2024

FREP WPH

Nutrient Management Conference

PROCEEDINGS

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

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Nitrogen Removal Coefficients for Planning and Reporting: Where We Are and Where We Are Going
Moderator: Ken Cassman, Emeritus Professor of Agronomy and Agricultural Consultant
Panelists: Ali Montazar, Irrigation and Water Management Advisor, UCCE; Ken Miller, Soil Scientist, Formation Environmental; Richard Smith, Emeritus Farm Advisor, UCCE; Sarah Lopez, Executive Director for Central Coast Water Quality Preservation, Inc.

Nutrient and Irrigation Management in Organic Production Systems
Moderator: Margaret Lloyd, Small Farms Advisor, UCCE
Panelists: Jim Durst, Durst Organic Growers; Phil Foster, Pinnacle Organic/Phil Foster Ranch; Javier Zamora, JSM Organics; Daniel Geisseler, Cooperative Extension Specialist, UC Davis

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INTRODUCTION

32nd 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 32 years, this conference has provided a forum where FREP grant recipients report findings of their projects and industry representatives share 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 nutrient and irrigation best 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 on two research and one outreach-focused FREP project, and a panel discussing the results from three FREP projects— one ongoing, one recently finished, and one starting in 2025. In addition, the agenda includes a grower panel, talks by agricultural professionals, and two participatory workshops.

Overview of Funded Research

Since 1991, FREP has committed over 31 million dollars to over 276 research, outreach, and demonstration protects focused on nutrient and irrigation management. These projects address management challenges and opportunities in several commodity areas and growing regions across California (Figure 1).

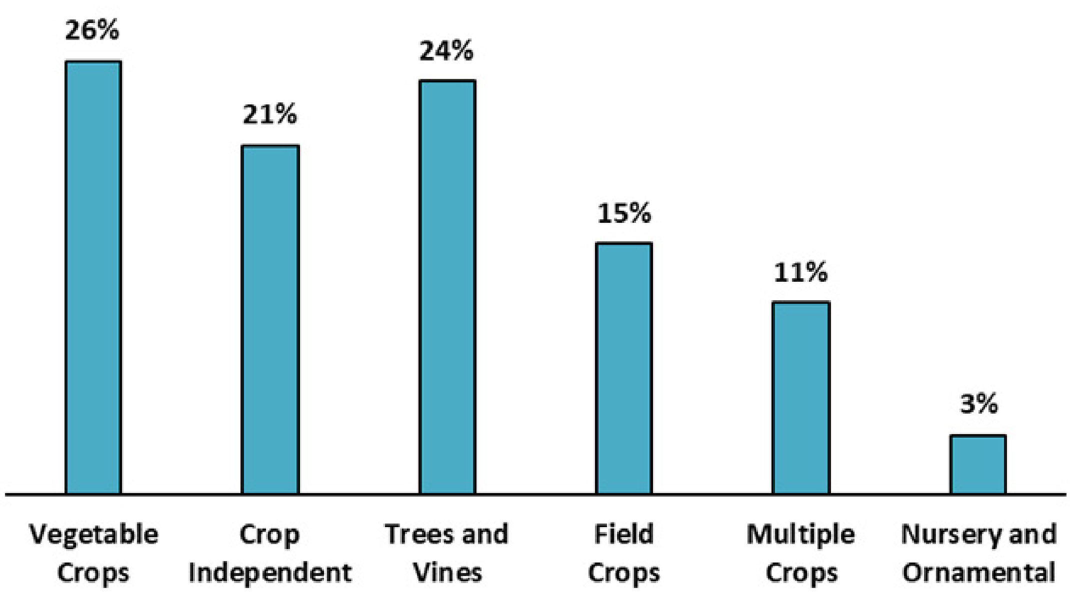

Figure 1. Distribution of commodities (%) represented in FREP-funded projects.

FREP is currently funding 24 innovative projects to promote the agronomically safe and environmentally sound use of fertilizing materials. These projects help us better understand grower decision making, provide important technical trainings, and glean more information about nutrient and irrigation management in California crops.

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

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

Future FREP Projects

FREP has committed to funding five new projects starting in January 2025. Four are focused on nutrient and irrigation management in the Central Valley, the Central Coast, and the Lower Desert region. The fifth project will serve organic producers throughout California.

In the Central Valley, Dr. Yufang Jin, Dr. Patrick Brown and Dr. Alireza Pourreza (University of California (UC), Davis) will develop practical and cost-effective remote sensing approaches to mapping leaf tissue nutrient status that will help almond growers optimize nutrient management. The project will create models that analyze leaf samples using hyperspectral satellite imagery to understand the spectral response of almond leaves at different nutritional contents. The project aims to lay the groundwork for developing aerial and remote strategies that can supplement traditional leaf sampling to provide for faster, more predictive, and spatially accurate nutrient mapping.

Ken Miller (Formation Environmental) will refine three preliminary citrus modules for CropManage, a UC Cooperative Extension free online support tool that provides nitrogen and irrigation recommendations to growers. The project will use nitrogen (N), water, satellite and drone-based imagery data collected from orange, mandarin, and lemon orchards. This field data, as well as data-driven modeling, will be used to calibrate and test the modules before releasing them to the public. Once developed, outreach to citrus growers will be provided through CropManage workshops and field days.

In the Imperial and Coachella Valleys, Dr. Ali Montazar (UC Cooperative Extension) will develop crop nitrogen removal coefficient values for 10 major annual and perennial commodities that account for more than 70% of regional crop acreage. In addition to documenting seasonal nitrogen applied and assessing plant uptake and N removal in the harvested product, the project will gather similar information on phosphorus (P) and potassium (K) for the 10 commodities. Results will be disseminated to growers through workshops and at local coalition, Farm Bureau and grower association meetings.

In the Central Coast counties of Monterey and San Benito, Nathan Harkleroad (Agriculture and Land-Based Training Association (ALBA) will lead an outreach project that focuses on educating primarily Spanish-speaking, socially disadvantaged organic farmers about soil fertility, plant nutrition and irrigation management techniques through their farmer incubation pro-gram. In addition, ALBA will work with Monterey and San Benito Resource Conservation Districts to provide technical assistance to ALBA graduates to implement these practices in their farming operations. ALBA will also work with FREP to translate the fertilization guidelines they use in their curriculum into Spanish.

Finally, Dr. Daniel Geisseler (UC Davis) will create a website that summarizes California-based research on nutrient availability in organic annual cropping systems. The site will include an online, interactive N, P and K budget calculator for major annual crops. This project will build on an available calculator that allows users to estimate the mineralization rates of certain organic amendments by conducting replicated field trials on commercial organic fields in the Sacramento Valley and on the Central Coast. Results from the trials will be used to validate the calculator and address existing knowledge gaps. Once completed, the website and online calculator will be publicized at grower meetings and workshops, conferences that draw organic growers and consultants, and on the FREP website.

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 (FIAB) Technical Advisory Subcommittee (TASC) 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. Robert Mikkelsen, Daniel Rodrigues, Dr. Sebastian Saa and Dr. Ehsan Toosi.

In addition, we thank the members of the FIAB 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, and William Oglesby.

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

Special recognition goes to the leadership at CDFA and Inspection Services Division. We also thank our retiring Feed, Fertilizer, Livestock Drugs Regulatory Services (FFLDRS) branch chief, Dr. Amadou Ba, and our new FFLDRS branch chief, Jenna Leal, for their contributions. Finally, we give recognition to Dr. Martin Burger, who provided valuable input during the annual FREP grant proposal review process until his retirement earlier this year.

SUMMARIES OF CURRENT FREP PROJECTS

Next Generation Nitrogen Management Training for Certified Crop Advisors

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Introduction

Use of nitrogen (N) fertilizer on major California crops has led to the degradation of water quality from nitrate leaching to groundwater. This outcome is the result of a combination of historic management practices including uniform rates of N fertilizer applied to land of heterogeneous soil types; poor timing, poor placement, or incorrect quantities of seasonal N applications; and irrigation in excess of crop water demand when abundant soil N is available. Where excess irrigation is applied when soil N concentrations exceed uptake capacity, N efficiency is reduced and leads to a greater risk of nitrate leaching. The overall goal of this program is to facilitate the learning of best N management practices and increase the ability of Certified Crop Advisors (CCAs) to make informed recommendations to growers, thereby improving both environmental quality and crop productivity.

Objectives

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

Description

Our project consisted of distinct phases – 1) CCA workshop; 2) Curriculum building; 3) Exam questions and video development; and 4) Test deployment and feedback. In March 2020, we conducted one CCA N training workshop following the 2-day agenda developed by our project team. In early 2020, we completed the study curriculum including 1) consolidation of training modules and study materials already developed by our team; 2) drafting of exam question categories and outlining levels of difficulty and; 3) organization of workshop slides to be developed into video content. From 2020 to 2024, we developed, implemented and expanded an online program for both the educational content and the exam to train CCAs for the California Nitrogen Specialty in an asynchronous, low-cost platform. We made progress with all of our major objectives. In March 2020, we hosted a CCA Training workshop in Fresno, CA attended by 65 CCAs. Later in 2020, we developed a study curriculum including seven competency areas each with specific performance objectives. After building a review committee for the exam, we designed an online course to support student learning. A video series was hosted as an online course that launched in October 2021. We recruited content experts to record a total of 17 videos in 2020 and expanded the course to include a 'Barriers to Adoption' module in 2021. Our online course recruited 57 students in 2020, 74 students in 2021, 35 students in 2022, and 24 students in 2023. A final updated exam was developed with 60+ questions by a team of content experts. The first version of the exam was deployed in February 2021 and is ongoing. To date, 83 students have taken the exam with an 86% pass rate. There is ongoing demand to host the course through 2025. We also completed an initial assessment of professional student learning for all the competency areas and learning objectives.

Results and Discussion

The following are the performance objectives developed by the team and measured in the learning platform reporting something learned and learn more below (Fig 2-4).

Competency Area 1. Environmental Impacts of Nitrogen Loss

A. Nonpoint Pollution B. Surface Runoff C. Water Quality D. Advisor Role

Competency Area 2. Nitrogen Cycling - Soil Transformations

A. Mineralization B. Immobilization C. Nitrification D. Denitrification E. Volatilization

Competency Area 3. Nitrogen Uptake - Plant Utilization

A. Uptake B. Assimilation C. Allocation

Competency Area 4. Nitrogen Sources

A. Fertilizer B. Organic Matter Amendments C. Irrigation Water D. Residual Soil E. Soil Organic Matter

Competency Area 5. Nitrogen Budgeting

A. Budget Terminologies B. Nitrogen Credits C. Budget Calculations D. Budget Units

Competency Area 6. Irrigation and Nitrogen Management

A. Irrigation Leaching B. Fertigation C. Evapotranspiration D. Leaching Salts

E. Distribution Uniformity

Competency Area 7. California Cropping systems

A. Annual Crops B. Permanent Crops

Evaluation

The team has been conducting qualitative research on the online courses offered thus far. We have downloaded comments and reflections from those who consented. Comments and reflections are from each of the online modules for five iterations of the online course. These were completed as learners completed each module and wrote a reflection to receive the code for continuing education units. Reflections were open ended but we provided a reflective prompt if needed. Data were downloaded and all identifying information about the respondents was removed. Data were uploaded into NVivo (a qualitative analysis software) and coded using an inductive coding method looking for common themes. Broad themes were developed in the first pass of coding. These themes were then regrouped and re-coded in a second pass.

Take home message

Our work shows demand for the California CCA N Management Specialty will continue in the years to come with internet-based methods for teaching and testing playing a vital role. The performance objectives were reviewed by twenty professionals and vetted for importance, relevance and frequency of use. We launched our online course in 2020, and offered it every year since. Overall, student reported a gain in knowledge scores between 20 and 29% (Fig 1). This evidence suggests the online course is delivering valuable knowledge gains for the targeted population.

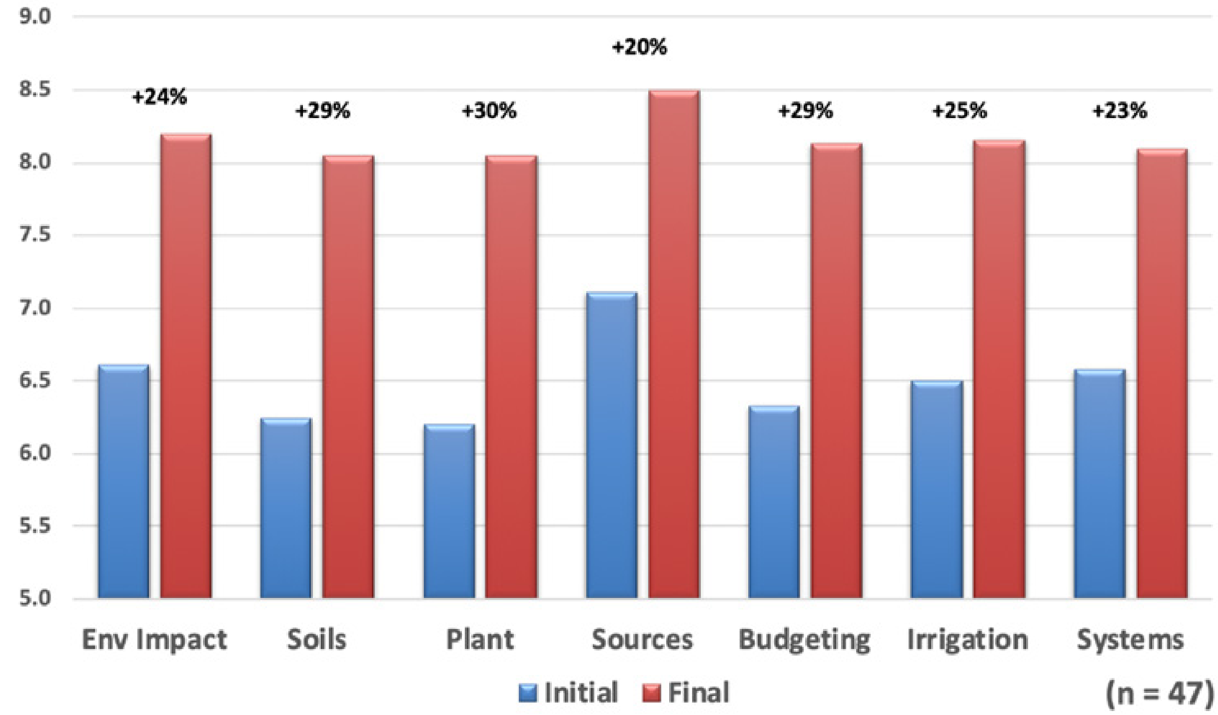

Figure 1. Student knowledge assessment for performance objectives aligned with each course module before starting the course and after completing the course.

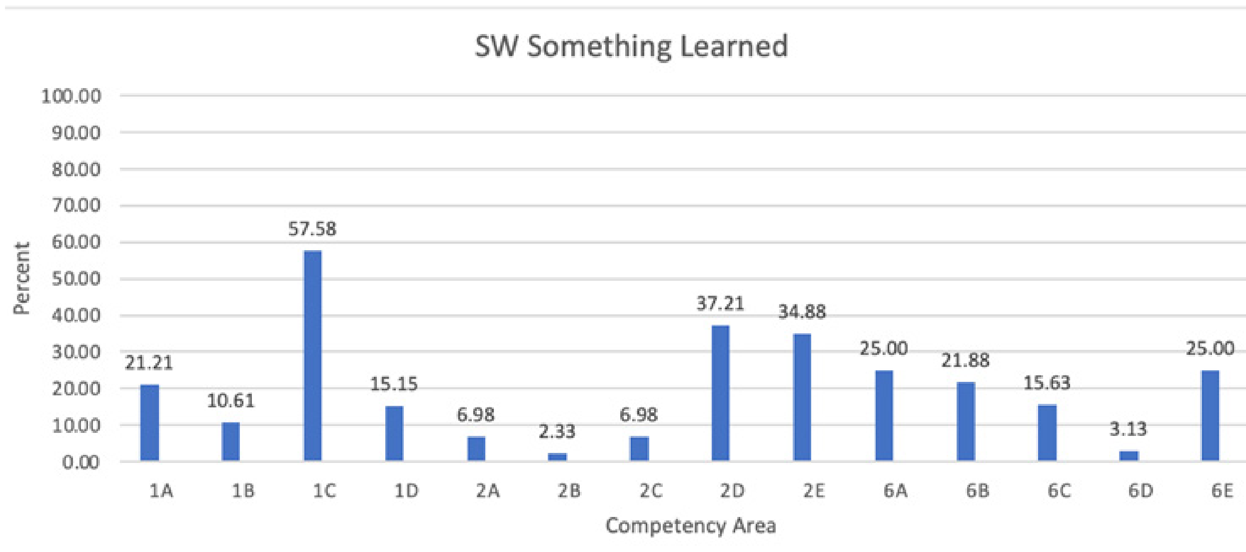

Figure 2. Percentage of student professionals identifying something learned for the soil and water (SW) modules/competency areas (1,2 and 6) and learning objectives (A-E). See additional information below to cross-reference the results.

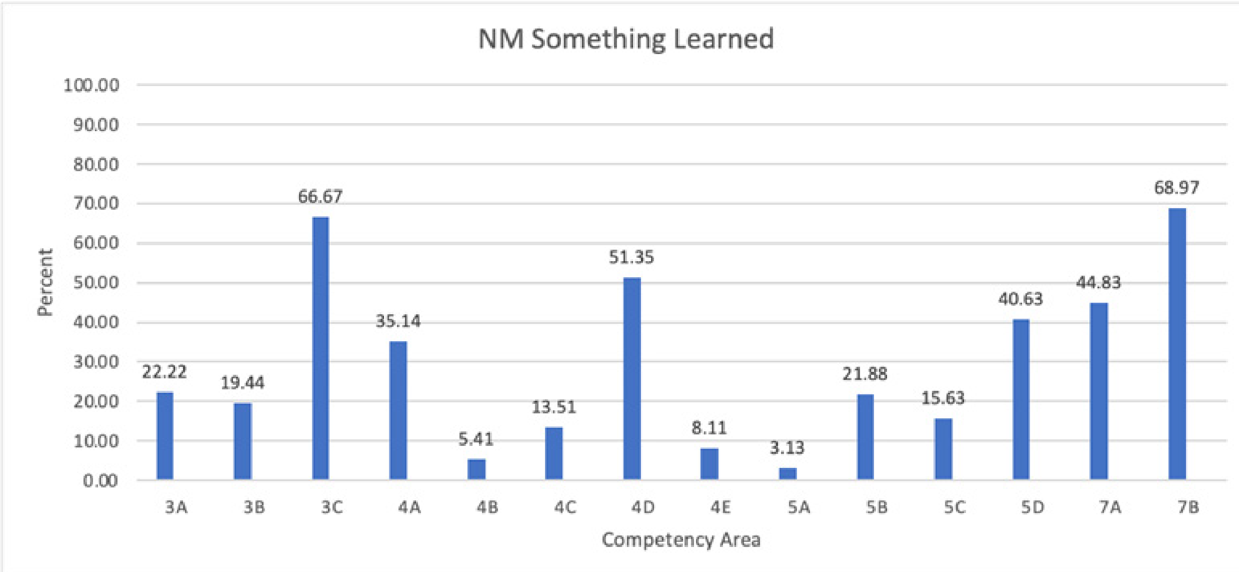

Figure 3. Percentage of student professionals identifying something learned for the nutrient management (NM) modules/competency areas (3, 4, 5 and 7) and learning objectives (A-E). See additional information below to cross-reference the results.

Acknowledgements

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

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

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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 with FREP funding in 2011 and now has more than 1,700 registered users. In recent years, the online advisory service has provided more than 1,000 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 field demonstration.

Description

1 Creating N mineralization database

We compiled existing data on N mineralization of organic fertilizers and amendments, crop residues, and soil organic matter from literature and past studies. N mineralization data of replicated incubation trials conducted under a controlled environment were gathered. Incubation trials are in progress to fill any gaps in the database that need to be addressed experimentally. N mineralization from strawberries and Brussels sprout residues was examined and trials with artichoke residues and some liquid and solid organic fertilizers are in progress.

2 Developing a simple N mineralization model

We selected a simple model to calculate net N mineralization rates for soil organic matter and organic amendments. 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.

3 Evaluate and validate the model in field trials

To evaluate the model, N mineralization rates of selected dry organic fertilizers and amendments and crop residues were determined under field conditions on organic farms in Coastal California. Two trials were completed.

The results of the second trial are reported below.

4 Integrate the model into CropManage (CM)

The model developed under Objective 2 is incorporated into CM. This process is ongoing.

5 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), and Sonoma County (4/26/24), and Santa Clara Master Gardener seminar (6/20/24).

Results and Discussion

To evaluate the N mineralization model we developed, and monitored N dynamics during baby lettuce production in a commercial organic field in Soledad, CA, from August to September 2022. A randomized complete block-designed field trial with 4 replicates was established. Treatments were soil-only (N0) and soil + pre-plant fertilizer (Nf) (Table 1).

Table 1. Nitrogen sources evaluated in the field trial.

Treatment	N source	Total N (lb-N/acre)	C/N	Date applied or sampled
Soil (N0)	Residual soil inorganic N and soil organic matter in 0-3ft depth	10,572	7.2	8/02/22
Soil + Pre-plant fertilizer (Nf)	Pelleted 6-6-2 Poultry Manure, Seabird Guano, and Meat & Bone Meal	90	5.1	8/03/22

Each plot was 27′ x 40′, including 4 80″ wide beds, of which the middle 2 beds were used for all samplings. The soil type is Arroyo Seco gravelly sandy loam. A mix of baby green leaf, baby green oak, baby tango, baby lola rosa, baby red leaf, and baby oak were directly seeded 28 plant lines per bed (8/09/22).

Total biomass-N in baby lettuce was measured at harvest (9/06/22), and soil inorganic N in 0′-1′, 1′-2′, and 2′-3′ depths were determined before pre-plant fertilizer application (8/02/22) and at harvest (9/05/22). Soil bulk density at 0′-1′, 1′-2′, and 2′-3′ depths were also measured (9/06-07/22). Nitrate and ammonium concentrations in irrigation water and irrigation rates were monitored during the trial period.

The mineralization rate of soil organic N during the trial was calculated as follows:

Soil organic N mineralization rate % = (Np0h – Nw + (Ns0h – Ns00)) / Nst x 100

where, Np0h = plant biomass N in N0 treatment at harvest (lb-N/acre), Nw = amount of inorganic N added via irrigation water (lb-N/acre), Ns0h = soil inorganic N in 0′-3′ depth at N0 treatment at harvest (lb-N/acre), Ns00 = soil inorganic N in 0′-3′ depth at N0 treatment before pre-plant fertilizer application (lb-N/acre), and Nst = soil total N in 0′-3′ depth at N0 treatment before pre-plant fertilizer application (lb-N/acre) (Table 2).

*Table 2. Estimated soil organic N mineralization rate at the field trial. *Average and SEM n=3 excluding block 1, where weed pressure was extremely high.*

Variable	**Average***	**SEM***
Np0h (lb-N/acre)	52.3	1.0
Nw (lb-N/acre)	16.3	0.0
Ns0h (lb-N/acre)	366	17.6
Ns00 (lb-N/acre)	405	23.5
Nst (lb-N/acre)	10,572	497
Soil Org. N Min. rate %	**-0.02**	**0.22**

The mineralization rate of pre-plant organic fertilizer N was calculated as follows:

Pre-plant organic fertilizer N mineralization rate % = ((Npfh – Np0h) + (Nsfh – Ns0h)) / Nft x 100

where Npfh = plant biomass N at Nf treatment at harvest (lb-N/acre), Np0h = plant biomass N at N0 treatment at harvest (lb-N/acre), Nsfh = soil inorganic N in 0′-3′ depth at Nf treatment at harvest (lb-N/acre), Ns0h = soil inorganic N in 0′-3′ depth at N0 treatment at harvest (lb-N/acre), and Nft = total N applied via pre-plant fertilizer at Nf treatment (lb-N/acre) (Table 3).

Table 3. Estimated pre-plant organic fertilizer N mineralization rate at the field trial.

Variable	**Average***	**SEM***
Npfh (lb-N/acre)	47.4	3.4
Np0h (lb-N/acre)	52.3	1.1
Nsfh (lb-N/acre)	433	47.5
Ns0h (lb-N/acre)	366	17.6
Nft (lb-N/acre)	88.1	0.0
Preplant fertilizer N Min. rate %	**71.0**	**50.7**

* See Table 2.

This and another field trial datasets will be used to validate the N mineralization model we developed.

Acknowledgements

We thank the staff and student workers of the UC Santa Cruz, and the staff of the UC Cooperative Extension, Monterey County, for assisting incubation and field trials for this project. We also appreciate the anonymous collaborative growers managing the field trials and the CDFA Fertilizer Research and Education Program (FREP), for funding this project.

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

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Introduction

Over 100,000 Central Valley (CV) residents lack safe drinking water because they rely on groundwater wells impacted with nitrate. Agriculture is a regionally significant source of nitrate in groundwater and is associated with leaching of fertilizers and confined animal facilities. During the past decade, millions of acres of croplands in the CV have been converted to orchards. Orchard crops have high nutrient demands; for example, almonds require approximately 170-225 kilograms (kg) nitrogen (N) per hectare (ha) annually, and have replaced crops with lower nutrient requirements (i.e. alfalfa). Following this trend, the continued degradation of rural groundwater supplies is likely without intervention.

The Irrigated Lands Regulatory Program (IRLP) developed by the Regional Water Boards (RWB) charges growers and their agricultural coalitions with implementing N management plans that are protective of groundwater quality by improving N use efficiency (NUE) and reducing N leaching to groundwater.

Previous research at the plot scale shows that high frequency low concentration (HFLC) fertigation can improve production through higher NUE, potentially reducing impacts to groundwater. This project not only provides commercial orchard scale implementation of HFLC but also novel direct measurements and modeling of resulting groundwater quality immediately underneath the orchard.

Objectives

1. Demonstrate, in a commercial scale almond orchard, that HFLC fertigation practices increase NUE while successfully producing high yields and reducing groundwater quality impacts.
2. Perform, compare, and assess three independent monitoring approaches to estimate groundwater nitrate contribution from an orchard.
3. Develop and calibrate an integrated groundwater-vadose zone-crop model to assess the long-term impacts of HFLC on shallow groundwater quality.
4. Inform and discuss interim and final findings with grower-collaborator, ILRP agricultural coalition representatives, nut and other commodity grower representatives, and orchard growers.

Description

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

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

The project further investigates the relationship between groundwater nitrate and fluxes through the year 2100 via the development of an unsaturated zone model and groundwater model.

Results and Discussion

Water and N mass balance monitoring

Water mass balance calculations were done on a daily basis, for each of the blocks in the orchard:

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

where R is the estimated recharge to groundwater, P is the precipitation measured and reported by the Modesto Irrigation District (MID), IR is the total irrigation, measured by the grower using a flow meter, ETa is actual evapotranspiration, and dS is the change in soil moisture storage.

During the current reporting period, an in-depth analysis of the estimated ETa at the orchard was performed. This included a two-step approach to validate the ETc, (crop evapotranspiration) calculated using ETo (reference evapotranspiration) from the nearest CIMIS station (#71) and Kc values published by the Almond Board: 1) Calibrate the estimated ETc to ETa measured by an in-field flux tower, and 2) compare the resulting water balance to measured changes in orchard soil moisture storage. Flux-tower measured ETa suggested that the "CIMIS x Kc" method was overestimating yearly ETa by at least 8%. Additionally, when comparing the resulting water balance, which utilized the flux-tower calibrated ETa, the resulting water balance still predicted a large loss of soil-moisture through time. This storage loss was not supported by measurements of soil-moisture made with a series of 30 neutron probes, which indicated a net-zero change through time. To alleviate this discrepancy, the predicted ETa was further reduced.

After performing this analysis, the resulting ETa was roughly 12% lower (on a cumulative yearly basis) than what CIMIS and the Almond Board Kc values suggested. We believe this estimate to be the most accurate representation of evaporative fluxes at the orchard, and that the CIMIS x Kc method regularly overestimates consumptive use at the orchard.

The N mass balance was calculated using the following:

Eq.2: N-Losses = (N-applied)+(N-deposition)+(N-mineralization)-(N-uptake)-(N-denitrification)

Applied N, N-applied, follows the HFLC practice. Atmospheric deposition, N-deposition, is set to 20 kg N ha^{-1} annually (a^{-1}) due to dairies upwind of the orchard. N-uptake is based on the harvested kernel weights as reported by the grower, calculated as (kernel weight)*68/1000, to which 45 kg N ha^{-1} a^{-1} are added for tree growth. Denitrification is assumed to equal 5% of N-applied, and mineralization is assumed to equal 44 kg N ha^{-1} a^{-1}. Unfortunately, a black-out in the grower's irrigation management system during GS 2023 prevented the accurate calculation of NUE for that year.

However, soil sampling performed at the end of GS 2023 indicated that there were similarly low levels of residual N in the root zone, meaning that NUE was likely as high as previous HFLC years (average HFLC NUE=82%). Pre-HFLC, average NUE was equal to 76%, therefore, we have observed a 6% increase in NUE in response to HFLC management.

Groundwater Monitoring

Groundwater monitoring uses a series of twenty shallow monitoring wells throughout the orchard. Since 2017, the mean concentration in the wells has increased from around 20 mg/L to 40 mg/L in 2024, indicating an increase in nitrate concentrations of about 3 mg/L per year. There also exists a high level of spatial variability. Concentrations have an average standard deviation of 19 mg/L between wells. We found that the spatial variability measured in groundwater nitrate concentrations was directly caused by the spatial variability in leaching (kg-N/yr) from the overlying blocks (Fig. 1).

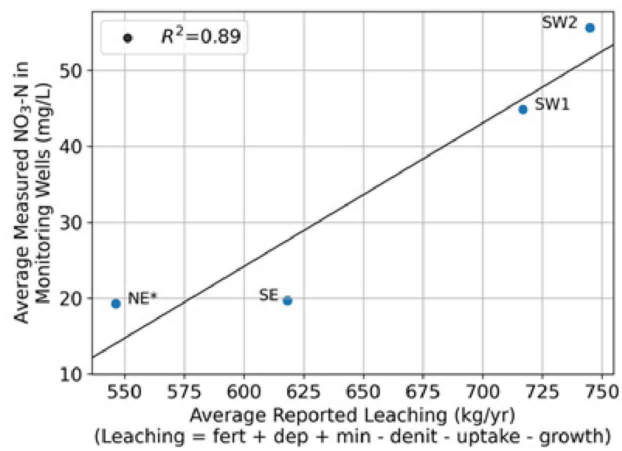

Figure 1: Linear relationship between measured groundwater nitrate and leaching.

Root zone monitoring occurs at seven monitoring stations distributed randomly throughout the 56 ha orchard. Each monitoring station is equipped with five pore water samplers located at depths of 30, 60, 90, 180 and 280 cm, and neutron probes at those same five depths are used for water content measurement (used to calculate change in orchard moisture-storage). Collection of pore water samples occurred every two weeks, on average, during the fertigation season.

Root Zone Modeling

In the previous reporting periods, we developed a physical model of the unsaturated zone during the period of 1957-2100 to assess the full effects of HFLC on N concentrations. During the current period, the model was re-run using the updated water balance (12% reduction in ETa, discussed in Water Balance Section). Updated model results predicted that under HFLC, NUE will improve from an average of 77% to 84%. There also exists a lag time between N inputs at the surface and leaching at the water table (7 m below) of 5-8 years due to the low recharge rates (average modeled groundwater-recharge is 14.5 cm/yr). Beginning around 5 years after the switch to HFLC, average nitrate concentrations in recharge rapidly decrease from 40 mg/L to a value of 25 mg/L under continued HFLC.

Groundwater Modeling

Our previous work showed that the effects of HFLC would take >30 years to be seen in the shallow groundwater due to long travel times and low rates of groundwater recharge. With the calibrated water balance (more recharge), updated simulation results suggest this is now expected to take only 8-15 years.

Take-Home Message

This study is monitoring the effectiveness of HFLC as a management practice and is seeking to determine resulting improvements in N groundwater concentrations. HFLC is shown, both with numerical models and field measurements, to decrease nitrate leaching into groundwater by increasing orchard-average NUE by 6-7%. Modeling results show that the vast majority of leaching occurs in wet years when residual N is flushed from the unsaturated zone, with much less leaching during years with low precipitation. Model simulations show that HFLC has the potential to lower nitrate loading to groundwater within 8-15 years, and that leaching concentrations will be reduced from 45 mg L^{-1} to 25 mg L^{-1}. Block-scale heterogeneity in measured groundwater nitrate concentrations were found to be a direct result of NUE variability between orchard blocks, suggesting that even if orchard-average NUE is high, if some blocks are more efficient than others, areas of high nitrate contamination can persist.

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"Crop Nutrient Minute" Video Series

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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 are able to fulfill their Continuing Education requirements. This project includes an "INMP Continuing Education" video series, creating seven 30-minute videos that will be posted on the CURES website and linked to other sites for self-certified growers and to use to complete their CEUs. The videos will also supplement the new Certified Crop Adviser (CCA) online training and facilitate CCAs in obtaining CEUs. The videos will cover seven crops including almonds, citrus, pistachios, processing tomatoes, wine grapes (high tonnage), strawberries and romaine lettuce. This CURES educational video series will focus on California's major acreage crops and be accessible to Central Valley and Central Coast growers and crop advisors.

Objectives

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

Description

Video content will be developed by the Project Leaders, University of California Cooperative Extension (UCCE) specialists and University of California (UC) personnel in each crop category. The foundational information for the videos will be the 4R principles (Right time, Right place, Right amount, and Right product) developed by FREP and the UC for California crops. Video content will also include information on soil health, nitrogen processes in the soil, leaf sampling, crop nutrient tracking and efficient irrigation practices, as well as tips gained from crop advisors, UCCE specialists and UC personnel who work with the crops featured in a specific video. Scripts for each of the seven 30-minute videos will then be written by the Project Leaders and Cooperators using information gathered from the CDFA Crop Nutrient Guidelines and findings from past FREP-funded research. Each draft script will be reviewed by a Review Committee, comprised of Project Leaders, Cooperators, and subject matter experts to obtain edits and comments. Once the scripts are approved by the Review Committee, videos will be taped using CURES, UC and Pest Control Advisors (PCAs)/CCAs with crop-specific footage recorded in the field. Animation and art will also be used to illustrate information. Videos will be recorded and produced in English and Spanish, using English- and Spanish-speaking farm advisors and PCAs/CCAs specializing in a specific crop.

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

These videos are modeled on a FREP-funded 4R video produced for walnuts: https://www.curesworks.org/best-management-practices/

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

Results and Discussion

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

Accomplishments

The research-based information delivered to growers and crop advisors by this project will help support the reduction of agricultural contributions of nitrate to groundwater in the Central Valley and Central Coast.

The management practice recommendations will be vital to the approximately 25,000 landowners/operators in the Central Valley and 2,000 on the Central Coast who are affected by requirements to improve nutrient and irrigation application practices for reducing salt and nitrate discharges to ground and surface water. Giving growers access to 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 will serve as a conduit to transfer the latest information on efficient nitrogen fertilizer applications and the practices that can minimize or prevent movement of nitrate to groundwater developed by FREP, UCCE and UC. Some new information is likely to come from interviews with Certified Crop Advisors, agronomists and farm advisors who have crop-specific tips, techniques or other knowledge gained through their work in the field. Much knowledge has already been developed through UC, UCCE and FREP projects to improve nitrogen efficiency and needs to be disseminated to growers and crop advisors who would benefit from the information. This project provides another option of communicating this information using media that is popular with an increasing number of growers and crop advisors.

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Ventura County Nitrogen Management Training Program

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Introduction

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

The required elements of the plans themselves, as well as the certification options, were modeled after the requirements already in effect for Central Valley growers. To provide local growers with the tools and training needed to implement these requirements, the Ventura County Agricultural Irrigated Lands Group (VCAILG, administered by the Farm Bureau of Ventura County) worked collaboratively with CDFA FREP, the University of California Cooperative Extension, and Fruit Growers Laboratory to expand the Central Valley self-certification training programs to Ventura County. Many more growers will need to complete this training and develop Irrigation and Nutrient Management Plans to comply with the recently adopted Ag Order, which incorporates the East San Joaquin River Watershed Waste Discharge Requirements precedential requirements related to nitrogen tracking and reporting. This Ag Order was adopted on September 28, 2023.

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

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

- 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 adoption of the Ag Order on September 28, 2023 now complete, VCAILG began working to develop the INMP and Irrigation and Nutrient Management Reports (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 of 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. The first training session has been scheduled for August 29th and 30th and will be held in-person and remotely via Zoom. Additional training sessions, including a session with active Spanish translation, will be held in late 2024, early 2025, and annually going forward.

To accommodate this revised timeline, this project has requested and been approved for a 1-year no cost extension through December 31, 2024. An additional and final extension has also been requested through December 31, 2025.

One project task that was able to progress independently of the Ag Order status is the Spanish translation of the recently updated CDFA FREP Irrigation and Nitrogen Management Training for Grower Self-Certification presentation material and associated workbook. These training materials were translated as part of this project in September 2023 and a group of Spanish-speaking growers and agricultural stakeholders was convened to review and provide comments on the accuracy and clarity of the translation. Recent updates made to the training for Ventura County growers will be incorporated into the Spanish-translated materials in late 2024.

Accomplishments

Although training sessions were temporarily put on hold while a new Ag Order was being developed and requirements were under consideration, we are actively working to finalize the training program updates and have an upcoming training scheduled for August 29th and 30th. We expect to finalize the Spanish translation of the Ventura County version of the training and its accompanying workbook by late 2024.

Acknowledgements

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

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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, among other things, information on field nitrogen (N) balances. In addition, the Agricultural Expert Panel convened by the State Water Resources Control Board recommended metrics composed of N applied (A) and N removed (R) to gauge program progress in reducing the mass of leachable N (Burt et al., 2014). 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 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 need 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 off-line 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, nectarines, cherries, pear, Valencia and Navel oranges, lemons, figs, table, raisin, and wine grapes, table and oil olive, sweet and grain corn, sorghum grain, non-alfalfa hay/haylage, cantaloupe, honeydew, watermelon, summer squash, pumpkin, onion, garlic, potato, sweet potato, fresh market tomato and bell pepper. Results will be incorporated into the assessment and planning tools available to growers, grower advisors, and coalitions. This includes updates of the N-Concentrations Report (Geisseler 2016, 2021, 2024) and the N removed calculator on the agmpep.com website.

Results and Discussion

Work completed since the commencement of Phase 1 includes coordination of seven 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) and have been incorporated into the N removed calculator on the agmpep.com website (https://agmpep.com/tools/calc-y2r/). These results are also presented in Table 1. The remaining results from Phase 2 will be available in early 2025 upon project completion.

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

	Crop	Current Study Av. Lbs N/ton	Current Study CV (%)	2016 Literature Review Av. Lbs N/ton	2016 Literature 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	-63.6
	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

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

Results from this project improve our understanding of N removed in harvested materials from crops grown within the Central Valley. As shown in Table 1, in some cases (e.g., corn silage, walnuts), the N-removal coefficient changed little based on new data from this project, while with other crops (e.g., peaches, pomegranates, citrus varieties), it changed substantially. Differences in updated coefficients can be caused by many factors related to how relevant and comprehensive the previously used data were to current Central Valley conditions. The collection and integration of current data from the Central Valley that span differing climates, soils, management practices, and years, provides a clearer and more confident picture of N removal dynamics within Central Valley agriculture and helps growers, advisors, and coalitions better assess N dynamics across the landscape and refine nutrient management planning.

Take-Home Message

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) reports provide key information on the coefficients including their associated yield units and presumed moisture contents, what plant materials are included, and how variable the coefficients were across samples. When determining a nutrient management plan, 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. Furthermore, following the 4R's will ensure that needed fertilizer N is delivered in a way that maximizes its recovery by crops.

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Development of Site-Specific Nitrogen Fertilization Recommendations for Annual Crops

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Introduction

Growers need reliable tools to determine optimal rates and timing of nitrogen (N) applications to minimize nitrate leaching to groundwater while maintaining high yields. These tools should be based on field-specific information, including availability of N from non-fertilizer sources, such as residual soil nitrate, nitrate in the irrigation water and N mineralization from soil organic matter (SOM).

In a recent project, we found that combining measures of soil texture as well as SOM content and quality can provide accurate site-specific N mineralization estimates. Particulate organic matter and fluorescein diacetate (FDA) hydrolysis, a measure for microbial activity, were good measures for SOM quality. However, these analytical methods for SOM quality require several steps and may not be attractive to commercial soil test labs, where growers and consultants routinely send their samples.

Another method, Fourier transform infrared spectroscopy (FTIR), has been shown to be useful to identify labile SOM fractions that are related to N mineralization. It has the potential to estimate soil quality measures such as particulate organic matter and FDA hydrolysis. Infrared spectroscopy is a rapid and cost-effective method that is already commonly used to characterize feed and forage samples, which would facilitate adoption by commercial labs.

The results of this study shall be used to generate site-specific estimates of N mineralization from SOM, improving the precision of N management planning budgets for annual crops.

Objectives

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

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

Description

Field trials were conducted in commercial fields in the Central Valley, including the Delta, as well as in the Tulelake basin from 2021 to 2023. Two treatments were included: (i) no N fertilizer applications in plots within the field and (ii) grower's standard N management. Soil samples were collected pre-plant from the top four feet of the profile in one-foot increments and analyzed for soil properties, including residual mineral N content and N mineralization potential. Post-harvest soil samples were collected from the same depths and analyzed for residual mineral N content. The aboveground biomass of crops from fertilized areas within the fields was harvested in 3-week intervals to determine dry matter biomass and its N concentration. This information was used to develop seasonal N uptake curves and N uptake per unit yield. Irrigation water samples were analyzed to determine the input of N with the irrigation water. At harvest, the aboveground biomass and its N concentration were also determined in the unfertilized plots. Net N mineralization in unfertilized plots was calculated as:

Net N mineralization=N outputs-N inputs

where N outputs include N in the aboveground biomass and residual mineral N in the soil profile at harvest. N inputs consist of preplant residual mineral N in the soil profile, N in irrigation water and atmospheric N deposition.

The FTIR-based method to assess SOM quality was conducted in fall 2022 and winter 2023. Air-dried samples collected from more than 70 fields across northern and central California in previous and ongoing projects were analyzed. Data analysis is ongoing.

Online N calculators are currently being developed with site-specific features based on the results of this study. They will be available on the PI's website (http://geisseler.ucdavis.edu/).

Results and Discussion

Field trials were conducted in a total of 35 fields during three growing seasons from 2021-23. Nitrogen uptake for all crops followed an S-shaped pattern, with low uptake during the first 3-4 weeks, followed by rapid uptake during the vegetative growth phase and low uptake during the last third of the season. Figure 1 shows the results for sunflower and grain corn. For both crops, yield and N in the biomass were well correlated (Figure 1). Smaller datasets were also obtained for cotton, spring wheat and silage corn (not shown).

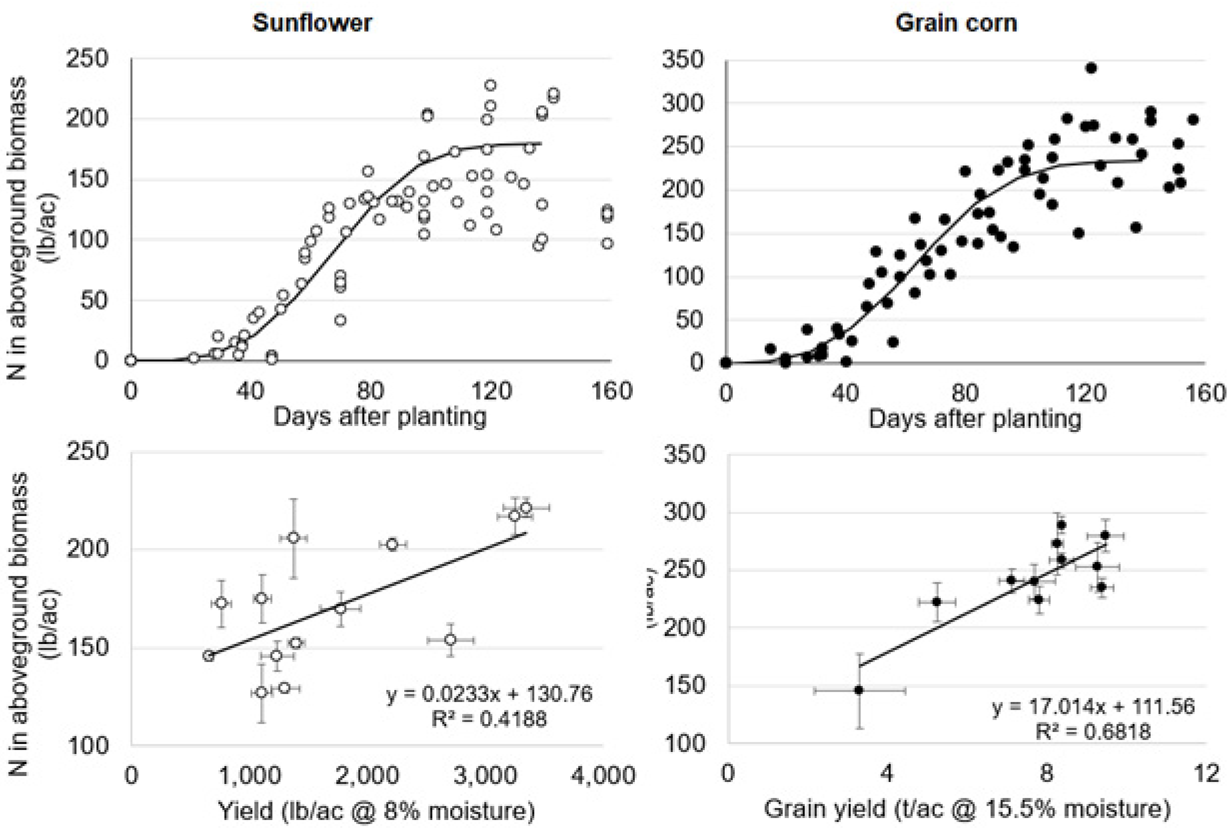

Figure 1: Increase in total nitrogen (N) in the aboveground biomass of sunflower and grain corn grown in fields in Northern and Central California (top). Correlation between total N in the biomass and yield of sunflower and corn (bottom). Data from 13 sunflower and 11 grain corn fields are included.

Nitrogen budgets for 13 fields located in the Central Valley (not including sites in the Delta) indicate that the N mineralization in the top two feet profile averaged 74 lb/ac. With most N taken up during the first 100 days of the season (Figure 1), N mineralization from SOM contributed on average 53 lb/ac of crop-available N. The collected FTIR data is currently being analyzed with the goal to support prediction of site-specific N mineralization rates.

Examples for how this information can be used to determine site-specific N fertilizer need are given in Table 1. In the examples, the expected yields represent average yields for California, based on USDA survey data. Residual soil nitrate, nitrate in the irrigation water, as well as irrigation water applied would be entered by the user. For the examples in Table 1, typical values measured in the fields of this project were entered. However, residual nitrate is highly variable across field sites and may differ from one year to the next at the same site. Therefore, for accurate estimates, residual soil nitrate needs to be measured in spring. The availability of non-fertilizer N, as well as the fertilizer N efficiency are also site-specific values, which rely heavily on the irrigation system and management. Under the assumptions of the examples, sunflower and corn uptake would equal 159 and 195 lb/ac, respectively. However, of the total uptake, only 56 and 91 lb/ac need to be supplied by fertilizers, as residual nitrate, irrigation water and soil N mineralization provide 103 lb/ac. Assuming a fertilizer use efficiency of 80%, 70 and 114 lb/ac of fertilizer-N need to be applied to supply enough N to sunflowers and corn, respectively, in these examples.

Table 1: Nitrogen budget for sunflower and grain corn grown in the Central Valley, not including sites in the delta with high soil organic matter contents.

	Sunflower			Corn		
			lb N/ac			lb N/ac
Expected yield	1210	lb/ac		4.9	t/ac	
Expected N uptake			**159**			**195**
Residual soil nitrate						
1st ft	10	ppm	36	10	ppm	36
2nd ft	5	ppm	18	5	ppm	18
Irrigation	20	in.		20	in.	
Irrigation water N	5	ppm	23	5	ppm	23
Soil N mineralization in top 2 ft			53			53
Non-fertilizer sources			129			129
Availability	*80*	*%*		*80*	*%*	
Available non-fertilizer N			**103**			**103**
Difference (uptake - non-fertilizer N)			56			91
Fertilizer N efficiency	*80*	*%*		*80*	*%*	
Fertilizer N			**70**			**114**

Acknowledgement

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

Certification and Distance Learning for Fertigation

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Introduction

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

Objectives

1. Develop 21 excellent distance-learning modules for various aspects of fertigation including nitrogen processes and management. These modules will utilize information available in the Irrigation Training and Research Center/FREP book Fertigation (2018) that was developed under FREP Grant Agreement 15-0393-SA.
2. Make fourteen of the basic modules available in both English and Spanish for free on YouTube.
3. Make the remaining seven modules in English, available for free on YouTube.
4. Expand the first fourteen modules to include interactive quiz questions. Develop and implement a "California Fertigator" certification with these, targeting employees and employers involved in fertigation. This will be housed on ITRC's online course website.
5. Provide the Irrigation Association with all materials and questions for a more complete Fertigation Certification program.

Description

The videos and training materials are improved versions of the Fertigation class that has been taught in the Cal Poly BioResource and Agricultural Engineering (BRAE) Department since about 1980. Farmers, farm employees, fertilizer salespersons, and agricultural consultants are the target audience for the project.

Results and Discussion

Twenty-two videos were completed in both English and Spanish – well beyond the original objective. All videos were uploaded to YouTube and are available to the general public as a playlist on the ITRC YouTube channel. The view counts over time of each video are shown in Figure 1 and Figure 2. There were over 13,000 unique module views since the modules were posted. Approximately 10 percent of the views were for the Spanish modules.

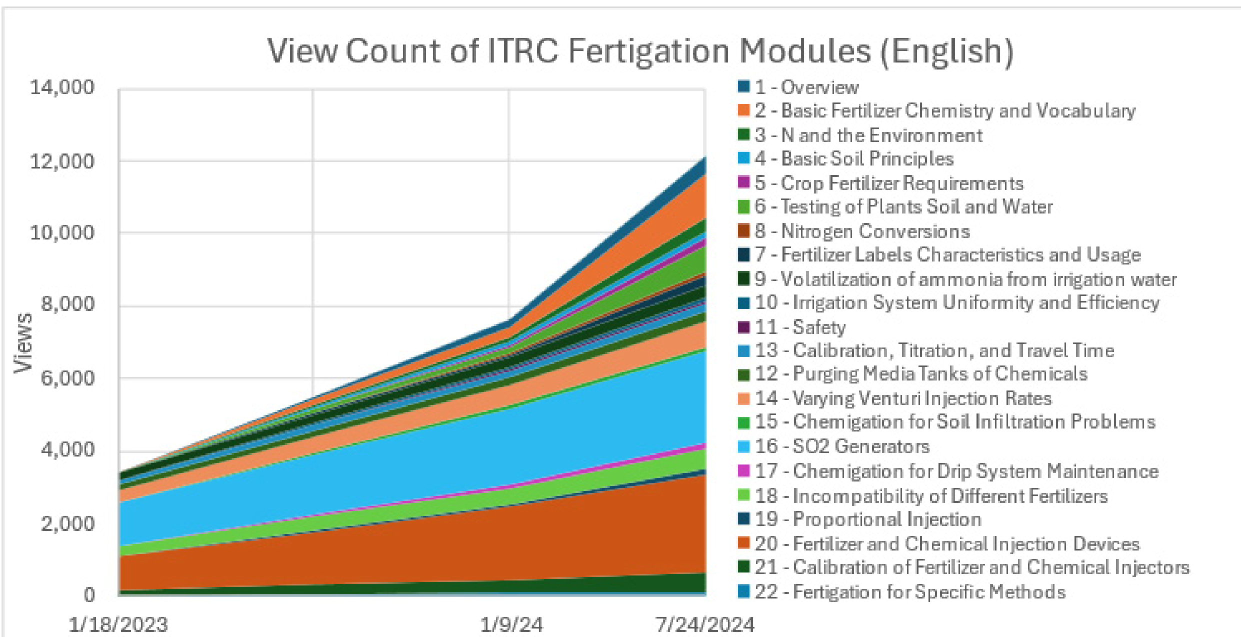

Figure 1. View count of ITRC fertigation modules (English)

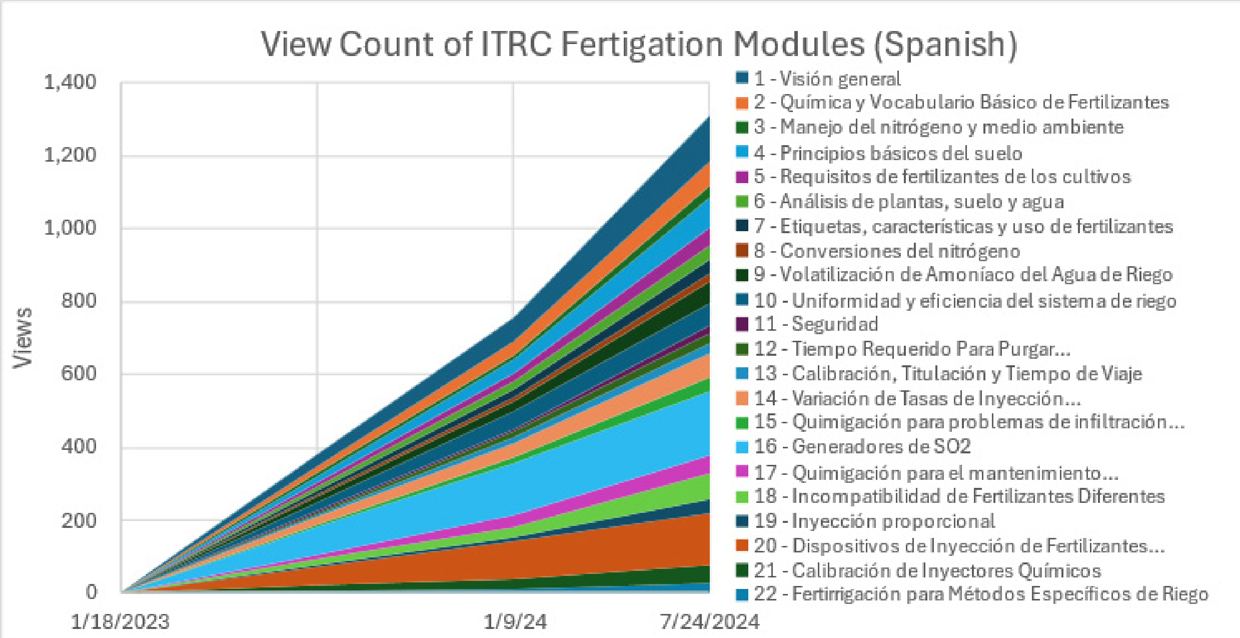

Figure 2. View count of ITRC fertigation modules (Spanish)

The Fertigation book was translated into Spanish using this budget, even though that was beyond the original objective. The book is available for free download at itrc.org.

Two asynchronous, online courses were developed based on the fertigation videos: one on the ITRC online course site for the general public, and one for Cal Poly BRAE students on Cal Poly's online learning management system, Canvas.

The offer to provide the materials to the Irrigation Association (IA) was made. ITRC was in contact with a revolving door of administrators for the IA. In each case, there was strong interest, but then the person left the organization. ITRC looked into additional ways to market the course and adapted the program into an in-house Certified Fertigator Program.

The in-house English-language Certified Fertigator Program is active and open for enrollment on ITRC's website. Participants who pass the exam at the end of the course with a score of 70% or higher receive a certificate of completion. The final components of the Spanish-language online certification program are still being developed; that program will also be available for enrollment through ITRC's website when completed.

The project has developed a tremendous suite of excellent educational/awareness products. The remaining steps are:

- Complete development of the Spanish-language Certified Fertigator Program
- Implement the Spanish-language Certified Fertigator Program in-house (with enrollment through ITRC's website)

- Promote the Certified Fertigator Programs
- Continue to engage the leadership of the Irrigation Association to promote their adoption of a national Certification Program (note that California has about 85% of the nation's drip irrigation, which is the primary location of high-tech fertigation).

Take-Home Message

A variety of excellent, free training materials in English and Spanish were developed through this program, including books, instructional videos, and an online course. The following books are now available for download via the ITRC website (www.itrc.org/books/):

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

A variety of educational videos regarding many aspects of fertigation are also available in English and Spanish at no cost on YouTube. See https://www.itrc.org/databases.htm, and select "Free Resources" on the home page.

Additionally, English and Spanish (pending) online Certified Fertigator Programs are available at no cost via the ITRC website (www.itrc.org/classes/fertigation.htm). Participants who pass an exam at the end of the course receive a certificate of completion.

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Acknowledgements

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

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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 nitrogen (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 N fertilizer to match the site-specific needs of their crops. CM also allows growers to track fertilizer and water applications on each of their fields. This record keeping capability of the software allows multiple users to share and review water and N applications on each field of their ranch, and for growers to maintain data required to comply with water quality regulations. With financial support of CDFA-FREP, CM was originally developed in 2011 to help farmers estimate irrigation schedules in lettuce using CIMIS ETo data and determine fertilizer N needs using the soil nitrate quick test and models of N uptake. Later, CM was expanded to include other coastal 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 10 years. Nevertheless, more outreach in the form of dedicated user support, hands-on workshops, and presentations at industry meetings could potentially boost grower adoption of the decision support tool, especially for regions such as the Central Valley and the southern desert where growers are less familiar with CM, or with the new features and commodities that have been recently added to the software. Also, training of technical support providers such as consultants, resource conservation staff, and extension advisors on CM 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 proposed project would accomplish two goals that would increase the impact of CM on improving irrigation and nutrient management in California:

1. Target outreach on irrigation and N management using the CM decision support tool for growers and industry groups producing commodities recently added to the software or unfamiliar with the decision support tool.
2. Develop and implement a plan that would generate funding to sustain CM software into the future.

Description

Outreach on CM 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) and 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.

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 eventually lead to revenue generation. These reports include summaries to assist growers with regulatory compliance such as calculating the applied N from fertilizer and water sources and 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. Visualization charts display an estimate of soil moisture status based on a soil water balance model outlined in FAO56. Additionally, the user interface was updated to allow tree and vineyard crop users to easily impose deficit irrigation strategies during specific periods of 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

CM was introduced at 10 grower and industry meetings held on the Central Coast, Central Valley, and in the Southern Desert regions of California. Indepth, hands-on workshops were also conducted in Stanislaus, Santa Cruz, and Santa Clara counties. 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 2024 that announced training opportunities. A Discord discussion group was also initiated so that CM users can post questions and receive answers to their queries. The CM homepage is in the process of being redesigned to offer more information about the online tool, as well as showcase research studies, and user testimonials.

As a result of these outreach efforts, CM use has steadily increased (Fig. 1). After a decline in use during and after the COVID pandemic, CM use rebounded in 2023 with the highest number of recommendations and events recorded since it was launched in 2011. Between January 1 and July 31, 2024, CM use remained high, providing 6,814 irrigation recommendations, 1,039 N fertilizer recommendations, and recording 844 soil samples events. An additional 860 irrigation recommendations were provided through the web API between May and July 2024. The number of registered users also increased to 4,440.

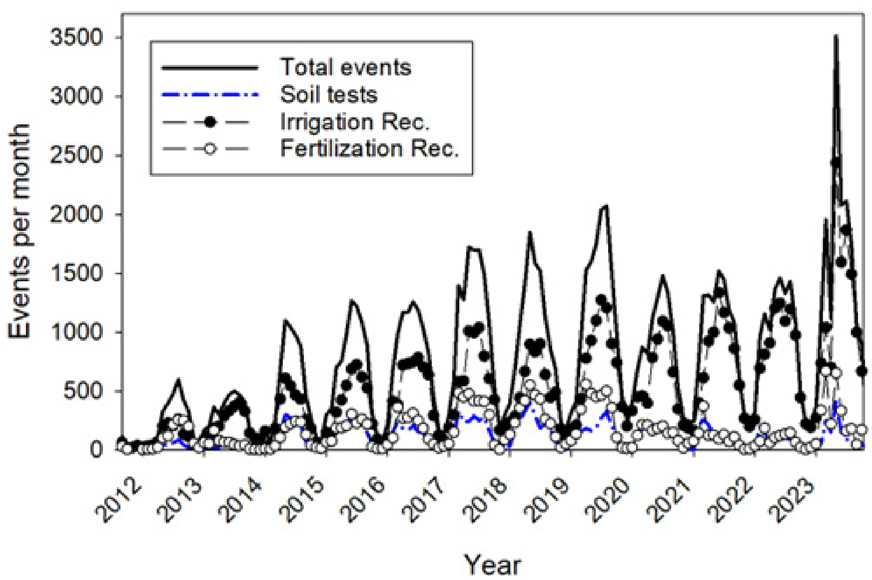

Figure 1. CropManage events recorded between 2012 and 2023

Acknowledgements

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

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

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Company Providing Chemotyping Analysis: Alkemist Laboratories (Dr. Bryan Fine)

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 2024 at University of CA West Side Research and Extension Center (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 2022 projects were the 2nd year of a two-year field project to evaluate fertilizer nitrogen (N) rate responses for two bio-types of industrial hemp grown for essential oils, autoflower/shorter season (AF) types, and full-season photoperiod-sensitive (PPS) types. In 2023 and 2024, 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 have evaluated in 2023 and in 2024 are photo-period-responsive plants that initiate reproductive development in response to shortening day lengths mid- to late-summer, so growing season length (and plant size/yields) are dependent upon planting date as well as harvest timing.

CBD-Type Nitrogen Responses.

The short-season autoflower (AF) varieties begin first cola (flower buds) development about 3-4 weeks earlier than photoperiod-sensitive full season (PPS) types at the planting dates evaluated. For this N fertilizer rate trial, we adjusted irrigation amounts and range of 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 going from the T1 on to the T3 level of N application (about 60 lbs N/acre), with less response to increasing N beyond the 60 or 90 lbs N/acre rate. There was little or no response to applied N rates with AF cultivars at UCD Alpha Nebula cultivar. Similar patterns were seen in 2022 cola yield responses to applied N at WSREC (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

In full-season transplanted photoperiod-sensitive full-season (PPS) cultivars in 2021 (Table 2) at both sites there was a cola yield response to increasing applied N fertilizer from T1 to T3 N treatments, with a more variable yield response to further increases in applied N. Yield responses to increasing applied N tended to be greater with cultivar "The Wife" than with cultivar "Scarlett" at both sites. Similar yield responses across N treatments were seen with direct-seeded cultivars at WSREC in 2022 but little response to applied N amounts was observed in cola dry weight yields at UCD site (Table 2).

Table 2. 2021-2022 cola (flower bud) yields (in lbs/acre) as a function of applied N treatments for Photo-period Sensitive 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. A partial analysis of N content of plants at harvest time in 2022 at WSREC is shown in table 3. Increases in cola N (lbs N/ac) with increasing N at WSREC in AF and PPS type cultivars reflected both increases in cola dry weights through T3/T4 levels, and increases in cola N% with increasing N. In both PPS and AF cultivars at WSREC site, leaf + stem and cola N content increased significantly up through T3 N application levels, and in PPS cultivar "Cookie Crush" and AF cultivar "Maverick" a continued increase in cola and leaf N increased total plant N content at T4, T5 levels. Cola yields peaked at T3 levels, indicating excess N uptake not related to cola yields.

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 and at UCD in 2021 have not shown any trend in THC or CBD levels to applied N rates; however, in several N treatment/cultivar combinations 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 – 2023-2024. The field sites in 2023 and 2024 with fiber hemp at WSREC had low soil nitrate-N (< 30 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 at this site for limited cultivars, and results showed significant biomass (dry weights) responses to applied N up to 165-170 lbs applied N/acre for the April and May planting dates, and up to 110 lbs N/ac rate for July planting. All biomass harvests were done in October/November, when male flowering had declined and colas were formed on female plants.

Greatly reduced yields were evident with July planting when compared with mid-April or May plantings (Table 6), 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. Planting date, N response studies continue in 2024 with the fiber-type cultivars.

Table 4. Fiber hemp dry biomass yields (harvest October/November) as a function of N fertilization rates in 2023 at UC WSREC. Difference in planting density for July date was due to hand planting (versus machine planting earlier dates) and limited seed availability.

Planting Date	Cultivar	Planting Density (1000's/ac)	Total Above Ground Biomass Dry Weight Yields (T/ac)			
			Nitrogen Treatment Levels			
			N-1 (110 lbs/ac)	N-2 (170 lbs/ac)	N-3 (230 lbs/ac)	N-4 (300 lbs/ac)
April	Han NE	340	9.81 b	17.01 a	18.04 a	17.17 a
April	Yuma	340	9.08 b	15.37 a	17.15 a	17.20 a
			N-1 (110 lbs/ac)	N-2 (165 lbs/ac)	N-3 (230 lbs/ac)	
May	Han NE	340	7.42 b	12.87 a	13.16 a	
May	Yuma	340	8.18 b	13.35 a	13.57 a	
			N-1 (60 lbs/ac)	N-2 (110 lbs/ac)	N-3 (160 lbs/ac)	
July	Han NE	155	3.06 b	4.05 a	3.68 a	
July	Yuma	155	2.87 b	3.69 ab	4.20 a	

Acknowledgements

Support from the CDFA-FREPas project #20-0964 and the UC Davis Plant Sci. Dept., UCD Farm and UC-ANR West Side REC is gratefully acknowledged. Hemp transplants, seed for trials were donated by multiple companies shown on the title page, along with donated services/discounted prices for THC, CBD analyses from Alkemist Labs (Garden Grove, CA). The hard work and great attention to detail provided by our field research staff, including Jorge Angeles, Maya Hotz, Chris de Ben, and additional part-time staff, plus staff at the UCD Farm and UC-ANR West Side REC are gratefully acknowledged.

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

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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 NO_3 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, NO_3 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).

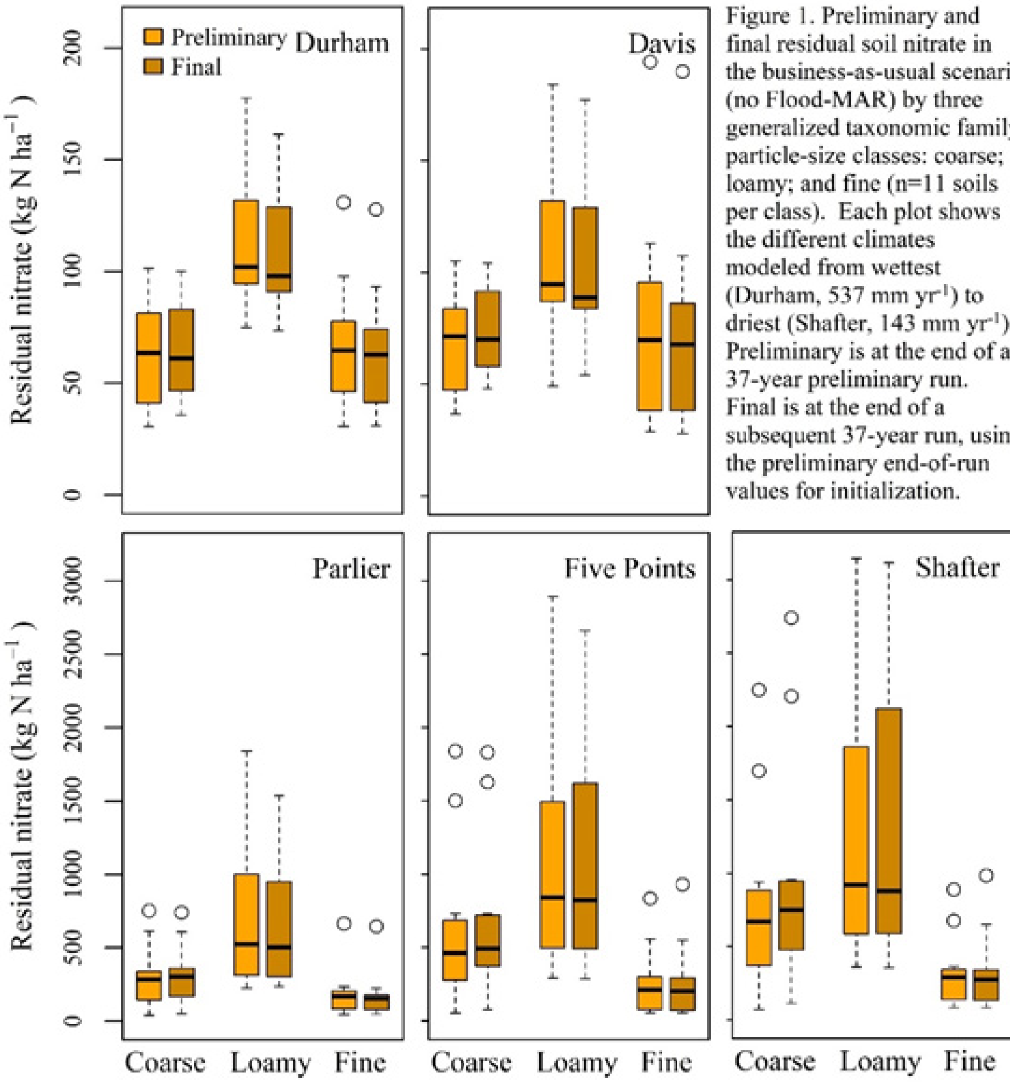

Figure 1. Preliminary and final residual soil nitrate in the business-as-usual scenario (no Flood-MAR) by three generalized taxonomic family particle-size classes: coarse; loamy; and fine (n=11 soils per class). Each plot shows the different climates modeled from wettest (Durham, 537 mm yr^{-1}) to driest (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.

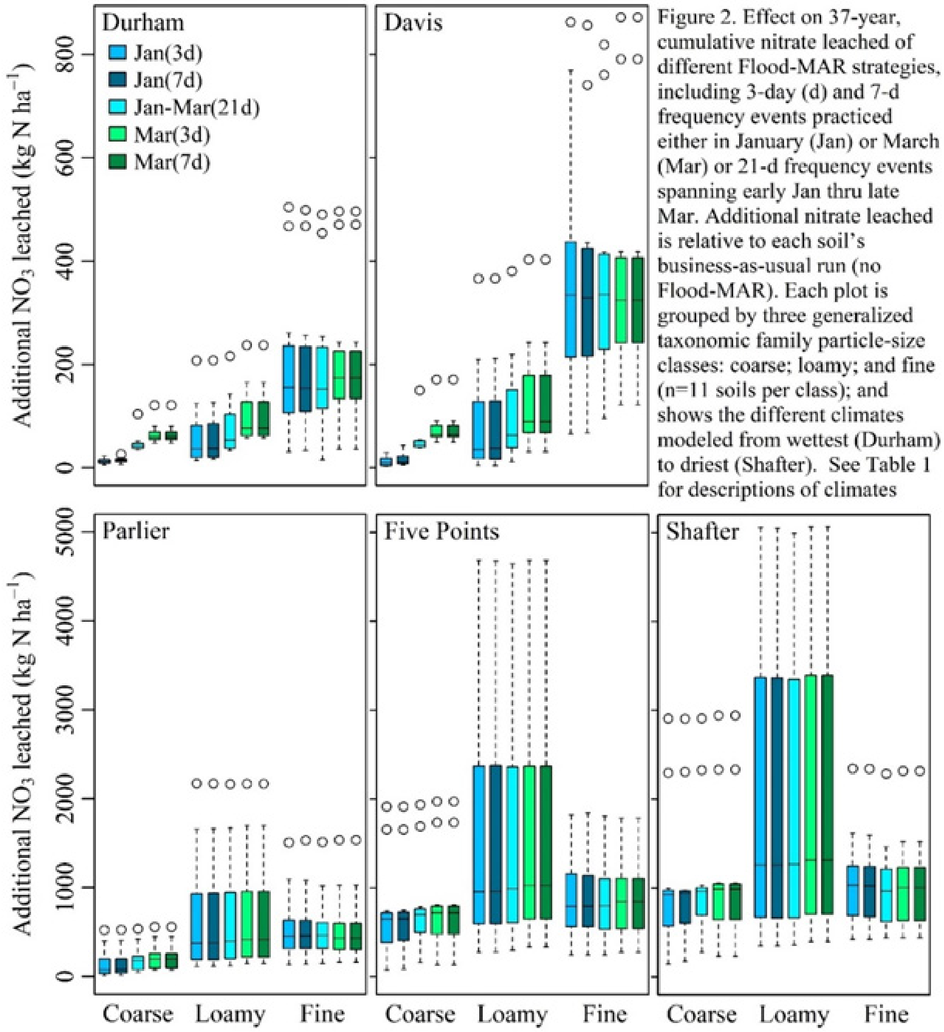

Figure 2. Effect on 37-year, cumulative nitrate leached of different Flood-MAR strategies, including 3-day (d) and 7-d frequency events practiced either in January (Jan) or March (Mar) or 21-d frequency events spanning early Jan thru late Mar. Additional nitrate leached is relative to each soil's business-as-usual 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

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. 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.

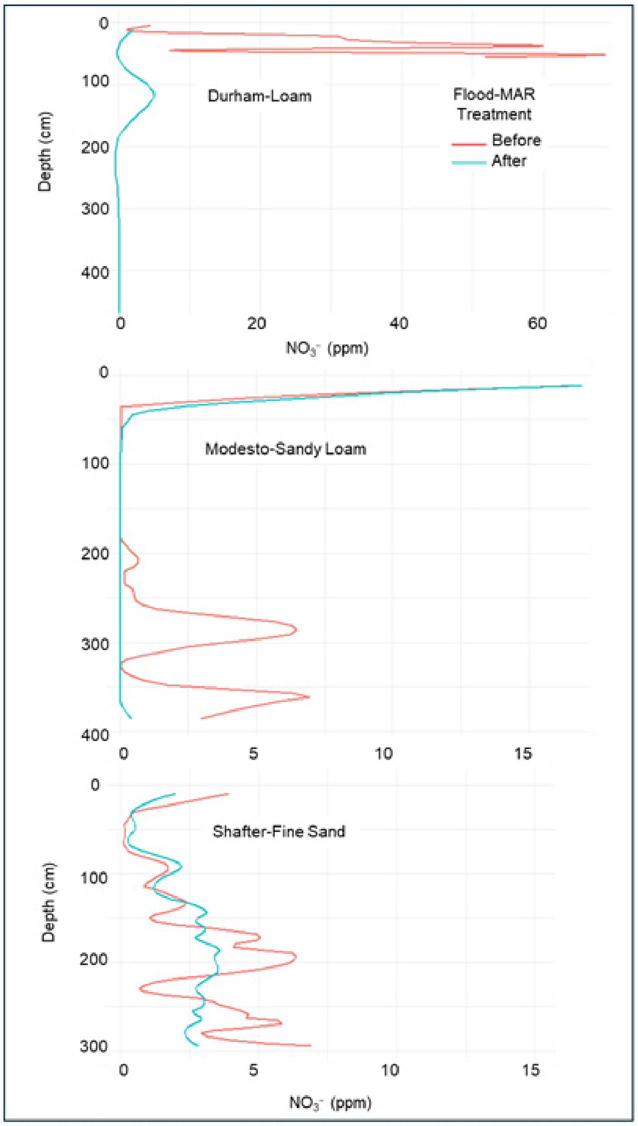

Figure 3. Mean nitrate concentration before and after Flood-MAR in soils near Modesto and Shafter.

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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Nutrient Management and Irrigation Efficiency Outreach and Education for Latino and Southeast Asian Farmers

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Introduction

Adopting changes for optimal nutrient management and irrigation efficiency is inherently complicated as it depends on crop types with different nutrient and water needs and timing, multiple site-specific factors (e.g., soil characteristics, slope, irrigation system), and climate (e.g., rainfall, temperatures). Furthermore, social and economic barriers and inequitable technical assistance (TA) provisions hinder management changes among farmers, many who do not speak English as a first language and therefore receive TA at lower rates than their English-speaking counterparts. Lack of TA delivery with linguistically and culturally proficient service providers familiar with small-scale diversified vegetable production, coupled with historical uneven distribution of services across ethnic and racial groups prevents California agriculture from realizing its nutrient management and irrigation efficiency potential.

Objectives

Given the above-mentioned issues related to lack of TA this project aims to:

1. Increase nutrient management and irrigation efficiency TA and information distribution for underserved farmers.
2. Increase management efficiencies and adoption of sustainable nutrient management and irrigation efficiency practices.

Description

The two objectives of this project are being carried out through outreach and relationship building strategies to understand and better serve Southeast Asian and Latino growers and farm workers in the Central Coast, Southern California, and San Joaquin Valley in the primary languages of the audience, Hmong and Spanish. The following outreach strategies were conducted:

Eleven on-farm tailgates focused on providing technical information to growers and demonstrating soil lab testing practices, analysis based on results of the lab tests, application and timing of fertilization; adoption of compost application, cover cropping, and compliance with nutrient management requirements, (depending on Regional Water Quality Control Board (RWQCB) jurisdictions from which growers and farm workers are attending). These 11 tailgates are collectively reaching 121 growers that will facilitate direct and potentially lasting connections with local TA providers, including agricultural consultants that speak their primary languages and agricultural retailers that can assist growers in development of Nitrogen Management Plans.

Four basic business development trainings are being provided to growers through a partnership with the Asian Business Institute and Resource Center (ABIRC). These trainings cover record keeping for general business health with an emphasis on cost and benefits in soil management practices. They are carried out in the Fresno area with Hmong growers and in the Santa Maria region with Latino growers, delivered to a minimum total of 80 growers over the course of the project.

To further expand outreach on these topics, 15 radio broadcasts are being organized in Spanish and Hmong in coordination with Radio Bilingue and Hmong Radio respectively. These broadcasts will also discuss basic concepts in farm business and soil health, share local technical and financial assistance available and will announce local farmer events in the regions AFT is working. The following topics have been covered during these radio broadcasts; Healthy Soil practices, Transition to Organic, Challenges and Advice from a farmer/landowner, Small Farm Tech Expo, AFT support and services, Farm Business Skills Development and Nutrient Budgeting for Soil Health.

Translation of carefully curated resources are being selected to offer into Spanish and Hmong and a preliminary list of existing resources. These resources will be used as educational aids in future outreach efforts to farming communities that prefer to speak in Hmong or Spanish.

Results and Discussion

In 2022, AFT staff organized three farmer tailgate meetings with partners ABIRC in Fresno and with Cachuma RCD in Santa Maria. In Fresno, the topic was in response to farmer concern on the impacts the drought will have on small scale producers in the San Joaquin Valley, local groundwater regulations and specific soil and water practices that can be implemented to address these resource concerns. Additionally, local technical service providers such as Sierra Resource Conservation District (SRCD) and the Natural Resource Conservation Service (NRCS) in Fresno were available for follow up implementation assistance. This event was conducted in English with interpretation to Hmong and Spanish to be able to reach farmer communities that have been historically underrepresented and under-resourced.

The Santa Maria farmer tailgate was focused on soil health and irrigation efficiencies where AFT partnered with the Cachuma Resource Conservation District (CRCD) to demonstrate the use of distribution uniformity evaluations (DU) and Nitrate Quick Tests (NQT) to help farmers identify the inefficiencies in irrigation and the ideal timing of the fertilization applications. These demonstrations are conducted in Spanish with a group of small-scale diversified vegetable and strawberry farmers.

In 2023, there were two tailgate and business skills events organized in response to farmer increased interest in bookkeeping for nutrient management including organic farming systems and market opportunities. One tailgate was in Fresno in partnership with ABIRC and AGQ labs to understand the importance of basic soil health concepts, how to take soil samples in the field and interpreting soil lab results before fertilizer applications. The other nutrient management tailgate and business skills event was in Merced at an organic farm in partnership with CCOF and Daily Harvest.

At both events, local TA providers were invited to a resource fair after the tailgate portion of the day to share resources, technical and financial assistance in Spanish to support planning and implementation of soil health practices, and explore various market channels.

In 2024, AFT staff and partners are better positioned to deliver an increased level of technical assistance from the previous years. The remainder of the project tailgates, resource fairs and business skills trainings will move from creating awareness and identifying TA providers to a more in field application of soil health practices, sharing farmer experiences and highlighting soil health economic case studies. These farmer experiences will come from the Hmong and Spanish speaking communities to make these management practices more relatable to underserved communities and thereby increasing nutrient management and business skills adoption.

Accomplishments

This project has resulted in a deeper connection with key partnerships who have technical capacity related to nutrient, irrigation management and business development and that can support underserved farmer communities in California with the implementation of these management practices. AFT staff has adapted and prioritized culturally appropriate outreach efforts by hiring native Spanish speaking TA providers from the community for long lasting relationships that can increase practice adoption. A notable accomplishment has been AFT's increased capacity to impact best management practices within the Hmong and Latino community of farmers in the Fresno and Santa Maria areas as well as a strong reputation within the ecosystem of TA providers (public and private) in their respective areas.

Acknowledgements

AFT wished to express gratitude to partners: Asian Business Institute and Resource Center (ABIRC), Cachuma Resource Conservation District (CRCD), as well as the additional organizations and consultants who collaborated with AFT staff and farmers who were not paid for by this grant yet committed to building relationships with underserved farmer communities; namely, DRAM consulting, AGQ Labs, Kitchen Table Advisors, California Farmlink, California Certified Crop Advisors, Daily Harvest, UC Cooperative Extension, Sierra RCD and UC Agriculture and Natural Resources. Finally, gratitude goes to the California Department of Food and Agriculture Fertilizer Research and Education Program (CDFA-FREP) for providing funding and technical support for this project.

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

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Introduction

The Imperial Valley is the major Sudan grass-producing region of California. Being a C4 and drought-resistant crop (Beybit et al., 2021), Sudan grass thrives well in the low desert, where maximum summer daily temperatures often exceed 115°F. The recommended fertilizer rate for Sudan grass production in the low desert is 100 lbs Nitrogen (N)/ac as pre-plant and 50-60 lbs N/ac after each cutting (Bachie, 2021). However, most Imperial Valley growers apply excessive amounts of N to maximize Sudan grass crop yield. Higher levels of NO_3-N in the soil or Sudan grass hay may leach out of the fields and cause environmental pollution or become toxic to livestock, respectively. Leaching of NO_3 can be exacerbated by high irrigation water. There is little guidance to growers on determining the optimum N fertility and irrigation to keep the fertilizer within crop roots or apply safe levels. This project planned to develop the best N fertilizer and irrigation management strategies for optimum yield and quality of Sudan grass hay production in the low desert. The study is being conducted at the UCANR Desert Research and Extension Center (DREC) in Holtville. This report consists of findings from the last harvest of the first year (2023) and the second harvest of the second year (2024) crop yield data. Not all project objectives were implemented during this reporting period.

Objectives

1. Develop N fertilization practices combined with best irrigation management that enhance yield and improve the efficiency of crop fertilizer use (NUE) and water use (WUE).

2. Lay out strategies that reduce N loss from agricultural crop fields and maintain Sudan grass crop yield of higher export quality and less risk of animal poisoning.
3. Develop fertilization practices that will improve the efficiency of fertilizer inputs, improve the marketability of hay production, and maximize the grower's economic benefit while reducing loss from Sudan grass production systems due to hay quality.

Description

Three irrigation strategies (main plots) and three fertilizer rates (subplots) were used as two-way factor treatments. Irrigation treatments are (1) 80% ET, (2) 100% ET, and (3) 120% ET, delivering 3,000, 3,500, and 4,000 gallons of water per field irrigation time, respectively. Fertilizer treatments were (N1) 50 lbs of fertilizer N / acre (lower rate) after each cutting, (N2) conventional N fertilizer rates of 80 lbs of fertilizer N / acre (higher rate), and (N3) N fertilizer based on crop fertilizer needs. 100 lbs N per 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 for crop establishment and converted to furrow irrigation controlled by gated pipes. Moisture sensors were used to measure crop water availability. Accordingly, soil moisture sensors for the 2023 trials showed that plots treated with the 80% ET irrigation exhibited relatively less soil water availability (higher soil water potential), imposing some crop water stress conditions. The 100% ET or 120% ET irrigation levels provided optimum amounts of water (Figure 1).

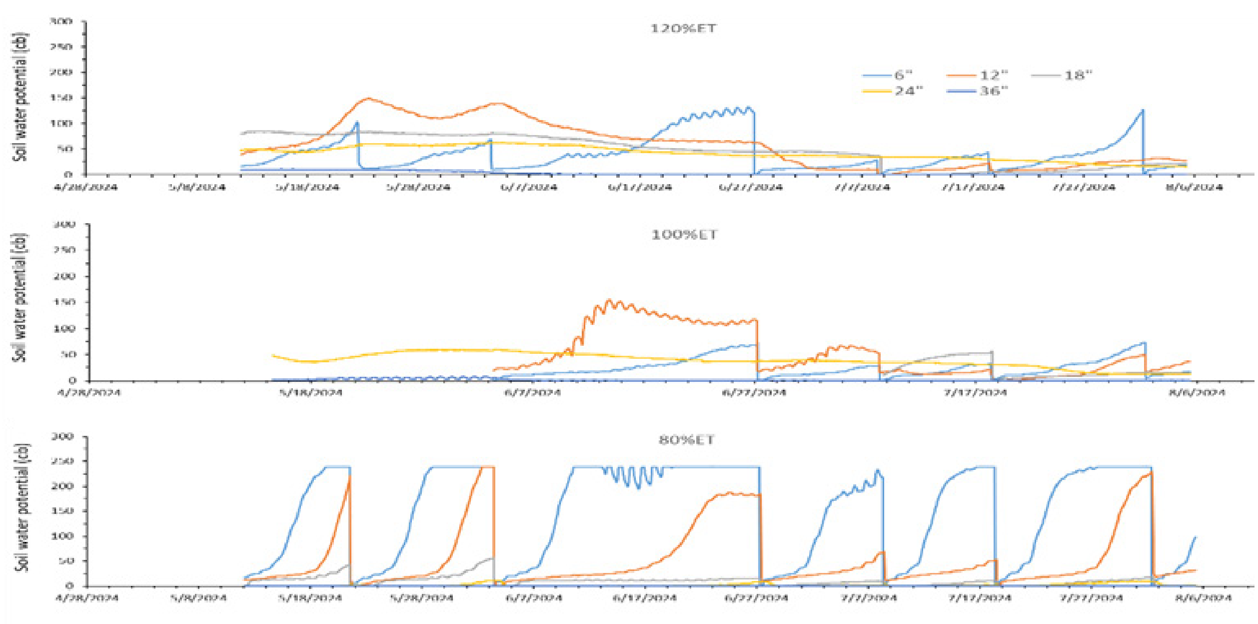

Figure 1: Soil water potential under the three irrigation schedules, 120ET (top), 100ET (middle), and 80ET (bottom), at 6, 12, 18, 24, and 36 inches of soil depth.

Soil samples were collected to measure soil residual nutrients at either pre-plant or after subsequent harvests. Soil residual fertilizer content and crop tissue NO_3 concentration were used to determine fertilizer rate for the N3 treatment. The soil analysis from the N3 treatment plots (after the first 2024 crop harvest) showed optimum NO_3-N content and that the soil was slightly alkaline. The average (4 samplings of the regrowing crop) crop tissue NO_3-N content of 1,273 PPM also reflected sufficient NO_3 concentration for livestock feed. High nitrate nitrogen (NO_3-N) levels in Sudan grass forages can poison ruminants (Sunaga et al., 2008). Sudan grass with forage tissue concentration between 1,000 to 2,000 PPM is considered safe for livestock. Considering sufficient residual soil and tissue NO_3-N concentrations, the N3 treatment plots were left unfertilized after the first 2024 crop harvest.

Results and Discussion

Sudan grass is usually harvested when the crop has 10 to 20% flowers. A typical Sudan grass production in the low desert involves 3 to 4 cuttings with a crop planted in early spring (March-April). Our findings in this report are from the third harvest of the 2023 crop and the second harvest of the 2024 crop. The first cutting for 2024 is used to determine the baseline biomass productivity under only pre-plant fertilizer supply. The mean baseline fresh biomass (averaged over four sample sites) was 17.1 tons/ac. The biomass productivity of Sudan grass for the 2023 (October harvest) and 2024 (August harvest) trials was analyzed using the SAS 9.4 statistical package. The three-way (Date*ET*fertilizer) interaction was insignificant (p=0.7730 and P=0.1190 for the 2023 and 2024 harvests, respectively). A two-way (ET*fertilizer) interaction was also insignificant, p = 0.0896 and P=0.1190, for the 2023 and 2024 harvests, respectively.

Our findings from both the 2023 and 2024 harvests showed that there were no significant differences in Sudan grass biomass production among irrigation treatments (Figure 2). Our findings clearly show a higher WUE from the lower (deficit) irrigation because similar biomass was produced.

In other words, Sudan grass can be produced under slight water stress without compromising productivity. Differences in biomass production between the fall 2023 and summer 2024 harvests could be due to high heat stress or crop size at harvest.

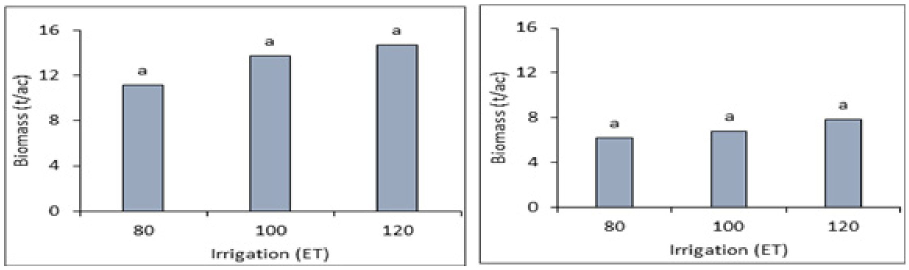

Figure 2: Sudan grass biomass for October 2023 harvest (left, p=0.0896) and August 2024 (p=0.1990). Bars followed by the same letter within each graph are not significantly different.

Statistically different biomass production was detected only for the fertilizer treatment (Figure 3). October harvested crops under the highest fertilizer rate (100 lbs N / ac) have the least biomass production. Reduced biomass production under higher fertilizer levels may indicate a diminishing return, suggesting that higher fertilizer rates are not necessarily good for higher yield of Sudan grass. 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 more productivity per lb fertilizer, suggesting a higher NUE. Sudan grass can be grown at a lower fertilizer rate of 50 lbs N/ac and still produce the same crop yield as the highest (100 lbs N/ac).

Similarly, there was no significant difference in crop biomass for different fertilizer rates at the August 2024 harvest, even for those not fertilized after every cutting (Figure 3). October harvested crops also had higher biomass than August 2024, although fertilizer rates were similar except for the N3 treatment, once again indicating the effect of seasonal crop stress conditions. The August 2024 biomass yield from the N3 treatment was from a no-fertilizer application after the first cutting. These findings suggest that growers can produce a similar yield of Sudan grass by skipping fertilizer applications after cuttings. While last year's findings revealed that all nutrient components (crude protein, ADF, NDF, Ash, TDN) of Sudan grass were similar for all irrigation and fertilizer treatments, a higher nitrate ion accumulation beyond acceptable hay nitrate concentrations was detected (Bachie et al., 2024a). Nutritional components of Sudan grass from the current year trial will be analyzed and presented in the upcoming report.

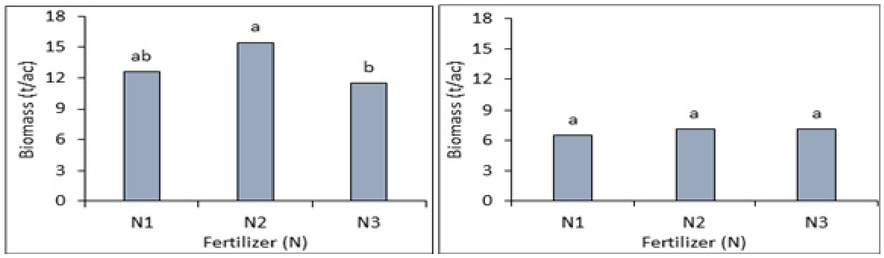

Figure 3: Sudan grass biomass harvested in Oct 2023 (left, p=0. 0451) and Aug 2024 (right, p=0.7000). Bars followed by the same letter within each graph are not significantly different.

Take-home Message

Our findings suggest that lower irrigation and fertilizer resources can be used for Sudan grass production without significantly compromising crop yields. We observed that Sudan grass can be stressed to 80% ET without significantly reducing biomass productivity. Optimum yield, comparable to using high fertilizer inputs, can also be achieved at lower fertilizer inputs of 50 lbs N/acre after every cutting or even skipping fertilizer applications after cuttings. Similar yields from lower irrigation and fertilization shows a higher WUE and NUE, respectively. In the meantime, growers can increase the marketability of their Sudan grass by producing hay with desirable nutrition and a safe level of NO_3. Reduced inputs optimize economic return, conserve resources, and reduce pollution from leaching or erosion into drainage or groundwater. N leaching and erosion factors were not tested during this season but will be covered in future studies.

Acknowledgment

CDFA FREP funded this study. We gratefully acknowledge resource management, crop maintenance, and data collection support from UCCE Imperial County and DREC staff.

Optimizing Nitrogen Fertilizer Concentration in Vegetable Transplant Production

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

Description

Experiments were completed with leaf lettuce, broccoli, processing tomato, and romaine lettuce. An experiment on celery was also completed, but the experiment will be run a second time, due to an issue with data collection. 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 was built on a weighing lysimeter to record daily evapotranspiration. Growing media was refilled to container capacity daily and daily water use was recorded. Plants were harvested after reaching commercial size.

At harvest, shoot samples were dried at 55^{o}C for 48 hours. Plant samples from each individual plug tray were kept together and dried in a single paper bag, resulting in a composite plant sample for each plug tray. 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).

Results and Discussion

Broccoli, processing tomato, romaine lettuce, and celery had significantly lower dry weights in the 50 ppm treatment, compared to the 200 and 400 ppm treatments. There was no difference in dry weight between the 200 and 400 ppm treatments for any of the crops we analyzed, indicating that these fertilizer solutions provided sufficient NPK. The only crop that did not have significantly different dry weights between any of the fertilizer treatments was leaf lettuce. For the vegetable transplant crops evaluated, plant P and K tissue content for the 50 ppm N treatment was significantly less than the 200 and 400 ppm N treatments, indicating that P and K provided in nutrient solution for 50 ppm N treatments was deficient. The 50 ppm N treatment had a significantly lower calculated fertilizer concentration of N and P than the 200 and 400 ppm N treatments.

The optimal NPK fertilizer concentration for broccoli was calculated as 437, 52, and 232 ppm N, P, and K, respectively (Table 1). The N concentration (Table 1) agrees 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 (Table 1).

Table 1. Mean values for vegetable transplant crop experiments. 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.

Crop	Applied nitrogen conc. (ppm)	Shoot DW (g)	Transpiration (L)	Shoot N (%)	Shoot P (%)	Shoot K (%)	Calculated Fertilizer Conc. (ppm) Nitrogen	Phosphorus	Potassium
'Grazion' Leaf Lettuce	50	1.66 a	10.046 a	2.1 a	0.36 a	3.2 a	69 a	12 a	109 a
	200	2.77 a	13.764 b	5.6 b	0.86 b	4.5 b	223 b	33 b	173 b
	400	2.00 a	10.757 a	7.2 c	0.89 b	4.4 b	269 b	33 b	164 ab
'Green Magic F1' Broccoli	50	1.44 a	6.293 a	2.4 a	0.35 a	1.9 a	118 a	17 a	96 a
	200	3.30 b	9.409 b	6.3 b	0.74 b	3.4 b	437 b	52 b	232 b
	400	3.47 b	8.975 b	9.5 c	0.60 c	3.6 b	732 c	47 b	277 b
'N 6428' Processing Tomato	50	0.77 a	7.08 a	2.0 a	0.32 a	2.0 a	48 a	8.0 a	48 a
	200	1.77 b	8.11 a	6.1 b	1.02 b	2.8 b	265 b	44 b	121 ab
	400	1.83 b	9.27 a	8.1 c	1.04 b	4.3 b	343 c	44 b	180 b
'Blue Rock' Romaine Lettuce	50	0.42 a	1.71 a	2.8 a	0.50 a	4.9 a	216 a	38 a	383 a
	200	0.60 b	2.95 a	5.6 b	0.90 b	6.8 b	232 a	37 a	280 a
	400	0.70 b	2.46 a	6.8 c	1.17 c	6.2 b	427 b	73 b	384 a
'Kelvin F1 OG' Celery	50	0.37 a	4.39 a	2.7 a	0.56 a	3.3 a	50 a	11 a	62 a
	200	1.03 b	4.41 a	5.4 b	0.92 b	4.9 b	262 b	45 b	242 ab
	400	0.95 b	3.01 a	6.5 c	0.92 b	5.4 b	420 c	61 b	358 b

Take-Home Message

We recommend using the mean of the calculated N, P, and K concentrations of the 200 and 400 ppm N treatments as the optimal fertilizer concentration for leaf lettuce and processing tomatoes. For the broccoli, we recommend using the calculated NPK concentration of the 200 ppm N treatment because shoot biomass was maximized at 200 ppm N (Table 1). We recommend using the calculated N, P, and K concentrations of the 200 ppm N treatment for optimal fertilizer concentration for romaine lettuce and celery (Table 1).

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

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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[1]. 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[2]. 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 30 cm[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[3]. 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[4].

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 30 cm increments to calibrate and validate our model with and have begun developing the modeling files (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 40 cm 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. Three of the rates were replicated three times (0, 7.6, and 22.8 Mg/ha) while other rates had one replicate. 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 (0-1 m) 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 will help shed light on whether N surpluses documented in Brennan's work were leached or stored deeper in the soil profile and to help calibrate the Ecosys model. Collaborator Brennan has assembled the data needed to calibrate the Ecosys model for his long-term experiment site and we are currently collating those files into the correct format.

Inorganic nitrogen and DON have been analyzed down to 60 cm from 28 fields and three different time points: transplant, mid-season, and harvest (1120 samples total). Once analyzed, this will allow determination of how soil variability can modulate DON loss from organic amendment applications and help validate the Ecosys model to see if it is performing adequately on varying soil types.

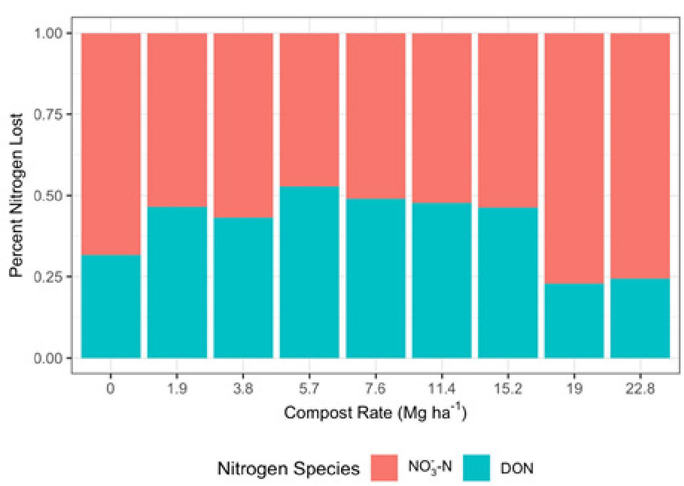

Figure 1: Percent of nitrogen leached as either dissolved organic nitrogen (DON) or nitrate (NO_3^-) across compost rate treatments summed over the duration of the sandy loam column experiment.

Results and Discussion

Preliminary results from the column experiments in the sandy loam suggest over the growing season for lettuce, the percentage of N leached as either DON or NO_3^- is similar when compost is added at low and mid-range rates (1.9 Mg ha^{-1} to 15.9 Mg ha^{-1}) (Figure 1). At very high rates of compost addition, the main N leaching pathway is via NO_3^- and DON leaching is comparable or lower to the treatment where no compost was added.

Total mean N lost across all irrigations for the entirety of the sandy loam column experiment were variable across compost treatments, with a slightly decreasing trend at the highest compost rates. Comparing the compost treatments that were replicated (0 Mg ha-1, 7.6 Mg ha^{-1}, 22.8 Mg ha^{-1}), no significant differences in NO_3^- or DON concentrations in leachate were found. However, significant differences were found for dissolved organic carbon (DOC) loss between the three compost application rates ($P<0.05$). Leached DOC increased linearly with increasing compost treatments for the first two irrigation events and remained constant across treatments for subsequent irrigation events (Figure 2). The 22.8 Mg ha^{-1} treatment had significantly higher rates of total mean DOC leached (1016.4 ug C/ml) compared to the 0 Mg ha^{-1} treatment (689.70 ug C/ml) with no significant differences between the 22.8 Mg ha^{-1} treatment and the 7.6 Mg ha^{-1} treatment (764.9 ug C/ml) and no differences between the 7.6 Mg ha^{-1} treatment and the 0 Mg ha^{-1} treatment.

The majority of N leached occurred after a disturbance event (packing of columns) and the first subsequent irrigation event (Figure 2). While NO_3^- values in the leachate after the first irrigation were above the 10 ppm maximum contaminant limit (MCL), subsequent irrigations led to NO_3^- loads below the MCL. After the third irrigation event, DON shifts to becoming the dominant N leaching pathway. Future analysis will examine how soil edaphic properties control N leaching pathways by examining differences between the sandy loam vs clay loam column experiments.

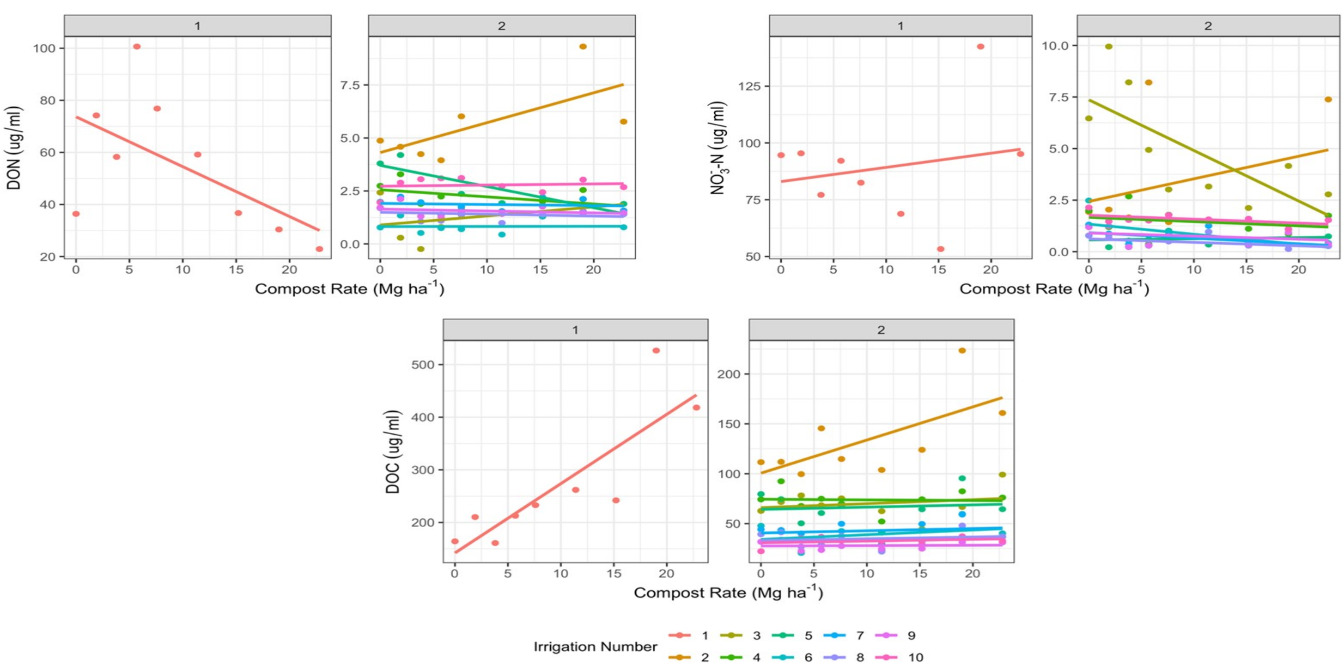

Figure 2: DON, NO_3^- concentrations (ug ml-1) in leachate across compost application treatments (Mg ha^{-1}) for each irrigation event. The first irrigation event is shown in the left facet due to the large discrepancy in values between the first irrigation

Accomplishments

Thus far, we have completed two greenhouse column experiments quantifying the N species in leachate lost from the root zone of a sandy loam and a clay loam soil. We are completing data cleaning and analysis for the clay column, with the sandy loam column complete. Deep coring down to a meter in the long-term trial (180 samples collected) was completed and samples have been analyzed for C and N, texture, CEC, and pH. We have finished all analyses across the 28 field sites. We have finished collating data for parameterizing the Ecosys model runs and are developing the files to run the model within the few months. Iterations of calibration and validation will occur prior to developing scenario analysis.

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

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Introduction

Nitrogen (N) and water management in lettuce is critical for increasing efficiency of crop production and decreasing costs and nitrate leaching losses. The overall purpose of this study is to fully understand the viability and applicability of current N and irrigation management practices in the low desert lettuce production systems. It aims to develop knowledge and information on improving and promoting adaptation of management practices that optimize N and irrigation water use efficiency in low desert lettuce.

Objectives

1. Provide data and information on crop water use, crop N uptake curve, and net N removal in low desert lettuce.
2. Develop recommendations on best N and water management practices in low desert lettuce.
3. Develop knowledge base information and data to adapt the CropManage (CM) tool for water and N management in low desert lettuce.

Description

The experiments were conducted in five commercial fields in the Imperial and Coachella Valleys consisting of three head and two romaine lettuce trial fields (Fig. 1 and Table 1). The trial field Com-1 was germinated by drip, and sprinklers were used to germinate the other commercial trials. All trial fields were irrigated using drip the entire season after plant establishment, except trial Com-5 that switched to furrow irrigation.

In addition, two head lettuce trials (40”-bed and 80”-bed) were carried out under two irrigation regimes and three N fertilizer strategies at the UC Desert Research and Extension Center (DREC) in a Randomized Complete Block Design with Split Plot Arrangement over four replications (Fig. 1 and Table 1).

Figure 1. A demonstration of the 40 inch bed romaine lettuce trial field in the Coachella Valley (a) and the 80 inch bed head lettuce trial at the DREC (b). The water applied was measured using a magnetic flowmeter attached to datalogger. The data of water applied was automat-ically imported and analyzed by CM tool.

To develop a crop coefficient model based on canopy development, images were taken on a weekly basis utilizing an infrared camera. The fertilizer applied was monitored throughout the crop season. The data of water applied was automatically imported and analyzed by the CM web-based tool in each site. The actual soil nitrate content and the total N concentration in the plants were determined five times per season through laboratory analysis. Soil samples were collected from three depths (0-10”, 10-20”, 20-30”). In addition, a soil quick N test was conducted from the top 10” of the soil in each trial field on a 10-day basis. Comprehensive yield quality data at harvest was collected including plant population, head weight, biomass, marketable yield, total N and dry matter concentration of head tissue.

Results and Discussion

Plant density.

A considerable difference of plant density was found across the trials ranging from 27,181 plants per acre at trial Com-5 to an average of 49,446 plants per acre at the DREC trials with 80”-bed.

Water and nitrogen applied.

Variable water and N application rates were observed at the experimental sites. A substantial difference was found between the N and water application rates recommended by the CM and grower practice at the field trials with sandy soil textures.

For instance, the seasonal irrigation water and N application rates were 20.3-in (115% more than the rate recommended by the CM) and 285 lbs. ac^{-1} (147% more than the rate recommended by CM) at the Com-4 trial, respectively. The N unit applications varied from 90 to 160 lbs. ac^{-1} at the DREC trials and other commercial fields with heavier soil texture.

Table 1. General information of the trial fields.

Trial	Soil texture	Crop/planting	Irrigation method	Wet date	Harvest date
Com-1	Silty clay	Head 80"-bed, 6 rows	Drip	29 Oct, 2022	15 Feb, 2023
Com-2	Silty clay	Romaine 80"-bed, 6 rows	Drip	5 Nov, 2022	15 Feb, 2023
Com-3	Loamy fine sand	Head 40"-bed, 2 rows	Drip	1 Nov, 2023	2 Feb, 2024
Com-4	Sandy loam	Romaine 40"-bed, 2 rows	Drip	11 Nov, 2023	15 Feb, 2024
Com-5	Silty clay	Head 40"-bed, 2 rows	Furrow	5 Oct, 2023	25 Dec, 2023
DREC-1 to DREC-6	Silty loam	Head 80"-bed, 6 rows	Drip	5 Nov, 2023	12 Feb, 2024
DREC-7 to DREC-12	Silty loam	Head 40"-bed, 2 rows	Drip	5 Nov, 2023	12 Feb, 2024

Notes: Trial fields Com-2 through Com-4 were switched to drip and trial field Com-5 to furrow irrigation after plant establishment using sprinklers. The other trials were established and irrigated using drip the entire crop season. The DREC trials were under different irrigation and nitrogen application regimes.

Soil nitrate concentration.

Across the trials, the average soil NO_3-N concentration in the top one foot varied from 21.9 ppm (trial Com-2) to 36.7 ppm (trial DREC-9) at post-thinning and ranged between 10.5 ppm (trial Com-4) and 82.1 ppm (trial DREC-3) at harvest.

Biomass yield.

Greater biomass yield (averagely 34%) was observed at the 80"-bed lettuce trials in comparison with the 40"-bed lettuce trials (Fig. 2). While a significant impact of N application rate on biomass yield wasn't found, a wide range of biomass yield was observed across the trials (24.5 t ac^{-1} at trial Com-3 to 48.4 t ac^{-1} at trial Com-1).

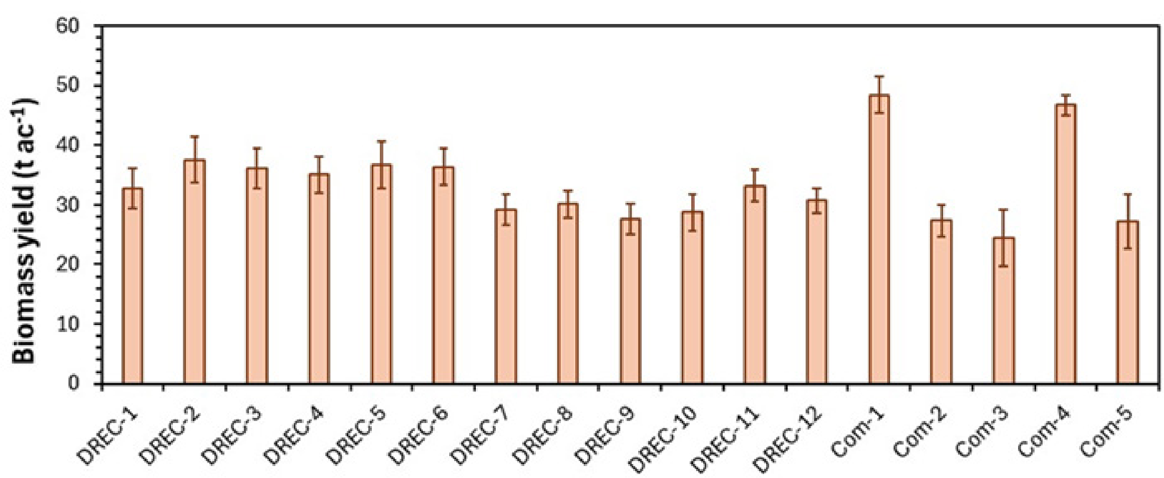

Figure 2. Biomass yield in different trials. Standard deviation of the corresponding biomass yields is shown on the bars.

N uptake at harvest.

A wide range of N uptake at harvest was determined across the experimental sites and treatments. Mean values varied from 82.1 lbs. ac^{-1} at trial Com-3 (a head lettuce field with 40"-beds) to 147.3 lbs. ac^{-1} in another head lettuce field with 80"-beds (Com-1) (Fig. 3). The results demonstrated more variations on the N uptake values than the biomass yields among the trials. For instance, there wasn't considerable biomass yield difference between trials Com-2 (27.4 t ac^{-1}) and Com-3 (24.5 t ac^{-1}), however, significant difference was found between N uptake at these trials (128.1 lbs. ac^{-1} vs. 82.4 lbs. ac^{-1}, respectively).

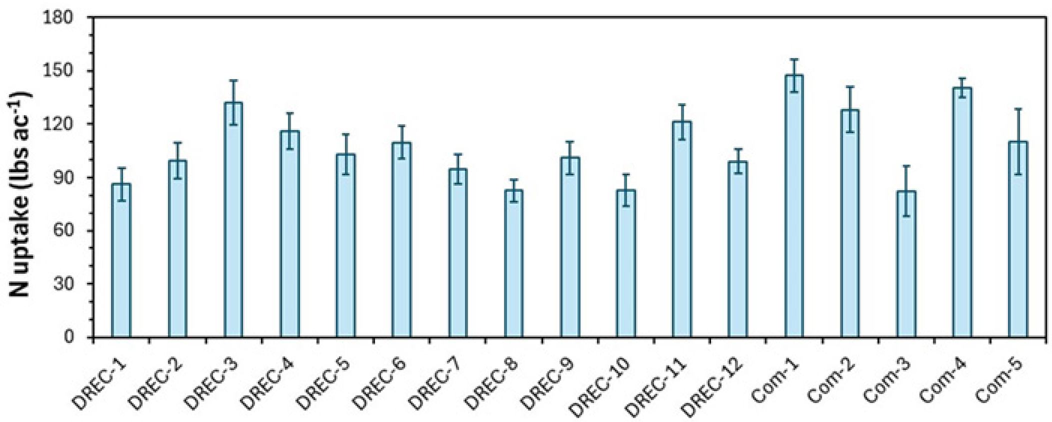

Figure 3. N uptake values in different trials. Standard deviation of the corresponding N uptake values is shown on the bars.

Conclusions

A wide range of N uptake values was obtained in desert head and romaine lettuces across the trials reported in this article and in our 2022-2023 trials, varied from less than 80 lbs. ac^{-1} to greater than 150 lbs. ac^{-1}. The findings of this study suggested that lettuce growth could be maximized by seasonal N fertilization and irrigation water application rates below current typical practices even in drip irrigated fields. A higher potential for improvements is expected in furrow irrigated lettuce fields and fields with sand-dominated soil textures. As a free decision-making tool, CropManage may assist local growers to maximize lettuce production and enhance the efficiency of N and water use.

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Development of Precision Yield Monitor for Almond and Pistachio

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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 laser scanning. A laser scanner will be placed above the conveyor belt of the harvester – after debris has been blown away - and used to measure the flow of the harvested crop volume. The estimated bulk density of the crop will be used to convert volume flow to mass flow, which will be combined with the GPS signal to estimate the yield map.
2. Measure yield using optical methods and validate the results with the known weight. Conveyor belts will be modified to include rollers with load cells and a non-contact moisture sensor, thus augmenting volume flow (from Objective 1) with the measured mass flow and water content.
3. Develop and integrate a real-time quality control vision system. A real-time vision system will be developed to estimate valuable parameters such as hull split (for almonds) and trash percentage.

Description

This project aims to provide the capability for single tree yield monitoring and tree identification at full commercial harvest speed. To achieve this goal, the project features a laser scanner mounted above the terminal section of a conventional commercial off-ground harvester. Engineered to operate continuously, the design avoids needing to halt the harvester during crop collection. Additionally, the harvester is outfitted with accurate GPS and a vibration sensor on the shaker head, enabling a precise yield estimation for each tree. The weighing conveyor used during the 2023 harvest made it difficult to maneuver the machine and was susceptible to excessive vibration, so has been removed for the 2024 season. Also, an exhaustive search of non-contact moisture sensors revealed that they would not work on a conveyor belt because of the variable nature of the almond flow, which ranges from a few nuts to a thick pile, and the need for frequent calibration. Furthermore, the cost of these sensors (in the order of $15,000 or more) renders them impractical for real-world use.

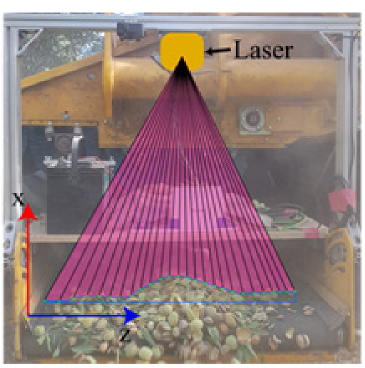
Sensing system

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 (right) provides an example of the resulting point cloud where the volume is calculated.



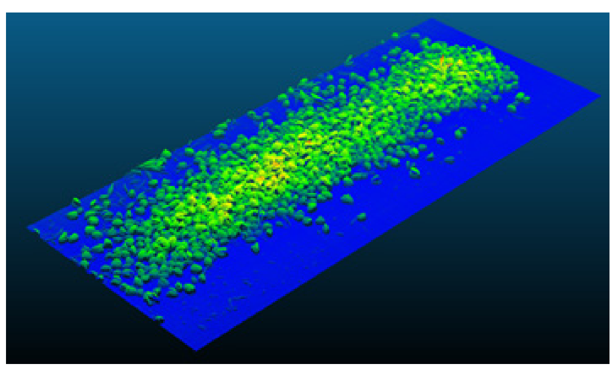


Figure 1. Almond profile reading with a laser (left); result of combining the laser profile and encoder readings (right).

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.

Individual tree yield.

The almond volume flow measured by the laser corresponds to the nuts harvested. Commercial harvesters aim to harvest quickly to maximize profit, causing overlap of almonds from neighboring trees. To address this, we used a mathematical model, specifically a Gaussian Model, to describe the volume flow for individual trees. This bell-shaped model was first tested on ground truth trees and then applied to all the trees in the orchard.

Non-almonds removal.

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 use an AI model to filter out the unwanted materials from the high-resolution laser data.

Results and Discussion

Controlled experiments were carried out in a lab setting to evaluate the precision of laser-based weight estimation techniques. The tests involved "Non-Pareil" almond quantities ranging from 1 kg up to 30 kg, and the conveyor belt was operated at speeds of 0.2 m/s, 0.4 m/s, 0.6 m/s, and 0.8 m/s. Data from the laser and encoder were utilized to calculate the volume of almonds moving across the belt. The mean absolute error was 0.3 kg and the relative absolute error was 3.4%.

We conducted a data acquisition campaign at Westwind Farms and Olam Group (KG Ranch). We validated our approach using measurements from ground-truth trees. The results are presented in Figure 2.

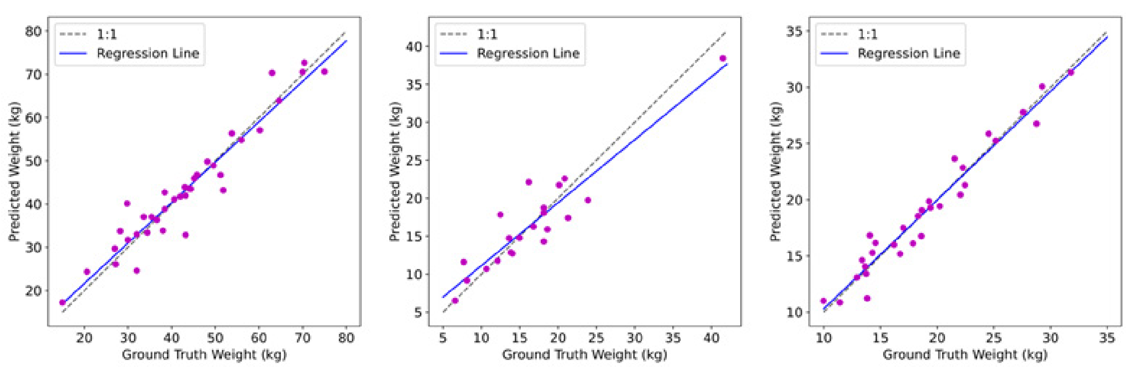


Figure 2. Validation of weight estimations in three crops from left to right, Westwind, NonPareil: R2=0.92, KG-ranch, NonPareil: R2=0.86 and KG-ranch, Monterey: R2=0.95. Estimated almond weight (y-axis) versus the actual weight (x-axis).

There was very good correlation, though the presence of a large number of leaves mixed with the KG-ranch NonPareil almonds might explain its lower performance compared to the other tests.

After applying the volume-to-weight method to the ground-truth trees, we used the described strategy on the almond volume flow obtained at commercial speeds. Figure 3 illustrates this process. The grey line represents the volume measured by the laser. Next, we determined the Gaussian Model parameters for the individual trees. Each bell-shaped curve in black dashed lines represents the volume flow per tree after finding the model parameters. These black dashed lines overlap due to the harvester's fast speed, which took approximately 12 seconds per tree.

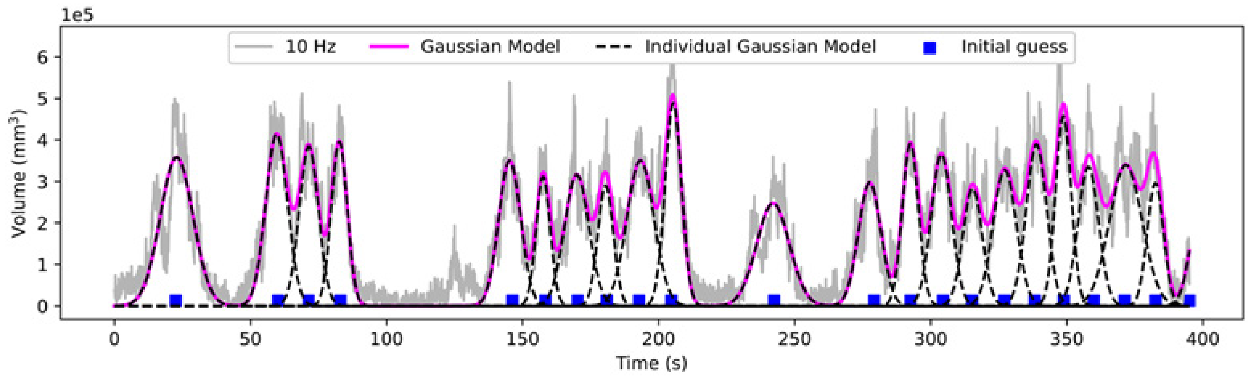


Figure 3. Estimation of individual volume flow (black dashed line) based on a continuous volume flow (grey line).

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

Take-Home Message

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.

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Noble, AE., TS Rosenstock, PH Brown, J Machta, A Hastings. 2018. Spatial patterns of tree yield explained by endogenous forces through a correspondence between the Ising model and ecology. Proceedings of the National Academy of Sciences 115 (8), 1825-1830 https://www.pnas.org/content/115/8/1825

Acknowledgments

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The Role of Irrigation Management for Improving Nitrogen Use Efficiency for Broccoli Grown with Nitrate-Contaminated Irrigation Water

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Introduction

In an effort to reduce nitrogen (N) pollution of ground and surface waters, growers are subjected to increasingly stringent regulation. Given that many irrigation water sources have high N loadings, growers are encouraged to take N inputs from irrigation water into account in their N budgets, a concept referred to as '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 nitrate contaminated irrigation water without supplemental fertilizer N have led to low yield, even though the total N input from irrigation water exceeded expected crop N uptake. For N contained in irrigation water to be available to the crop, it is imperative that the irrigation water stays within the root zone. Therefore, any efforts to increase N use efficiency (NUE) will be affected by irrigation management. 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.

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

To date, we have conducted four controlled on-farm field trials in California's Santa Maria Valley to study the effects of N rate and irrigation management on N dynamics and yield in broccoli production. The experiments took place in Spring 2022, Fall 2022, Winter 2023-2024, and Spring 2024. Fertilizer rates ranged between 23 and 300 lbs N/acre (Table 1). Fertilizer was applied to the top of the soil along the drip line using a manual backpack sprayer with an hour of irrigation before and after application to move the fertilizer into the root zone and mimic the grower fertigation practice. The two irrigation treatments are referred to as grower standard (GS) and ET-based irrigation management (ETI). The ET-based irrigation followed recommendations by CropManage (Cahn et al., 2015), a free online decision support tool calibrated for local crops and growing conditions. A manifold was designed to modify drip irrigation inputs in the ETI treatment, and flow meters were installed to monitor the water input in GS versus ETI. We measured yield, aboveground plant N uptake, and soil N concentrations preplant, midseason and postharvest. In trial 1 and 2, soil N concentrations were measured in the 0-12" and 12-24" depth increments, while trial 3 and 4 included the 0-6", 6-12", 12-24" and 24-36" depth increments. In trial 4, we were not able to implement the irrigation treatment, because the field stayed on sprinkler irrigation for aphid management purposes.

Table 1: Key characteristics of trials conducted to date

	Trial 1 Spring 2022	**Trial 2** Fall 2022	**Trial 3** Winter 2023-2024	**Trial 4** Spring 2024
Management	Conventional	Conventional	Conventional	Organic
Topsoil texture	sandy loam	sandy loam	Sandy loam	Clay loam
Topsoil SOM (%)	0.92	0.90	1.5	3
N rate range (lbs N/acre)	50-250	75-300	32-272	23-263
Irrigation water NO_3^--N (mg/L)	8	8	13.14	14.8

Results and Discussion

In trial 1, 2 and 3, the ETI treatment used 26%, 15% and 13% less irrigation water compared to the grower practice. In trial 1 and 2, ETI showed greater yields and N uptake than the GS treatment, while there was no significant difference in yield between the ETI and GS treatment in trial 3 (Figure 1). Yield responses to N rates varied drastically between trials. In trial 1, there was a linear response of yield to fertilizer rate, implying that N rates above 250 lbs N/acre may have been necessary to achieve maximum yield. In trial 2, there was a quadratic yield response to fertilizer rate, with the ETI treatment showing a higher maximum yield and a lower N rate needed to maximize yield compared to the GS treatments. In trial 3, yield increased with increasing N rate in GS, but not in ETI, while there was no significant difference in yield between the two irrigation treatments. In trial 4, high aphid pressure precluded the implementation of the irrigation treatment. The pest pressure also caused relatively low yield, with no yield response to fertilizer N rate.

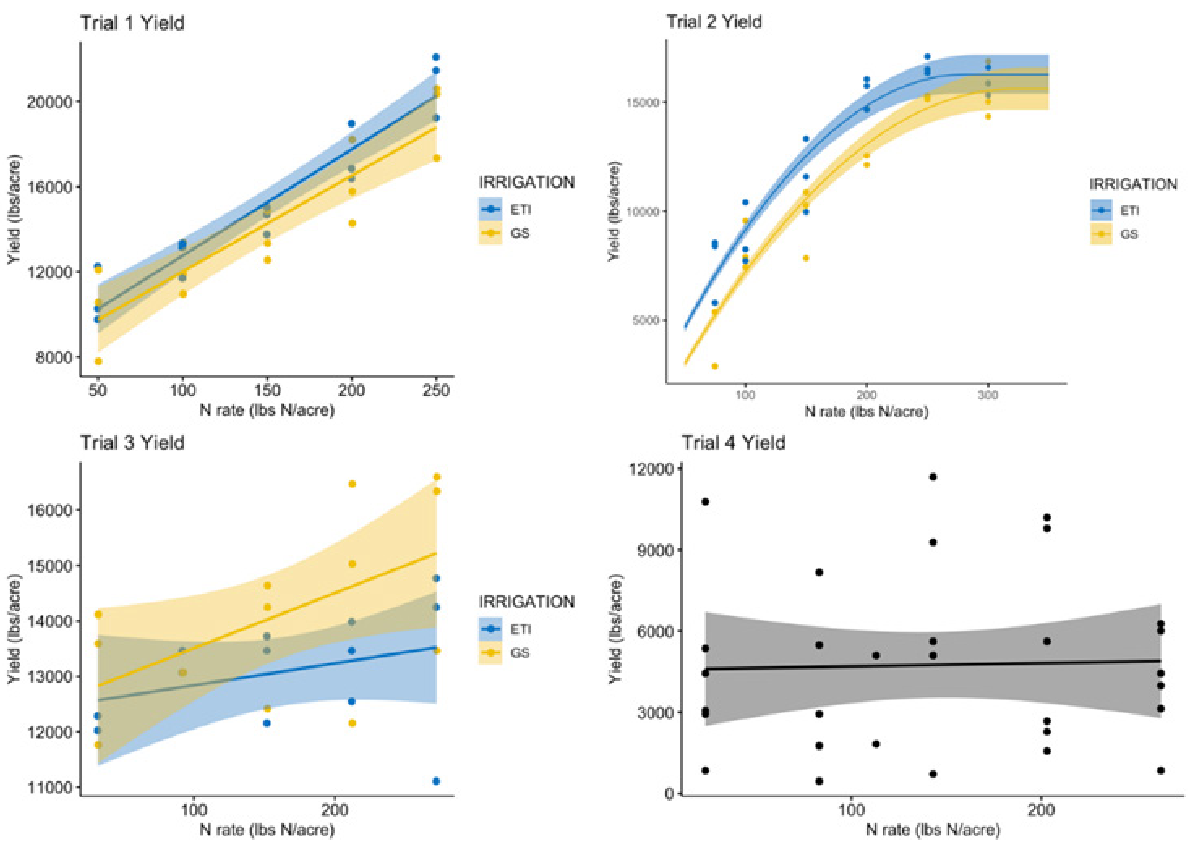

Figure 1. Response of broccoli yield (lbs ac^{-1}) to N fertilizer rate (lbs N ac^{-1}) for the grower standard (GS) and ET-based irrigation (ETI) practice for Trial 1 (top left), Trial 2 (top right), Trial 3 (bottom left), Trial 4 (bottom right). Shading indicates 95% confidence intervals.

Soil nitrate concentrations were significantly affected by irrigation management (data not shown). In the 12-24″ depth increment during the postharvest testing period in trial 1, mean soil nitrate concentrations were 4.6 ppm for ETI and 5.1 ppm for GS, suggesting that more N may have moved below 12″ in the GS treatments. In trial 2 midseason testing period, mean nitrate concentrations were 20.2 ppm for ETI and 17.1 ppm for GS in the 0-12″ depth increment, while nitrate concentrations were 20.2 ppm for ETI and 22.1 ppm for GS in the 12-24″ depth. This indicates retention of N in the topsoil ETI treatment and potential leaching of N into the second foot in the GS treatment.

Data analysis for assessing the effect of irrigation management and N rate on soil mineral N concentrations in trial 3 and 4 is underway.

Take-Home Message

Using ET based scheduling to optimize irrigation rates not only reduced water inputs, but also increased yield and N use efficiency in two out of three trials in this study. Our findings suggest that optimizing irrigation scheduling is one tool growers can use to reduce N rates in efforts to comply with increasingly stringent regulation. The lack of effect of N rate on yield in trial 3 and trial 4 illustrates the importance of other factors, such as soil organic matter concentration, residual mineral N in the soil profile, and pest pressure for fine-tuning N management. Future trials will further assess how irrigation management and other factors control N dynamics on conventional and organic ranches with varying N loadings in irrigation water.

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Acknowledgements

We thank staff at Betteravia farms for support in the management of the trials and analysis of samples. We are grateful for financial support from FREP for the continuation of this project.

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

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Introduction

Intensive specialty crop rotations in the central coast region depend on abundant (and costly) nitrogen (N) inputs and often leave a considerable amount of residual N in the soil, which is highly susceptible to leaching below the root zone, especially during winter rains. Losing residual N is a missed cost-savings opportunity and can also cause water quality impairment, affecting environmental and human health. With good management, residual N 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 N from crop residue mineralization and excessive fertilizer application through 'N scavenging'. This practice has been incorporated as a valid 'removal' strategy in the context of balancing 'applied (A)' and 'removed (R)' N 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 'N 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 'N 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 N (C:N) ratio ≥ 20:1.

To help growers meet these requirements, USDA-ARS, UCANR, CLGRB and the RCDs of Monterey and Santa Cruz Counties recently 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, 1:1 technical assistance and cost-share for cover crop implementation.

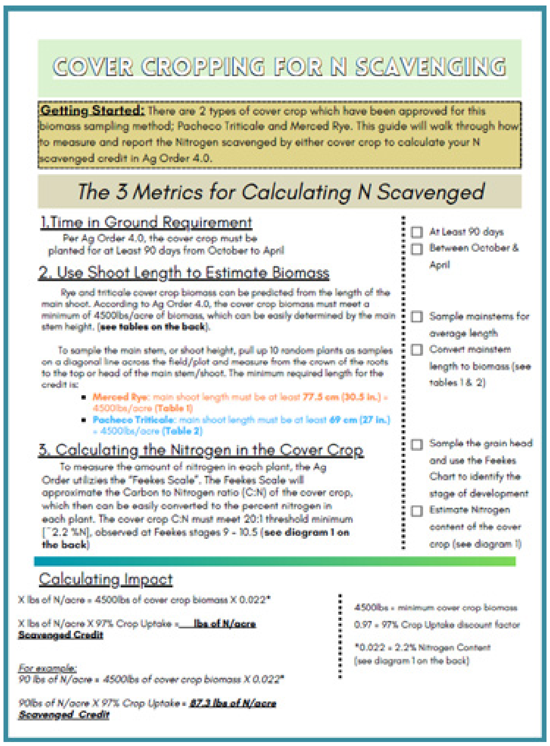
Objectives

1. Educate central coast growers on the practical application of a validated, robust, simple, and field-based method to estimate the biomass and C:N ratio of a winter cereal cover crop (at least 90 days after planting), which can help them to demonstrate residual N 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 N scavenging verification method to reduce residual N loss and receive full credit for 'N removal' in the context of Ag Order 4.0's Applied (A) minus Removed (R) N 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-backed 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, or some variation of them, will still be applicable after the remand process currently in progress is concluded). The project will use 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 will be implemented on commercial fields during winter in years 1-3. Merced Rye and/or Pacheco Triticale cereal grass cover crops will be planted on 20-30 fields each year after the end of the last crop cycle and prior to winter. Cost-share for cover crop seed will be offered to participating growers. Soil N concentration will be measured on all fields using the soil nitrate quick test before and after each cover crop cycle. Participating growers will be trained on how to collect simple measurements of a cover crop 3 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 will be 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 will be tailored to growers of different scales, crops and cropping systems, and will 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 N 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.



COVER CROPPING FOR N SCAVENGING

Getting Started: There are 2 types of cover crop which have been approved for this biomass sampling method; Pacheco Triticale and Merced Rye. This guide will walk through how to measure and report the Nitrogen scavenged by either cover crop to calculate your N scavenged credit in Ag Order 4.0.

The 3 Metrics for Calculating N Scavenged

1.Time in Ground Requirement

Per Ag Order 4.0, the cover crop must be planted for at Least 90 days from October to April

- ☐ At Least 90 days
- ☐ Between October & April

2. Use Shoot Length to Estimate Biomass

Rye and triticale cover crop biomass can be predicted from the length of the main shoot. According to Ag Order 4.0, the cover crop biomass must meet a minimum of 4500lbs/acre of biomass, which can be easily determined by the main stem height. (**see tables on the back**).

To sample the main stem, or shoot height, pull up 10 random plants as samples on a diagonal line across the field/plot and measure from the crown of the roots to the top or head of the main stem/shoot. The minimum required length for the credit is:

- **Merced Rye:** main shoot length must be at least **77.5 cm (30.5 in.)** = 4500lbs/acre **(Table 1)**
- **Pacheco Triticale:** main shoot length must be at least **69 cm (27 in.)** = 4500lbs/acre **(Table 2)**

- ☐ Sample mainstems for average length
- ☐ Convert mainstem length to biomass (see tables 1 & 2)

3. Calculating the Nitrogen in the Cover Crop

To measure the amount of nitrogen in each plant, the Ag Order utilizies the "Feekes Scale". The Feekes Scale will approximate the Carbon to Nitrogen ratio (C:N) of the cover crop, which then can be easily converted to the percent nitrogen in each plant. The cover crop C:N must meet 20:1 threshold minimum [~2.2 %N], observed at Feekes stages 9 - 10.5 (**see diagram 1 on the back**)

- ☐ Sample the grain head and use the Feekes Chart to identify the stage of development
- ☐ Estimate Nitrogen content of the cover crop (see diagram 1)

Calculating Impact

X lbs of N/acre = 4500lbs of cover crop biomass X 0.022*

X lbs of N/acre X 97% Crop Uptake = **___ lbs of N/acre Scavenged Credit**

For example:
*90 lbs of N/acre = 4500lbs of cover crop biomass X 0.022**

90lbs of N/acre X 97% Crop Uptake = ***87.3 lbs of N/acre Scavenged Credit***

4500lbs = minimum cover crop biomass

0.97 = 97% Crop Uptake discount factor

*0.022 = 2.2% Nitrogen Content (see diagram 1 on the back)

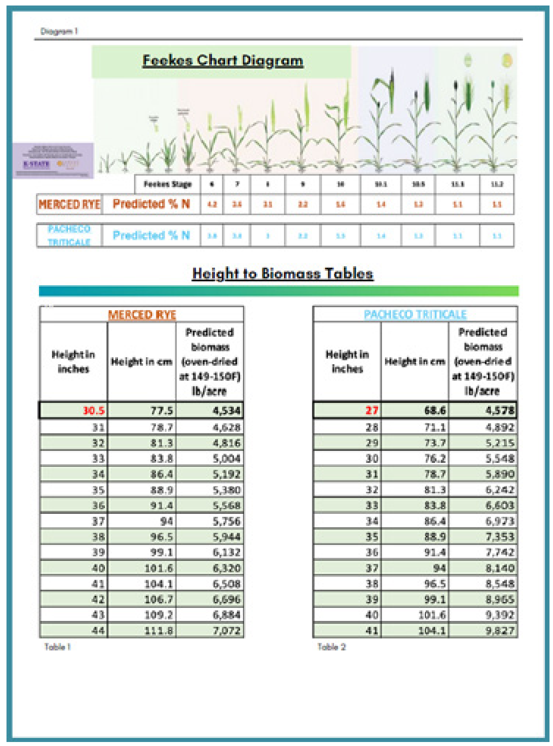


Diagram 1

Feekes Chart Diagram

Height to Biomass Tables

MERCED RYE		
Height in inches	Height in cm	Predicted biomass (oven-dried at 149-150F) lb/acre
30.5	77.5	4,534
31	78.7	4,628
32	81.3	4,816
33	83.8	5,004
34	86.4	5,192
35	88.9	5,380
36	91.4	5,568
37	94	5,756
38	96.5	5,944
39	99.1	6,132
40	101.6	6,320
41	104.1	6,508
42	106.7	6,696
43	109.2	6,884
44	111.8	7,072

Table 1

PACHECO TRITICALE		
Height in inches	Height in cm	Predicted biomass (oven-dried at 149-150F) lb/acre
27	68.6	4,578
28	71.1	4,892
29	73.7	5,215
30	76.2	5,548
31	78.7	5,890
32	81.3	6,242
33	83.8	6,603
34	86.4	6,973
35	88.9	7,353
36	91.4	7,742
37	94	8,140
38	96.5	8,548
39	99.1	8,965
40	101.6	9,392
41	104.1	9,827

Table 2

Figure 1. Draft field guide to calculate Cover Crop N scavenging (lb N) for Ag Order 4.0 credit.

Partial Results and Accomplishments (0-6 months)

Direct individual assistance to growers:

- During the first half of Yr1 the project team reached out to 27 potentially interested growers and initiated enrollment of participants for winter cover crop planting in 2024 and training on N scavenging quantification in early 2025.

- A complete list of participants for winter of Yr1 will be confirmed in September of 2024, and one-on-one assistance with cover crop seed cost-share, planting guidelines, and soil N sampling will be initiated in October-November 2024.

Education and Outreach:

- The project team has been working with project supporters and technical advisors to develop a first draft of outreach materials that will be used in upcoming grower trainings and education events (Fig 1).
- The project team has maintained communication with staff from ag industry groups, grower and shipping companies and academic researchers working on the central coast region, to identify and coordinate opportunities for cover crop and N management education and outreach events under this project.
- The project team will present the scope of this project and a general overview of multiple benefits from the use of cover crops (including N management optimization in the context of Ag Order 4.0) during the Latino Farmer Conference in November 2024.
- The project team will host an educational field day focusing on the use of cover crops for N management with a group of 8 Spanish-speaking growers who are part of land access project facilitated by Kitchen Table Advisors (KTA). These growers will be organically farming and co-managing 8 contiguous fields at an 88 ac ranch in Watsonville and are also part of a larger cohort of growers receiving dedicated technical and financial assistance from the RCD of Monterey County in collaboration with the RCD of Santa Cruz County.

Take-Home Message

Using winter cover crops to recover and recycle end-of-year residual N 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) N 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.

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Estimating Mineralization and N Utilization from Banded Compost Applications

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Introduction

Organic fertilizers and composts are important sources of nutrients for crops and are increasingly popular to maintain or improve soil health. The contribution of organic materials to crop-available nitrogen (N) depends on net N mineralization, which is affected by temperature, moisture, soil texture, the properties of the organic materials, and their management. In Merced County, the application of poultry 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 is frequently incorporated in a band above the buried drip tape. As with sweetpotatoes, additional N is supplied through the drip system during the growing season.

Completed and ongoing FREP projects in California cropping systems have contributed greatly to our understanding of N availability from incorporated organic materials. Based on our research, 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, the calculator may underestimate N availability from the poultry manure compost. Consequently, the application rate for poultry manure compost and in-season N fertilizer would be overestimated, increasing the risk of excess N being leached as nitrate. The most likely reasons for an underestimation of N mineralization are the very low clay content of the soils, high surface temperatures, frequent irrigation using drip irrigation, and cultivation for weeds.

Objectives

The objective of the project is to develop N budgets for sweetpotato and processing tomato production in Merced County where the crop nutrient sources include both organic amendments and mineral fertilizers as fertilizer sources. Specific objectives are:

1. Determine N release of commonly used poultry manure composts and other organic fertilizers 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 sweetpotato plants throughout the growing season.
4. Conduct outreach and develop user-friendly tools for growers and consultants.

Description

The project started in spring 2024 in two commercial sweetpotato fields near Ballico, CA. 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).

Table 1: Soil properties at the two trial sites. Samples were collected in spring 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
1	0.70	0.04	6.83	0.12	84	3	loamy sand
2	0.99	0.05	6.44	0.17	78	5	loamy sand

A compost made from poultry manure, steer manure and almond hulls was applied in both fields prior to transplanting the sweetpotatoes. The compost was machine applied in a band in the center of the bed at 3.9 t/ac at site 1 and 5.9 t/ac at site 2 (Figure 1). Each trial consists of two treatments with four replicates: (i) control plots without compost and (ii) plots with the growers' compost application rate. Plot size was 3 beds wide (20 ft) and 50 ft long.

Sweetpotatoes were transplanted on May 1st and 17th at sites 1 and 2, 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 (Figure 1). and soil moisture and temperature sensors were installed at depths of 3 and 6 in.

Figure 1: Banded compost applications were made using a commercial 3-row applicator calibrated at 8 cu yds/ac (left). Litter bags were placed after transplanting and marked for later removal (right).

Every three weeks during the growing season, soil samples from the center of the bed are collected from the top 2 ft of the profile from both treatments. These samples are analyzed for ammonium-N and nitrate-N. At the same time, four replicated litter bags are removed and analyzed for total dry matter, as well as for carbon and N content in the dry matter. The soil and litter bag analyses will contribute to our understanding of compost decomposition and release of N over time (Objective 1).

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

At harvest, plant dry matter, yield and N concentration in the biomass will be determined in plots with and without compost application. 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 both treatments.

Trials in processing tomato fields are planned to begin with fall compost applications for the 2025 growing season.

Results and Discussion

The compost had C to N ratios of 15.4 and 13.8 at sites 1 and 2, respectively (Table 2). Preliminary analyses of the soil samples taken from the center of the bed in 3-week intervals suggest that the compost only slightly increased plant-available N in the soil.

Sampling and data collection will continue throughout the season.

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

Site	Total C (% in DM)	Total N (% in DM)	C to N ratio	DM (%)	Application rate (t/ac as is)	Application date
1	13.9	0.9	15.4	68	4.0	04/30/2024
2	15.3	1.1	13.8	74	5.9	05/17/2024

A comparison of the soil temperature measured at field site 1 and at the Denair II weather station, which is less than 6 miles away, shows that the temperature at the field site was much higher during the day than at the Denair weather station between early May and late June (Figure 2). During this period, the plants were still small and did not reach the center of the bed where the sensors were located. At the weather station, soil temperature is measured under permanent grass cover. In July, the plants covered most of the bed, shading the soil above the sensors, and the average temperature at the field site was similar to the temperature at the weather station. However, daily fluctuations were much more pronounced at the field site. These preliminary data suggest that N mineralization rates calculated using soil temperatures measured at CIMIS stations may underestimate actual mineralization rates in the field during the early stages of the growing season.

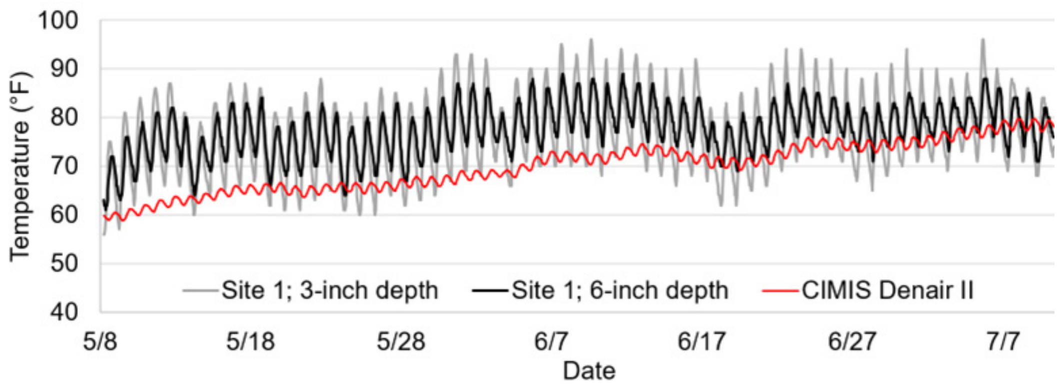

Figure 2: Comparison of soil temperature measured at a depth of 3 and 6 inches below the surface drip tape at site 1 and at a depth of 6 inches at the CIMIS Denair II weather station located 6 miles northwest of field site 1.

Acknowledgement

We would like to thank Zhixu Zhang, Fred Brott, Hailey Romero, and Brian Hartman for help with laboratory analyses and field work, and Brandon Silveira for his help and cooperation. Funding for this project was provided by the CDFA Fertilizer Research and Education Program.

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

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Introduction

To comply with the Central Valley (CV) Irrigated Lands Regulatory Program (ILRP) and 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 data. Project leaders have created an extensive Cal Vadose Zone Monitoring Network to study nitrate leaching in key crops including almonds, oranges, and processing tomato rotation. 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 rates of nitrate leaching.
2. Evaluate uncertainty in predicted nutrient 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 modelling 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 3 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.

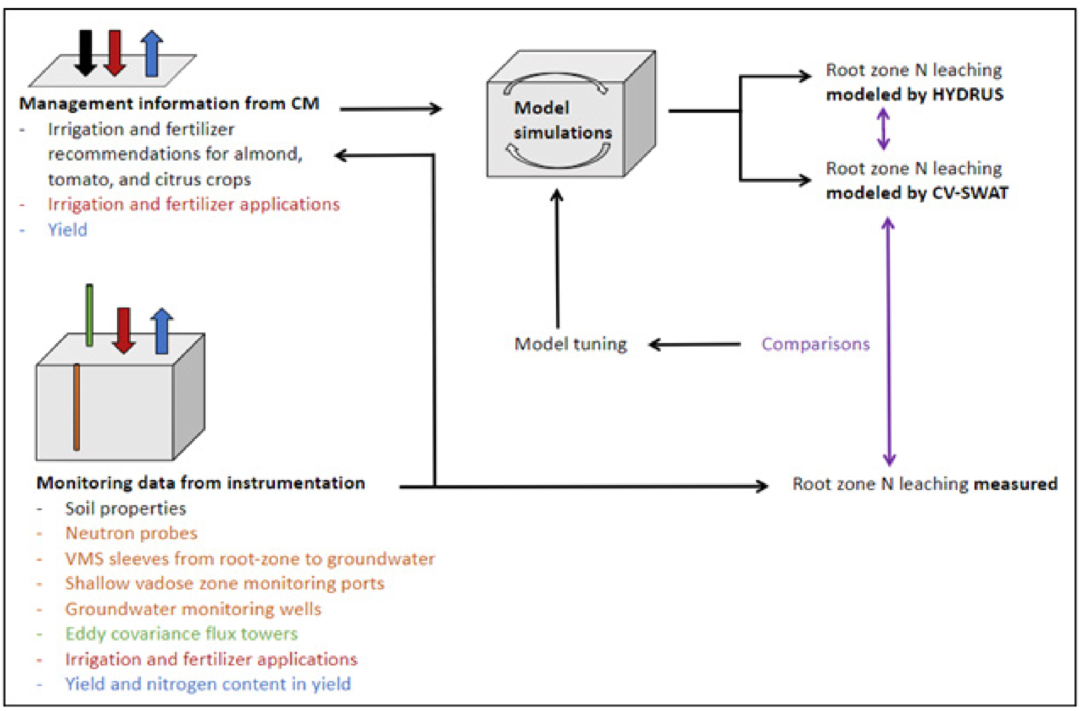

Figure 1. Project schematic integrating management data, monitoring data, and modeling simulations.

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 vadose zone sleeves and monitoring ports, eddy covariance flux towers, irrigation and fertilizer applications, groundwater observation well networks, neutron probe, remote sensing, soil sampling, and yield (Raij-Hoffman et al., 2024). Using these data, this project will evaluate and verify CM efficacy in minimizing nitrate leaching while maintaining or improving production. Monitoring and management data will be integrated into CM to derive recommendations that will be compared against actual practices. This data will also be used to create CV-SWAT modeling scenarios for each site. First, we will compare measured leaching against modeled leaching estimates using the "Root-zone Library" of existing, calibrated model scenarios. Second, we will compare measured and modeled water and nitrogen balances using detailed CV-SWAT simulations, customized to reflect on-farm management. Third, CV-SWAT output will be compared to other calibrated root-zone model(s) (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 and preliminary findings are:

- Nitrate leaching occurs during heavy winter rainfall following dry summers.
- Stacking conservation practices (e.g., cover crops, irrigation nitrogen credit) reduces residual soil nitrogen at the end of the crop season that could be leached in the winter.
- 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 deep vadose zone to groundwater table.

CropManage Evaluations.

Utilization of CM at the 3 study sites is ongoing and monitoring data will be compared to CM recommendations for irrigation and N application at the end of the growing season to inform recommendations for next year's management. The grower managing the almond site began using decision-support technology several years ago to automate site-specific irrigation scheduling based on ET and soil moisture and 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.

Moving forward, canopy cover measurements will be taken and integrated into CM to locally refine crop coefficients. The tomato grower's applied water has been relatively consistent with CM recommendations throughout the growing season. For the citrus site, an existing proxy crop model has been employed with adjusted crop coefficients, canopy curves, and N demand to allow for monitoring data integration into CM to prepare for crop model refinement and review of recommendations.

Root-zone Modeling.

Local CV-SWAT models have been delineated to represent each site and integration of historical management information and crop model calibration is ongoing. Data from the Root-zone Library were compared against historical management data for almond blocks revealing consistency in existing CV-SWAT modeled scenarios to actual historical data (Figure 2a. and 2b.) We analyzed the fate of applied N in these scenarios (Figure 2c) and the reduction in nitrate leaching after the adoption of irrigation/fertigation technology

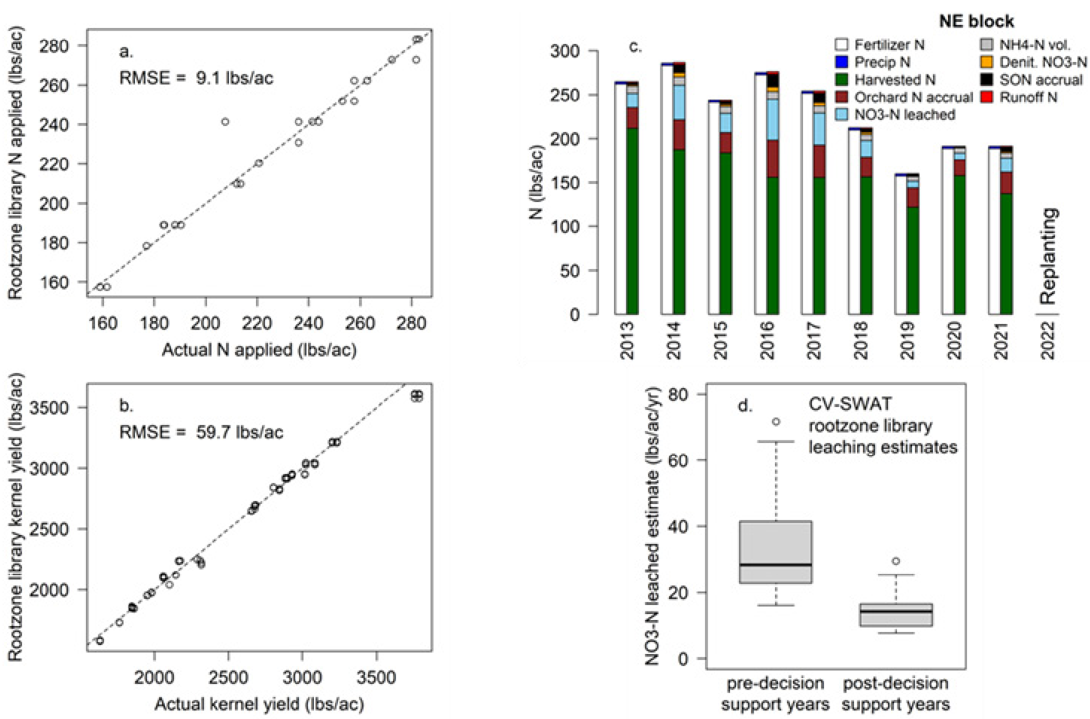

Figure 2. CV-SWAT model simulation results from the Root-zone Library that match historical crop x climate x soil x N application x yield data for the almond site. Panes a and b illustrate the quality of matches to N application and yield, pane c depicts the fate of applied N in these scenarios, and pane d shows the estimated response in nitrate leaching after the adoption of decision support technology.

Accomplishments

- Installed flow meters and telemetric data loggers at the 3 sites and linked them to CM.
- Introduced CM to growers from 2 sites.
- Collected data in the Cal Vadose Zone Monitoring Network for 7 months.
- Delineated CV-SWAT models to represent each of the 3 monitoring sites.
- Compiled and integrated management information into the almond CV-SWAT model to enable validation against measurement data and comparison to HYDRUS 2D/3D.
- Identified the need for local refinement of crop coefficients based on canopy cover.
- Demonstrated improvements in N recovery from the use of decision-support tools

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Acknowledgements

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

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Introduction

The sustainability of California rice systems is being threatened by ongoing droughts. Over the past decade rice production area has been reduced by 15-50% in five of those years. In four of the five years, reductions were directly related to drought. This has impacted the economic livelihoods of rice growers as well as having environmental impacts on valuable waterfowl habitat during the winter.

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 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 a NT system. Primary among them are ensuring good stand establishment, optimizing weed control and developing best management practices for nutrient management. Further complicating the challenge are a wide range of potential field conditions that are likely before planting. Differences in field condition relate to how fields were managed over the previous year. This includes where fields were fallowed in the previous year and tilled (common following drought years), and second, where rice was grown, straw may have been left on the surface, removed for off-site use or burned. In this project, our goal is to develop the agronomic information required to make these systems viable and sustainable, specifically by determining N management practices and identifying herbicide programs. In addition, we are quantifying water use in these systems.

Objectives

In the first year of the study, the research will begin on-station at the Rice Experiment Station, where we have better control and management. We will:

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

In the second and third years, research will continue on-station but also move more on-farm and be evaluated at field-scale. Throughout this whole process, we will be engaging with farmers, CCAs and PCAs through field days, winter grower meetings and informal meetings.

Description

In 2024, we initiated an experiment at the Rice Experiment Station with three no-till drill seeded (NT-DS) systems. In brief, we no-till drilled and seeded into three different seed beds: (1) a seedbed that was fallowed and worked the previous year (summer-prep), (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. In the seedbeds 2 and 3, the fields were winter flooded. The fields were planted on May 1, flushed on May 2 and drained on May 6. On average across treatments, 50% of the crop had emerged by May 14.

No further irrigation was applied until May 29 and 30 when the fields were flooded for a permanent flood. Just before the permanent flood (May 26), we applied N fertilizer (urea) and herbicides (Pendimethalin, Super Wham and Loyant). On July 11, we applied Clincher. We implemented a number of trials within these plots including (1) N management trials (N source, timing and rates), (2) herbicide trials, (3) gibberellic acid seed treatment, and (4) water use. Preliminary data are currently available on the use of gibberellic acid and the rate of emergence, and water use during the establishment phase.

Results and Discussion

This is the first year of this study. As such we have relatively little data to present at this time as the crop will not be harvested until September/October. However, we have data related to two objectives of this study related to optimizing stand establishment and water use.

Stand establishment

We tested the use of gibberellic acid (GA) as a seed treatment to promote and speed up emergence. Among the three treatments, seedling emergence was more rapid relative to the Chopped where full emergence occurred about two days later (Figure 1, left). These differences were likely due to differences in soil temperature which averaged 74.6, 70.8 and 67.9 F for Fallow, Removed, and Chopped, respectively. GA had a small effect on emergence and resulted in emergence occurring about a day earlier. We will look at this again next year, but based on these findings, GA does not appear to be necessary.

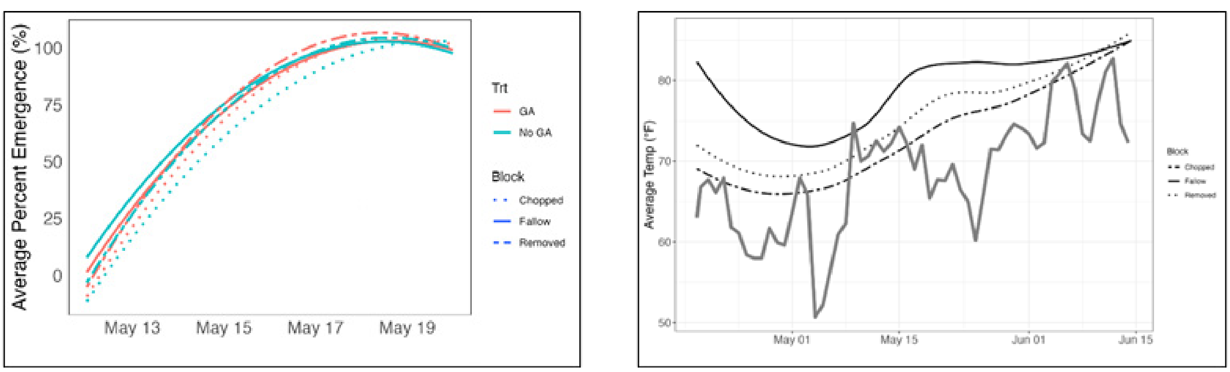

Figure 1. Effect of gibberellic acid (GA) on seedling emergence (left) and soil temperature at 5 cm below soil surface (right).

Water savings

These systems conserve water in two ways. First, they use water that is available in the soil. With conventional tillage, the soil is dried out to prepare a seed bed. In these systems, planting occurs as soon the soil is dry enough to support equipment and not gum up the planter. Compared to conventional tillage, at the time of planting, there was about two inches more water in the drill seeded systems. The second way water is conserved is that there is no standing flood water on the field for the first month.

In conventional systems most of the water lost during the first month is due to evaporation. We are able to minimize evaporation in these systems.

Compared to conventional water seeded rice, evaporative losses were 4.8 inches less. Consumptive water use (evapotranspiration-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 water seeded conventional till. CT-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 system (CT) (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

Accomplishments

We initiated the field experiments as planned. We further had a well-attended field day on June 18. There was a lot of interest in these systems.

Recommendations

Too early to make any at this time.

Take-Home Message

Preliminary take-home messages are that these systems do conserve water. They also allow for an earlier planting date. We do not think a GA seed treatment is required.

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Acknowledgements

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

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Introduction

Almond production in California's Central Valley heavily impacts groundwater quality due to high nitrogen (N) use. Current harvest practices limit the enhancement of soil organic matter, while large quantities of almond hulls and shells are removed and used in other industries, primarily dairy farms. With almond production surpassing dairy growth, alternative strategies are necessary. This project focuses on recycling hulls and shells in almond orchards to influence N, potassium (K), and carbon (C) cycling, thereby improving soil health and productivity. Previous studies show hull/shell amendments can meet around 80% of orchard potassium needs, but N supplementation and its release dynamics are less understood. Field trials will explore three strategies: 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, enhance nutrient use efficiency, and assess reapplication economics. Stakeholder engagement and educational outreach will help identify scalable, sustainable hull/shell use opportunities in almond 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 variety. The study used a randomized 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.
- Monthly soil and hull/shell sampling from March to July to assess nitrogen release and absorption; leaf sampling from April to July to evaluate plant nutrient status and interactions with K, magnesium, calcium, and sodium, continuing until fall 2025.
- Evaluated changes in soil N and hull/shell nutrient composition to understand N release dynamics and comparing treatments with evaluations continuing until fall 2025.
- Compared nutrient release and water use in hull/shell amended trees with off-ground versus traditional on-ground harvesting.
- Assessed trunk circumference and Leaf Area Index (LAI) from May to July to determine growth rates, with evaluations continuing until fall 2025.
- 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 Nitrate-Nitrogen (NO_3-N) and Ammonia-Nitrogen (NH_4-N) levels at 0-10 cm depth were ~ 50 % higher in hull/shell amended blocks compared to unamended blocks across all three assessments from March through May (Figure 1A and B). There were no noticeable differences between the hull/shell amended blocks using on-ground and off-ground harvesting methods. The results clearly indicate that the hull/shell amendments applied in fall began adding nitrogen (N) to the soil during the growing season without interacting negatively with N fertilization. However, soil NO_3-N levels measured in the fall (September 30) were significantly lower in the hull/shell amended blocks that were harvested using on-ground method, indicating its interaction with the fall N application (Figure 1C).

In contrast, there was no noticeable difference in soil N between unamended blocks and those amended with hulls/shells using off-ground harvesters.

Decomposition of hulls/shells applied in fall influenced by irrigation, rainfall, and microbial activity, might have reduced its initial high C to N ratio (> 60:1) to an optimal level by March and started releasing N to the soil during the leaf-out period when the trees needed it most. The decomposition rate of the applied amendments under field conditions was approximately 50% within one year (Andrews, 2022). Consequently, in blocks harvested with off-ground harvesters, the remaining residues stayed in the topsoil, balancing the nitrogen absorption of the newly applied hulls/shells, which have a high C to N ratio. However, when amended blocks were harvested with on-ground harvesters, the semi- or fully decomposed nitrogen-rich residues were removed during fruit sweeping. As a result, when fresh hulls/shells were re-applied, they interacted with the fall nitrogen application and existing soil nitrogen to initiate its decomposition. However, the exchangeable potassium (K) concentrations in the amended blocks were significantly higher than those in the unamended blocks (Figure 1C). Additionally, soil moisture content was higher in the amended blocks, underscoring its role in water conservation by reducing evaporation (Figure 1D).

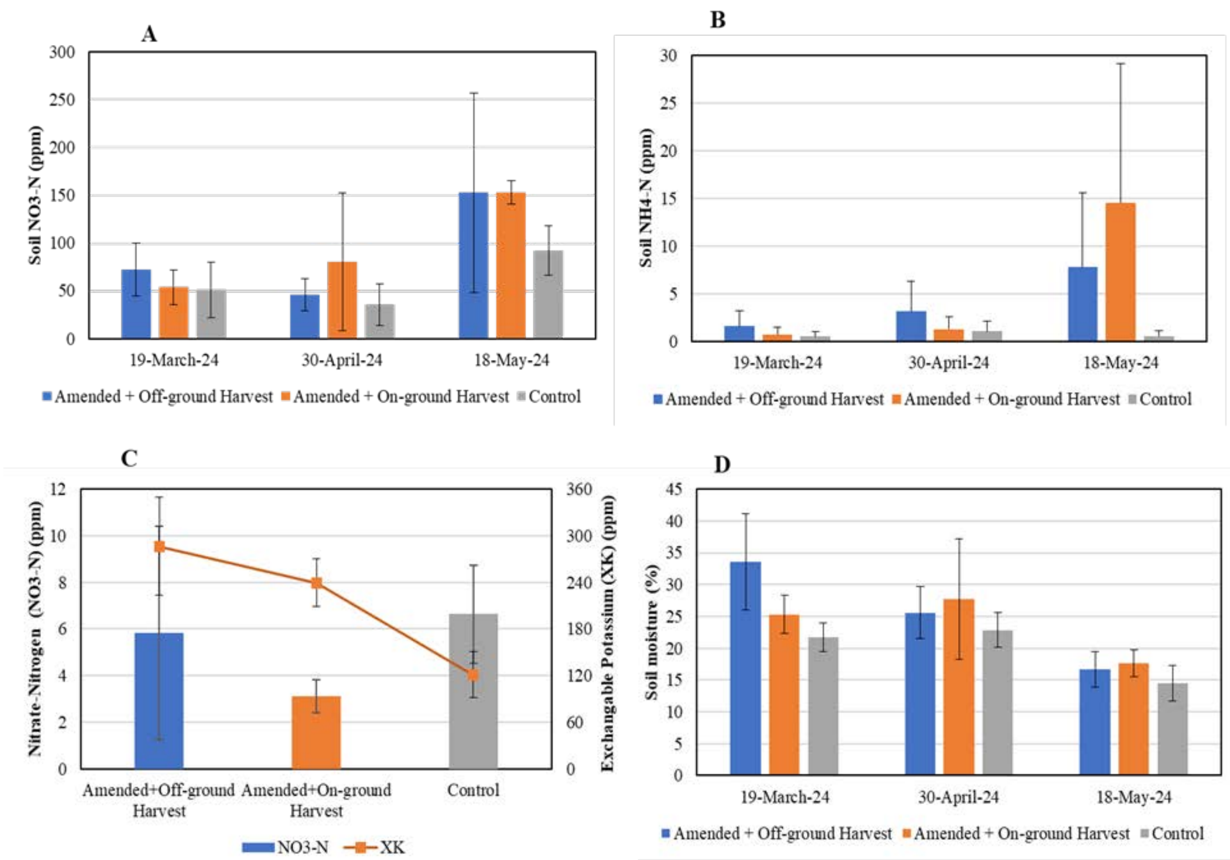

Figure 1. Soil N and moisture content under different treatments over time. A. Soil NO_3-N concentrations measured from March through May 2024. B. Soil NH_4-N concentrations measured from March through May 2024. C. Soil NO_3-N concentrations measured in September 2023. D. Soil moisture content recorded during the growing season. Error bars represents standard deviation.

Further, the addition of N along with other nutrients from the hulls/shells over the years contributed to higher trunk circumferences in trees compared to those in unamended blocks (Figure 2A). The average LAI of trees in all three treatments decreased from May through July, with LAI slightly higher in hull/shell amended blocks with on-ground harvesting (Figure 2C). Similarly, trunk growth from May through July was slightly higher in these blocks and explains the role of leaf area in trees' growth (Figure 2B). Additionally, we observed a positive correlation between soil N and trunk growth, highlighting the critical role of N in trees' vegetative growth. However, vegetative growth of trees in a season depends on the fruit load of trees determined by the successful pollination and fruit-set during blooming (Karunakaran, et al. 2023). Therefore, it's essential to observe the yield in these blocks to delineate the role of hull/shell amendments in the trees' vegetative performance.

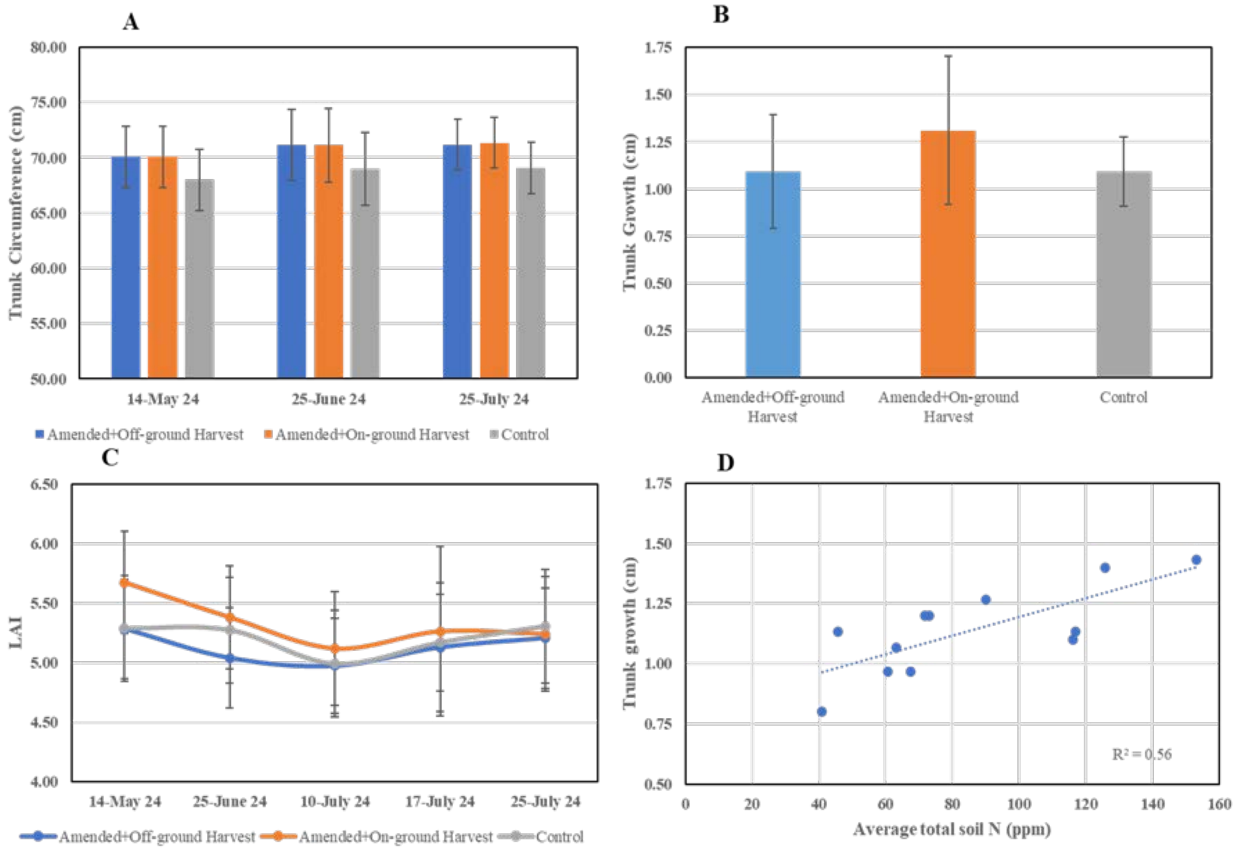

Figure 2. Trunk and leaf growth of almond trees under different treatments over time. A. Trunk circumference of trees from May through July 2024. B. Trunk growth of trees between May and July 2024. C. Leaf area index of trees from May through July 2024. D. Correlation between soil N and trunk growth of trees

Recommendations

Applying hull/shell amendments at fall increases soil N during the growing season, enhances moisture retention, and promotes tree growth. When combined with off-ground harvesting, it minimizes soil disturbance, allowing the released N from previous application to balance the N absorption of re-applied amendments without negatively interacting with existing soil or fall fertilizer N.

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Acknowledgements

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Optimizing Potassium (K) Fertilization Management in Almond Orchards

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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

This project aims to improve the methodology used to determine plant and soil K to aid growers in making fertilization decisions.

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 EMI, and a GR Spectrometer. We combined the data coming from the sensors with the soil samples data and used Empirical Bayesian Kriging (EBK) to map the spatial distribution of K.
- Collect leaf samples from seven 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 (7:00, 13:00 and 19:00, and on July 2023 at 4:00) 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 from seven focus trees. We are still processing these data.
- Collaborate with Professor Alireza Pourreza's lab, utilizing hyperspectral images in an attempt to build a remote sensed model for leaf K.

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 significant K deficit (Figure 1). Soil solution K and exchangeable K were only weakly positively correlated.

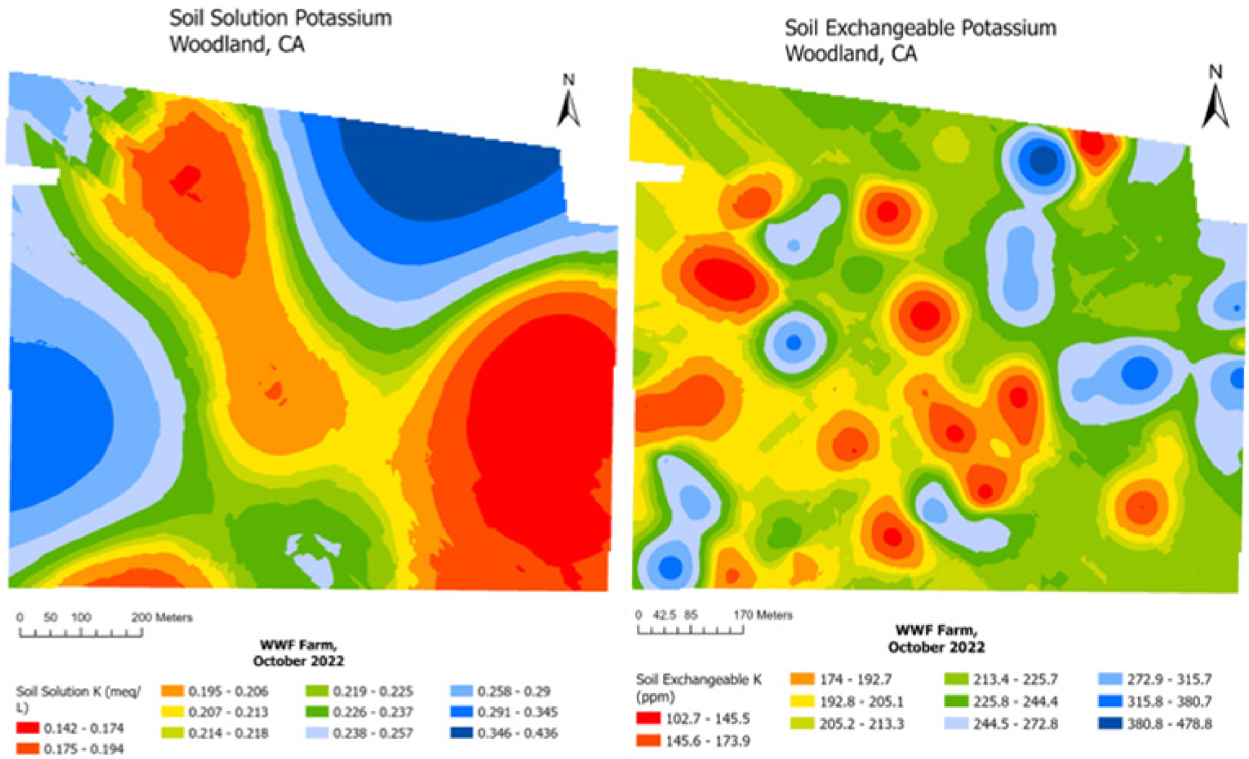

Figure 1. Soil solution K (meq/L) and Exchangeable K (ppm) in Westwind Farm. The soils were mapped on October 27, 2022. The maps were created using Ordinary Kriging in ArcGIS Pro (version 3.0.0).

Exchangeable K shows some consistent positive correlations with cation exchange capacity, soil moisture, clay percentage, and exchangeable form of Ca and Mg, while soil solution K displayed more variability over the different soil samplings. The model found with EBK in Westwind for exchangeable K had a good performance, and is therefore indicated as a potential explanatory model.

In July 2023, leaf K was extremely variable between samples in both locations, ranging in July 2023 from 0.7% to 3.8% in KG Olam and from 1% to 3.2% in Westwind. The distribution of K within the canopy was shown to be consistently non-uniform (top of the canopy has consistently lower level of leaf K). While not always significant, there is a consistent trend suggesting that sampling time also may affect K leaf concentration. The highest concentration of K leaf was observed in the morning and after that, a general decrease in K leaf was detected in both orchards. We are still working on the physiological explanation of this pattern.

In August 2022 and August 2023, the yield of all the investigated trees was collected. We did not see any correlation between April or July leaf K concentration and yield data.

The final product will be the development and calibration of novel soil and aerial methodologies for K variability mapping, a greatly improved understanding of the causes of this variability, and guidance on the management practices needed to optimize fertilizer practices. To make results practical for growers, we will develop an optimized subset of measurement practices to effectively identify areas of differential K demand and response.

Accomplishments

During Year 1 of the project, we shared our findings via the following conferences:

- Poster presentation at the VIII International Symposium on Almonds and Pistachios for publication in Acta Horticulture in Davis (CA) May 7-11 2023.
- Poster presentation at the Almond Board Conference in Sacramento in December 2023.
- Oral presentation at the Fertilizer Research Forum in Fort Worth (TX) in March 2024.
- Oral presentation at the X International Symposium on Plant Nutrition of Fruit Crops in Wenatchee (WA) in June 2024.

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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.

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

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

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

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*

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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*

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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*

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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*

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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*

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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*

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

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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*

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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*

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

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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*

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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*

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

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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*

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

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

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

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

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

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

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

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

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