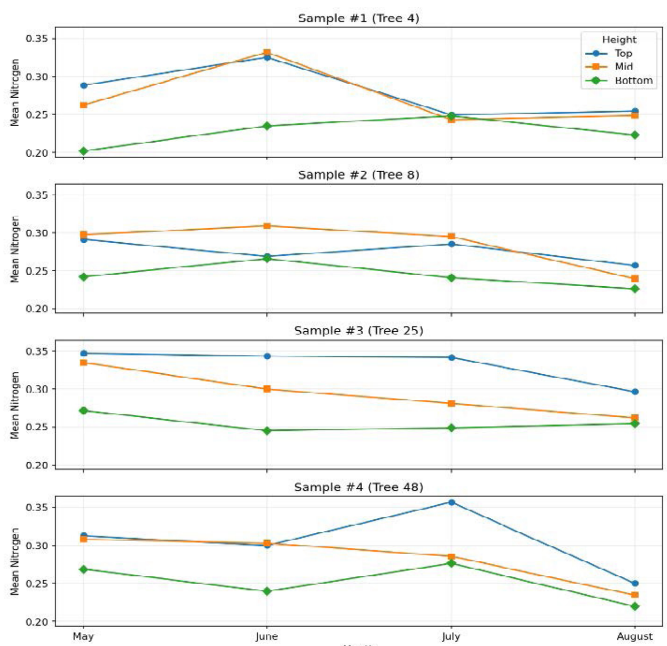

Figure 1. Seasonal dynamics of average leaf nitrogen concentration by canopy height for four sampled almond trees.

AI-based model predictions showed variability both between individual trees and within canopy layers in essential nutrients including Nitrogen (N), Phosphorus (P), Potassium (K), Calcium (Ca), Magnesium (Mg), Zinc (Zn), Manganese (Mn), Iron (Fe), Copper (Cu), Boron (B), Chlorophyll (CHL), Carotenoids (CAR), Anthocyanins (ANT), Equivalent Water Thickness (EWT), Leaf Mass per Area (LMA), and Structural Number (NStruct), which represents leaf thickness. This variability highlights the limitations of conventional composite sampling for capturing true orchard nutrient status.

Furthermore, these results showed promise in predicting nutrient status directly from spectral signatures, offering a pathway toward robust, non-destructive nutrient monitoring.

Figure 2 illustrates the seasonal dynamics of key nutrient and physiological traits, showing both overall trends across the May–August period and variability among individual data points. Additionally, micronutrients such as Zn and Mn showed tighter seasonal clustering, while Cu and B displayed higher variability both within and among trees. This suggests that some nutrients may be more amenable to remote prediction than others. EWT and LMA, which declined toward harvest, provide indirect signals of leaf water status and structural investment, parameters that may help refine irrigation–nutrition interactions in future models.

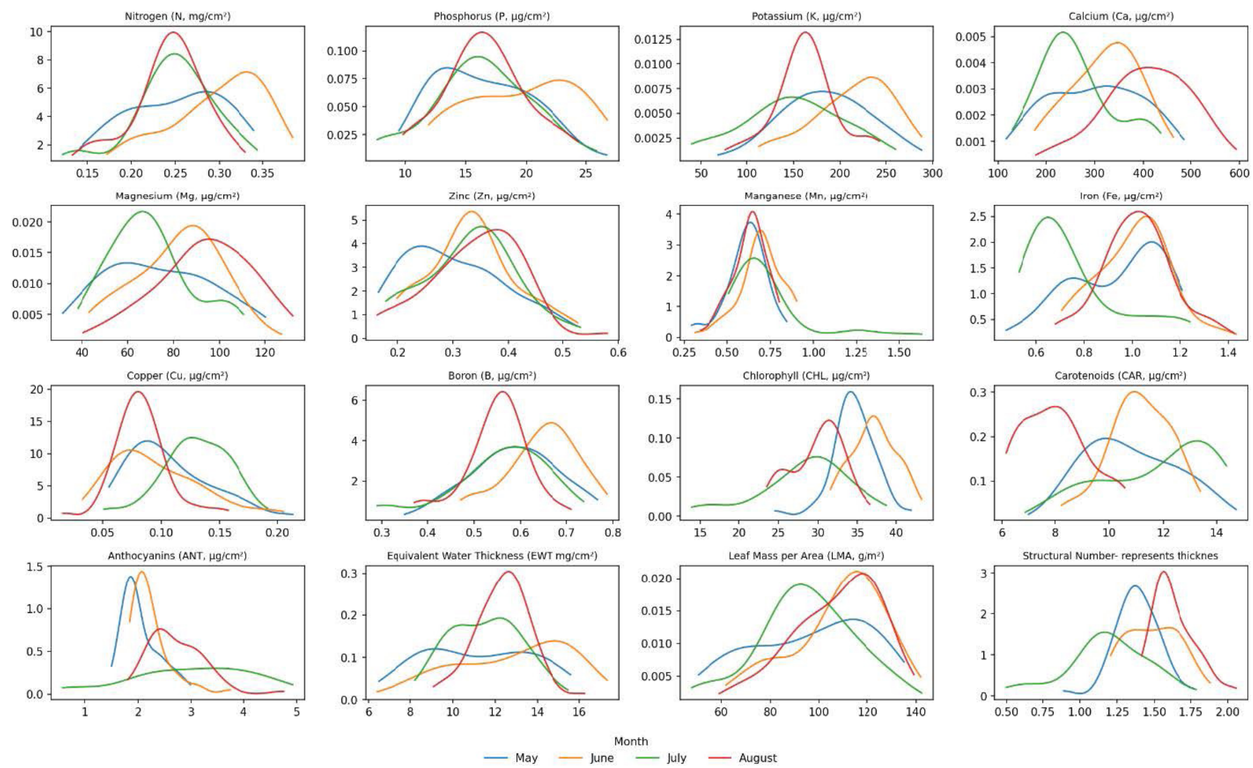

Figure 2. Seasonal variation in leaf nutrient concentrations, pigments, and structural traits of almond trees across four sampling campaigns (May–August).

These findings demonstrate the potential of combining hyperspectral measurements with advanced modeling to detect nutrient differences across space and time in almond orchards. The observed variability emphasizes the need for site-specific nutrient management strategies rather than uniform fertilizer applications. Adoption of such approaches can increase nutrient use efficiency, reduce environmental losses, and improve yield consistency. By linking leaf-level measurements with aerial and satellite imagery, the project moves toward scalable monitoring tools that can be deployed at orchard and regional scales.

Conclusions

This project demonstrates that combining spectral data from leaves, drones, and satellites with advanced modeling can reveal nutrient dynamics in almond orchards that are not captured by standard sampling. Seasonal shifts, canopy height effects, and tree-to-tree variability underscore the importance of site-specific monitoring for more precise fertilizer management. The approach shows potential for reducing costs, improving yield stability, and limiting environmental losses by guiding targeted applications. As these tools are refined, advisors and practitioners can expect remote sensing–based platforms to become practical aids for nutrient decision-making, with extension programs playing a key role in supporting adoption.

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Development of Three Citrus Modules in the Decision Support Tool CropManage for Orange, Mandarin, and Lemon

Project Leader

Ken Miller
SSJV MPEP Technical Program Manager
Formation Environmental
kmiller@formationenv.com

Co-PIs

Dr. Manpreet Singh
Technology and Innovation for Small Farms Advisor
UCCE Fresno County

Donald Ikemiya, PE
SSJV MPEP Program Coordinator
Kaweah Basin Water Quality Association

Dr. Michael Cahn
Irrigation and Water Resource Advisor
UCCE Monterey County

Introduction

As citrus growers in California's Central Valley grapple with significant water quality and quantity issues and associated regulations, the need for precise fertilization and irrigation practices is more critical than ever. Currently, citrus growers farm over 200,000 acres in the valley but lack access to a specialized, free decision-support tool that could guide them in making informed in-season decisions about irrigation and fertilizer applications. The crops' physiological characteristics are unique amongst commodities grown in the valley, adding a layer of complexity to developing such a tool.

The goal of this project is to build a decision-support tool to address this need. This project builds off years of research, experimentation, and software development efforts and will culminate in the development of three new citrus-specific modules for the University of California's (UC) CropManage (CM) online platform, namely oranges, mandarins, and lemons. CM is a free, publicly available irrigation and nitrogen (N) application decision support tool developed by UC researchers with funding from FREP, CDFA, USDA, UC Agriculture and Natural Resources, and the Department of Water Resources. The tool integrates crop water and N use data and models with local weather information from the California Irrigation Management Information System (CIMIS), soil information from the NRCS and other sources, grower management, and soil/plant sample data to make in-season recommendations for a variety of horticultural crops.

The tool was originally developed for Central Coast vegetable and berry cropping systems and later expanded to include predominant crops in other regions like Central Valley. This project supports this expansion.

The potential impacts of this initiative are significant. By providing citrus growers and advisors with access to a refined decision-support tool, this project can lead to increased adoption rates of CM and the management practices embedded within it, resulting in more efficient fertilizer and water use. This, in turn, enhances the likelihood of regulatory success while maintaining and enhancing a productive and diverse agricultural landscape.

Objectives

The overall objective of this project is to develop CM modules for orange, mandarin, and lemon varieties. Specific objectives include the following:

1. Improve the understanding of N and water use dynamics in micro-irrigated citrus orchards grown under the atmospheric conditions of the San Joaquin Valley and Tulare Lake Basin, through field measurements, monitoring, and data-driven modeling
2. Refine the experimental version of three citrus modules within CM with knowledge gained from field studies and modeling
3. Ground-truth CM recommendations for N and water applications at heavily monitored citrus study orchards
4. Conduct outreach and training on the developed modules to citrus growers and advisors

Description

This project consists of 1) identifying cooperating growers to establish monitoring sites and receive critical input on module development/refinement, 2) collecting necessary water and N data (soil N, tissue N, applied water, N in water) across space and time from multiple study sites to refine experimental modules and verify CM recommendations, 3) fine tuning CM citrus modules based on collected data and grower feedback, and 4) conveying findings and offering outreach and training opportunities to the citrus grower and advisor community. Through these steps, this project will deliver a needed free, accurate, and reliable tool for citrus growers to farm efficiently and with confidence.

Results and Discussion

During the first year of the project, efforts have been focused on planning, setup for monitoring, and initial data collection. A total of 9 commercial orchards have been identified for study across Fresno, Tulare, and Kern Counties, three each for orange, mandarin, and lemon. Of these, three sites support existing research on crop water use, with one also being studied to assess nitrate fate and transport, thus leveraging additional data for the project.

Data collection is designed to monitor water and N together as CM considers both and they need to be co-managed to achieve optimal efficiency. Each site has been outfitted with flowmeters and soil moisture sensors to a depth of 4 feet to track irrigation applications and volumetric soil water content. This data is relayed to CM via dataloggers equipped with cell phone modems. A subset of fields are being monitored for crop evapotranspiration (ET) using Eddy Covariance equipment. In addition, monthly drone flights are being conducted to monitor changes in canopy cover in response to plant growth and pruning/hedging that affect crop ET and thus irrigation recommendations. These high-resolution data will also be compared to the publicly available satellite imagery used in CM. A nitrogen model specific for citrus based on previous research will be integrated into CM. Plans for plant, soil, and irrigation water sampling for N are being developed for sites and will be implemented beginning in 2026. Lastly, grower meetings will be held this winter to review collected monitoring data, demo CM, and plan for trialing and refining CM modules over the next two growing seasons.

Conclusions

Strategies and tools are needed to support growers in coping with mounting pressures to protect and conserve water resources. CM is a practical option for making informed in-season decisions about when and how much N and water to apply to efficiently produce a full crop. When managed together, the utilization of these inputs can be optimized.

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Nutrient Management Education on the Central Coast of CA

Project Leader

Nathan Harkleroad
Program Director of ALBA
nathan@albafarmers.org

Introduction

The Agriculture and Land-Based Training Association (ALBA), a 501(c)3 non-profit based in the Salinas Valley, is in its first year of a project focused on practices that help reduce environmental issues, particularly groundwater contamination with nitrates, as well as increasing access to knowledge and resources on nutrient management for farmers and a wider community of Agricultural Science college students and service providers.

Objectives

1. Educate 175+ farmers, 30 college students, and another 25 agricultural professionals/service providers on soil fertility and plant nutrition management techniques
2. Provide direct technical assistance to 60+ farmers on the use of innovative and proven conservation practices that protect groundwater resources
3. Perform outreach to 500+ farmers, college students, and agricultural professionals on project results and CDFA, UCCE, and other agencies' tools and resources for nutrient management best practices

Description

With a legacy extending to the 1970s, ALBA and its predecessors have built a reputation of providing a safe, bilingual learning environment, which connects training topics directly with tangible learning that participants can understand and use. The methodology of the project will include a combination of trainings, direct technical assistance, and project promotion that smoothly fits into ALBA's ongoing program for aspiring farmers.

Education:

ALBA's annual bilingual Farmer Education Course is 250+ hours of experiential learning for individuals who wish to launch an independent organic farm. The course consists of five 8-week modules. The summer module is on Organic Production, during which two introductory workshops (Plant Nutrition, Irrigation Principles) and two field days (soil nitrate quick testing and distribution uniformity) will be held. In the slower months, additional topics will be covered (Crop Manage, Cover Crops, Nitrogen Management).

Finally, an annual alumni event will be held in which all the practices will be showcased during the first half of the day. The second half will be followed by a resource fair in which ALBA invites CDFA, USDA agencies, NRCS included, as well as other NGO and private service providers to share opportunities.

ALBA will leverage its 1-acre demonstration field to showcase practices and engage in hands-on learning. Signage will be created to explain the project and placed in a visible location at the edge of the field. ALBA receives hundreds of visitors each year who will have a chance to learn about the project's activities.

Technical assistance:

The Organic Farm Incubator is a reduced-risk and supportive environment to launch an organic farm. Farmers receive subsidized access to land, equipment, and irrigation infrastructure while receiving free technical assistance from ALBA staff and partners. ALBA and the Resource Conservation District of Monterey County (RCDMC) routinely provide direct assistance to farmers on a range of production and conservation topics. ALBA's office and classroom sit at the center of the 100-acre training site, surrounded by 35-40 start-up farmers being incubated on the land. ALBA staff advise farmer tenants on a daily basis and the RCDMC visits on a weekly basis to help farmers with soil fertility and irrigation management. The Farm Manager and Sustainable Farming Advisor work directly with each farmer on land management and crop production. The Sustainable Farming Advisor works in concert with the RCDMC on coordinating and assisting farmers with specific practices, such as those being highlighted in this project. The RCDMC will further extend support to other farmers in Monterey County, many of which are ALBA alumni. Similarly, the Resource Conservation District of San Benito (RCDSB) will extend support to farmers in San Benito and Santa Clara counties.

Results and Discussion

While only in its first year of three, the project aims to directly impact 225 participants and 600+ acres of farmland on the Central Coast.

Key results will include:

- 150+ farmers gain knowledge on innovative and proven irrigation and nutrient management techniques
- 30-50 farmers implementing new management practices
- 1,000+ participants receiving project updates
- Bilingual nutrient and irrigation management resources through text, e-mail and social media
- 60+ participants learning about the project through webinars and presentations at conferences.

Conclusions

Given that we are in the first year of the project, we have no conclusions to report.

Acknowledgements

CDFA FREP and the Resource Conservation District of Monterey County.

COMPLETED FREP PROJECTS

Completed FREP Projects

The following is a chronological list of final reports for FREP-funded research. Following the title is the name of the principal investigator and the project reference number. We invite you to view the full final reports by visiting https://www.cdfa.ca.gov/is/ffldrs/frep/Research.html You may also contact the program at frep@cdfa.ca.gov.

Nutrient Management and Irrigation Efficiency Outreach and Education for Latino and Southeast Asian Farmers • *Deborah Nares, 21-0573*

University of California Nursery and Floriculture Alliance Fertilizers and Plant Nutrition Workshops for Greenhouse and Nursery Growers • *Lorence Oki, 20-0963*

Certification and Distance Learning for Fertigation • *Stuart Styles, 20-0961*

Enhancing Nitrogen and Water Use Efficiency in California Carrot Production Through Management Tools and Practices • *Ali Montazar, 20-0960*

Development of site-specific nitrogen fertilization recommendations for annual crops • *Daniel Geisseler, 20-0880*

Nitrogen Content of the Harvested Portion of Specialty Crops to Estimate Crop Nitrogen Removal and Improve Nitrogen Management in Crops • *Richard Smith, 20-0250*

Irrigation and Nitrogen Management, Monitoring, and Assessment to Improve Nut Production While Minimizing Nitrate Leaching to Groundwater • *Thomas Harter, 19-0968*

Immobilization of Nitrate in Winter-Fallow Vegetable Production Beds to Reduce Nitrate Leaching • *Richard Smith, 19-0955*

Development of Nutrient Budget and Nutrient Demand Model for Nitrogen Management in Cherry • *Patrick Brown, 19-0954*

Achieving Efficient Nitrogen Fertilizer Management in California Wheat • *Mark Lundy, 19-0953*

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 • *Sacha Lozano, 19-0950*

Next Generation N Management Training for Certified Crop Advisors • *Erik Porse, 19-0591*

Pima Cotton Nitrogen Management, Uptake, Removal - Impacts of Varieties, Subsurface Drip & Furrow Irrigation • *Robert Hutmacher, 18-0597*

Understanding Influences on Grower Decision-Making and Adoption of Improved Nitrogen Management Practices in the Southern San Joaquin Valley • *Sat Darshan Khalsa and Mark Lubell, 18-0596*

Efficient Water and Nitrogen Management Practices for Mixed Leafy Baby Green Vegetables in the Desert •*Charles A. Sanchez, 18-0593*

Assessing Drip Irrigation and Nitrogen Management of Fresh Onions Produced in California Low Desert •*Jairo Diaz, 18-0592*

Improving Nitrate and Salinity Management Strategies for Almond Grown Under MicroIrrigation • *Patrick Brown, 18-0549*

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*

A System Nitrogen Balance for Container Plant Production •*Lorence Oki, 17-0516*

Evaluation of Nitrogen Uptake and Applied Irrigation Water in Asian Vegetables Bok Choy, Water Spinach, Garlic Chives, Moringa, and Lemongrass •*Aparna Gazula, 17-0515*

Training on Crop Management and Integrated Climate, Soil and Irrigation System Data to Minimize Nutrient Loss and Optimize Irrigation Efficiency •*Trina Walley, 17-0489*

Assessment of Harvested and Sequestered Nitrogen Content to Improve Nitrogen Management in Perennial Crops •*Charlotte Gallock, 17-0488*

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*

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

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*

Evaluation of Certified Organic Fertilizers for Long-Term Nutrient Planning •*William Horwath and Xia Zhu-Barker, 16-0670*

Evaluation of Biochar for On-Farm Soil Management in California •*Sanjai Parikh, 16-0662*

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

Expanding the California Fertilization Guidelines to Support Nutrient Management Decisions for Minor Crops •*Daniel Geisseler, 16-0610*

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

Soil Biochar Amendment To Improve Nitrogen And Water Management •*Suduan Gao, 15-0597*

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

N And P Management In Organic Leafy Greens •*Richard Smith,* 15-0522

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

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

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*

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*

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

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

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

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

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

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

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*

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*

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*

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*

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*

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

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 *•Michael 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 *•Dave 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, Nurseries and 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*

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*

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

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*

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

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*

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*

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

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