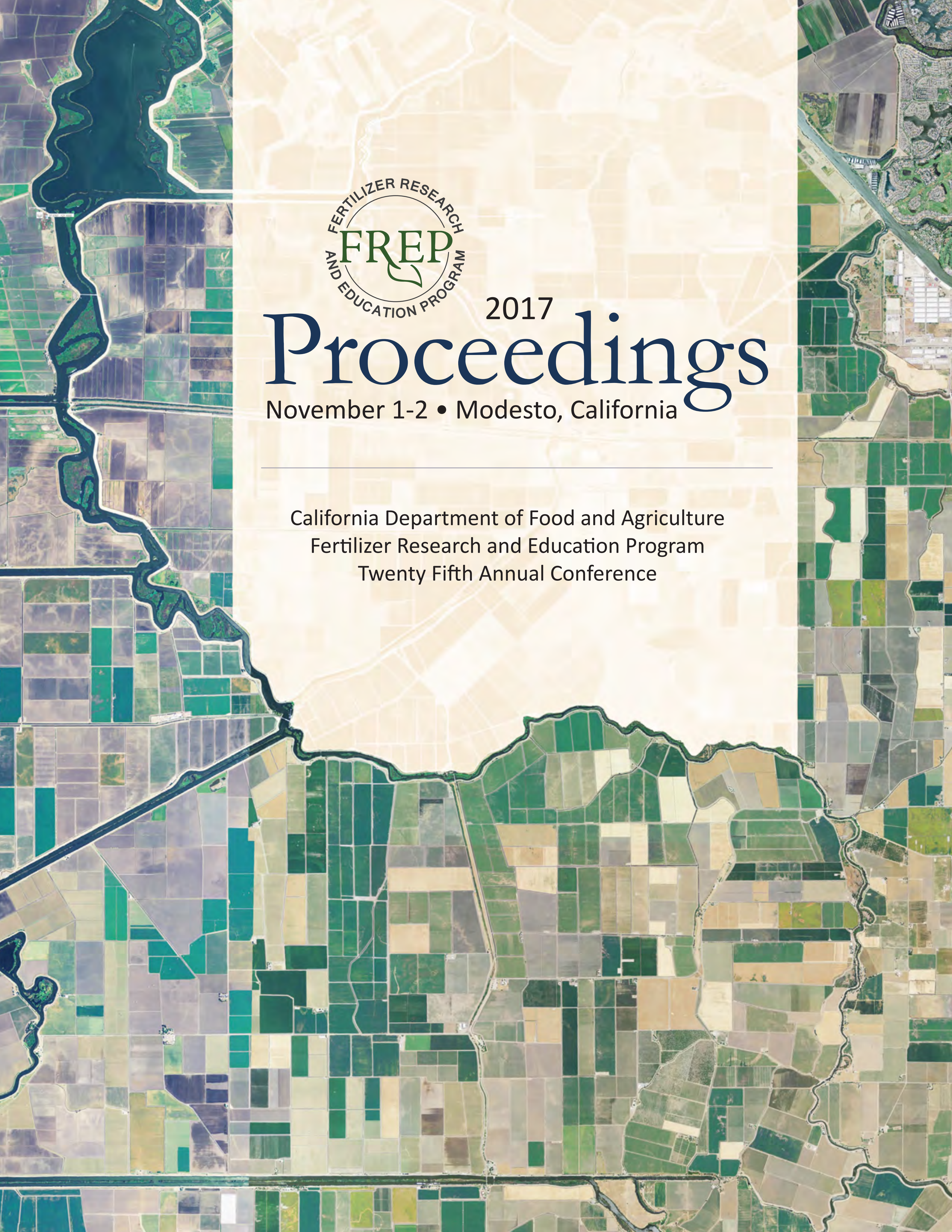
2017 Proceedings

November 1-2 • Modesto, California

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



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Fertilizer Research and Education Program
Twenty Fifth Annual Conference

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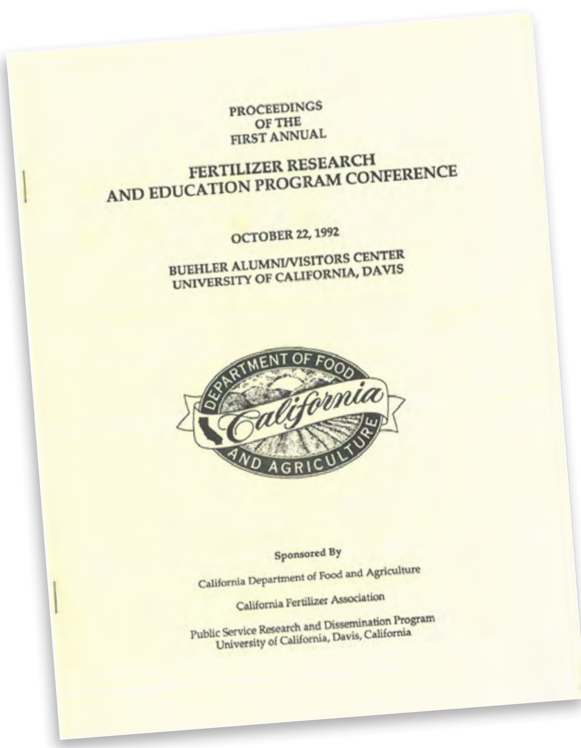
INTRODUCTION

We are CELEBRATING 25 YEARS

of the California Department of Food and Agriculture (CDFA) Fertilizer Research and Education Program (FREP) annual nutrient management conference.

2017 marks the twelfth year of collaboration between FREP and the Western Plant Health Association (WPHA). This joint event is the combination of FREP's annual conference and WPHA's Central Valley Regional Nutrient Seminar. Our partnership extends our outreach to a broad agricultural audience, including consultants, growers, public agency personnel, industry professionals, and academic researchers. The conference partners continue to seek out ways to keep this event in the forefront of agricultural learning opportunities and highly relevant in the ever-changing conditions of California agriculture.

FREP held the first annual conference on October 22, 1992, at the University of California, Davis. The Proceedings booklet was 28 black and white pages, with a cardstock front cover and two staples on the side.


PROCEEDINGS
OF THE
FIRST ANNUAL

FERTILIZER RESEARCH
AND EDUCATION PROGRAM CONFERENCE

OCTOBER 22, 1992

BUEHLER ALUMNI/VISITORS CENTER
UNIVERSITY OF CALIFORNIA, DAVIS

DEPARTMENT OF FOOD California AND AGRICULTURE

Sponsored By

California Department of Food and Agriculture

California Fertilizer Association

Public Service Research and Dissemination Program
University of California, Davis, California

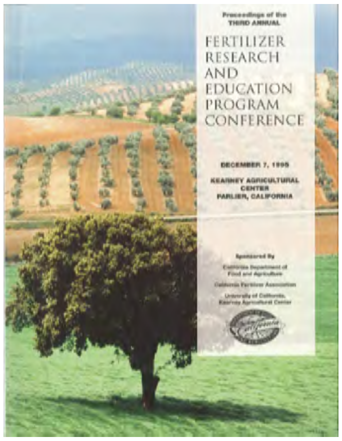
FREP was in its third year of existence, and hosted the first conference after establishing program goals, securing funding and expertise, and funding the first research and education projects.

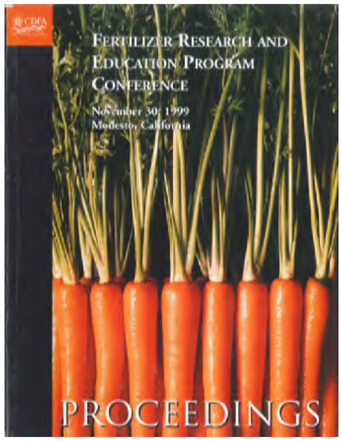
Things have changed since that first conference. Water quality regulations have become part of agricultural life in California as irrigated agriculture has come under greater scrutiny and increased requirements over the past several years, based on the widespread presence of nitrate in aquifers around the state. Many of the regional water quality control boards currently require some or all growers to report their nitrogen applications, either to a grower coalition, or directly to the board. These reports ask for all sources of nitrogen, including from well water, compost applications, and cover crops, in addition to fertilizers.

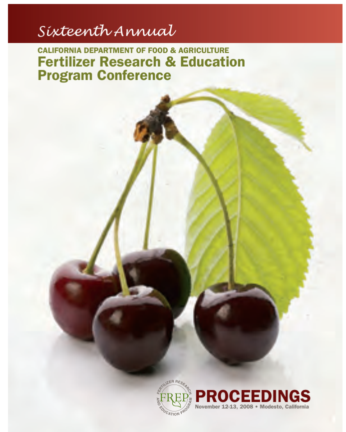
Meanwhile, the State Water Resources Control Board is in the process of issuing agricultural water quality orders that set precedents for all the regional boards. This process should result in consistent yet stringent requirements for nitrogen management planning and reporting across the state.

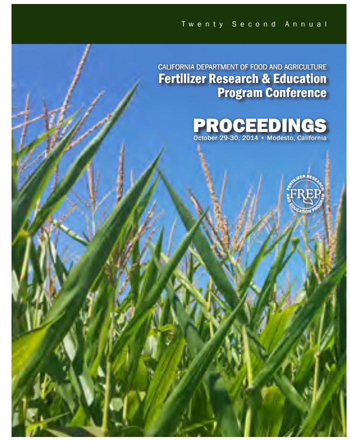
The research and education projects funded by FREP are a leading source of information and assistance for growers and crop consultants who are seeking to comply with water quality regulations. This year's conference program reflects this orientation with numerous presentations focusing on nitrogen and irrigation management, nitrate leaching, and information requirements for nitrogen reporting. In addition, we feature much of the important research updates and practical field-ready information that has characterized this conference in the past.

Frequent conference attendees may notice changes we have been making to the program over the past few years. For the previous two conference, we have









assembled panel discussions to illuminate current issues and practices from a field perspective, and last year, we held a FREP conference poster session. These additions have been well received, and this year we are introducing a short segment that called "Speed Updating." This portion of the conference gives current grant recipients the opportunity to provide a very brief summary of their FREP projects, and the attendees are able to inquire further about specifics that interest them.

The poster session will close the first day of the conference, will highlight nutrient management research and education projects from across California, and will give conference attendees an opportunity to engage with poster presenters and each other on new and emerging nutrient management issues.

Included in these Proceedings are summaries of FREP-funded projects, relevant research presented during the conference, and a list of completed FREP research projects.

In 1990, the California Legislature established FREP with support from the fertilizer industry. California Food and Agricultural Code authorizes an assessment not to exceed one mill ($0.001) on the sale of fertilizing materials to provide funding for research, education, and outreach regarding the use and handling of fertilizing materials.

The primary focus was to reduce nitrate migration to groundwater. As stated on page five of the first FREP Proceedings, "We hope that participants will gain a greater understanding and appreciation for the complexities involved in protecting one of California's most important resources." While that focus remains, with even greater urgency, today's FREP projects address many plant nutrients and a wide range California nutrient management challenges.

To date, FREP has funded over 220 research and education projects, totaling over $17 million in financial support. FREP serves a wide variety of agriculture stakeholders, including growers, agricultural supply and service professionals, university extension and public agency personnel, and other interested parties.

ACKNOWLEDGEMENTS

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

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

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

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

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

Special recognition also goes to the leadership at the California Department of Food and Agriculture, including Secretary Karen Ross; Science Advisor Dr. Amrith Gunasekara; Inspection Services Division Director Natalie Krout-Greenberg; Dr. Amadou Ba, Environmental Program Manager II; Brooke Elliott, Research Analyst I; Dr. Doug West, Environmental Scientist; Dr. Barzin A. Moradi, Senior Environmental Scientist (Supervisory); Mark Cady, Senior Environmental Scientist (Specialist), Natalie Jacuzzi, Environmental Scientist, and Nicole Crouch, Agricultural Aide. In addition, special thanks to Dr. Daniel Geisseler, Cooperative Extension Specialist, and Patricia Lazicki, Assistant Specialist, both with the UC Davis Department of Land, Air and Water Resources, for their diligent work on creating and expanding the FREP research database and Crop Fertilization Guidelines.

CONFERENCE PROGRAM

WEDNESDAY, NOVEMBER 1, 2017

Facilitator: *Dr. Sebastian Braum, Tremont/Lyman Groups*

9:00 - 9:20 **Welcome**
Renee Pinel, Executive Director, WPHA
Karen Ross, Secretary, CDFA

9:20 – 9:45 **A Data Driven Nitrate Leaching Hazard Index and BMP Assessment Tool**
Dr. Toby O'Geen, Soil Resource Specialist, UC Davis Department of Land, Air, and Water Resources

9:45 – 10:10 **Nitrogen Removed with Harvested Crops**
Dr. Daniel Geisseler, Cooperative Extension Specialist, UC Davis Department of Land, Air and Water Resources

10:10 - 10:35 **Field Evaluation and Demonstration of Controlled Release N Fertilizers in the Western United States**
Dr. Charles Sanchez, Professor, University of Arizona

10:35 - 10:50 **Break**

10:50 - 11:15 **CAPCA and CCA Update**
Adam Barsanti, Outreach Relations Manager, California Association of Pest Control Advisers

11:15 - 11:40 **Plant Nutrients in the Classroom**
Judy Culbertson, Executive Director, California Foundation for Agriculture in the Classroom

11:40 – 1:00 **Lunch**

1:00 –2:30 **Panel Discussion: Navigating the Complexities of Nitrogen Reporting in the Central Valley**
Moderator: Dan Munk. Panel: Mike Wackman, Anne Collins-Burkholder, Dan Errotabere, and Melissa Yerxa Ortiz

2:30 – 2:55 **New Fertigation Book**
Dr. Charles Burt, Chairman of Irrigation Training & Research Center, and Professor Emeritus at Cal Poly State University, San Luis Obispo

2:55 – 3:10 **Break**

3:10 – 3:35 **Salinity Management: Correcting a Saline Soil**
Keith Backman, Consultant Manager, Dellavalle Laboratory, Inc.

3:35 – 4:00 **Plant Nutrition: Past, Present, and Future**
Dr. Marja Koivunen, Product Development Manager for Western Region, AMVAC Chemical Corporation

4:00 – 4:40 **Speed Updating: Five Ongoing FREP Projects**
Richard Smith, Dr. Patrick Brown, Daniela Reineke, Parry Klassen, and Dr. Arlene Haffa

4:40 – 6:00 **Poster Session: Nutrient Management Research and Projects**

THURSDAY, NOVEMBER 2, 2017

Facilitator: *Don Wolf, Helena Chemical Co.*

9:00 - 9:05 **Welcome and Recap**

9:05 - 9:30 **Nitrogen Fertilizer Loading to Groundwater in the Central Valley**
Dr. Thomas Harter, Chair of Water Management and Policy, UC Davis Department of Land, Air, and Water Resources

9:30 – 9:55 **What is the Nitrogen Contribution from Added Organic Materials?**
Dr. Rob Mikkelsen, Vice President, International Plant Nutrition Institute

9:55 – 10:20 **Impact of Improved Plant Nutrition on Pest Management**
Dr. Steve Petrie, Director of Agronomic Services, Yara North America

10:20 - 10:30 **Break**

10:30 - 10:55 **Nitrogen Management in Table Grapes**
Dr. Matthew Fidelibus, CE Specialist, Department of Viticulture and Enology, UC Davis

10:55 - 11:20 **Micronutrient Formulations and How They Fit into Fertilization Regimens**
Jay Irvine, President and CEO, Mar Vista Resources

11:20 - 11:45 **Update on Walnut Nitrogen Uptake**
Dr. Katherine Pope, UCCE Orchard Systems Advisor, UC Division of Agriculture and Natural Resources

11:45 - 11:50 **Closing Remarks**

SUMMARIES OF PRESENTED FREP PROJECTS

A Data Driven Nitrate Hazard Index and BMP Assessment Tool

Project Leader

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Professor of Soil Science and Soil Resource Specialist in Cooperative Extension

Co-Investigators

Stathis Diamantopoulos
Project Scientist

Thomas Harter
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INTRODUCTION

California's agricultural regions have an incredible diversity of soils that encompass a range of properties. Considering differences in soil, climate, crops and management, our understanding of the fate of nitrogen in the environment is limited. In light of emerging groundwater regulations, place-based decision support tools are needed to identify settings prone to nitrate leaching and guide decisions to reduce nitrate loss.

The Nitrate Groundwater Pollution Hazard Index (HI) was created several years ago as a tool for growers and regulatory agencies to understand the potential for nitrate contamination of groundwater (Wu et al., 2005). The tool evaluates the relative hazard of nitrate loss as deep percolation for most soil series in agricultural regions of California. There are some shortcomings associated with the index. Mainly that it is based on expert opinion, it is difficult to update, it does not consider crop and climatic differences, and it does not directly provide growers with options to improve N management.

The overall goal of this project is to develop a data-driven nitrate hazard leaching index for every agricultural soil in California. The tool will be developed by linking digital soil survey data with, a process-based hydrological model capable of predicting nitrate leaching over infinite scenarios of soil variability. In addition to soils, the modeling will include 58 different crops, three nitrogen fertilization scenarios and three irrigation efficiency scenarios. The model output will become an interactive decision support tool to evaluate the likelihood of nitrate loss beyond the soil (1.5 m).

OBJECTIVES

The specific objectives of this project are:

1. Create a state-wide, updated digital database of soil survey information
2. Model nitrate leaching using HYDRUS 1-D for agricultural across combinations of soil, crop, climate, irrigation and fertilization
3. Develop an interactive online decision support tool in Google Maps

DESCRIPTION

In theory, soil survey data is the perfect data source to run the HYDRUS-1D model. USDA-NRCS SSURGO data is a widely used publically available digital soil survey dataset. However, we encountered some barriers to using SSURGO. Older soil surveys did not populate complete soil profiles with physical properties needed for the model. Plus, different map unit phases created a massive soil dataset that could not be modeled in a reasonable timeframe. We created a modified soils database combining SSURGO data with measured soil properties from the Soil Survey Pedon database in order to obtain the best soils input data for every soil type (totaling 5685) in agricultural areas of California.

A crop database was prepared for 58 major agricultural crops in CA. The database contains all the required information for Hydrus parameterization in terms of root depth, water uptake, and crop coefficient (Kc) for irrigation of each crop. The crop database was constructed based on a crop list described in (Viers et al., 2012) which also provides mean values of nitrogen application rates and nitrogen content of the harvest. Finally, in order to incorporate the effect of climate in our study, we defined seven

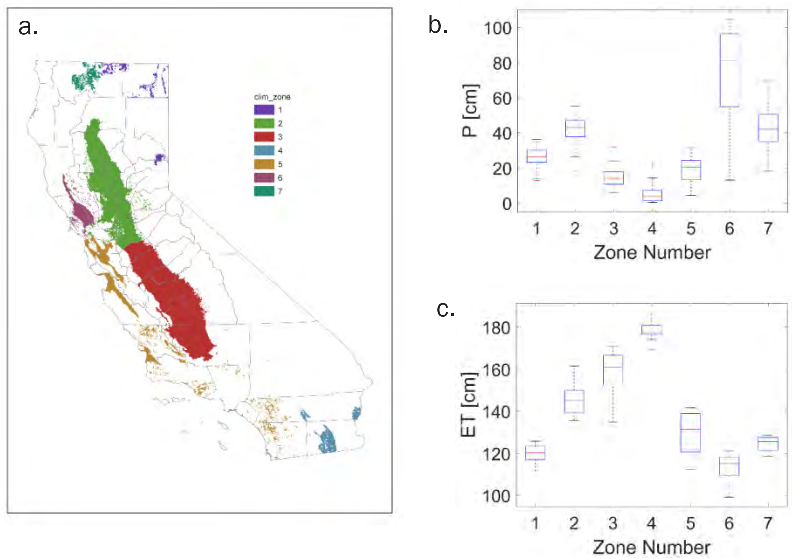


Figure 1. *Seven climatic zones established to run the Hydrus model (a). Differences in annual precipitation (b) and evapotranspiration (c) over a 21-year period (from 1/1/1995 until 12/31/2015) by climatic zone.*

climate zones (Figure 1), which are representative of the climatic variability in the state.

We conducted Hydrus simulations for 58 crops and the thousands of soil-climate combinations. The simulation period was 21 years (1/1/1995 to 12/31/2015). Three irrigation schemes were evaluated based on irrigation efficiencies of 60%, 75% and 90% simulating surface application, sprinkler, and drip respectively. The applied water was based on plant demand, thus it was different for each simulation since it is influenced by the crop type, the climate zone and soil properties. Three different fertilization timing schemes were used to evaluate optimum times of application to minimize nitrate loss: pre-plant-one application at time of planting, in season-one application at the stage of rapid growth, split application-3 three times during early and rapid growth stages. After conducting the simulations for the 21-year period we discarded the first 10 years as a warm-up period. Model output includes a range of information on hydrology and fate of nitrate for a scenario (Table 1).

Model output was integrated into an online interactive decision support tool. The tool is essentially an interactive map that operates in Google Maps. It allows users to select a location, choose a crop, and returns information such as nitrate leached (Table 1) based on crop-climate-soil combination at relative to the scenarios of irrigation and fertilization.

RESULTS AND DISCUSSION

We used estimates of N in crop harvests as a way to evaluate the model. Applied nitrogen rates were taken from Viers et al., (2012). In order to calculate N yield, Viers et al., (2012) combined crop production data with a database of crop N and moisture content. They used a four step process to convert the production data listed by crop to harvested N.

Some simulations overestimated the mass of N taken up by the plant, especially for fruit trees and subtropical fruits (Figure 2). This discrepancy is a result of N being allocated to other parts of the plant besides the harvest such as leaves and wood. However, this discrepancy may also be due to the

Water Dynamics	Units	Nitrate Dynamics	Units
Rainfall	inches	Nitrate leached	lbs/ac
Irrigation water applied	inches	Leaching fraction	%
Deep percolation	inches	Nitrate concentration in leached water	ppm
Runoff	inches	Leaching hazard rating	na
Leaching fraction	%		
Irrigation efficiency	%		

Table 1. *Output information summarized by the nitrate leaching decision support tool.*

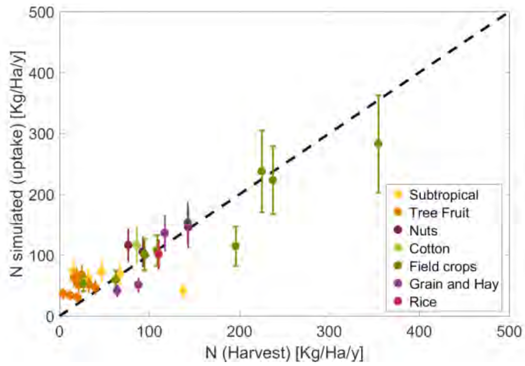
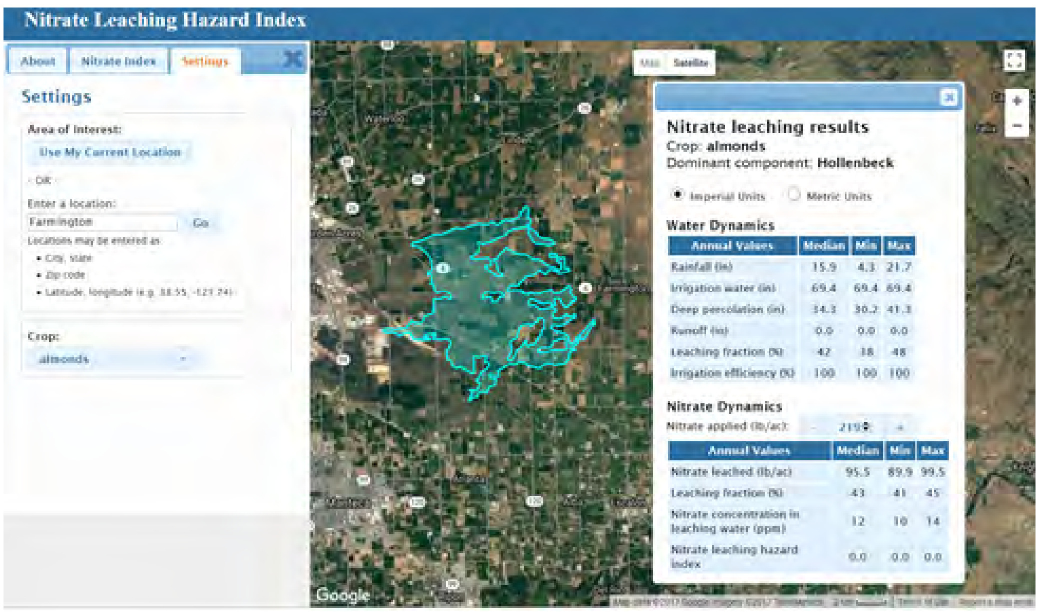


Figure 2 (left). *Calculated N Harvest (N in yield) in Kg/Ha/yr (Viers et al., 2012) vs simulated N uptake by the plant roots for the major crops in CA. The error bars depict the effect of soil and climate in our model.*

Figure 3 (below). *Nitrate leaching hazard decision support tool.*



assumption of passive nitrate uptake in the Hydrus model, which assumes that the root system can take up all available N in the root zone.

Based on the results of the simulations, we created a demo version of the interactive app (Figure 3). This can be found at the following web address: https://soilmap2-1.lawr.ucdavis.edu/nitrate/. Currently, the user can choose a location, a crop type and applied nitrate and the tool returns output variables described in Table 1 for the respective soil type, climate zone and crop. The user can also simulate the removal of a root restrictive layer by deep tillage.

TAKE-HOME MESSAGE

We created a user friendly decision support tool to predict nitrate leaching for all agricultural soils in California. The tool is place-based simulating the effects of climate zones and 58 different crops (i.e. rooting depths). It enables users to evaluate changes in management by considering different irrigation efficiencies and nitrogen application times.

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ACKNOWLEDGEMENTS

This project was supported by CDFA-FREP and UC-ANR Strategic Initiatives Grant Program.

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

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INTRODUCTION

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

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

OBJECTIVES

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

DESCRIPTION

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

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

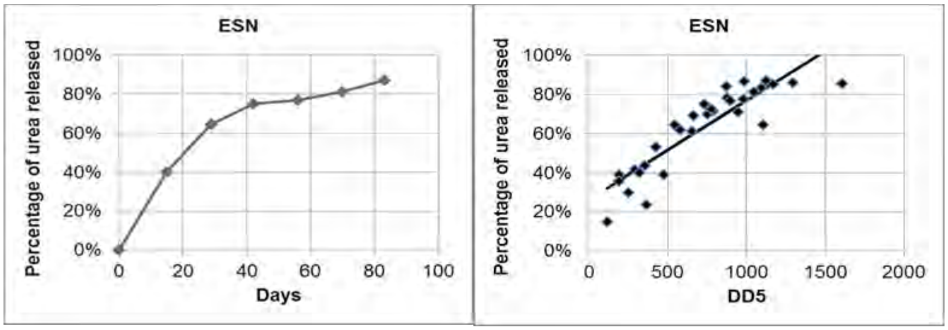

Figure 1. *Example of N release from ESN. Similar approach used to match other products with crop-seasons.*

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

monitored with N tissue and soil testing. Marketable yields were collected at harvest in all experiment-demonstrations.

RESULTS AND DISCUSSION

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

TAKE HOME MESSAGE

Overall, the data show that CRN management has promise as a tool for efficient N management in vegetable cropping systems in the western United States. In some instances we observed increased growth and yield compared to GSP. In many cases production is maximized at lower N rates. There are risks of damage when CRN 90 is used in warm falls. The solution would be using CRN120 or band placement. Many growers have incorporated CRN into their management programs. Most of the grower cooperators we worked with are interested in cooperating with us further in 2017-2018.

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

GSP = grower standard practice; LSD = least significant different (p>0.05)

Table 1. *Response of spinach to CRN management in Riverside County*

Treatment	Practice	N Rate	Marketable Yield (MT/ha)
1	GSP	3-35-0 (25 lb N) sd-AN20 (105 lb N) sd-AN20 (105 lb N) **Total = 235 lb N/ac**	47.0
2	CRN#1	3-35/0 25 lb N pp-CRN (115 lb N) sd-AN20 (23 lb N) **Total = 193 lb N/ac**	52.5
3	CRN#2	3-35-0 (25 lb N) pp-CRN (165 N) **Total = 190 lb N/ac**	58.6
LSD			5.0

GSP = grower standard practice; LSD = least significant different (p>0.05)

Table 2. *Yield response of romaine hearts to CRN management*

Figure 3. *One of the spinach demonstrations.*

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

LSD = least significant different at p>0.05, NS- not significant

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

Hiller, J., C. Hawes, G. R. Squire, A. Hilton, S. Wale, and P. Smith. 2009. The carbon foot prints of food production. International. J. Agric. Sustain. 7:107-118.

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ACKNOWLEDGMENTS

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

Plant Nutrients in the Classroom

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INTRODUCTION

As a $43.5 billion industry, California continues to lead the nation in agriculture production. Challenges within the industry are numerous and California producers continually investigate the solution to feeding a growing population with finite resources. With these challenges in mind, it is increasingly important for farmers and ranchers to produce food, clothing, forest and floral products on less land for more people. Plant nutrients play a crucial role in improving agricultural efficiency.

Students will be our leaders and decision-makers in the future. It is essential for our industry to educate young people about the challenges facing agriculture, and the delicate balance between maximizing production and minimizing environmental impacts. California Foundation for Agriculture in the Classroom (CFAITC) has developed four units of lesson plans focusing on agriculture and plant nutrients and wants to increase implementation of these lessons in elementary, middle, and high school classrooms through the development of a promotion plan. All educators should be aware that these free resources are available and will help them address California Content Standards though hands-on lessons that are related to the food we eat every day.

This project benefited hundreds of teachers and thousands of students. CFAITC provided teachers with free and easy access to plant nutrient curriculum and accompanying lab kits that fit the needs of their classrooms. Lessons and lab activities are aligned to the most recent California Content Standards including Common Core and Next Generation Science Standards, providing teachers with an engaging way to teach problem-solving and critical thinking skills across academic disciplines while familiarizing students with California's crop production.

OBJECTIVES

1. Engage marketing partners such as the Discovery Museum Science and Space Center of Sacramento and other science centers to teach CFAITC's plant nutrient lessons to students attending afterschool programs and to encourage teachers to utilize CFAITC lessons in their classrooms.
2. Engage a public relations agency to develop and implement promotion strategies for CFAITC's plant nutrient lessons to education audiences throughout the state.
3. Advertise in California Science Teacher Association publication, California Agriculture Teacher's Association Golden Slate newsletter, and other educational publications.
4. Engage an evaluation specialist to measure the number of teachers and students reached through promotional activities, and what students learned using CFAITC plant nutrient resources.
5. Provide 60 educators in the Bay Area and Southern California with grade appropriate lab kits for use with plant nutrient lessons.

   CFAITC purchased materials and assemble lab kits specific for each of the following FREP-sponsored, plant nutrient units:

   - K-3 grade *Educator's Guide to Fun With the Plant Nutrient Team*
   - 2-4 grade *What Do Plants Need To Grow?*
   - *5-8 grade Too Much? Too Little?*
   - 9-12 grade *Chemistry, Fertilizer, and the Environment*

6 Require teachers receiving the lab kits to participate in a survey which will allow CFAITC to understand what students are learning from plant nutrient lessons.

7 Engage the California Fertilizer Foundation to help distribute and promote CFAITC's lab kits and plant nutrient units to teachers in their garden grant program.

8 Identify science centers to supply with lab kits and plant nutrient units.

9 Establish a web page containing CFAITC developed and approved resources relating to plant nutrients. On average, more than 5,000 visitors access resources from CFAITC's website every month.

10 Participate in a minimum of three educator conferences to network with science, technology, engineering and math educators and to promote plant nutrient units.

11 Print an appropriate supply (over a three year period) of plant nutrient units:

- 3,000 copies of *Educator's Guide to Fun With the Plant Nutrient Team*
- 3,000 copies of *What Do Plants Need To Grow?*
- 3,000 copies of *Too Much? Too Little?*
- 1,500 copies of *Chemistry, Fertilizer, and the Environment*

DESCRIPTION

This project included updating four comprehensive plant nutrient units, grade levels K-12, to current California Education Standards, sharing the updated units with current and new audiences, working with science centers throughout the state to train teachers and use the curriculum in their summer and afterschool programs, and creating new packaging to draw interest to the program.

We exhibited and gave workshops on Plant Nutrients at nine conferences and multiple trainings. Furthermore, we created promotional items to advertise the units with new pull up and table top displays, Plant Nutrient teacher folders, newly designed pamphlets, and a new tablecloth for conference exhibits. We also created digital and print advertisements that are currently running/ran on the National Science Teachers Association website, Homeschool.com website, California Science Teachers Association (CSTA), and a variety of websites through programmatic advertising, California Farm Bureau's Ag Alert newspaper, California Agriculture Teachers Association's Golden Slate magazine, and the California Teachers Association California Educator magazine, and through multiple social media platforms.

We continue to update the *LearnAboutAg...Plant Nutrients* page on our website which includes all four units, as well as Nitrogen, Phosphorus, and Potassium fact sheets, and *What's Growin' On? Elements for Life*.

RESULTS AND DISCUSSION

As of September 1, 2017, we have distributed more than 5,500 physical copies and have had more than 1,000 digital downloads of the Plant Nutrient lesson plans. While it is difficult to estimate the total number of students impacted, we estimate more than 200,000 students have been reached through this project.

The ability for the lesson plans and materials to be adjusted to fit the needs of all teachers, educators, and events allows the project to have a wide impact.

TAKE-HOME MESSAGE

California is the leading agricultural producer in the United States. As our population increases and farmland disappears to commercial and residential development, farmers and ranchers work to produce food, clothing, forest, and floral products on less land for more people. Plant nutrients play a crucial role in meeting these needs. Students make up a large portion of our consumer population, are forming opinions about food production, and are needed to fill the roles of future agricultural and food professionals. It is essential, for the vitality of our industry and California, to prepare young people to make informed decisions about agricultural issues as they mature into adults.

ACKNOWLEDGEMENTS

California Foundation for Agriculture in the Classroom would like to recognize the following individuals and organizations for their significant contributions to this project:

California Department of Food and Agriculture, Fertilizer Research and Education Program; Fertilizer Inspection Advisory Board; CALAMCO; California Farm Bureau Federation; Powerhouse Science Center; Western Plant Health Association; DeAnn Tenhunfeld, past California Foundation for Agriculture in the Classroom; Mindy DeRohan, past California Foundation for Agriculture in the Classroom

New Fertigation Book

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INTRODUCTION

The goal of this work is to improve the understanding of good fertigation practices by practitioners (i.e., farmers, foremen, farm managers). The improved understanding will hopefully result in farmers implementing better irrigation and fertilization practices. Those good practices will improve crop yields while protecting the environment. To meet the objective, the old (20+ years) Cal Poly ITRC *Fertigation* book is being updated, and a variety of short courses are being held.

OBJECTIVES

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

DESCRIPTION

The new book has nineteen chapters, as follows:

1. Introduction
2. Safety
3. Chemical injectors
4. Proportional fertigation
5. SO2, gypsum, and solids injection
6. Irrigation principles, leaching, and fertilizer uniformity
7. Injection techniques for various irrigation methods
8. Nitrogen transformations and processes
9. Nitrogen uptake, including nitrogen balances, A/R ratio, and groundwater legislation and protection
10. Other nutrient processes
11. Specific fertilizers
12. Biostimulants
13. Organic fertilizers
14. Air and oxygen injection
15. Plant and soil testing
16. Specific crop requirements
17. Sample fertigation calculations
18. Drip system maintenance
19. Infiltration problems

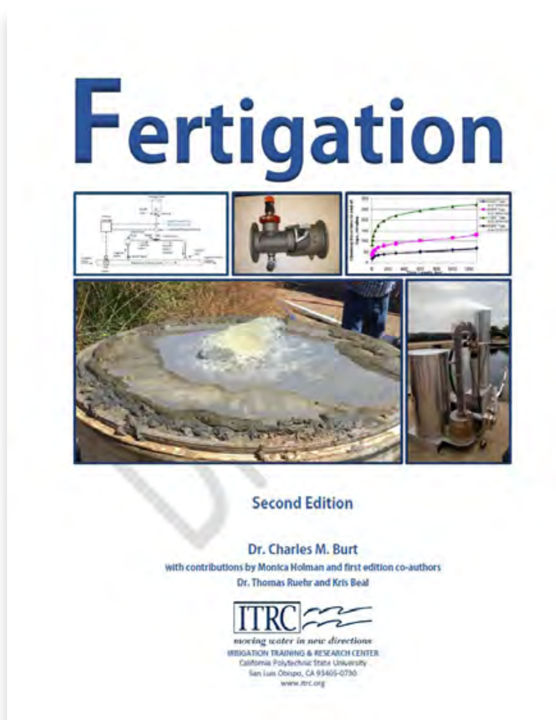

Figure 1. *Cover page of new book*

RESULTS AND DISCUSSION

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

1. The discussion of the Applied/Removed ratio of nitrogen, which is of interest for many people that are concerned with groundwater protection and various rules. The section describes the uncertainties and challenges associated with applying even this "relatively simple" concept.
2. It is commonly understood that applying more nitrogen and water will result in more nitrate leaching to the groundwater. As a very small but important component of this book, ITRC used the USDA/ARS Root Zone Water Quality Model (RZWQM) to model combinations of different nitrogen fertilizer mixes, N rates, water application depths, and timing of N applications. The results are shown in Figures 2 and 3.
3. The move to proportional fertigation (automatically maintaining a constant ppm of a nutrient in the irrigation water) is slowly becoming more popular. The book describes multiple ways to achieve this, and provides a recommendation of the best combination of equipment – all of which are commercially available. A sketch of one example is shown in Figure 4.

RECOMMENDATIONS

The two primary recommendations are:

1. Obtain the book at www.itrc.org when it is available (expected January 2018)
2. Attend one of the upcoming 1-day short courses on Fertigation to be held at ITRC. These are listed on the web site www.itrc.org under "classes". The next scheduled class is March 5, 2018.

ACKNOWLEDGEMENTS

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

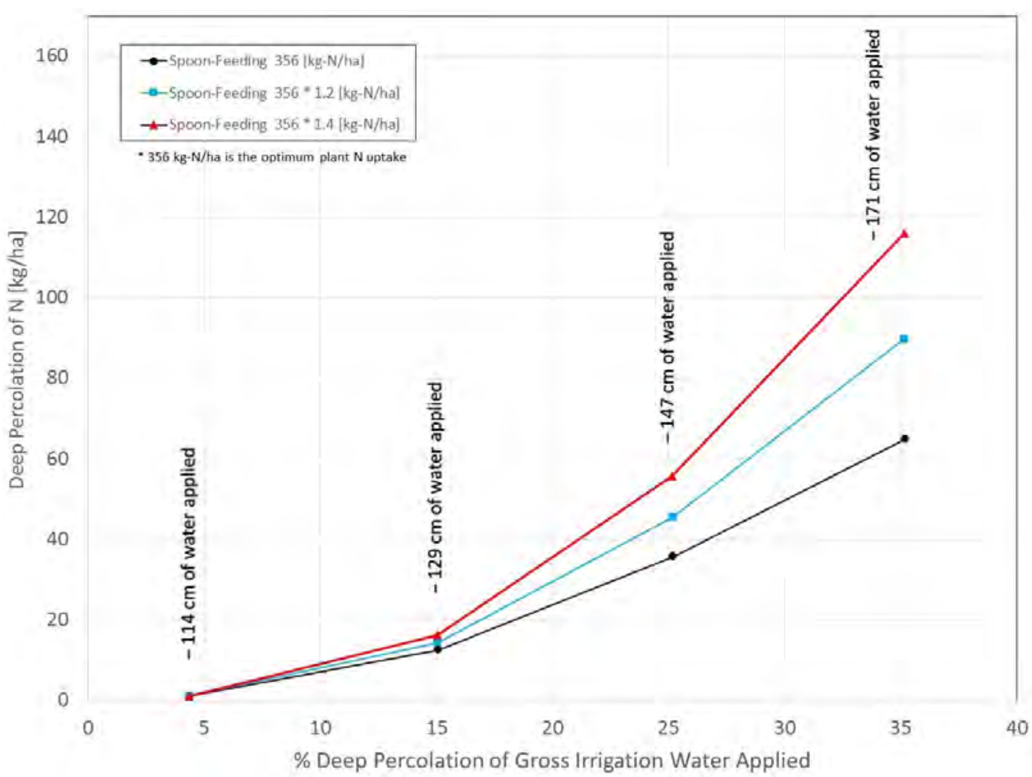

***Figure 2.** Deep percolation of N as a function of irrigation water deep percolated and different N application amounts – all spoonfed.*

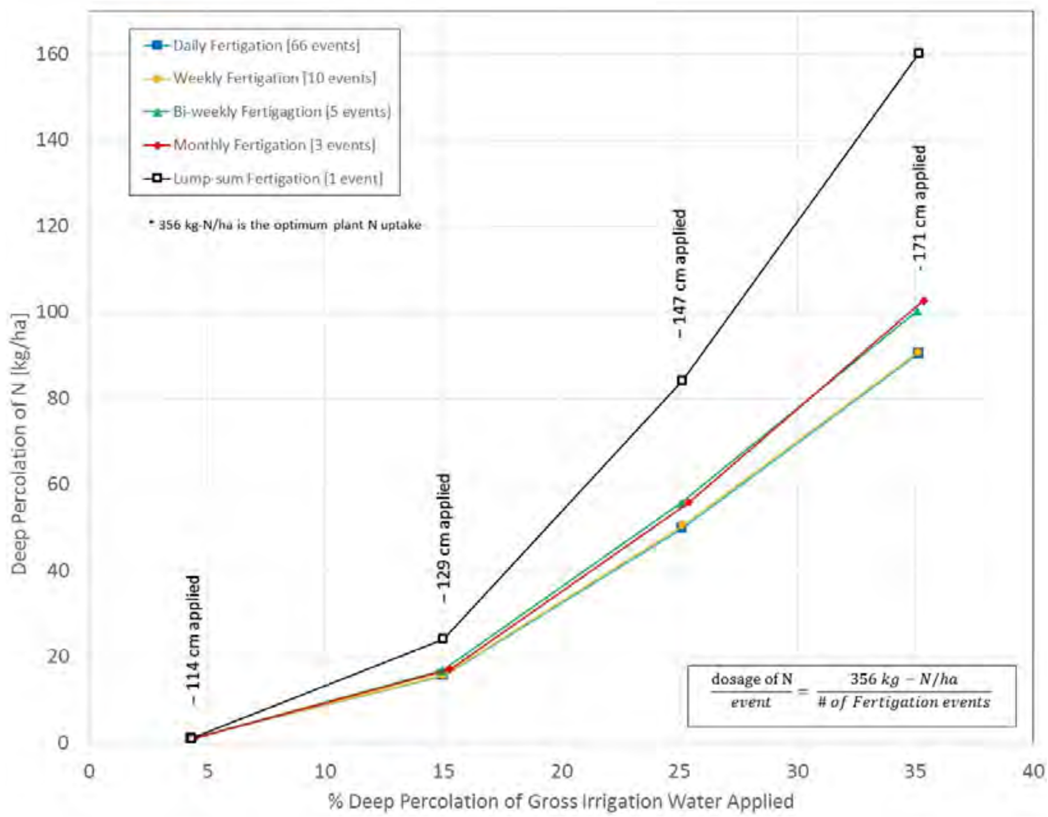

Figure 3. *Deep percolation of N as a function of irrigation water deep percolated, and N application schedule.*

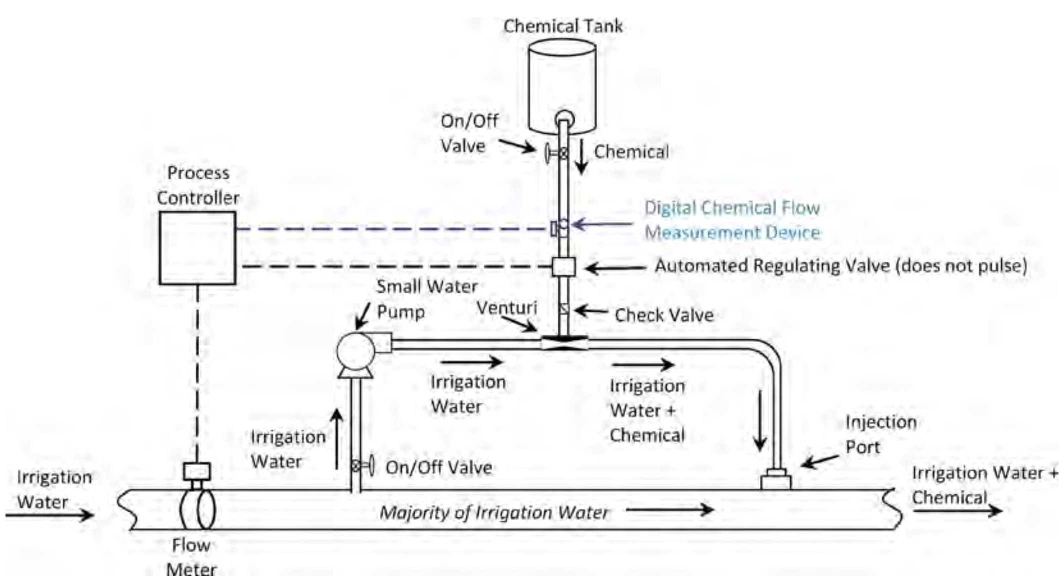

Figure 4. *Recommended configuration of hardware for proportional fertigation.*

Nitrogen Fertilizer Loading to Groundwater in the Central Valley

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PROJECT OBJECTIVES

1. Develop a field-scale nitrogen mass balance for all major irrigated crops and other landuses across the entire Central Valley.
2. Determine nitrogen leaching to groundwater as closure term to the nitrogen mass balance, where possible, and from literature review, where nitrogen mass balance is not possible, e.g., septic systems and other non-cropped areas.
3. Apply the nitrogen loading rates with our non-point source assessment tool to several large pilot areas in the Tulare Lake Basin, the San Joaquin Valley, and the Sacramento Valley for a groundwater nitrate pollution assessment and assess the prediction uncertainty inherent in the approach.
4. Provide results within a GIS atlas that is publishable on the web and in the form of extension and outreach activities, including newsletter articles, interviews with news outlets, web-based materials, and publication in California Agriculture and other grower-geared magazines, and in peer-reviewed scientific journals.

INTRODUCTION

Nitrogen in form of nitrate is the most common pollutant found in the Central Valley aquifer system of California. This project provides a long-term assessment of past and current potential nitrogen loading to groundwater on irrigated and natural lands across the entire Central Valley of California using a nitrogen mass balance approach; assesses the long-term implications for groundwater quality in the Central Valley (Sacramento Valley, San Joaquin Valley, and Tulare Lake Basin); evaluates potential best management practices to reduce groundwater nitrogen loading from irrigated lands; and provides a planning tool to better understand local and regional groundwater quality response to specific best management practices and policy/regulatory actions. The project complements other work to assess the vulnerability of Central Valley groundwater to nitrate contamination, sources of nitrate in groundwater, and how to reduce source loading.

METHODS/MANAGEMENT

The primary tool for this Central Valley assessment are field-scale, crop-scale, crop-group scale, county-scale, groundwater-basin scale, and Central Valley-wide nitrogen mass balance computations that can be linked to groundwater transport models. We developed a GIS framework and a compilation of spatial land use data, collecting and digitizing data for performance of the nitrogen mass balance (historic and current). Data collection included a comprehensive assessment of historic and current nitrogen applications to cropland (from atmospheric, fertilizer, animal, and human sources) and field nitrogen removal (harvest removal, atmospheric losses, surface runoff). Agricultural Commissioner reported crop area and production data have been used to determine the mean period harvest removal rates of nitrogen. We used the tabularized county-by-county crop acreage information and a number of existing geospatial databases to generate digital maps of current and 1990 landuses; and then developed an algorithm that backcasts agricultural crop maps of the Central Valley to the mid-1970s, late 1950s/early 1960s and to the 1940s when fertilizer use in the Central Valley first started to be widespread. Published N fertilization rates (Viers et al. 2012, Rosenstock et al. 2013) were updated through an extensive interview process and used to estimate total synthetic N applications based on reported crop area. New concepts for handling various components of crop data emerged, and extensive quality control was performed on the data collected.

For comparison of synthetic fertilizer nitrogen loading to that from other sources, we tabularized nitrogen loading from wastewater treatment plants, food processors, and from septic systems. Dairy manure nitrogen amounts and fate were assessed through review of existing research results and by performing dairy nitrogen mass balances.

We also extended the computational performance of groundwater transport modeling software: The groundwater nitrate transport modeling tool developed here allows computation of long-term transport of nitrate to individual domestic/municipal/irrigation wells, based on the spatially distributed, field-by-field, annual nitrogen loading to groundwater. We have developed new solver capacities and the ability to run the software program on parallel computing machines, with initial runs of a highly detailed flow and transport model for several basins in the Central Valley.

FINDINGS

This report updates and expands the 2012 SBX2 1 Report "Addressing Nitrate in Groundwater", which focused geographically on the Tulare Lake Basin and Salinas Valley. The data presented here confirm the major findings of the earlier report and the information submitted since then by agricultural coalitions and CV-SALTS to the Central Valley Regional Water Quality Control Board.

The largest nitrogen fluxes into the agricultural landscape include synthetic fertilizer (504 Gg N/yr), land application of manure on dairy cropland or exported

Table 1. *Summary of potential groundwater nitrogen loading from Central Valley sources assessed in this report.*

Mg N/yr	1945	1960	1975	1990	2005	2020	2035	2050
Cropland (incl Alfalfa)	36,714	49,490	124,979	254,348	330,680	351,527	378,527	392,966
Urban	2,131	3,492	5,118	7,166	9,543	9,543	9,543	9,543
Golf Courses	66	66	66	66	66	66	66	66
Lagoons	0	0	2787	2,787	2,787	2,787	2,787	2,787
Corrals	0	0	2243	2,243	2,243	2,243	2,243	2,243
WWTP Percolation Basins	680	1,113	1,480	2,273	2,988	3,609	4,503	5,311
FP Percolation Basins	62	102	136	208	274	331	413	487
tons N/yr	**1945**	**1960**	**1975**	**1990**	**2005**	**2020**	**2035**	**2050**
Cropland (incl Alfalfa)	40,458	54,538	137,727	280,292	364,409	387,383	417,137	433,049
Urban	2,348	3,848	5,640	7,897	10,517	10,517	10,517	10,517
Golf Courses	73	73	73	73	73	73	73	73
Lagoons	0	0	3,071	3,071	3,071	3,071	3,071	3,071
Corrals	0	0	2,472	2,472	2,472	2,472	2,472	2,472
WWTP Percolation Basins	749	1,227	1,630	2,504	3,293	3,978	4,962	5,852
FP Percolation Basins	69	113	150	230	302	365	455	537

to other crops and land application of wastewater effluent (220 Gg N/yr), and nitrogen fixation in alfalfa (115 Gg N/yr). The largest nitrogen fluxes out of the agricultural landscape include harvested nitrogen (450 Gg N/yr including alfalfa), potential nitrogen losses to groundwater from cropland (331 Gg N/yr), and atmospheric nitrogen losses (209 Gg N/yr, which includes 131 Gg N/yr of atmospheric N losses from dairy manure prior to land application).

The Tulare Lake Basin accounts for the largest nitrogen fluxes but it also reflects nearly half of the total irrigated cropland area – 1.5 million ha of 3.2 million ha in the Central Valley. Nitrogen flux rates in the Tulare Lake Basin largely mirror those in the San Joaquin Valley, with large amounts and rates of manure land applications.

The Sacramento Valley, in contrast, has only small amounts of dairy cropland with manure land applications and little manure export. Lacking manure nitrogen sources to augment synthetic fertilizer, the Sacramento Valley in turn has a slightly higher rate of synthetic nitrogen application (175 kg N/ha/yr instead of 165 and 158 kg N/ha/yr in the San Joaquin Valley and Tulare Lake Basin, respectively).

To reduce potential groundwater nitrogen loading from cropland across the Central Valley and thus improve the quality of recharge water from the agricultural landscape, there are only a few options, dictated by the magnitude of nitrogen fluxes:

- Increase the amount of harvest without also increasing the amount of synthetic or organic fertilizer
- Reduce the nitrogen input to the agricultural landscape. However, of all fluxes into the agricultural landscape, only synthetic fertilizer use can be reduced significantly without significantly changing Central Valley landuse: Cities and particularly dairy farming are generating large amounts of nitrogen

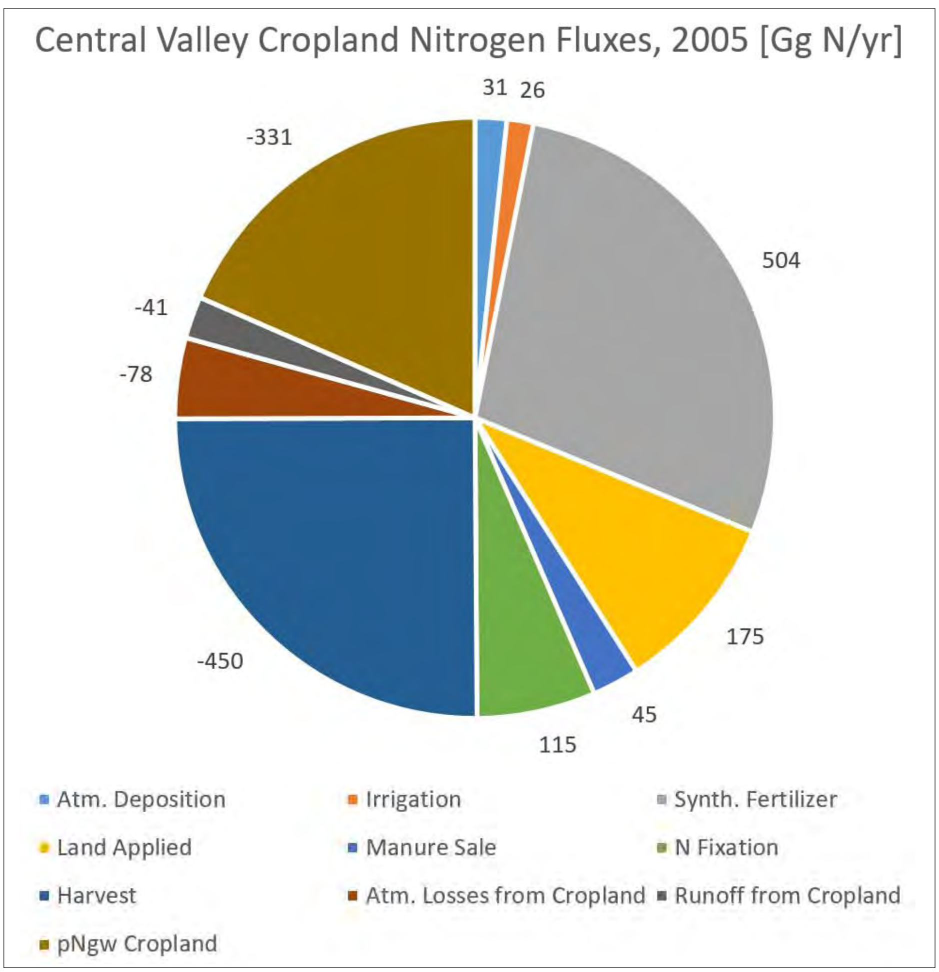

Figure 1. *Sum of all GNLM simulated nitrogen fluxes in Central Valley Cropland [Gg N/yr]. 1 Gg N is 1,100 tons of nitrogen.*

that is currently recycled in the agricultural landscape.

A central challenge to improving groundwater quality in the Central Valley is to develop nutrient management practices that make more efficient and effective use of animal derived nutrients to allow growers to increasingly rely on organic fertilizer. This will require the development of new processes to transform manure into a fertilizer product that can be marketed and that performs much like synthetic fertilizer.

In the meantime, a wide range of agricultural practices have been documented, as part of this work, as part of CDFA FREP's work, and elsewhere, that significantly improve crop nitrogen use efficiency at a region-wide scale from today's practices. Extending this knowledge to growers will be a key goal for the agricultural coalitions in the Central Valley that are engaged in the implementation of the Irrigated Lands Regulatory Program and the Dairy General Order. Agricultural management improvements are urgently needed to prevent further degradation of groundwater recharge quality, even if improvements of groundwater quality in supply wells will only be felt at decadal time-scales, due to the slow-moving nature of groundwater.

TAKE HOME MESSAGES

- Agricultural lands are the largest contributor of nitrate to Central Valley groundwater. Urban and domestic contributions to potential groundwater nitrogen loading are less than 10%.
- Synthetic fertilizer contributes nearly 60%, dairy manure nearly 20% of nitrogen to croplands.
- New technologies are urgently needed to derive synthetic fertilizer-like materials from dairy manure to address the largest pollution risks.
- A wide range of agricultural practices are available to improve crop nitrogen use efficiency at a region-wide scale.
- Agricultural management improvements will only gradually affect groundwater quality in supply wells, at decadal time-scales.
- New modeling tools can assess future groundwater quality trends including those achievable from broader adoption of currently available or future best agricultural practices.

WEBSITES

- http://groundwaternitrate.ucdavis.edu
- http://groundwater.ucdavis.edu
- http://ag-groundwater.org

Evaluation of the Multiple Benefits of Nitrogen Management Practices in Walnuts

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INTRODUCTION

Nitrate is a major contaminant in groundwater in the Central Valley region. Elevated concentrations are in part attributed to nitrogen fertilizers applied to crops that leach past the root zone. Growers in the Central Valley are required through the Irrigated Lands Regulatory Program (ILRP) to keep an "on farm" Nitrogen Management Plan (NMP) to track nitrogen fertilizer applications. The key objective of requiring growers to complete a NMP is to provide them with a planning tool that they can use to manage their nitrogen applications.

While the planning tool may point to the need for better nitrogen management, fertilizer applications can best be managed by applying nitrogen at the right time, right place, with the right type, and the right rate (4R's). The 4R's are crop-specific in that they must provide nitrogen to the plant when the plant needs and is taking up nitrogen from the soil. Consequently, while the generic recommendations can be useful, very little is known about the amount of nitrate moving past the root zone in most crops under most management regimes. It is imperative that additional studies on specific management practices be conducted to determine the potential movement of nitrate past the root zone. Because of this need, agricultural coalitions in the Central Valley are required through their General Orders to implement a Management Practices Evaluation Program (MPEP). The MPEP has several specific objectives including identifying management practices that are protective of groundwater quality, determining whether newly implemented management practices are improving or may result in improving groundwater quality, developing an estimate of the effect of coalition members' discharge of nitrogen on groundwater quality and utilizing the results to determine whether practices need to be improved.

There are data gaps in understanding the effectiveness of management practices on reducing the amount of nitrogen fertilizers moving past the root zone in walnut orchards. The focus of this project is to evaluate the management of nitrate on two walnut orchards over a two-year period. This project documents the amount of nitrogen applied and measures the amount of nitrogen moving past the root zone using a combination of soil cores and pore water samples. Measurements capture the movement of nitrate during both the irrigation season and periods of winter rain.

OBJECTIVES

1. Identify the management practices being implemented to reduce the amount of nitrogen moving through the root zone for two orchards (Orchard 1 and Orchard 2) of similar size.
2. Determine the amount and timing of nitrogen moving past the root zone.
3. Identify the multiple benefits of nitrogen management practices implemented in Orchard 1 and Orchard 2, including potential cost savings (reduced water costs, reduced amount of money spent on fertilizer) and groundwater protection (reduction in the amount of nitrogen that is moving past the root zone).
4. Determine if additional practices could be implemented to further reduce the amount of nitrogen moving past the root zone.
5. Disseminate results to growers of walnuts and develop outreach materials.

DESCRIPTION

The two walnut orchards being utilized in this study are located near Ceres, CA. The orchards are approximately 5.8 acres and 4.0 acres. The management practices on both of the orchards include a combination of microsprinklers and flood irrigation. Fertilizer was applied by fertigation and pellets/granules amended into the soil during the first year, and by fertigation only during year 2. For sampling, each block was divided into a grid system containing 15 grid cells. Each grid cell is sampled by a combination of lysimeters to collect pore water, soil cores for nitrogen and carbon content, and moisture sensors to collect volumetric water content (Figure1 and Figure 2). During year 1, lysimeters were located at a depth of 4 ft, and during year 2, lysimeters were located at both 4-ft and 10-ft. The larger orchard block is irrigated/fertigated using two different piping systems leading to two different fertigation regimes. As a result, the study consists of three treatments, West, Center, and East.

Prior to the beginning of each growing season, soil cores were collected from a random subset of grid cells in each orchard (Figures 1 and 2) to measure the immobile fraction of nitrogen. The concentration of nitrate in irrigation water was measured to determine the amount of nitrate applied via irrigation water. Lysimeters located below the root zone were used to evaluate amount of nitrogen moving past the roots after fertigation and/or irrigation events. Soil samples were collected to determine the amount of immobile nitrogen at end of the irrigation season. Walnuts were collected and submitted for analysis of nitrogen immediately prior to harvest to determine the amount of nitrogen removed from the orchards. Volumetric water content is being used to estimate the volume of water moving past the root zone. The data collected for this project are being utilized as input parameters for 1-D HYDRUS to model nitrogen fate and transport in the orchards.

Figure 1. *The grid system and sampling device locations on the west block orchard.*

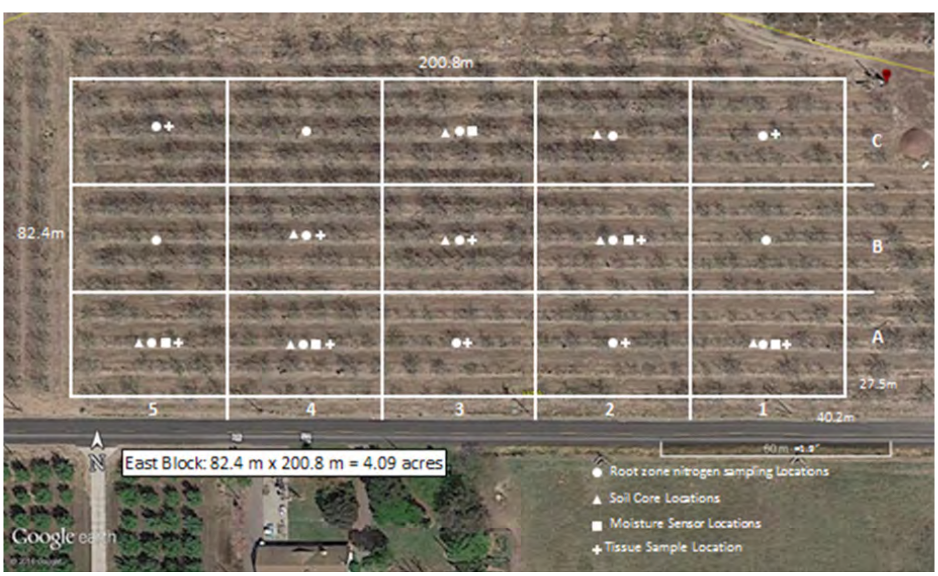

Figure 2. *The grid system and sampling device locations on the east block orchard.*

RESULTS AND DISCUSSION

In year 1, there were 22 sampling events resulting in 167 pore water samples, 83 soil samples, 4 microsprinkler irrigation samples, 2 flood irrigation samples, and 1 water sample from the irrigation well. In year 2, 28 sampling events resulted in 559 pore water samples, 96 soil samples, and 16 microsprinkler water samples. Nitrate leaching depends upon the amount and timing of N and water inputs, the storage capacity of the soil, and the amount and timing of N uptake by plants. Both the weekly mass balance and the Darcy flux method indicate that there were nitrate leaching losses during the 2016 and 2017 growing seasons, suggesting that there is room for improvement in the timing and amount of nitrogen fertilizer applied to meet crop demands and minimize leaching losses. Losses are also a function of the irrigation practices. During 2016, the cooperator used a combination of sprinklers and flood irrigation during the period when fertilizer was applied. In 2017, during the period when fertilizer was applied, the grower used sprinklers exclusively and rotated to flood irrigation after applications were completed. Despite the change in irrigation practices, nitrate was detected in the lysimeters at 4-ft in both 2016 and 2017, and in the 10-ft lysimeters in 2017 (Figure 3). Although the 4-ft lysimeters may be considered as within the root zone, 10-ft lysimeters are almost certainly below the root zone indicating that nitrate leaching to groundwater is occurring.

The in-season leaching result indicated by lysimeter data is supported by the HYDRUS model results. The timing of leaching losses in model output during 2016 is informative, suggesting that management practices during the irrigation season (banding and flooding) become more likely to leach N in-season on coarser textured soils such as WB4. Winter leaching at this site is also apparent, though it is a smaller portion of the total leaching losses at this site than at the finer textured sites. Outputs from HYDRUS uniformly give low estimates as compared with the other three estimation methods, possibly due to the assumption of no preferential flow. HYDRUS model results in 2017 indicate that splitting applications may be effective in preventing leaching as deep percolation losses are higher for the site receiving three applications of 43lb/ac as compared with 6 applications of 25 lbs/ac (Table 5).

ACKNOWLEGDMENTS

Funding for this project was provided by the California Department of Food and Agriculture's Fertilizer Research and Education Program, and five Central Valley Irrigated Lands Regulatory Program Agricultural Coalitions (East San Joaquin Water Quality Coalition, Westside San Joaquin River Watershed Coalition, San Joaquin County and Delta Water Quality Coalition, Sacramento Valley Water Quality Coalition, Westlands Water Quality Coalition).

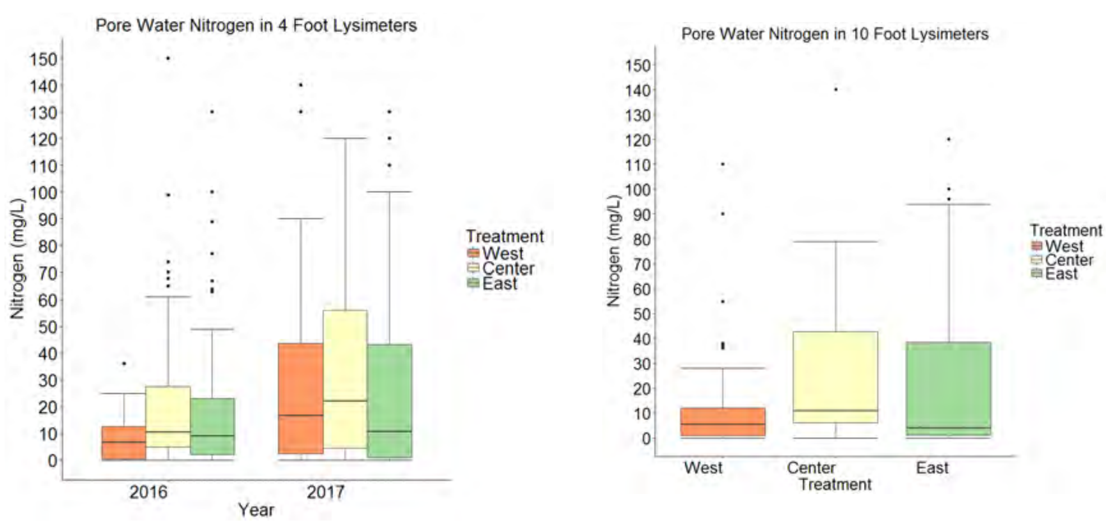

__Figure 3.__ Concentration of nitrate in lysimeters in 4 ft lysimeters (2016 and 2017) and 10 ft lysimeters (2017).

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

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INTRODUCTION

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

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

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

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

OBJECTIVES

1. Characterize the patterns of root nitrate uptake and plant response when plants are grown with roots in soils of different salinity status (as typically occurs under micro-irrigation).
2. Use HYDRUS (Šimůnek et al., 2012) to model solute transport, plant response (water and nitrate uptake) to salinity, and specific ions (Cl, Na, B) under a variety of irrigation scenarios and different conditions such as soil type, environment, timing, distribution, irrigation system, and water quality.
3. Use the information in objectives 1 and 2 to develop site and cultivar specific models and guidelines for nitrate sensitive salinity management and to produce a series of written and online grower guidelines and tools for irrigation design and scheduling.
4. Produce a robust modeling platform for the advanced grower, consultant, advisor, irrigation industry representative and researcher to

develop novel and site-specific irrigation design and scheduling practices for nitrate sensitive salinity management.

DESCRIPTION

1. Twelve tomato truck bins measuring 28 x 8 x 5 ft (L×W×D) were equipped with drainage pipe at the bottom and filled with a sandy loam, a common soil type in almond orchards in California (Figure 1A and 1B). Two almond trees were planted in each of the bins, one with a Viking rootstock and one with a Nemaguard rootstock (Figure 1C). The trees are drip-irrigated and three different irrigation frequencies are tested.
2. Soil water content, salt and nitrate concentrations of the soil solution will be measured at different locations in the root zone. Plant performance under the different treatments will be evaluated using leaf tissue analysis and measurements of stem water potential and tree growth.
3. A computer model that is able to predict water and nutrient uptake of almond trees will be developed and calibrated for the use in almond orchards using the measured data obtained in step 2. In addition, measured values of soil hydraulic properties as well as plant physiological parameters determined in previously conducted greenhouse studies will be incorporated into the model. Once the model has been calibrated and validated sufficiently, soil salinity and plant water and nutrient uptake will be simulated for various soils and climatic conditions and for different irrigation and fertilization management regimes. The results will be used to improve recommendations on nitrate and salinity measurements in almond orchards.

RESULTS AND DISCUSSION

The hydraulic properties of the soil were measured in the laboratory (Figure 2A) and the results were used to run preliminary simulations of water flow and salt and nitrate accumulation in the root zone. An example of a simulation of salt accumulation for different irrigation frequencies is shown in Figure 2B. The simulations show that salt tends to accumulate at the margin of the zone that is wetted by the dripline, while salt concentrations in the remaining root zone can be relatively low. Once enough measured data are available from the experiment, the measurements will be compared to the simulations and can be used to improve and calibrate the model. The model can then be used to predict the consequences of various management strategies under different conditions and will help to develop guidelines for salinity and nitrate management in almond orchards.

ACCOMPLISHMENTS

A lysimeter experiment has been set up that allows the quantification of nitrate leaching and simultaneously provides detailed information of the water, salt and nitrate distribution in the root zone of drip irrigated almond trees. The data from this experiment will help to improve the understanding of the interactions

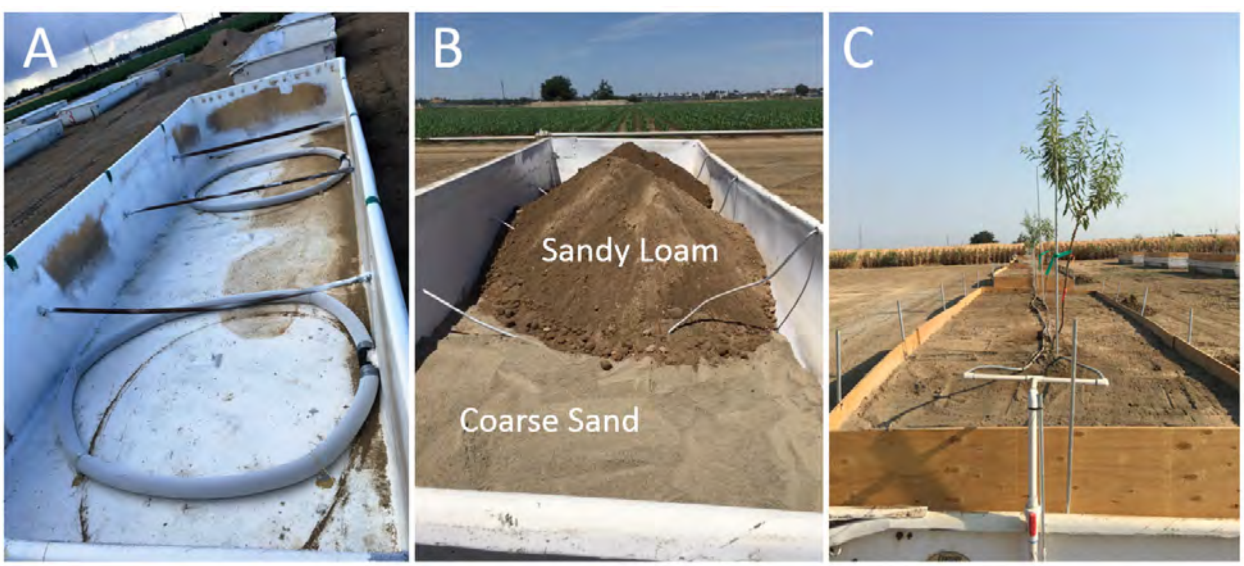

Figure 1. *Setup of the lysimeter experiment. A- installation of drainage pipe, B- bin is being filled with soil, C- almond trees planted in the bins.*

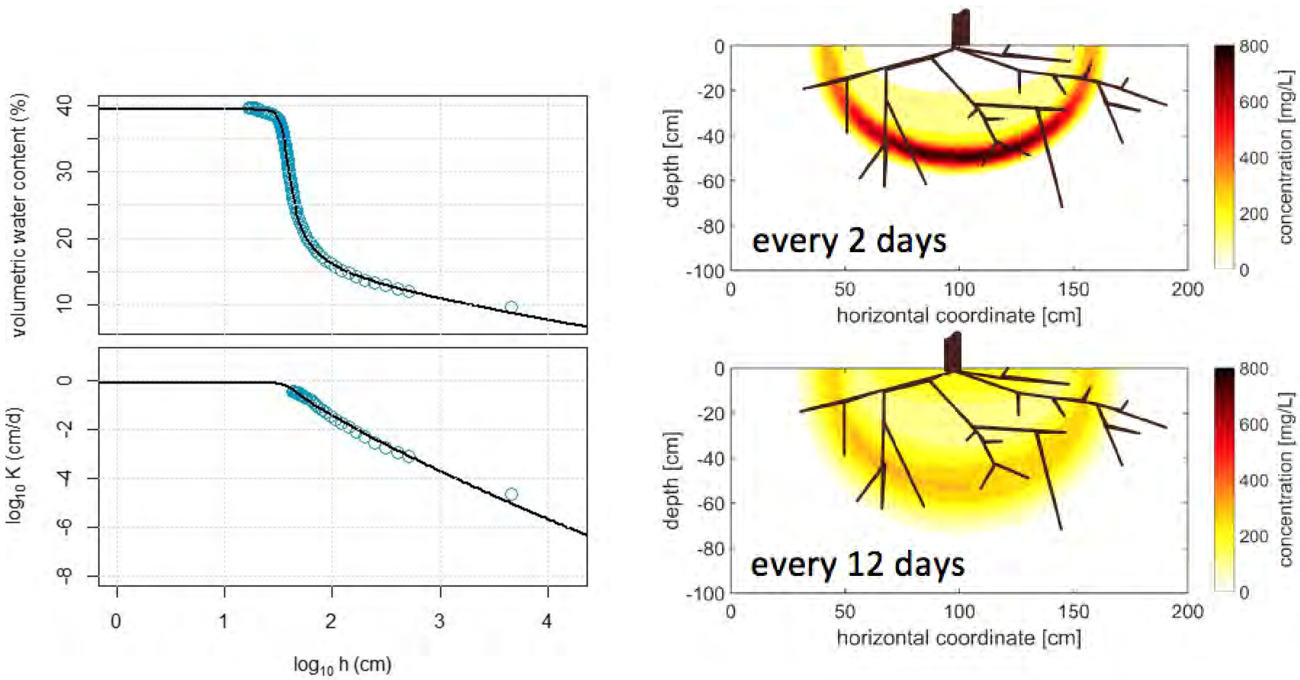

Figure 2. *A- Measured (blue circles) and fitted (black line) soil water retention and hydraulic conductivity as a function of matrix potential (h). B- Example of a simulation result showing the salt concentration in the root zone of a drip irrigated almond tree for two different irrigation frequencies.*

between irrigation management, salt and nutrient distribution in the root zone and plant response.

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ACKNOWLEDGEMENTS

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

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

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INTRODUCTION

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

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

Similar to the work done in almonds and pistachios, this new FREP project aims to develop tools that can predict tree nitrogen status for commercially grown walnuts, prunes and pears.

California growers of walnuts, prunes and pears are the primary audience that will benefit from this research. Commercial Analytical labs will also benefit by offering an improved product to their customers. The walnut, prune and pear industry will benefit by improving compliance with current and future N regulations as well as improving the quality of their products. Consumers and the general public will also benefit from an improved supply of healthy fruits and nuts with decreased environmental impacts.

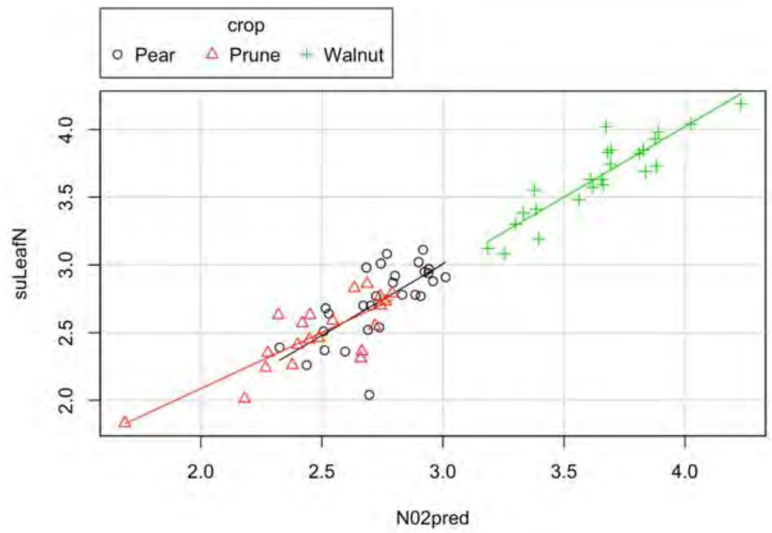

Figure 1. *A graphic of predicted (NO2pred) versus observed nitrogen values in summer (suLeafN) using a partial least squares model.*

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

OBJECTIVES

This project is designed to achieve the following three objectives:

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

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

RESULTS AND DISCUSSION

Model development was completed by March 2017. Several models were built using different statistical approaches (nutrient ratios, principal component analysis, stepwise selection, etc.) with the 2016 data. Among the different models, a partial least squares model was selected by cross- validation using the root mean square of prediction errors (RMSEP). The model included all soil and leaf variables measured in spring, as well as crop species and the interactions (Figure 1). The best models ranged from having 1 to 11 components, each being a linear combination of all effects in the full model. The model with a single component was stable across validation sets and also had the lowest RMSEP. The single component has to be explored in more detail to determine the explanatory variables that are more heavily loaded in it and develop more explicit models accordingly. Predictions are within 0.28 percent of the true value with 90% confidence for individual orchards and within 0.04 for the population mean. 2017 data will be used to fully validate this model, and others.

ACKNOWLEDGEMENTS

Particular thanks to the California Dried Plum Board, California Walnut Board, California Pear Advisory Board, and Fruit Growers Laboratory for their support in this research. This project was funded (in part) by a grant from the California Department of Food and Agriculture's Fertilizer Research and Education Program (FREP) and the Fertilizer Inspection Advisory Board.

Quantifying N_2O Emissions under Different On-farm Irrigation and Nutrient Management BMPs that Reduce Groundwater Nitrate Loading and Applied Water

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INTRODUCTION

There are economic and environmental sustainability challenges associated with the nutrient intensive production of specialty crops grown in the Pajaro and Salinas Valleys. Nitrate-N fertilizer applications in excess of crop use uptake may result in additional irrigation and fertilizer costs, nitrous oxide (N_2O) gas emissions to the atmosphere, and nitrate leaching to groundwater. N_2O is 300 times more effective than carbon dioxide at warming the atmosphere, and the majority of N_2O in the U.S. is emitted by agriculture soils. N_2O is produced by microorganisms that convert available nitrogen to N_2O gas as a biproduct of metabolic processes. Direct emissions are a release of gas from the soil, and indirect emissions occur when leached nitrate (NO_3^-) is transformed into N_2O in downstream aquatic environments (De Klein et al., 2006). Few studies address both direct and indirect N_2O emissions due to row crop soil management. We are evaluating the potential for evapotranspiration-based (ET-based) irrigation to mitigate N_2O emissions and NO_3^- leaching as a result of improved crop N uptake. The goal is to assist growers in optimizing water and fertilizer use in a way that reduces crop production costs while minimizing losses of excess N to the environment.

OBJECTIVES

1. Establish standard and alternative irrigation management treatments in split-block designed strawberry and subsequently lettuce-broccoli crop rotations
2. Measure direct soil N_2O emissions and total applied water from these cropping systems
3. Estimate direct and indirect N_2O emissions in conjunction with NO_3^- leaching data
4. Quantify direct and indirect N_2O emissions in relation to yield quantity and quality differences, input costs and total water applied
5. Characterize N_2O emissions based on environmental factors
6. Analyze the pathway of N transformation in soil through physical NH_3 oxidation due to water and oxic/pH conditions

DESCRIPTION

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

RESULTS AND DISCUSSION

Cumulative area-based direct N_2O emissions were lower in the ET 100 treatment for broccoli, but were similar across treatments for strawberries and Romaine lettuce (Figure 1). This suggests that there could be a limit to the reduction in direct N_2O emissions even when growers are following BMPs. Based on cumulative NO_3- leaching, indirect emissions in the ET 130 treatment for strawberries and Romaine lettuce were three times greater than ET 100 treatment; no difference was observed in broccoli due to grower practice applying approximately the same amount of fertilizer and water as ET 100.

Preliminary N-budget analysis for each crop trial is presented in Figure 2. Unaccounted for in this budget, and for which data are in progress, are quantities of residual N in soil at the beginning and end of trials, actual N uptake and plant biomass, and gaseous N losses other than N_2O- which were not measured in this study, and are considered less substantial emissions. For example, pre-planting treatments, like a cover crop and composting of the strawberry fields, and the tilling in of lettuce at the broccoli site would have provided additional N. N as protein is estimated from the USDA website, but plant tissue samples from the trials will be analyzed to include total N. Even with these small data gaps, we are observing that a majority of N applied is taken up by the crops. Leaching and associated indirect emissions estimates are higher in ET 130 treatments. There are notable reductions in N losses under ET 100 for strawberries and lettuce while also achieving comparable yield for both crops. This validates the efficacy of CropManage for recommending BMPs for irrigation and nutrient management without compromising yield.

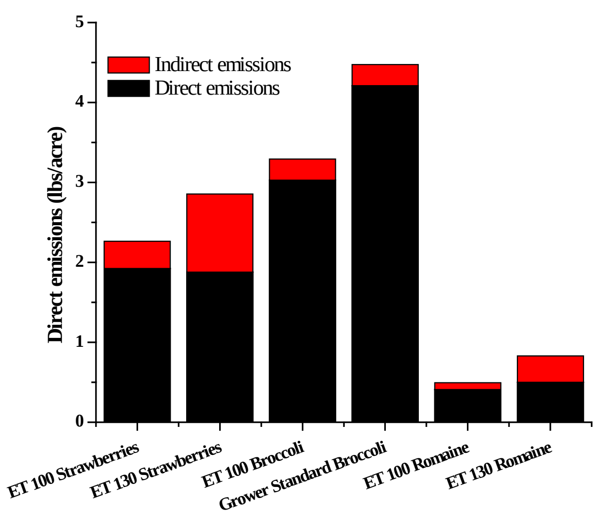

Figure 1. *Direct + indirect [DI] N2O emissions.*

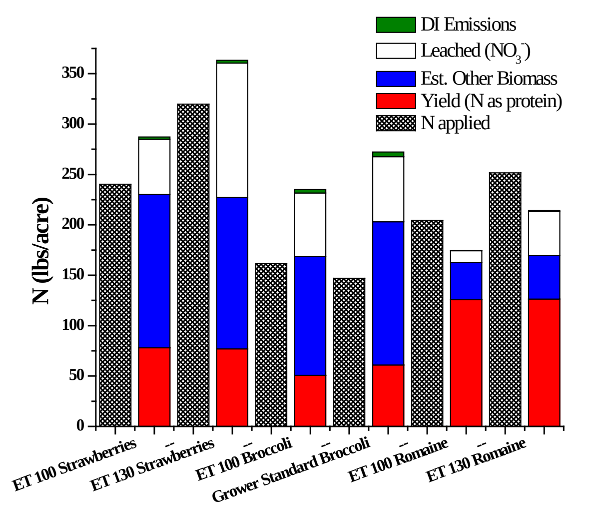

Figure 2. *N applied and N lost through leaching, direct + indirect (DI) N_2O emissions, and as N in plant material (yield and other biomass as estimated by N as protein) via tissue samples, as well as residual soil N at the beginning and end of each trial.*

The Horwath laboratory evaluated the effects of soil moisture content and fertilizer N source with and without a nitrification inhibitor on N_2O production in the strawberry soil. Results show that the dominant process of N_2O production was due to nitrification of ammonia, not via metabolism of NO_3^-. The N_2O production was greater in the aqua ammonia than the NO_3^- treatments. Moreover, the nitrification inhibitor reduced N_2O production to control levels in both fertilizer treatments. Therefore, even in the nitrate treatment, the majority of the N_2O production was due to nitrification. The rates tended to increase with increasing soil moisture. (Zhu 2013).

TAKE-HOME MESSAGE

These data are in the preliminary stages of analysis. It should be noted that the grower practices of the commercial growers we worked with often were more conservative in their irrigation and fertigation management practices than the ET130 treatments, which were designed to achieve application rates consistent with the midpoint of UC ANR recommendations for seasonal totals. There appears to be a limit to the direct N_2O emitted from crops, and thus strategies to mitigate indirect emissions due to leaching could be a more promising strategy for reducing both nitrate leaching and N_2O emissions. One strategy we hope to test in the future is the addition of carbon to immobilize N losses. These data indicate that CropManage-based nutrient and irrigation scheduling is an effective tool for reducing N losses to the environment while sustaining crop yields and the economic viability of specialty crop production.

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Evaluation and Demonstration of Nitrogen and Phosphorus Management in Organic Leafy Green Vegetables Production 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 $572 million in 2016. A large percentage of the organic value is from leafy green vegetable production. Large-scale organic production continues to expand given strong market demand. The central coast is a key center of production of leafy green vegetables due to optimal climatic conditions and the sales & shipping infrastructure in the area. Little science-based information is available for managing nitrogen (N) in organic programs. Fertilizer practices vary widely among growers and residual soil nitrate or potentially mineralizable N is not commonly included in fertilizer decisions for crop N needs. The industry relies heavily on organic N fertilizers and amendments, mostly derived from animal by products that often have high phosphorus (P):N ratios. Surveys of soil P values in the Salinas Valley have shown that organic production fields can have soil P values comparable with conventional production. Management of P in organic production systems is an important challenge facing producers because it can adversely affect surface water quality.

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

OBJECTIVES

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

DESCRIPTION

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

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

RESULTS AND DISCUSSION

Evaluations of N mineralization from soil and fertilizer were conducted with cooperating growers in commercial vegetable production fields during the 2016 and 2017. The sites comprised a wide range of soil types from loamy sands to clays. In-field estimates of soil mineralization over the course of the cropping cycle were conducted at each site. The technique consisted of use of a plastic mulch on unfertilized plots to eliminate N removal by crop removal and leaching and allowing an estimate of N mineralization from the soil. In eight of the ten sites soil mineral N levels increase in the plastic mulch treatments over the course of the crop cycle, providing a measurement of net N mineralization (Table 1). The amount of N mineralized from soil organic matter ranged from 0.6 to 3.3 lbs N/A/day. Fertilizer applications resulted in an increase in yield in 8 of the 10 sites (yield increase ranged from 0 to 93%). These studies indicate that the quantity of nitrate-N at the beginning of the cropping cycle appeared to be the best indication of the amount of soil N to supply these short-season leafy green vegetables. Early-season testing is the only option for evaluating the soil N status for short-season baby vegetables that mature in 30 days or less, because of the lag time between application of organic fertilizers and the release of mineral nitrogen to the crop.

Two evaluations of the amount of N mineralized from 4-4-2 dry fertilizers was conducted. 4-4-2 is made from chicken manure and bone and meat meal blend. 20 grams of fertilizer were placed in polyethylene pouches; at the beginning of the crop cycle, pouches were either placed on the soil surface (to simulate a drop-on-top fertilizer application) or buried 3-4 inches deep in the soil (to simulate incorporated fertilizer application). The dry weight of the fertilizer in the pouches declined rapidly from day 0 to day 10 and then declined more slowly and steadily thereafter (Table 2). N loss from the pouches followed a similar pattern. Fertilizer dry weight and N released was more rapid in the buried pouches and resulted in 70.2% loss of N from the pouches by day 63 compared to 48.2% for the pouches on the soil surface. Phosphorus released from the fertilizer was 17% for both the surface and buried pouches by day 63. Potassium released in 63 days from the pouches was 92.7% and 82.6%, for buried and surface pouches, respectively.

There were robust amounts of P added to the crops from fertilizer at all sites. This was often due to the use of materials that had P in similar proportions to N. In six of the nine evaluations, there was no increase in soil P in the fertilized treatments at the end of the cropping cycle. 4-4-2 fertilizer is a blend of chicken manure and meat and bone meal, and the P from the bone meal is insoluble at the high soil pH's at all sites. Despite the high amounts of P applied to these crops, bicarbonate soil P values were relatively modest, except for one site located on an old dairy. We hypothesize that P applied in these fertilizers that is from bone meal may not be soluble due to the high soil pH's mentioned above.

TAKE-HOME MESSAGE

Measureable amounts of N are mineralized from soil organic matter over the course of the crop cycle. However, short-season leafy green vegetables have a high N demand which makes relying on N mineralized from the soil exceedingly difficult. The quantity of mineral N at the beginning of the crop cycle may be a better source of information on the quantity of soil N useful for these crops. The P contained in fertilizers such as 4-4-2 is not readily soluble and does not appear to be building up high levels of bicarbonate extractable P in soil. This is due to the fact that a large portion of the P in 4-4-2 is from bone meal and is not soluble at soil pH's greater than 7.2 which were found at all sites in these evaluations.

Table 1. *2016 evaluations: Estimates of sources of N available to organic vegetables*

Site	Total fertilizer N applied lbs/A	Net lbs N/A mineralized from fertilizer[1]	Initial mineral N in soil lbs/A	N mineralized from soil lbs/A[2]	Nitrate-N in water lbs/A	Total available N lbs/A
1	210	126	49	57.5	2.7	235.6
2	120	36	129	---	56.1	221.3
3	90	24	30	16.2	11.2	81.8
4	120	36	57	33.0	17.8	143.8
5	437	219	67	---	20.1	305.6
6	160	72	86	72.5	4.9	235.7
7	160	72	97	82.4	12.5	263.4
8	160	54	16	28.6	15.4	114.3
9	360	204	76	59.4	30.5	369.9
10	160	72	133	78.3	4.8	288.1

1 – Estimated based on pouch evaluations

2 – Estimate of N mineralized from soil organic matter from in-field mineralization study

Table 2. *Estimate of N, P and K released from 4-4-2 fertilizer in polyethylene bags placed on soil surface or buried in the soil.*

Days	On soil surface				Buried in soil			
	dry wt	N % released	P % released	K % released	dry wt	N % released	P % released	K % released
0	18.01	0.0	0.0	0.0	18.01	0.0	0.0	0.0
10	15.24	30.4	15.5	79.7	13.06	50.4	8.6	83.5
18	15.14	31.1	11.4	78.1	11.35	60.9	13.9	87.9
25	15.48	35.8	18.5	81.3	10.96	64.6	14.7	90.9
31	15.47	33.9	14.2	82.8	11.24	63.6	14.2	90.6
38	15.63	41.5	17.4	80.7	10.80	65.7	13.3	92.1
44	15.64	44.6	17.6	78.8	10.48	68.4	15.7	92.3
52	14.82	47.0	18.2	83.0	10.34	69.2	15.9	93.0
60	14.62	50.1	19.5	82.2	10.64	65.9	11.5	92.2
63	14.57	48.2	17.4	82.6	10.22	70.2	17.2	92.7

ACKNOWLEDGEMENTS

We are grateful for the support of the California Department of Food and Agriculture's Fertilizer Research and Education Program (FREP) and the Fertilizer Inspection Advisory Board for funding for this project. We are grateful to the support of UCCE Staff Research Associates and Assistants, Tricia Love, Bibiana Urbina, Jose Delgado, Karina Mendez and Kacie Wynn. We are also grateful to the support of cooperating growers and True Organics and J.R. Simplot for fertilizers.

SUMMARIES OF CURRENT FREP PROJECTS

Determining the Fertilizer Value of Ambient Nitrogen in Irrigation Water

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INTRODUCTION

Irrigation water from many wells on the central coast contains a significant amount of nitrate-nitrogen (NO_3-N); recycled water from the Monterey Regional Water Pollution Control Agency (MRWPCA), the sole water source for approximately 12,000 acres of prime Monterey County farmland, is high in both NO_3-N and NH_4-N. Growers historically have been reluctant to modify their N fertilization practices on the basis of irrigation water N content because it is unclear how one can reliably calculate the 'fertilizer value' of this N.

This issue has taken on added significance with the adoption of the new 'Ag Order' by the Central Coast Region Water Quality Control Board during March, 2012. The revised Ag Order requires growers to report the total amount of nitrogen applied to crop land, including N contained in irrigation water. It is also unclear what distinction, if any, the Board will make between fertilizer and water sources of N, but it is clear that the Board expects growers to modify their N management practices based on the N content of irrigation water applied to their crops.

Unfortunately, a limited body of research documents the efficiency of crop uptake of N from irrigation water upon which to base an estimate of 'fertilizer value' under normal irrigation and N management practices. Central coast vegetable growers have several concerns with a simplistic concentration × volume approach to estimating the fertilizer value of ambient N in irrigation water. High N water sources, including both groundwater and recycled water, often also have significant levels of sodium and chloride. It is unclear what portion of the N in the irrigation water applied to leach salts should be credited as N value to the crop since that water would percolate below the root zone. Similarly, variation in irrigation uniformity in a field also affects the portion of N in irrigation water that can be credited as N value to a crop since some areas of a field would have more deep percolation than other areas. Crops such as lettuce and broccoli with characteristically different rooting depths may also have varying abilities to utilize ambient N contained in applied irrigation water. A second concern is that relatively low N concentrations in irrigation water may not significantly contribute to crop N uptake under normal production conditions. In fertilized vegetable root zones, soil water NO_3-N concentration is typically 50-150 PPM. In growers' minds it is unclear if the addition of water with much lower N concentration represents a significant net benefit to crop N nutrition.

An additional concern about the fertilizer N value of irrigation water is specific to MRWPCA recycled water used to annually irrigate more than 12,000 acres of vegetables and berries grown on the central coast. A major portion of the N in this water is in the NH_4^+ form. Because of NH_4^+ is a cation it would be less likely to leach than NO_3^-, and therefore may have more fertilizer value than NO_3-N.

OBJECTIVES

1. Document broccoli and lettuce N uptake and N recovery efficiency (NRE) of irrigation water N over the range of 10-40 PPM, and at high and low irrigation efficiencies.
2. Determine the contribution of irrigation water N to broccoli and lettuce N fertility under a range of typical drip irrigation and fertigation practices.

DESCRIPTION

This project developed information and guidelines for utilizing ambient N in irrigation water for lettuce and broccoli, the primary vegetable crops in this region. A total of 7 replicated field trials were conducted in the Salinas Valley from 2013-15. Three trials focused on determining the efficiency of lettuce and broccoli to recover N from irrigation water, as affected by concentration and irrigation efficiency. The remaining trials examined the practical contribution of irrigation water N to crop fertility under a range of typical irrigation and N fertigation regimes. This project has had a strong outreach component, including newsletter and trade journal articles, oral presentations, and online resources. We will add an algorithm for calculating the fertilizer value of NO_3/NH_4 in irrigation water to CropManage, an online irrigation and N management tool.

Procedures

Replicated field trials were conducted on the USDA Spence research facility near Salinas in 2013 and 2014 to address objective 1 for lettuce and broccoli. Irrigation water with N concentrations ranging from 2 to 42 ppm and were compared to an unfertilized control and a fertilized standard treatment (seasonal total of 150 lb N [AN20] applied in weekly fertigations). In addition, we included a treatment to evaluate crop N recovery from water dominated by NH_4-N. Water-powered proportional injectors were used to enrich all drip applied water to the target concentrations of treatments. Injected NO_3-N was a blend of $Ca(NO_3)_2$ and $NaNO_3$ to maintain the cation balance in the water.

To observe the interaction of irrigation efficiency and crop nitrogen recovery, each N treatment was evaluated at two levels of applied water: 1. standard water rate equal to 110% of crop ET, and 2. High water rate of 160% to 180% of crop ET, which correspond to 40 to 50% leaching fractions.

Lettuce (cv. Telluride), was seeded on 40-inch wide beds and germinated using overhead sprinklers. Water treatments were begun after the crop was thinned and cultivated, and the field was converted to surface drip. Plots measured 4 beds × 40 ft. Treatments were replicated 4 times and arranged in a split-plot randomized complete block design (water rate = main plot; nitrate concentration = sub-plot). Broccoli crops (cv. Patron) were also direct seeded, and followed the same experimental design and procedures as described for lettuce, with the exception that the fertilizer N treatment equaled 220 lbs N/acre.

The remaining field trials directly compared crop N recovery from irrigation water and fertilizer. Irrigation water with concentrations of 14, 25, and 44 ppm NO_3-N were compared with fertigation applications of AN20 of seasonal totals equal to 0, 20, 60, and 150 lbs N/acre in lettuce and 0, 40, 80, and 200 lbs N/acre for broccoli. The experimental design for these trials was the same as described above, with 4 replications, and following a split-plot randomized complete block design.

All trials were harvested when the highest fertilizer treatment reached commercial maturity. Above ground fresh and dry biomass yield was evaluated in the center two beds of the plots. Whole plant N content was determined so that crop N recovery efficiency (NRE) could be estimated. NRE was calculated for the water treatments as the increase in crop N uptake compared to the unfertilized control divided by the amount of NO_3-N applied in the irrigation water.

RESULTS AND DISCUSSION

Results of the lettuce trials demonstrated that the concentration of nitrogen in the irrigation water significantly affected lettuce plant size, N content of tissue, biomass yield (data not presented) and confirmed that a significant portion of the N in the irrigation water was taken up by the lettuce crops (Figure 1). Even relatively low concentrations of NO_3-N in the irrigation water were utilized by the crop. Similar results were also observed in the broccoli trial (Figure 2). Crop N uptake increased with increasing concentration of nitrate in the irrigation water.

The source of N in the irrigation water (NH_4 vs NO_3) had no significant effect on N recovery by the crop (data not presented). Presumably NH_4 would quickly transform to NO_3 when added to the soil. The volume of water applied to the lettuce crops did not affect the recovery of N from the water treatments (Figure 1), implying that all of the applied water could be credited as having N value to the crop. For broccoli, NRE was lower under the high water rate (180% ET) than the standard water rate (110% ET). However, the recovery of N from the standard fertilizer treatment was also less under the high water rate (Figure 2). Marketable yield of broccoli was not significantly different under the high and low water rates (data not presented).

The second set of trials which directly compared crop N recovery from irrigation water and fertilizer, demonstrated similar NRE from water and fertilizer sources of N in lettuce (Figure 3) and broccoli (Figure 4). Regression lines were fit to the N uptake response to the fertilizer treatments and the symbols represent mean N uptake response from the water N treatments. Crop N uptake from the water treatments was equal or greater than from corresponding fertilizer treatments. Crops were able to recover N from water with concentrations of nitrate as low as 14 ppm N. NRE was similar under high and standard water rates for lettuce but as found in earlier trials with broccoli, NRE declined for both the fertilizer and the water N treatments under the high water rate (Figure 4).

CONCLUSIONS

The results of these field trials demonstrated that N in irrigation water has fertilizer value for both shallow (lettuce) and deep (broccoli) rooted vegetables, even when the N concentration in the water was low (< 20 ppm N). The trials also showed that the volume of water applied did not affect the crop recovery rate of N from water more than from fertilizer, suggesting

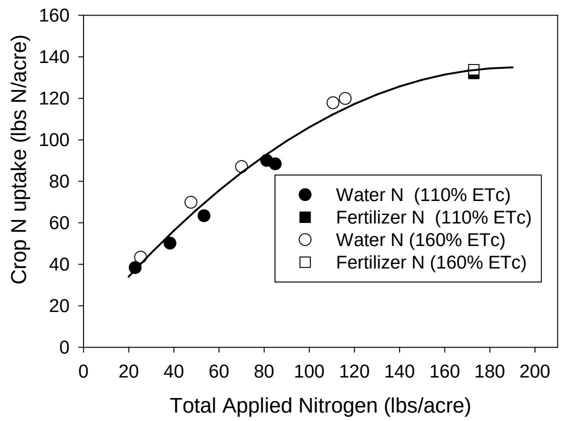

Figure 1. *N uptake by lettuce (spring crop) from water and fertilizer sources of N at standard (110% ET) and high water rates (160% ET).*

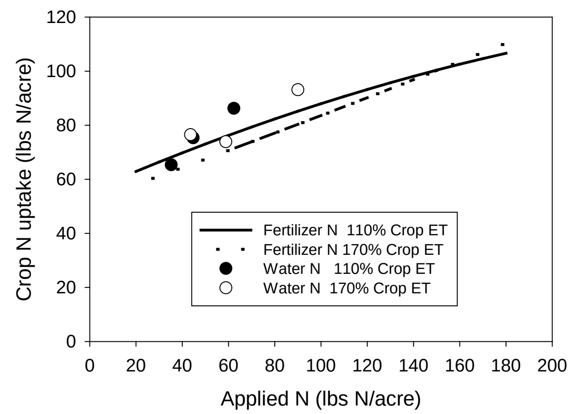

Figure 3. *N uptake by lettuce from water and fertilizer sources of N at standard (110% ET) and high water rates (170% ET). Regression curves were fit to data from treatments receiving only fertilizer N. Symbols represent the means of the water N treatments.*

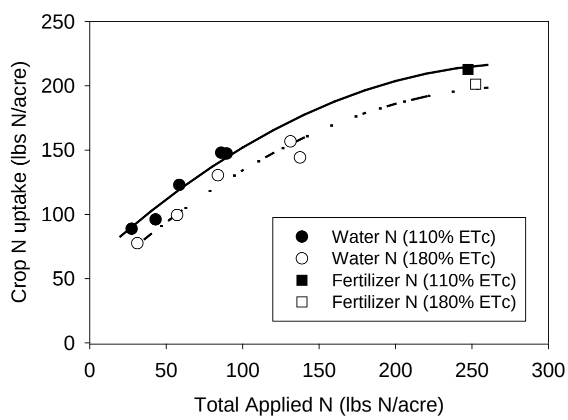

Figure 2. *N uptake by broccoli from water and fertilizer sources of N at standard (110% ET) and high water rates (180% ET).*

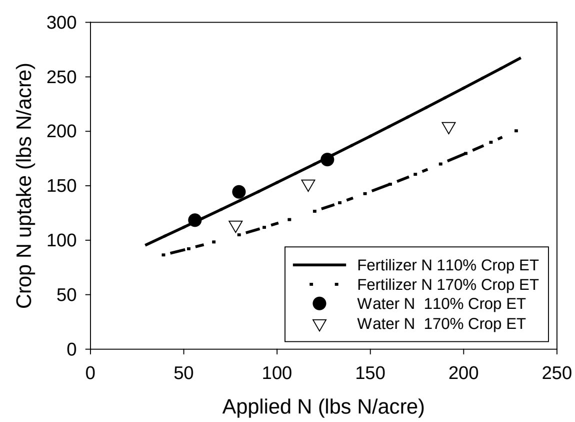

Figure 4. *N uptake by broccoli from water and fertilizer sources of N at standard (110% ET) and high water (170% ET) rates. Regression curves were fit to data from treatments receiving only fertilizer N. Symbols represent the means of the water N treatments.*

that it is reasonable to credit all the N applied in water as having fertilizer value to the crop. These results were attained under a well-managed drip irrigation system, with a high application uniformity and frequent irrigations so that irrigation volumes were small, which likely minimized leaching losses. It is possible that under poor water management or less efficient irrigation methods (eg. furrow), recovery of N would be less than was reported in these trials.

ACKNOWLEGEMENTS

We are grateful for the assistance of UCCE Staff Research Associates, Laura Murphy, Barry Farrara, Thomas Lockhart, and Patricia Love. Sharon Benzen and David Lara of the USDA-ARS in Salinas, are also acknowledged for assistance with replicated trials. This project was funded by a grant from the California Department of Food and Agriculture's Fertilizer Research and Education Program (FREP) and the Fertilizer Inspection Advisory Board.

California Certified Crop Advisor Educational Project

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INTRODUCTION

The California Certified Crop Advisor (CA CCA) program consists of grass roots professionals who serve to promote the educational goals of FREP with regard to soil, water, crop and nutrient source management and enhance the viability of crop advisor certification. The CA CCA program tests potential advisors using standardized, scientifically based exams, sets professional requirements, and provides certification for continuing education. The CCA certification is an accreditation for achievement and knowledge for nutrient management practices and not a regulatory-related license.

CA CCA currently certifies over 1,100 professional advisors, and is the heart of competency certification for nutrient management professionals in California. The CA CCA educational project has grown significantly in recent years, and has as its goal to provide a needs-based mechanism for the educational credits and certification of qualified individuals to enhance the core base of fertilizer experts. The CA CCA program has developed a unique role in California since being tasked with the ability to sign off on Nitrogen Management Plans.

Funding received during the grant period for the CA CCA educational project from CDFA/FREP enabled the all-volunteer CA CCA Board to achieve work objectives and have professional and efficient program administration.

OBJECTIVES

1. Provide responsible program administration, leadership and CCA awareness for the CA fertilizer industry.
2. Strengthen program & certifications through awareness of CCA role.
3. Achieve sustainability as an organization.
4. Efficiently administer the CA CCA program on a day-to-day basis providing services to the International Certified Crop Advisor program (ICCA), CDFA/FREP and all CA CCA certificate holders or candidates.

DESCRIPTION AND ACCOMPLISHMENTS

- CA CCA directors and the CAPCA CEO have engaged in educational discussions with CDFA Staff, CA Regional Water Quality Control Board representatives and UC during the reporting period to identify best management practices and educational goals to improve total industry knowledge in addressing nitrate issues. CAPCA assisted UC and CDFA FREP in conducting a two-day educational seminar that provided training in efficient nitrogen management practices to more than 85 CCAs. CAPCA conducted 6 fertilizer focused seminars during the reporting period, with 3 additional seminars planned for 2017.
- The CA CCA Board of Directors (BOD) will conduct bi-annual elections in October, 2017, maintaining the diversity of the Board. The BOD solicited non-director volunteers to help expand the reach of the CCA program. CA CCA has established regional committees for 2016 to build towards sustainability. Regional Committees in the Desert of southern California and Arizona, the Central Valley and the Central Coast empower CA CCAs to get involved locally, provide relevant continuing education meetings, articles and marketing outreach. The Regional Committees also provide a mechanism to ensure regional representation on the CA CCA Board.

- CAPCA as the grant Cooperator provided the professional management services guaranteeing responsible program administration and support to volunteer CA CCA directors. CAPCA ED has provided educational support, managing one additional Regional Committee continuing education (CE) course in addition to CCA CE and fertilizer seminars.
- The CA CCA program has demonstrated a positive growth and retention trend due to awareness efforts and ground water regulatory requirements. The CA CCA BOD continues to offer exam study seminars and on-line practice questions to aide candidates in their test preparation. The BOD continues to solicit feedback and edits for a CA study guide for the California exam. The number of CA CCAs for 2016 was 1140 and the program has 1192 as of September 30, 2017. A total of 158 candidates tested for ICCA in February 2017 with 61 passing the exam. Likewise, 153 tested for the CA exam with 72 passing the test. Additionally, the CA CCA BOD has engaged with ICCA to conduct an annual Anghoff Review of current CA Exam questions to maintain the integrity of the exam and knowledge expectations for new CCAs.
- The mainstream communications tool for CCA awareness continues to be the CAPCA *Adviser* magazine (6 issues), with constant contact newsletter and member survey and social media as the electronic marketing tools. CAPCA staff supports candidates in both email and telephone inquiries. During this reporting period, the CCA program continues to maintain a record number of CE courses and hours in 2017.
- CA CCA BOD will hold its 9th annual meeting in conjunction with their Modesto CE in November 2017.
- WPHA and CAPCA have included a CCA outreach/awareness effort in both the California University Student dinners and Pathway to PCA outreach programs whereby the message is conveyed to students to choose a career in agronomy, plant health and seek a professional license/credential to validate their expertise.
- CEU seminars covering urban and traditional agriculture have expanded CEU credits during the reporting period. The CCA BOD and ICCA work together to retain current CCA certificate holders.
- Dues paying membership of at least 1,000 has greatly assisted to make the CA CCA program self-sustaining. The CA CCA BOD is pleased that this membership goal has been reached and that normal administrative and operational support can be realized within the CA CCA program. The CA BOD and UC Project Leader continue to provide reviews and evaluations to CDFA/FREP. A CDFA representative attends all BOD meetings.

SUMMARY

CDFA-FREP support has enabled the CA CCA program to become a highly successful resource for fertilizer education and awareness, with significant growth over recent years. The CA CCA Board would have been financially challenged to administer the day to day operations and awareness efforts much less realize the positive growth in CA CCA numbers without the support of FREP. The CA CCA program is heavily invested in the educational component of the FREP objectives, and in developing long-term basic expertise and competency embodied in the more than 1,100 Certified Crop Advisors in California.

For more information on the program please contact: CA CCA Program, Ruthann Anderson (916-928-1625 x 7) or correspond to CA CCA 2300 River Plaza Drive, Suite 120, Sacramento, CA 95833. Fax 916-928-0705, www.cacca.org.

ACKNOWLEDGEMENTS

The CA CCA Program is grateful to the CDFA-FREP program for generous support of this vital educational program.

CERTIFIED
CROP ADVISER

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

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INTRODUCTION

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

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

This project proposes to develop such a decision support tool for irrigation and N management in processing tomatoes based on the framework of an existing tool, CropManage, which has been successfully developed and introduced for cool season vegetables on the Central Coast. The proposed project also includes outreach activities, such as workshops to train growers and consultants in the use of the tool.

OBJECTIVES

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

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

RESULTS AND DISCUSSION

Collecting soil and plant related data in commercial fields

Field work for the project began in spring 2016. Six commercial processing tomato production fields using subsurface drip irrigation were selected for the study in 2016 and another 5 commercial sites in 2017 (Table 1). In addition, a replicated trial has been set up at UC Davis in spring 2017 (site Y5).

In each field preplant samples to 2 feet in 1-foot increment were taken and analyzed for soil moisture as well as ammonium and nitrate concentrations. The preplant nitrate-N concentrations ranged from 18 to 325 lbs/acre in the top foot and from 15 to 160 lbs/acre in the second foot of the profile. These values are based on an estimated bulk density of 1.2 g/cm^3. The large differences among sites highlight the need for a site-specific tool that takes into account residual soil nitrate.

In-season soil and plant samples were collected in three-week intervals. In 2016, tomato plants took up between 257 and 395 lbs N/ac. It took approximately 40 days for the plants to accumulate 40 lbs N/ac, indicating that early season N requirements are low. Between 170 and 264 lbs N/ac of the total aboveground N was allocated to the fruits, which contained close to 3 lbs N/ton. Across all sites, the plants took up an average of 320 lbs N/ac by harvest, with 33% of the N being in the vines and 67% in the fruits. At the time this report was due, analyses of the 2017 samples were still ongoing.

In addition, canopy coverage was measured by infrared camera. The canopy cover first started with a slow initial growth phase, followed by rapid growth eventually reaching its full canopy, at that point the coverage stabilized (Figure 1). Canopy cover will be used to calculate the crop coefficient (k_c), which, combined with the reference evapotranspiration (ET_0) from the nearest weather station, will allow determining irrigation water needs.

Replicated trial at UC Davis

The trial is located at Campbell Tract, west of the UC Davis campus. The drip tape was installed in early April and the tomatoes were transplanted on May 1st, 2017.

The trial includes four treatments, each replicated five times. Each plot is 200 feet long and three beds wide. The four treatments are:

- 175 lbs N/ac; irrigation 100% ET
- 225 lbs N/ac; irrigation 100% ET
- 225 lbs N/ac; irrigation 130% ET
- 275 lbs N/ac; irrigation 100% ET

Based on the results from commercial fields in 2016 and an expected yield of 55 tons/acre, N uptake was estimated to be 246 lbs/acre. Subtracting residual soil nitrate and N in the irrigation water, the fertilizer N requirements were estimated to be 225 lbs/acre. This application rate includes starter N and an N use efficiency of 90%.

Irrigation water need was calculated based on modeled canopy development (Figure 1) and average weather data of the previous four years. On a weekly basis, irrigation water requirements were recalculated based on the current years' weather data and corrections were made if necessary.

Table 1. *Location, soil type, transplanting dates and plant densities of the fields included in the study.*

Year	County	Site	Coordinates (rounded to the nearest 5')	Date transplanted	Density (plants/ac)
2016	Yolo	Y 1	Sycamore	April 12	9,825
		Y 2	Maria silt loam	April 16	10,024
	San Joaquin	SJ 1	Hollenbeck silty clay	May 16	9,294
		SJ 2	Capay clay	May 12	7,634
		SJ 3	Egbert silty clay loam	May 4	8,697
	Fresno	FR 1	Westhaven clay loam	May 9	8,912
2017	Yolo	Y 3	Yolo silt loam	April 25	8,564
		Y 4	Reiff very fine sandy loam	April 17	10,555
		Y 5	Yolo silt loam	May 1	9,400
	San Joaquin	SJ 4	Capay clay	April 28	8,896
		SJ 5	Egbert silty clay loam	April 27	8,829
	Fresno	FR 2	Westhaven clay loam	April 13	8,614

The tomatoes were harvested on August 25, 2017 (Figure 2). The marketable yield averaged 58 tons/ac. A preliminary analysis of the results indicated that there were no statistically significant differences between treatments. Plant analyses and soil N mineralization data will reveal whether N uptake was over-estimated or the capacity of the soil to provide N during the growing season was underestimated.

OUTLOOK

The replicated trial at UC Davis will be continued in 2018. The data collected during the 2016 and 2017 seasons will be used to improve algorithms and equations of CropManage. Outreach activities and training sessions for growers and consultants will start during winter 2017/18.

ACKNOWLEDGEMENTS

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

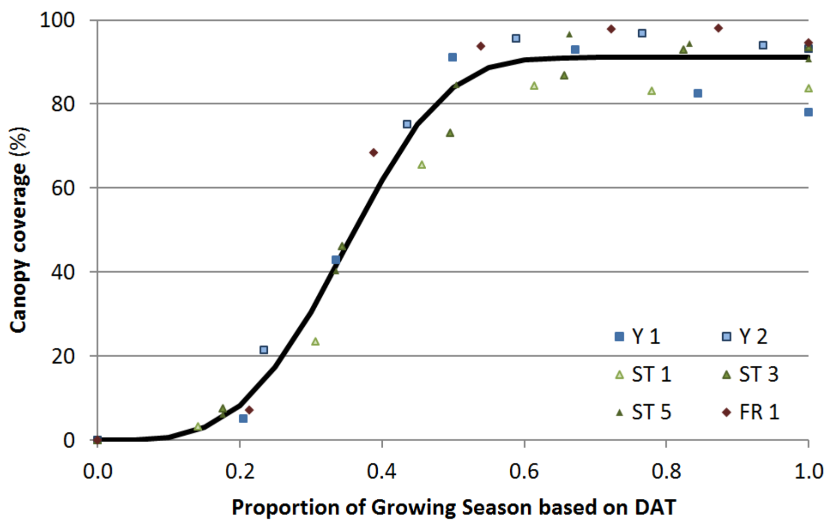

Figure 1. *Measured (symbols) and modeled (line) canopy coverage across all six sites included in 2016.*

Figure 2. *Harvest of the field of the replicated trial on August 25, 2017.*

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

Project Leader

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INTRODUCTION

California growers produce a wide range of different crops. For many crops, a comprehensive overview and synthesis of the current research on fertilizer use and management has long been missing. With support from FREP (projects 11-0485-SA and 15-0231), we have been closing this gap by writing online fertilization guidelines for about 30 major crops grown in California. However, for many smaller-acreage crops, very little information on nutrient management under California's conditions is currently available.

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

OBJECTIVES

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

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

DESCRIPTION OF PROJECT

Work on the project began in spring 2017. The following tasks are ongoing:

We are creating a generalized nutrient management web page discussing efficient nutrient management practices. The web site will be in the same user-friendly, interactive format as the existing crop-specific guidelines. This page will highlight important points that need to be considered when making nutrient management decisions. Topics will include the 4R's of nutrient management, (right rate, right time, right source and right place) soil test interpretation and plant tissue test interpretation. The webpage will focus on practices specific to cropping systems and environmental conditions in California. As is the case with the existing crop-specific guidelines, the discussion will cover N, phosphorus (P) and potassium (K).

We are creating an online N calculator for a number of annual crops, such as sugar beets, sweet potatoes, cucumbers, squash, sweet corn, triticale, and peppers. The calculator will be linked to the web page. Application rates and optimal time of application heavily depend on field-specific factors. These factors will be taken into account in the N calculator. Users will be able to enter basic information about their crop and the cropping system, such as crop type, yield goal, residual soil nitrate and irrigation system. The calculator will then estimate the total amount of N required (fertilizer N and non-fertilizer N) to achieve the target yield. The calculation will be based on data about crop removal at harvest and total N uptake.

The calculator shall also provide information about timing of N uptake. Optimal time of application depends on the seasonal N uptake curve. An N uptake curve may not be available for many smaller-acreage crops. In the absence of a published curve, the N calculator will create an uptake curve based on total N uptake with crop-specific adjustment. In general, the N uptake curve is S-shaped for annual plants, with the N uptake rate being low during germination and seedling growth, reaching a maximum during vegetative growth and slowing down during generative growth. The calculator will modify the shape of the curve depending on method of planting (seeding or transplanting), the growth stage the crop at harvest (during vegetative growth or at maturity), and the growth pattern (indeterminate or determinate).

ACKNOWLEDGEMENTS

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

Train the Trainer: A Nitrogen Management Training Program for Growers

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INTRODUCTION

Growers who belong to California's Central Valley Water Quality Coalitions and who are in areas designated as high vulnerability are under requirements from the Irrigated Lands Regulatory Program (ILRP) to keep "on farm" a certified Nitrogen Management Plan (NMP) to track nitrogen fertilizer applications. The Waste Discharge Requirements General Orders for the Central Valley allows growers to self-certify their own nitrogen management plans if they attend a training program approved by the California Department of Food and Agriculture. The 12 Central Valley coalitions, with funding from FREP, have instituted a grower training program for their members. The training program is based on a curriculum developed for training Certified Crop Advisors (CCAs) by the University of California. Between November 2015 and September 2017, the coalitions hosted 53 grower certification meetings throughout the Central Valley. More than 2,950 growers have attended the trainings and 80% of them passed the exam. Additionally, each grower needs to obtain three hours of continuing education to maintain their certification in the three years after completing the training. This continuing education component is being orchestrated through the FREP-funded project entitled "Developing a Review Process for Continuing Education Courses for Growers who Complete the Nitrogen Management Plan Training Course."

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

OBJECTIVES

1. Conduct outreach to attract potential trainers for the grower self-certification trainings.
2. Organize and conduct the Train-the-Trainer sessions using educational materials developed by University of California for the grower self-certification trainings. Trainers are considered qualified for this program once they have completed this curriculum training.
3. Manage the interaction between those requesting a trainer for a grower training session and the trainer.
4. Provide grower testing, keep records of attendance, successful completion, and conduct trainer evaluation.
5. Review and certify both content and trainers to conduct this activity.

DESCRIPTION

1. Outreach conducted with Certified Crop Advisor contacts to attract potential trainers for the NMP Grower Self-Certification Sessions.
2. Train-the-Trainer sessions were conducted with the potential trainers using the educational materials developed by UC for the grower self-certification trainings. Upon successful completion of the Train-the-Trainer session, a trainer qualifies to facilitate the NMP Grower Certification program.
3. Program manages the interaction between those requesting a trainer for a grower training session—i.e. a coalition, grower group, private business, etc.—and the trainer.
4. The host organization provides space and equipment, keeps records of attendance, successful completion and conducts trainer and program evaluations.
5. After the initial grower self-certification, three additional hours of continuing education are required.
6. The complementary program reviews and certifies content for the Organization to conduct this activity.

RESULTS AND DISCUSSION

To date, CURES has hosted 5 CCA trainings which produced 28 Certified Professionals eligible to lead a NMP grower self-certification session. As of September 2017, 53 grower self-certification sessions have been held, with a total of 2,953 attendees, 80% of whom have passed the exam. In addition, coalitions have organized 39 test retake sessions.

Figure 1. *Average class size and score comparison of Northern and Southern coalitions*

	Northern Valley	Southern Valley
Average number of attendees	39	63
Average score	84%	80%

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

ACKNOWLEDGEMENTS

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

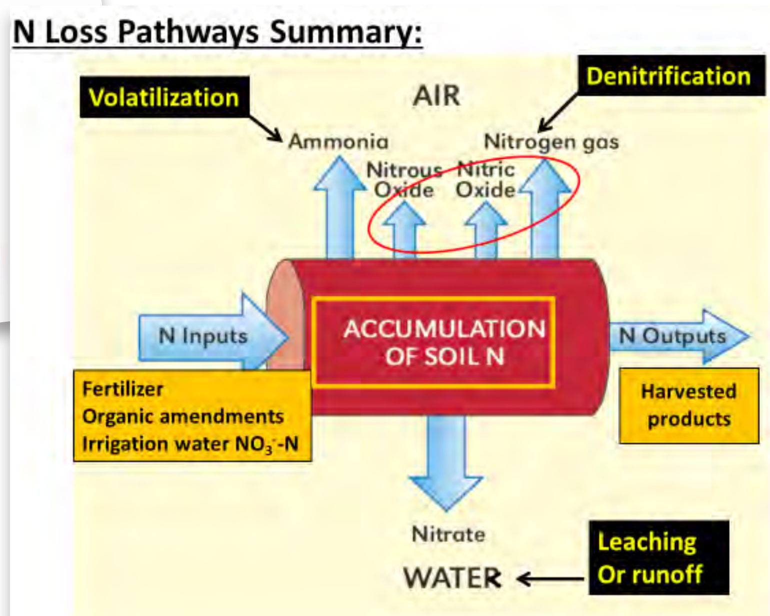
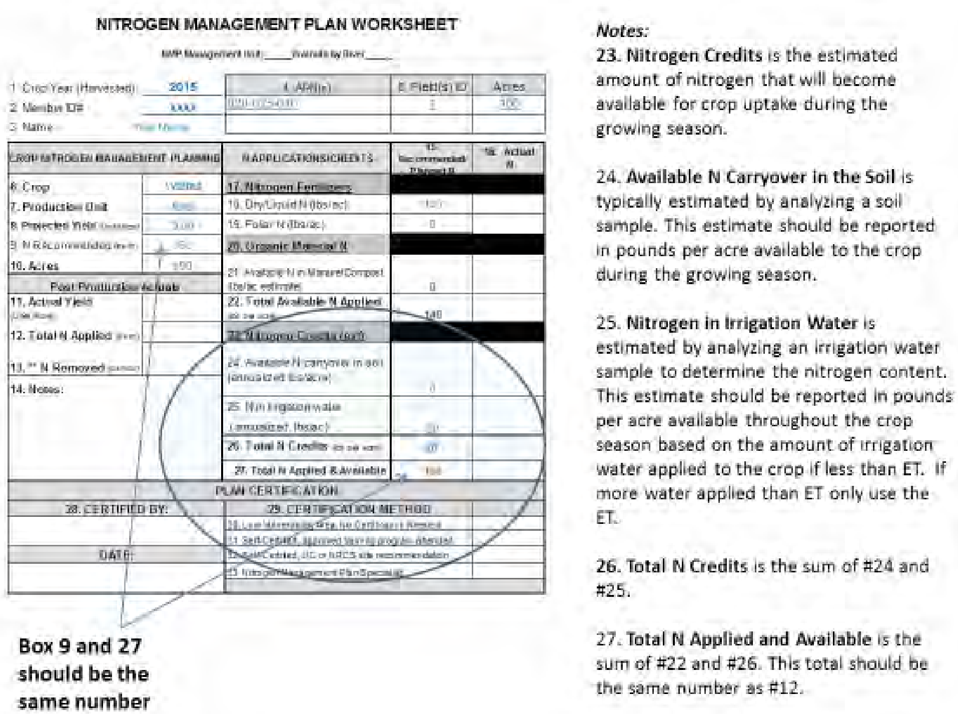


Figure 2 (above). *Nitrogen Management Training Curriculum, front cover*

Figure 3 (right). *'N Loss Pathways Summary' diagram, p. 52 in Nitrogen Management Training Curriculum*

Figure 4 (below). *Step by step direction and helpful hints on how to fill out the NMP Summary Report, p. 184 in Nitrogen Management Training Curriculum*



Improving N Use Efficiency of Cool Season Vegetable Production Systems with Broccoli Rotations

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INTRODUCTION

Nitrate leaching in vegetable production in the Salinas Valley is a continuing problem that affects the ability of municipalities to access drinking water that meet federal water quality standards. Regulations by the Central Coast Regional Water Quality Control Board (CCRWQCB) require growers to improve nitrogen use efficiency (NUE) in production fields. The FREP funded a project entitled, “Survey of nitrogen uptake and applied irrigation water in broccoli, cauliflower and cabbage production in the Salinas Valley” demonstrated that the average above ground biomass nitrogen (N) averaged 327, 327 and 284 lbs/A for broccoli, cabbage and cauliflower, respectively with average N fertilization rates of 186, 249 and 228 lbs/A. These data indicate that these crops typically scavenge N from the soil. Broccoli is a key rotational crop and has the potential to scavenge residual soil N left by previous crops such as lettuce. This project was undertaken to measure the impact of broccoli rotations on nitrate leaching in the cool season production region of the central coast.

OBJECTIVES

1. Evaluate the rooting depth of broccoli and examine how deep in the soil profile that it is removing nitrogen for crop growth
2. Evaluate soil sampling to two feet with the nitrate quick test to determine soil nitrate threshold for guiding N fertilizer applications in broccoli
3. Evaluate the ability of broccoli to remove residual nitrate from the soil following a lettuce crop under normal production practices
4. Examine the mineralization rate and quantity of nitrate mineralized from broccoli residue to assist its utilization by subsequent crops

DESCRIPTION

Trials were conducted in 2014 and 2015 at the USDA Spence Research Station, Salinas to evaluate the impact on broccoli production of applying N at various depths in the soil. Drip tape was mechanically injected 12, 18 and 24 inches deep to facilitate placement of the nitrogen fertilizer in the soil. Nitrogen in the standard treatment was applied as UN32 in drip tape on the soil surface. Calcium nitrate was used at the N source in the 12, 18 and 24 inch treatments. A total of 150 lbs N was applied to the treatments in three applications of 50 lbs N/acre on 27, 38 and 48 days after the first germination water. Soil samples to three feet were collected on six dates during the crop cycle and crop yield and biomass were collected at harvest.

A survey of the nitrogen budget of ten commercial broccoli fields grown following a prior lettuce crop was conducted in 2014 and 2015. Residual soil nitrate levels down to three feet were collected four times during the crop cycle. There were three to four replications of the grower standard and untreated control strips in each field. Total irrigation water applied to the fields was monitored with a flow meter to determine the degree of leaching. Measurements of the number of roots down to three feet deep were conducted at three of the five survey sites each year. Crop biomass and biomass N were measured on the same day as soil samples were collected.

In five of the survey fields, replicated areas measuring 40 foot by 40 foot were cleared of broccoli residue at the end of the crop cycle. The grower tilled the field using standard practices and no preplant N fertilizer was applied. The fields were fallow over the winter. Soil nitrate levels were measured in the top two feet of soil every two weeks over the winter fallow period in the areas with and without broccoli residue.

RESULTS AND DISCUSSION

Evaluations of the ability of broccoli to take up residual soil nitrate were conducted with cooperating growers in commercial broccoli fields and in research station studies. Evaluations included surveys of the amount of nitrate taken up by broccoli from the top three feet of soil during the cropping cycle, broccoli rooting depth and the total quantity of N taken up by broccoli. In a survey of 10 commercial broccoli production fields, we observed that growers typically apply moderate quantities of fertilizer N to broccoli (app. 180 lbs N/acre) while the crop routinely takes up >300 lbs N/acre from the soil; this indicates that the crop routinely scavenges N from the soil. However, the efficiency of recovery of residual soil nitrate-nitrogen (NO_3-N) declines if residual NO_3-N in the top 3 feet of soil at the beginning of the broccoli crop cycle is greater than 200 lbs/acre (Table 1). Therefore to take full advantage of the nitrate scavenging ability of broccoli, it is necessary to have low to moderate levels of residual soil nitrate left over from the prior crop rotation. Best management practices (BMP) that can help to reduce excess residual soil nitrate from the prior rotation include: the use of the nitrate quick test to account for residual soil nitrate, accounting for nitrate levels in the irrigation water and adjusting fertilizer rates accordingly.

Broccoli is capable of scavenging nitrate from the soil because of its deep rooting habit. We measured broccoli roots extending to 40 inches deep by the end of the crop cycle (Figure 1); however, the density of broccoli roots in the 2nd foot of soil increases significantly by 50 days after seeding. Soil samples taken of the 2nd foot at this time can help determine if sufficient residual soil nitrate is present to determine if late-season fertilizer applications are needed to finish out the crop, and may provide an opportunity to further improve fertilizer use efficiency. About 1/3 of the N taken up by the broccoli crop during the growing season is removed from the field in the harvested product; as a result, broccoli routinely returns 200-250 lbs N to the soil in crop residue. Approximately 50 to 60% of the N contained the crop residue is mineralized in the first 4-6 weeks following incorporation into the soil. The nitrate mineralized from broccoli crop residue can be effectively utilized by subsequent crops if careful irrigation management and soil testing to account for the residual soil N occur. However, nitrate released from broccoli residue incorporated prior to winter fallow is at risk for leaching. Winter-grown cover crops could effectively capture the nitrate released from broccoli residues, but unfortunately in the Salinas Valley, the use of winter grown cover crops is limited by planting schedules and economic factors. These results indicate that broccoli can serve as a BMP for capturing nitrate that otherwise might be lost to leaching, but that care needs to be taken to account for the N in the residues that are returned to the soil.

TAKE-HOME MESSAGE

This project provided information on the potential benefits of reducing nitrate leaching by broccoli rotations in the leafy green production areas. Given

Table 1. *Nitrogen budget. Summary of 10 fields evaluated in 2014 and 2015.*

Data	Initial residual soil mineral N[1] lbs/A	Total fertilizer N applied lbs/A	Total available mineral N lbs/A	Total N uptake by broccoli crop lbs/A	Percent of total N taken up by broccoli	Final residual soil mineral N[1] lbs/A	Total soil residual and crop uptake N lbs/A	Total N potentially leached[2] lbs/A
Mean	265.3	189.1	454.4	312.9	73.3	68.5	381.4	103.0
Range: low high	134.3 431.3	169.1 240.0	324.4 637.2	220.5 370.0	40.2 106.1	4.6 191.5	312.6 502.6	-14.0 214.8

1 – total N in the top three feet of soil at the beginning of the crop cycle; 2 – calculated by subtracting total residual soil N and crop uptake plus total mineral N from total available mineral N (also includes an estimate of N mineralized from soil organic matter of 30 lbs N/acre as part of the total available mineral N)

the high value of the land and intensive production schedules, there is little opportunity to fit cover crops into the rotations and this study showed that under certain situations, broccoli can play the role of a cover crop, when initial levels of residual soil nitrate in the top three feet of soil are <200 lbs N/acre and fertilizer programs are moderate (<180 lbs N/acre). However, only 1/3 of the N contained in the broccoli crop is contained in the harvestable portion of the crop. Broccoli crop residues routinely contain 200-250 lbs N/acre and 50-60% of the N contained in them mineralizes within 4-6 weeks. Therefore careful management of the N released from broccoli crop residues is necessary to fully realize the benefits obtained from nitrate scavenging by broccoli grown in rotation with prior lettuce crops.

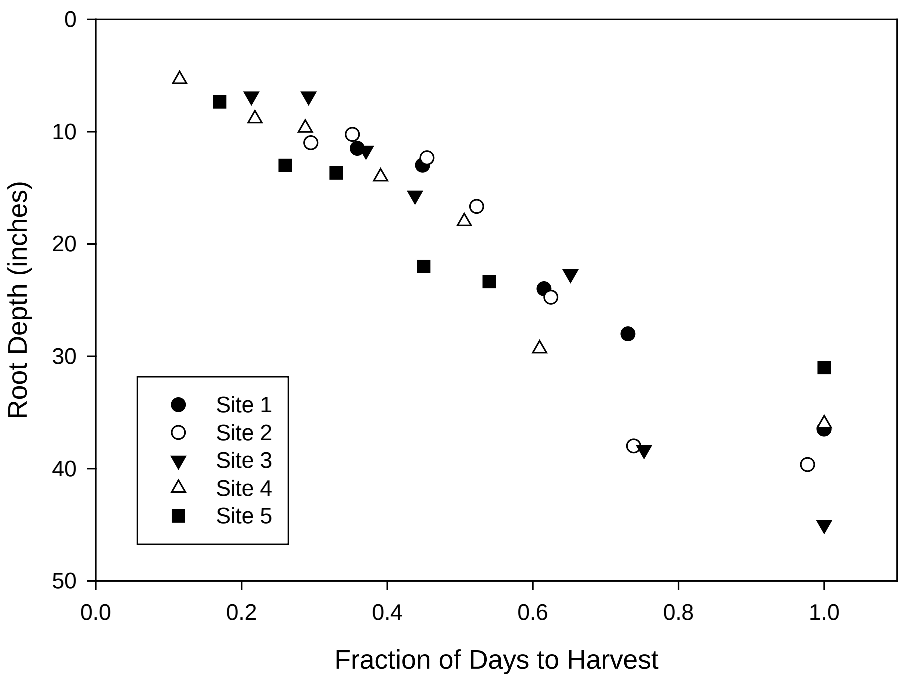
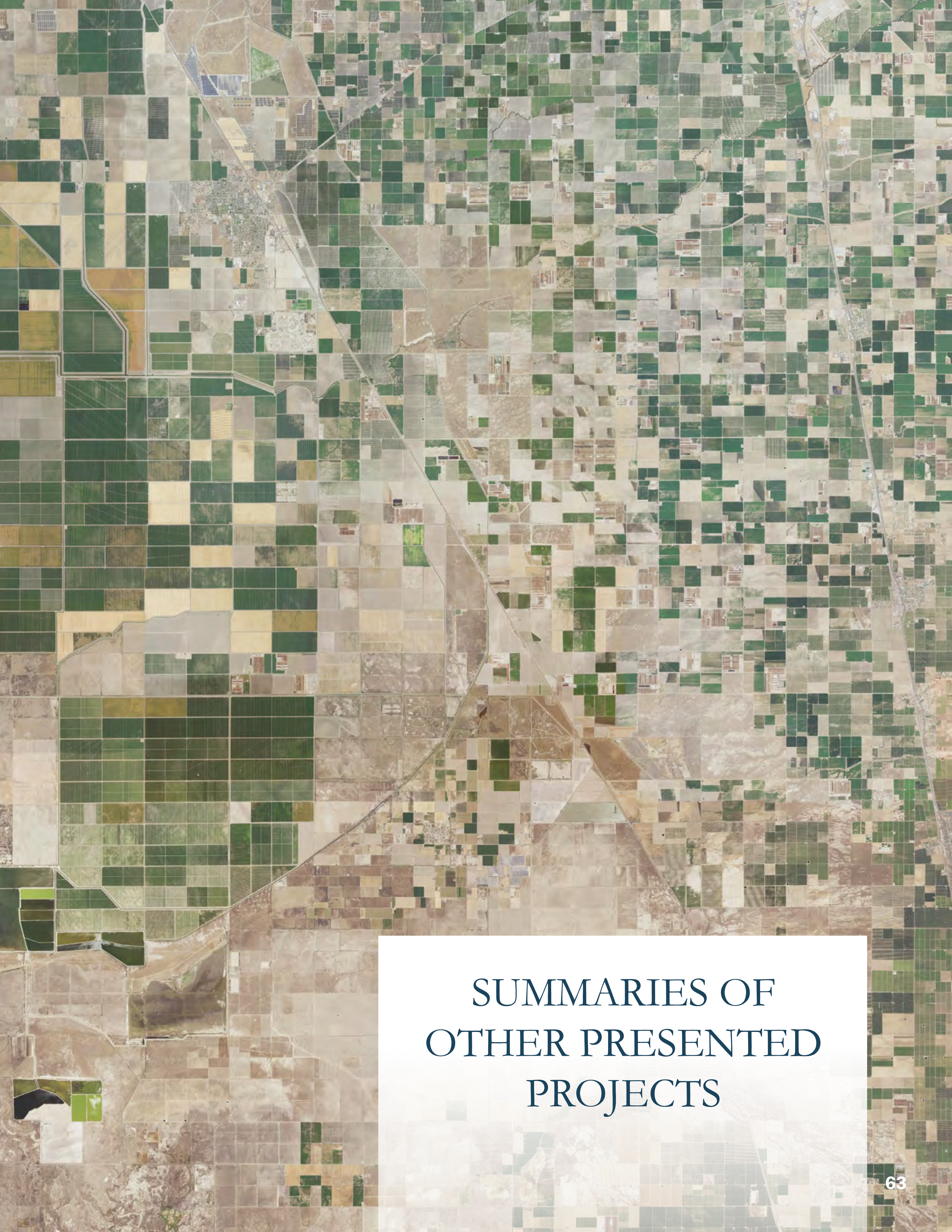


Figure 1. *Rooting depth of broccoli over the course of the crop cycle*

ACKNOWLEDGEMENTS

We are grateful for the support of the California Department of Food and Agriculture's Fertilizer Research and Education Program (FREP) and the Fertilizer Inspection Advisory Board for funding for this project. We are grateful to the support of UCCE Staff Research Associates, Tricia Love, Laura Murphy, Tom Lockhart and Barry Farrara and the USDA-ARS Staff Sharon Benzen, David Lara and Jerry Ochoa. We are also grateful to the support of cooperating growers and Wilbur Ellis and Performance Ag for fertilizers.



SUMMARIES OF OTHER PRESENTED PROJECTS

Nitrogen Removed with Harvested Crops

Daniel Geisseler
Department of Land, Air and Water Resources, UC Davis

Nitrogen balances in agricultural fields are an important component of the Central Valley Irrigated Lands Regulatory Program. The ratio of nitrogen applied to nitrogen removed is a key metric for the State and Central Valley Regional Water Boards. While the nitrogen application rates and yields are known by the growers, the nitrogen concentrations in the harvested plant parts are generally not determined. To obtain an overview of nitrogen concentrations in the harvested parts of crops and the variability of these values, I conducted a literature review for some 70 commodities. In my presentation I will focus on the key findings of the review. The report is available online (https://apps1.cdfa.ca.gov/FertilizerResearch/docs/Geisseler_Report_2016_12_02.pdf).

For some crops, extensive datasets from California were available, while for many other crops only few if any values could be found. Therefore, for many crops, the dataset needs to be supplemented with additional samples from Central Valley fields to support a robust estimate of the nitrogen concentrations in harvested plant parts.

The nitrogen concentration in harvested plant parts can be quite variable and is affected by a number of factors. For most crops included in the report, year of harvest, nitrogen availability and variety contributed most to the observed variability. These factors seem to affect nitrogen concentrations in field crops, vegetables and tree crops equally. Other factors, such as fruit size, dry matter content of the harvested plant part, percent marketable yield, or growth stage when harvested may also be important for some crops. With nitrogen concentrations in harvested crop parts varying considerably from one year to the next, the calculated value for nitrogen removed is only accurate on a multi-year basis, but may not be accurate for a specific year.

An alternative to using average values is to have growers take representative samples at harvest and have them analyzed in a lab. However, this approach would be costly and time consuming for growers. Furthermore, taking a sample that represents the entire field can be challenging for some crops and the sampling protocol depends on the crop. An inappropriate sampling protocol may result in an inaccurate estimate of the nitrogen concentration in the harvested crop parts. Based on these considerations, using average values is a simple approach which can provide a useful estimate of nitrogen removed at harvest as long as the limitations are taken into account.

CAPCA and CCA Update

Adam Barsanti
California Association of Pest Control Advisers (CAPCA)

The Certified Crop Adviser (CCA) Program here in California has long been subsidized by FREP Grant Funding to build a sustainable program within the unique regulatory structure of the state. As the current FREP funding sunsets for the CCA program in 2017, we are proud to discuss the strength of the current program and our vision to continue to grow the value of the CCA program here in California. With CAPCA continuing as the program administrator, there are organic ways to build education, outreach and professionalism. CAPCA works to maintain an excellent working relationship with CCA's, as nearly 85% of the CCA's also hold PCA licenses.

Some of the issues that we will be addressing during our presentation will be the development of the role and importance of the CCA program within the State of CA. Being a CCA in California holds a unique set of circumstances compared to the rest of the country due to California's climate and regulatory system.

How does CAPCA support nutrient management? CAPCA supports further education and training of CCAs and PCAs through its Continuing Education Units, publication, Adviser Magazine, as well as Applicator Alerts Newsletter. The future of the CCA program in CA will include further education to provide expertise on the local level, as well as providing state specific resources that are relevant to the CCA program. CAPCA also plans to work with CDFA and FREP to help improve nutrient management trainings and other CE opportunities to support the CCA program.

Salinity Management: Correcting a Saline Soil

Keith M. Backman
Consultant Manager, CCA, MS Pomologist
Dellavalle Laboratory, Inc.

In California, the problematic salts are primarily sodium, chloride and/or boron. Use of poor quality ground water has created problems in many farming areas over the past few years. Growers often speak of the difficulties in creating a leaching program that improves the situation. My experience is that often the leaching programs used are at points in the growing season when they are ineffective.

Salt damage to crops is often due to salt accumulation over time, rather than just salty irrigation water. A single irrigation or a single season usually does not bring crop-damaging salt levels. Many of the problems we see in the field are the result of multiple seasons of neglect.

Keep these rules in mind when planning your salinity management:

1. Leach when the crop is using little or no water.
2. The crop should be dormant or the field should be open.
3. Start early in open fields.
4. Multiple irrigations are required.
5. Plan the direction of your water flow.
6. Precede the leaching with the necessary calcium already available in the soil.
7. Ripping and slip plough can be beneficial, and
8. Yes, you can improve the situation using poor water!

These points can help to create an optimum salt leaching program.

Plant Nutrition: Past, Present, and Future

Marja Koivunen
AMVAC Chemical Corporation

The science of plant nutrition has greatly advanced from the time when von Liebig's 'Law of the minimum' was first introduced in 1873 (Figure 1). At the time, the idea of balanced nutrition was new and exciting, and it focused future research on the intricate balance of the macro and micro nutrients and environmental conditions on plant growth and ultimately, the yield.

The development of chemical processes to manufacture commercial fertilizers after WWI was the key to intensified agriculture that used inorganic fertilizer inputs instead of on-farm nutrient sources such as manure. Improved knowledge on plant nutrient requirements and uptake mechanisms contributed to the increased nutrient efficiency as well as higher yields and profitability of agriculture as we know it.

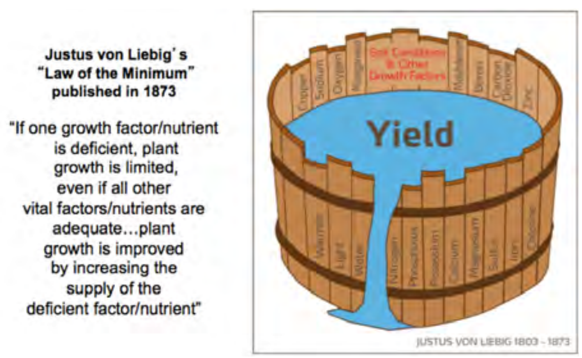


Figure 1. *Liebig's Law of Minimum (http://www.kemnovation.com)*

Even though the basic principles of plant nutrition have stayed the same, the goal of improved nutrient efficiency, together with increased environmental regulations have pushed growers and fertilizer manufacturers to expand their horizons and to think outside the box. The 4R Nutrient Stewardship Concept (Right Source at the Right Rate, Time and Place) reflects the need to feed the crop to fulfill its needs during the growing season without any harmful effects to the environment. Growers in the 21st century acknowledge the importance of application timing that follows the plant's nutrient requirements, and have adopted practices such as slow or controlled-release fertilizers and application of nutrients with irrigation water according to the crop's physiological needs. Through the advances of application technology, the use of soil analysis data that allows site-specific fertilizer application is now possible, and no longer a fantasy. On the other hand, a growing awareness of Soil Health as a limiting factor for plant growth and soil productivity has brought new insights in the discussion about the importance of soil organic matter and microbial activity in plant growth and nutrient uptake.

What about the future and the next steps in our learning curve in plant nutrition? In the recent years, the number of fertilizer products that claim biostimulant effects such as enhanced plant nutrient uptake and improved resistance to drought, heat and other environmental stress factors has increased tremendously. Instead of inorganic nutrients, these biostimulant products contain compounds that stimulate enzymes required for plant nutrient uptake. Modern molecular biology with novel imaging and analytical techniques have shown that ion transport through the root cell membrane is regulated by specific carriers and metabolic enzymes that can be targeted with biostimulant active compounds. This new era of plant nutrition is more focused on manipulating the plant nutrient uptake process, instead of simply improving the nutrient content and availability in the soil. Time will show if this new biostimulant approach leads to consistent improvement of yield quantity and quality. At the moment, an unclear regulatory path at the Federal and State level is limiting the number of interested industry partners, and slows down the research and commercial development of plant nutrition products in this sector.

What is the Nitrogen Contribution from Added Organic Materials?

Robert Mikkelsen
Vice President, International Plant Nutrition Institute

The Water Quality Control Board *Nitrogen Management Plan Worksheet* requires that farmers report the quantity of N supplied from fertilizer and organic material applied to each field.

While this appears as a single value in the worksheet, the complexity of determining the N availability from organic materials is one of the most challenging tasks that farmers and soil scientists face in nutrient planning.

Difficulties in accurately predicting the plant nutritional value of N from organic matter arise from (1) accurately characterizing the organic matter and (2) predicting the complex chemical and biological reactions after application to the soil. This uncertainty in estimating “plant-available N” (PAN, fertilizer replacement value) makes it challenging to use organic resources to their maximum nutrient advantage. The majority of the P in most organic materials becomes available for plant uptake relatively quickly and the K in organic matter behaves similarly to fertilizer K sources. However, the behavior of N in organic matter is more complex. In addition to their potential nutrient value, organic amendments can make a valuable contribution to the soil physical properties and biological activity when applied in significant quantities.

Organic Materials

There is great variability in the release of PAN depending on the nature of the organic matter. To use a local example, Dr. Tim Hartz et al. (2000) published the N release rates of 31 organic materials incubated in a Yolo silt loam soil after 4, 8, or 12 weeks (Table 1). They reported that the rate of N mineralization was extremely varied among the material types, and even within a single class of material. For example, dried poultry manure (#1 and #20) released considerable N, while aged poultry manure (#3) released no PAN after 8 weeks of incubation. Several of the composts showed net immobilization (negative N release) after 8 weeks and would be entirely unsatisfactory as a nutrient source within one growing season (Figure 1).

A similar N mineralization study was conducted by Van Kessel and Reeves (2002) where they collected 107 individual samples of dairy manure and incubated them for 8 weeks to determine PAN. They found that the release of PAN from dairy manure is highly variable and could not be predicted with much certainty, even when the soil and environmental conditions remained constant. Of the 107 samples, an average of 13% of the organic N was mineralized, but 19 samples had net immobilization, while mineralization from the remaining samples ranged from zero to 55% (Figure 2). Their results highlight the absolute necessity to understanding the specific properties of an organic source in order to accurately predict the nutrient supplying properties.

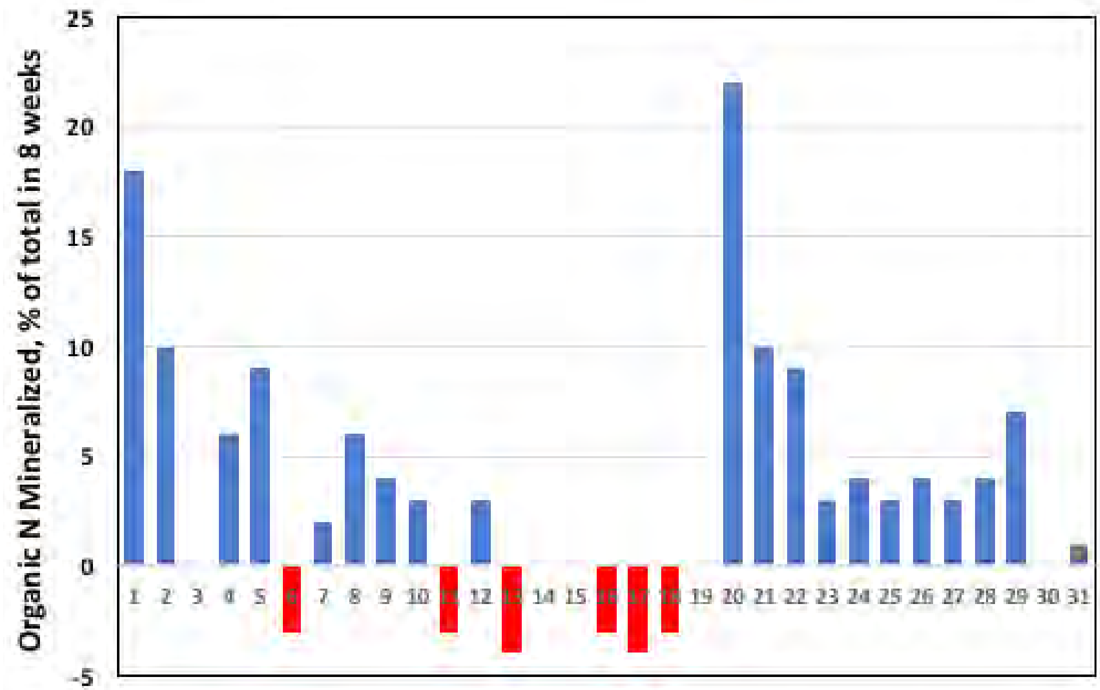
If it is not possible to test the chemical composition of the organic material before applying to the field, the materials should still be analyzed after application and the later fertilizer additions can be adjusted accordingly.

The contribution of N into the soil from cover crops can also be significant. Grass species are especially effective at scavenging excess nitrate from the root zone, and gradually releasing the biomass N after they are killed. Leguminous cover crops that fix N_2 can make a significant contribution to the total N budget of a farm. The N release from legume and non-legume cover also requires some estimations to properly predict their nutritional value to the succeeding crop. This topic will not be addressed in this presentation however.

Soil and Environmental Factors

The soil environment surrounding the applied organic matter will also determine the rate of N release. Nitrogen mineralization is largely a microbiological process, so conditions that favor rapid biological activity will speed decomposition. Some of these environmental factors include adequate soil moisture, moderate pH, good soil contact, warm temperature, adequate aeration, etc. In general, soil conditions that favor healthy root growth are also optimal for N mineralization and organic matter decomposition.

Figure 1. *Nitrogen mineralization of the organic N fraction of 31 materials following 8 week of incubation in Yolo silt loam. Mineralization ranged from +22% to -4% (immobilization) depending on the nature of the organic material. (Hartz et al., 2000; HortSci 35:209-212)*



Organic materials that are left on the soil surface may be susceptible to ammonia volatilization losses. These losses can range from very small to over 50% of the N in fresh animal manures. Ammonia volatilization results in a loss of a valuable plant nutrient, but also can contribute to deterioration of air quality as it contributes to the formation of haze and particulates. Organic materials that remain dry on the soil surface during hot California summers have very little biological decomposition. When feasible, fresh organic materials should be placed below the soil surface or incorporated to maximize their benefit. However, this soil disturbance may not fit into a no-till management strategy.

Making a Decision?

With the uncertainly involved with both the measuring chemical composition of the organic materials and estimating their behavior in soil, it is impossible to make a perfect prediction of N release rates. However, there are tools, calculators, and working estimates that can be used for making management decisions. For example, The Oregon State Organic Fertilizer Calculator provides an Excel-based estimate of N release for planning purposes. A number of University of California publications also provide useful estimates of N mineralization. These planning tools will be highlighted in the presentation.

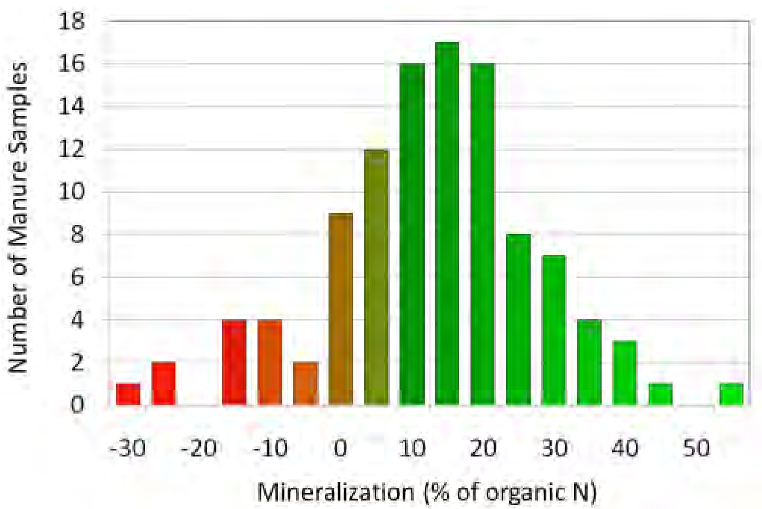


Figure 2. *Nitrogen mineralization from 107 individual dairy manure samples after 8 weeks of incubation. On average, 13% of the organic N was mineralized, but 19 samples had net immobilization, while mineralization from the remainder samples ranged from zero to 55%. (Van Kessel and Reeves, 2002. Biol. Fertil. Soils. 36:118-123).*

Table 1. *Partial description and chemical composition of 31 organic materials evaluated for N mineralization (Hartz et al. 2000).*

Amendment number	Description	Total N	Total C	C/N Ratio
		--- g/kg---		
1	Pelletized poultry manure	47	213	4.5
2	Aged poultry manure	31	282	9.1
3		27	268	9.8
4	Aged feedlot manure	20	250	12.4
5	Poultry manure compost	38	217	5.7
6		27	249	9.1
7		24	210	8.8
8		20	162	8.0
9		20	158	7.8
10		13	136	10.2
11	Feedlot manure compost	22	251	11.4
12		21	185	8.8
13	Crop residue compost	12	111	9.3
14	Muni. yard waste compost	16	236	14.4
15		14	191	13.3
16		16	208	13.0
17		16	221	13.8
18		13	200	15.4
19		10	120	12.0
20	Dewatered poultry manure	33	298	9.0
21	Aged poultry manure	25	292	11.6
22	Aged feedlot manure	24	302	12.5
23	Poultry manure compost	26	181	7.0
24	Feedlot manure compost	22	174	9.3
25		20	167	8.2
26		20	201	10.1
27		19	174	9.3
28	Dairy manure compost	15	155	10.5
29		12	173	14.0
30	Muni. yard waste compost	14	217	15.5
31		17	220	12.9

T.K. Hartz, J.P. Mitchell, and C. Giannini. 2000. Nitrogen and Carbon Mineralization Dynamics of Manures and Composts. HortSci 35:209-212.

Impact of Improved Plant Nutrition on Pest Management

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

Pathogenic plant diseases are caused by several types of pests but the most common pests are bacteria, fungi, and viruses. Whether these pathogens infect crop plants and the incidence and severity of the infection are affected by the host plant and environment in which the pathogen and host plant are growing. These three factors are commonly referred to as the "disease triangle".

For the disease to occur, all three factors must be favorable. In other words, the plant must be susceptible to the pathogen, the pathogen must have sufficient virulence and must be present in sufficient quantities to infect the plant and, finally, the environment must be favorable for the pathogen to survive and infect the plant. If the host plant is resistant to the pathogen or the environmental conditions are unfavorable for the pathogen, then the disease will be less severe or may not occur.

The environment is usually taken to be weather factors such as temperature and relative humidity. We need to consider additional environmental factors that affect the pathogen and the plant such as the soil pH and nutrient availability and form as these factors can directly and indirectly affect both the host plant and the pathogen.

Fertilizers are not pesticides and fertilizers do not have direct effects on plant pests. Fertilizers supply nutrients needed by crops so they can achieve the greatest yield within the genetic potential of the crop and the limitations of the environment. Crops that are well-supplied with plant nutrients are better able

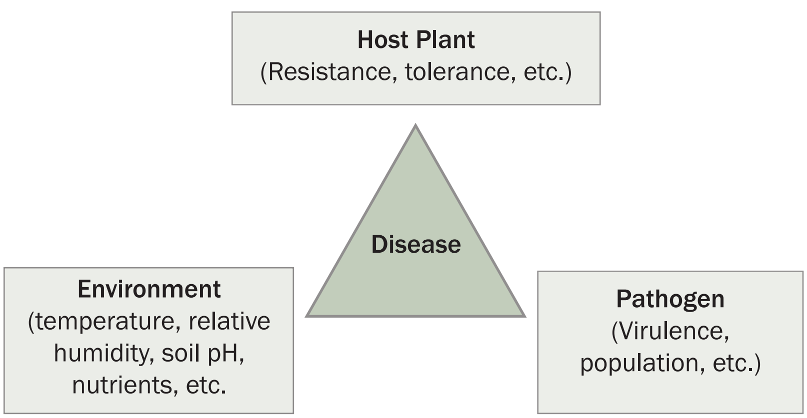


Figure 1 (left). *Plant disease triangle*

Table 1 (below). *Differential nitrogen rate effects on facultative and obligate pests*

Pathogen		Disease severity	
		Low N	High N
Puccinia graminis	Obligate	Decrease	Increase
Erysiphe graminis	Obligate	Decrease	Increase
Oidirium lycopersicum	Obligate	Decrease	Increase
Alteneria solani	Facultative	Increase	Decrease
Fusarium oxysporum	Facultative	Increase	Decrease
Xanthomonas vesicatoria	Facultative	Increase	Decrease

to resist stresses resulting from both pests and environmental conditions. Crops are better able to create physical barriers to pests (hardening off) through the stimulation of natural defense compounds including anti-oxidants, flavenoids, and phytoalexins.

Plant nutrients, including nitrogen, phosphorus, potassium, and calcium, as well as several micronutrients have been shown to affect the incidence and severity of plant pests.

Nitrogen rate and form can markedly affect the ability of pathogens to successfully infect crop plants. Obligate pathogens tend to be favored by high nitrogen availability while facultative pathogens tend to be favored by low nitrogen availability (Table 1). Nitrogen form also affects some plant pathogens, usually due to changes in the rhizosphere pH in response to root uptake of ammonium or nitrate (Table 2). Root uptake of ammonium tends to lower the rhizosphere pH while uptake of nitrate tends to increase rhizosphere pH which affects the ability of the pathogen to infect the plant.

Phosphorus has not been associated with consistent effects on plant diseases but there is some research showing that phosphorus reduced Hessian fly infestation of wheat.

Potassium is the fertilizer nutrient most often associated with suppressing diseases. Several comprehensive research reviews have shown that improved potassium nutrition reduced the incidence or severity of diseases caused by bacteria, fungi, and viruses.

Crops that have been shown to benefit from improved potassium nutrition range from apples to wheat. There are a few studies showing that nematodes, microscopic worms that can infect plants, responded positively to potassium fertilization and they were more virulent.

Calcium is a constituent of cell walls and membranes and plants that are well supplied with calcium have been shown to have thicker cell walls and more robust cell membranes making these cells less susceptible to attack from pathogens. In addition, calcium reduces the activity of the enzymes that pathogens use to degrade the cell walls and membranes. Finally, calcium functions as a secondary messenger to trigger the plant's natural defense mechanisms.

Increasing the calcium concentration in solution culture increased the leaf calcium concentration in both susceptible and resistant tomato varieties, although the calcium concentration was greater in the resistant variety. Increasing the calcium concentration markedly reduced the disease rating in both susceptible and resistant varieties.

Calcium also plays an important role in reducing the adverse effects of environmental stresses such as cold and heat, salinity, sodicity, and water stress on plants.

Improved micronutrient nutrition also plays a role in disease suppression. Chloride has been associated

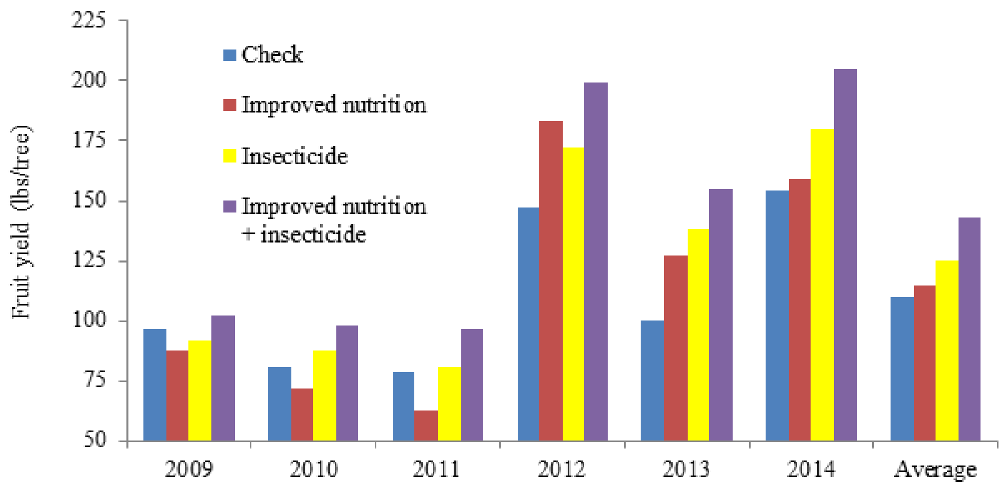
Table 2. *Differential nitrogen form effects on plant pests*

Diseases favored by ammonium	Diseases favored by nitrate
Gibberella zeae	Botrytis cinera
Pyricularia spp	Fusarium oxysporum
Sclerotium rolfsii	Pythium spp
Thielaviopsis basicola	Rhizoctonia solani

Table 3. *Calcium effects of bacterial canker of tomato*

Ca supply	Ca content (%)		Disease rating	
mg/liter	Susceptible	Resistant	Susceptible	Resistant
0	0.12	0.14	84	56
100	0.37	0.42	27	12
200	0.43	0.55	37	6
300	0.44	0.58	27	8

Figure 2. *Effects of improved plant nutrition and insecticides on fruit yield, 2009-2014.*



with reduced incidence or severity of several diseases including stalk rot in corn, and stem rust, leaf rust, and take-all in wheat. The mechanism is unclear but it may involve a hypersensitive response and/or alteration in the plant water relations. It is not a chlorine disinfection response.

Manganese has been found to affect several diseases including powdery mildew, downy mildew, take-all of wheat, common scab of potatoes, and various fusarium pests of cotton.

Boron, along with calcium, plays a role in cell wall structure and cell membrane integrity and boron has been implicated in reduction of diseases of crucifers, tomatoes, and wheat.

Research has shown that improved plant nutrition can complement the use of pesticides. For example, the results of a six-year study on oranges by the University of Florida showed that the use of insecticides or improved tree nutrition individually increased fruit yield on HLB infected trees. The combination of insecticides and improved tree nutrition, however, increased fruit yield even more than the additive effects of the individual practices.

SUMMARY

Fertilizers are not pesticides and they do not have direct effects on plant pathogens. Plants that are well-supplied with nutrients are better able to resist attack from plant pathogens and reduce the adverse effects of environmental stresses such as heat, cold, salinity, and sodicity. Appropriate management of nitrogen rate and form, phosphorus, potassium, calcium, and micronutrients can reduce the incidence and severity of plant diseases and help increase the efficacy of other pest management practices.

Nitrogen Management in Table Grapes

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Nitrogen (N) is the most used fertilizer in California vineyards. Most previous studies to determine vine N demands were conducted on own-rooted Thompson Seedless grapevines. Only a few studies have quantified the amount of N that other cultivars or grafted vines on rootstocks may require to meet growth demands, and there is little, if any, information on the nitrogen requirements of newer table grape varieties subjected to modern production practices. Modern table grape vineyards are generally far more productive than traditional raisin vineyards and would be expected to require significantly greater amounts of N. Therefore, we conducted a series of studies in commercial table grape vineyards, to develop vine N budgets, and to determine the effect of different N fertilizer treatments on vine growth, productivity, and fruit quality. We also estimated vine N fertilizer recovery efficiency (RE_N), and compared petiole analyses to analyses of other plant tissues. Across all varieties, the concentration of N (% dry wt. basis) in the leaves and stems decreased from bloom to veraison to harvest, whereas the concentration of N in the cluster generally decreased from bloom to veraison and then remaining constant through harvest. The RE_N at harvest ranged from 33 to 100%, depending on the vineyard, amount of N applied, and year. The highest RE_N was observed in a vineyard with the lowest vine N content. Fertilizer effects on fruit yield and quality varied among the different vineyards. In vineyards with moderate to high N status, fertilization had little effect on yield but generally delayed ripening, whereas in an N-deficient vineyard, N fertilization increased yield and improved fruit quality. Results suggest that replacing the N removed in fruit may be sufficient in vineyards with moderate to high N status, but more than replacement N may be needed to optimize yield and fruit quality in vineyards having vines with low N status.

Micronutrient Formulations and How They Fit into Fertilization Regimens

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Mar Vista Resources

Micronutrients are the essential elements that include Boron, Cobalt, Copper, Iron, Manganese, Molybdenum and Zinc. They are necessary for plants to complete their life cycle, but are used in such small amounts they are often overlooked and applied or purchased as an afterthought to other fertilizers. There can often be confusion about micronutrient chemistry and how they should be used for best agronomic response. Many products and formulation types are available and it is difficult to determine which formulations will be most efficacious and cost effective in any given situation. The formulation used must be appropriate for the means of application, whether applied to the soil, fertigated or sprayed on foliage. In this presentation, we will look at the major modes of application and the formulations most efficient for those applications.

Update on Walnut Nitrogen Uptake

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The timing and scale of walnut nutrient needs on typical soils with good yields and contemporary cultivars were assessed in a four year project funded by the California Department of Food and Agriculture and the California Walnut Board. Samples were taken from 10 trees from Chandler and Tulare orchards at 3 sites per cultivar (near Los Molinos, Linden, Hanford) in the last 7 days of each month and analyzed for nitrogen (N) content in 2013, 2014 and 2015.

Total season walnut nitrogen accumulation (N accumulation at harvest) varied from 23.2-30.2 lbs in 2013, 26.5-31.1 lbs in 2014 and 23.4-35.4 lbs in 2015 per ton of in-shell harvested nuts. Observed total N content in one ton of nuts is lower than that observed by previous UC research. At some sites, some nuts approach as much N accumulation as was previously reported, indicating that our larger sample size may show more variability than was captured by previous research. Importantly, our figures do not yet include N allocation for perennial tissue growth. It is likely that the upper range of N use in our sites will overlap with previous figures once perennial tissue growth is added to the total nitrogen budget.

Nitrogen accumulation in the fruit for every eventually harvested ton of nuts ranged from 5.5-14.1 lbs in May, 11.8-28.3 lbs in June, 16.4-39.6 lbs in July, 20.0-46.4 lbs in August and 23.2-35.4 lbs at harvest. Nitrogen accumulation in fruit was observed to be fairly evenly distributed over the course of the growing season for all cultivars and sites. This is in keeping with research previously done in almonds in California, and research done on walnuts in Europe. This indicates that an even division of nitrogen application over the growing season may be a simple, straightforward approach to increasing nitrogen use efficiency, rather than asking growers to keep higher or lower percentages of use in mind for different months when dividing their applications.

POSTER ABSTRACTS

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

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California has diverse agroecosystems throughout the state including low desert irrigated areas in Imperial County. California is the largest onion producer in the nation with a farm gate value of almost $230 million. Growers in the Imperial Valley are adopting more efficient irrigation systems (sprinkler and drip) and scientific-based irrigation scheduling methods (soil moisture, weather-based techniques) motivated by themselves and through the Imperial Irrigation District On-Farm Efficiency Conservation Program. Further scientific information about nutrient and irrigation management methods is needed in the California low desert area to achieve societal and environmental sustainability goals.

The main goal of this project was to evaluate the effects of water management techniques and nitrogen fertilization rates on yield and quality of fresh onion bulb production in arid regions. The assessment was carried out with three replicates in a split-plot design with drip irrigation treatments in the main plot and three nitrogen (N)-fertilization rates at the subplot level. An additional surface irrigation treatment was evaluated using surge irrigation and no tail runoff. Three irrigation levels were established in drip treatments: 70, 100, and 130% of crop evapotranspiration (ETc). Three fertilizer treatments were assessed: pre-plant plus 150 lbs N per acre; pre-plant plus 200 lbs N per acre; and pre-plant plus 250 lbs per acre. In the surface irrigation treatment, only one irrigation level (100% ETc) and one fertilizer rate (pre-plant plus 200 lbs N per acre) were tested. Onion quality parameters, including size (minimum and maximum diameters), weight, overall quality, and firmness were measured on 5 randomly selected onions, after onion harvest and curing.

In the first year of this study (November 2016 to May 2017), yield differences were not statistically different between drip irrigation (179 to 202 lbs) and fertilizer (192 to 196 lbs) treatments. The total applied water in the drip irrigation treatments ranged from 2.4 ft (in the 70% ETc trial) to 3.4 ft (in the 130% ETc trial). Applied water in the surge irrigation trial (3.3 ft) was similar (at the 0.05 probability level) to the drip treatment with 130% ETc. Yields in the surface irrigation treatment (238 lbs) were significantly higher ($P < 0.05$) than the yields recorded in the drip treatment with 130% ETc and 200 lbs N per acre (196 lbs). Onion size distributions (prepack, medium, jumbo, and colossal) were not statistically different ($P < 0.05$) among drip and fertilizer treatments. Jumbo and colossal onion size distributions were higher in the surge irrigation trial than the other treatments. Measured onion quality parameters were not statistically different between drip and fertilizer treatments. Overall, the furrow irrigation treatment with 200 lbs N per acre, three surges and zero tail runoff produced the highest yield in the first year of the study. We are planning to conduct a second-year trial in the 2017-2018 growing season.

California Fertilization Guidelines

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California growers are facing increasing pressure to improve nitrogen (N) use efficiency in crop production to reduce nitrate leaching to the groundwater. For many crops, a comprehensive overview and synthesis of the current research on fertilizer use and management has long been missing. With support from FREP (projects 11-0485-SA and 15-0231), we have been closing this gap by writing online fertilization guidelines for major crops grown in California. Currently, guidelines for about 30 major crops are freely available online at: https://apps1.cdfa.ca.gov/FertilizerResearch/docs/Guidelines.html.

The guidelines are a synthesis of relevant results from research projects. They present accurate and timely crop nutrient information in a user-friendly, visually interactive interface. Information about application rates, time of application, fertilizer placement and types of fertilizers (the 4Rs) is included. The guidelines provide information about N, phosphorus, and potassium management. In addition, they describe deficiency symptoms, discuss the use of soil and plant tissue analysis, and provide instructions for representative sampling. Furthermore, information about the seasonal N uptake curve, the partitioning of N in the plant and values for total N uptake and N in harvested plant parts is available. An extensive list of references and links to sites with additional information complement the guidelines.

Manure Fertilizer and Antibiotic Resistance Genes Residue in Farm Environment

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Manure produced in an animal-agriculture system such as dairy and livestock operations is considered to be a source of a diverse microbial population including pathogens, which may pose risks to the health of public, animal and environment. Manure produced in dairy operations also carries antibiotic resistance genes (ARGs). The application of manure as fertilizer has a potential to disseminate the ARGs to cropland receiving manure as fertilizers, and subsequently ARGs may reach to ambient water bodies such as surface and ground water through water flow. To understand the potential influx of ARGs into cropland through the application of manure fertilizers, we studied five genes (*sul*II, *tet*W, *erm*F, *int*I1, *tnp*A). Both field and lab based studies were conducted to understand the impacts of manure management methods on the persistence of these genes. Results showed that solid separation, manure piling, and lagoon treatment methods may have limited effects on the ARGs levels. A preliminary study was designed to study the effect of anaerobic digestions (AD) process on manure borne ARGs levels. Results indicated that higher temperature AD was more effective in reducing quantities of genes. We anticipate that these preliminary results will provide additional insights in terms of understanding the risk of manure borne ARGs transport in farm environment.

Keywords: dairy manure; antibiotic resistance genes, anaerobic digestion, dairy farm environment

Timing of Nitrate Storage and Usage in Pistachios

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OBJECTIVE

Growers are experts on what goes on *outside* the Pistachio Tree. The objective of this analysis was to determine what goes on *inside* the Pistachio Tree. To achieve an inside-the-tree appraisal, the objective was to specifically determine the progression of physical and chemical changes in the extracellular fluid in the sapwood of the trunk, vegetative and reproductive branches.

METHOD

Four production pistachio orchards, two in Arizona (Cochise County) and two in California, (Kern County) were monitored every half hour from April to October, 2016 with electrochemical sensors permanently resident in the extracellular volume of the sapwood. Three of the Sites were UCB1/Kerman rootstock/scion combination. One site in Arizona was UCB1/Golden Hills rootstock/scion combination. Thirty two electrochemical sensors were implanted in the extracellular volume of the sapwood of the trunk, reproductive branch and vegetative branch of four pistachio tree at each of the four sites.

RESULTS AND CONCLUSIONS

The extracellular volume of the trunk functions as a nitrate storage volume. At the three UCB1\Kerman Sites, nitrate built up in the trunk during April, May and June. The maximum level of nitrate storage occurred in late June. This level is sustained until late August.

At the UCB1/Golden Hills site the pattern was distinctly different. No buildup of nitrate occurred during the April, May and June period. In general, this site did not exhibit the high levels of ion population observed in the trunk at the other sites. The cause of this difference was attributed to more juvenile Golden Hills trees.

There was a decline in ion population between late August and mid October at all four sites.

Water content increased in all four sites between early April and late August. This indicated ample water was applied throughout this period at all four sites.

Transfer of nitrate from the trunk through to the nuts was not discernible with the sensors in the extracellular volume. A statistically very significant difference was observed between the electrical potential of the fluid in the trunk and the fluid in the rachis of the cluster. This suggests that movement of nitrate between the trunk and the nut normally occurs in the phloem and is driven by an electrical potential gradient.

At one site in Arizona there were very strong short term conventional nitrate transfer through the xylem during August. This transfer was characterized by simultaneous nighttime water content pulses in both the trunk and the branches. Ion population and identity during this pulse indicated nitrate movement. The causal mechanism for this transfer is not known.

RECOMMENDATIONS

1. Nitrate should be applied only up to late June to conform to the tree's nitrate storage timing.
2. Implants of sensors in the petioles should be tested as an early warning indicator of water stress.
3. Carryover of nitrate within the tree should be monitored during the period from October to April.
4. Sites with a high nitrate storage level in late June should consider a test period from April to June wherein nitrate application is reduced 20%.
5. The causal mechanism of the strong nitrate uptake in August at the Cochise County Site in Arizona should be determined.
6. More emphasis should be placed on nitrate application in March in the northern Kern County Site in California.

Optimizing Accuracy of Protocols for Measuring Dry Matter and Nutrient Yield of Forage Crops

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Nutrient management planning and evaluation require accurate measurements of nutrients both applied to and removed from cropland to improve fertilizer use efficiency and reduce nutrient pollution. The accuracy of protocols currently used to measure dry matter (DM), nitrogen (N), potassium (K), and phosphorus (P) yields from forage crops harvested for silage are unknown. The 'true' yield values were estimated by weighing and sampling every truckload of harvested forage from three fields each of corn, sorghum, and small grain in California. The DM yield was calculated as the product of average DM concentration, average load weight, and the number of trucks. Nutrient yields were the product of DM yield and average nutrient concentration. The accuracy of DM and nutrient yields measured using common industry protocols and more rigorous protocols were quantified through simulations that repeatedly subsampled the complete dataset for each field. Simulations of yield measurement protocols did not show significant differences in accuracy between forages. In minimal measurement protocols where one load per truck was weighed and one load sample was collected, simulated measurements differed from the true DM, N, P, and K yields by up to ±43%, ±47%, ±44%, and ±46%, respectively, among fields. The greatest inaccuracy was observed for fields where truckload weight was extremely variable both between trucks and within the loads carried by the same truck. In simulations where all loads were weighed and 10 load samples were collected, measurements differed from the true DM, N, P, and K yields by less than ±7%, ±9%, ±11%, and ±14%, respectively, among fields. Sufficient accuracy is achieved by weighing all truckloads and increasing load samples; however, if minimal protocols are used, yield measurements are not accurate enough to inform nutrient management plans or to calculate nutrient use efficiency.

The South San Joaquin Valley Management Practices Evaluation Program Management Online Support Tools

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The Management Practices Evaluation Program, or MPEP, was devised to complement other components of the Region 5 Irrigated Lands General Orders. This is where we go beyond simple metrics that might indicate a problem, and go through the steps required to solve problems. Seven coalitions, representing about 1.85 million acres of irrigated land south of Fresno, are implementing a joint MPEP workplan.

Several MPEP activities combine to deliver what is needed. With the help of management practice literature and expertise (growers, farm and Certified Crop Advisers, researchers), we will compile known protective practices, relate them to circumstances where they can and should be applied, and reach out to our membership to raise levels of awareness, understanding, and implementation. At the same time, we will prioritize groups of crop, soil, and groundwater conditions, focusing on situations with the greatest potential to improve groundwater quality protection. We will identify weaknesses in our existing knowledge and barriers to adoption, and then develop, test, and verify new or revised, protective practices that feed into the next generation of outreach.

The key to successful implementation of the MPEP is providing management practice information to growers and their advisors so that they can easily access and implement it. Such information is not always easy to find, or available in an easy-to-use format. The Southern San Joaquin Valley MPEP is developing and compiling the following online tools and resources to fill this need:

Y-to-R Calculator: The Crop Yield to Nitrogen Removed Calculator (also known as the Y-to-R Calculator) estimates N removed (R) and the ratio of N applied (A) to N removed (A/R). Results can be calculated on inputs for a single crop or for multiple crops. Conversion factors were developed by UC Davis (Geisseler 2016) based on the best available information. The conversion factors will continue to be refined as additional research becomes available.

Irrigation Water N Calculator: This calculator allows users to calculate N supply from inches of applied water and N (nitrate and/or ammonium) content. A simple mode considers a single water source. Another mode allows two sources (e.g., one surface water, and one groundwater source) to be considered together. Online and offline modes are available.

Within-field Variability Viewer: Individual fields or blocks may contain very distinct units due to soil or topographic variation. This tool allows the user to zoom into areas of interest in a convenient map interface, complete with field boundaries, and view mapped and quantitative pictures of a field's internal variability in seasonal total and peak-month, actual evapotranspiration.

Management Practice Performance (MaPP) Decision Support Tool (in development): This online interactive tool will allow irrigators to select a location and crop, and evaluate management options from the standpoint of the relative risk of N loss through leaching from the root zone. Irrigated landscapes vary greatly with respect to the degree of difficulty in retaining N in the root zone for use by crops. The performance of various combinations of management practices applied to a specific crop is influenced by soil, climatic, topographic, and other agronomic factors. MPEP modeling efforts will assess common sets of management practices across the full range of Central Valley conditions.

N-management Information Events Calendar and Resources: An N-management Information Events Calendar consolidates information on as many relevant events as practicable, allowing the user to sort by crop, topic, or locale to identify the most relevant events. The Resources page similarly contains links to a broad range of online information resources to support grower knowledge and management decision making.

Connection Between Nitrate in Root Zone and Groundwater as Affected by Crop and Soil Management

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Groundwater quality in some areas of the Central Valley (CV) is impaired due to nitrates and salinity. Nitrate leaching and salinity distribution in the root zone are strongly affected by irrigation scheduling; fertigation timing; the extent to which irrigation events are adjusted based on soil moisture or climatic conditions; and the extent to which fertilizer amount and timing are matched to crop demand and uptake patterns. Irrigation and fertigation decisions, in turn, depend on growers' a) knowledge of site conditions, and b) ability to control the infrastructure. Therefore, the proportion of applied nitrogen (N) used by the plant (N-use efficiency [NUE]) depends on system operation, which in turn depends on the design of the monitoring, irrigation, and fertigation components of the system. Adding urgency to the issue is the increased risk of leaching root-zone nitrate from increased groundwater recharge by heavy, dormant-season irrigation of highly permeable soils, a key strategy of the 2014 Sustainable Groundwater Management Act (SGMA).

High-frequency, low-rate (HFLR, i.e., drip and microspray) irrigation systems are increasingly common in California, particularly (but not exclusively) for permanent crops. They are often cited as a management practice to increase both irrigation efficiency and NUE. Increases to NUE are partly due to greater control of irrigation water containing nitrate, which allows the crop, over the course of a year, to recover a greater proportion of applied N. Certain operation modes facilitate irrigation and fertigation that deliver applied N more precisely into root zones to better match crop N demand timing and ability to acquire it through their roots. Indeed, the very high yields achieved with some of these systems indirectly attest to the efficacy of these delivery systems.

This project will demonstrate that information about the fate of water and nitrogen (N) in the root zone, as determined by crop and soil measurements, can be used to infer the amount of nitrate moving into groundwater, and that even in a well-managed, HFLR (drip or microspray) irrigated orchard, environmental performance can be significantly improved through correct application of system automation. This project also will demonstrate strategies that extend N residence time in and uptake from the root zone, even as other salts continue to move outward, to avoid damaging levels of salinity.

This study is located on a medium-size fruit and nut production field near Fresno, California on the Kings River fan. The study site encompasses 47 acres, with 29 acres devoted to relatively shallow-rooted oranges and 18 acres to relatively deep-rooted almonds. Situated on highly permeable, moderately coarse-textured soils with occasional gravel stringers, the study site sits above shallow groundwater (approximately 18-20 feet below ground surface). These conditions result in relatively rapid movement of nitrate out of the root zone to the underlying groundwater, which flows from the east-northeast to west-southwest.

Project objectives are to 1) quantify the yield, quality, WUE, and NUE benefits of converting from a non-automated irrigation system (operated weekly) to widely available, replicable systems that provide more frequent and precisely timed irrigation and fertigation through automation and SMM feedback; 2) Relate these management changes to reductions in the amount of nitrate transiting to groundwater, and 3) work with growers, commodities groups, and NRCS to develop an initiative that would facilitate cost-share funding of these types of system upgrades, encouraging and enabling their broader adoption.

Site information and initial monitoring results will be presented.

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

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Through the Irrigated Lands Regulatory Program (ILRP), the CV Regional Water Quality Control Board (CV Water Board) now requires producers in the CV 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 the ratio of N applied (A) to N removed (R) as a simple metric to gauge program progress in reducing the mass of leachable N (Burt et al., 2014). This metric was adopted by CV Water Board. Discussion of alternative formulations, such as A minus R (approximately the N surplus) continues. However, all formulations require estimates of N removed (including both the marketable component, and any other material (e.g., almond hulls, cotton seed, etc.).

To do this, producers and their coalitions need reliable data about N removed from fields in harvested crop materials. Growers need such information to inform nutrient management planning, while also minimizing excess N at risk of nitrate leaching below the root zone. *Nitrogen Concentrations in Harvested Plant Parts - A Literature Overview* (N-concentrations Report) by Dr. Geisseler (2016), presents literature-based yield-to-N-removed conversion factors for 72 crops, representing more than 98 percent of CV irrigated lands. However, the N-concentrations Report noted that most of these factors are based on datasets that were small, more than 20 years old, or from outside the Central Valley.

This project develops updated conversion factors for 22 crops covering 57 percent of the Central Valley. Specifically, this project will assess N concentration of harvested material removed from fields (N removed [R]) for approximately 22 crops over several growing seasons. For six crops, this will entail collecting and analyzing crop material samples; for the remaining 12 crops, data are either available or under development through other projects and will be shared with this project. Similarly, we will establish values for the annual amount of N sequestered in standing biomass for seven perennial crops. Tissue samples will be collected and analyzed for one of those crops as part of this Project. Data for the remaining six crops will come from existing sources.

These data will be incorporated into updates of the N-concentrations Report under this Project. The existing Y-to-R calculator (http://agmpep.com/calc-y2r/) will be revised to reflect the Project's findings, and the results will be used to update the assessment and planning tools available to growers, grower advisors, coalitions, and regulators.

Results from initial sampling of peaches will be presented.

Unmanned Aerial Vehicles for Precision Agriculture Using Multispectral Images and Machine Learning

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The overall goal of the project is to use Unmanned Aerial Vehicle (UAV)-based remote sensing technology and machine learning for precision agriculture. The main advantage of UAV-based remote sensing is the reduced cost and immediate availability of high resolution data. This helps detect crop stresses throughout the crop season. Near infrared (NIR) images obtained using remote sensing techniques help determine the crop performances and stresses of a large area in a short amount of time for precision agriculture, which aims to optimize the amount of water, fertilizers, and pesticides using site-specific management of crops. However, to be useful for real-world applications, the accuracy of remote sensing data must be validated using the proven ground-based methods. UAVs equipped with multispectral sensors and digital cameras were flown over lettuce and citrus plots at Cal Poly Pomona's Spadra farm. The multispectral images are used in the determination of normalized differential vegetation index (NDVI) that provides information on the health of the plant. Soil moisture and nitrogen contents were found prior to beginning the study. Machine learning classifiers were developed using the RGB images. Handheld Spectroradiometer, Water Potential Meter, and Chlorophyll Meter are used for ground-truthing. Correlation between NDVI, chlorophyll content, and water potential are shown. The developed machine learning algorithm is able to predict the health of the plant reasonably well with the limited data collected so far.

Conventional methods of remote sensing use satellites and manned aircraft. However, the images have low resolutions, and have large revisit periods. Also, these methods cost \$8,000 to \$10,000 per data capture of a 200 hectare farm. Using UAVs can save \$105/hectare for remote sensing. Also, a saving of 20%-90% in water, chemicals, and labor is estimated due to the use of UAVs for remote sensing and precision agriculture. California is one of the world's largest agriculture producers and exporters. California's agriculture is also one of the largest users of chemicals and water resources. Any savings in chemicals and water will reduce the cost of production and environmental impact, and help conserve water.

The Effects of Salinity and Nitrogen Fertilizer on Growth and Nitrogen Acquisition in Alfalfa

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The response of alfalfa to three levels of salinity and four rates of nitrogen (N) was measured in a pot study at California State University, Chico.

Seeds were inoculated with a commercial rhizobia inoculant and planted in plug trays in the greenhouse. Seedlings were transplanted into 5-gallon buckets filled with a mixture of soil, sand and peat moss, and placed in an open field. All plants received macro- and micro-nutrients, plus equivalent to 30 kg ha^{-1} starter N at the planting. Plants receive four levels of urea fertilizer (0, 30, 60, and 120 kg N ha^{-1}) with the first irrigation after each cut.

At the onset of salinity treatments, all plants were cut to just above the crown, and subsequently, the plants were watered with tap water, low salinity (EC=~5 ds/m) or high salinity (EC= ~10ds/m) water with the saline solutions prepared using NaCl, Na_2SO_4, $MgSO_4$ and $CaSO_4{\cdot}2H_2O$. Daily watering was based on the total plant evapotranspiration and the pot field capacity to eliminate leaching.

Preliminary results from the second cut show that plants irrigated with tap water (non-saline) produced 10 and 27% more biomass than plants under the low EC and high EC, respectively. Plant biomass and total plant N (g/pot) were similar across the three N fertilizer treatments; however, on the average, N-treated plants produced 18% more biomass and accumulated 45% more N compared to the control (0 N fertilizer).

Results will be presented in more detail including plant biomass, N content, and $\delta^{15}N$ of the second and third cuts to compare N acquisition of alfalfa from biological N fixation vs. applied mineral N.

Can Amending Soils with Biochar Improve Fertilizer Use Efficiency?

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Biochar offers a number of potential solutions to some of the most pressing agricultural issues including nitrate leaching, nutrient use efficiency, soil water retention, soil carbon stocks, and waste management. Previous research shows inconsistent results on the ability of biochar to address these issues, due to differences in biochar feedstock, production methods, soil properties, climate, and cropping systems. Furthermore, these results have limited relevance to field-scale agriculture, as biochar studies are dominated by short-term, laboratory experiments that are difficult to extrapolate to California cropping systems.

To inform the use and regulation of biochar, it is essential that farmers and policymakers have access to reliable, place-based data. This study aims to fill a gap in literature by providing long-term, field-scale data about the potential of biochar as a soil amendment in California. Results from preliminary laboratory and greenhouse experiments will inform the implementation of one-acre field trials in two locations with contrasting, but representative, California agricultural soils. These trials will be placed under a tomato-grain rotation and managed for a minimum of three years. Seven biochars of diverse feedstock and production methods will be used at varying application rates, in conjunction with low and high fertilization rates. Data will be collected on the impact of biochar on soil properties such as nitrogen dynamics, water holding capacity, and soil carbon. This information will be evaluated along with a complete analysis of soil properties and biochar parameters, in order to assess the conditions most likely to lead to beneficial outcomes.

In the final stage of the project, results will be used with yield and cost data to conduct a life cycle analysis that considers the economic and environmental feasibility of widespread biochar adoption in California. Results from this project will be delivered to CA stakeholder groups through outreach activities and publications.

Corn Root Growth and Yield in Response to Phosphorus Solubilizer Inoculants in Northern California

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Beneficial microorganisms can improve soil health and contribute to increase crop yield. From commercialized microbial products, phosphorus (P) solubilizers can enhance plant P uptake and yield by adjusting the pH of rhizosphere soil, and by stimulating root growth rate. Improved P availability, which is strongly limited by several soil factors, can increase crop nutrient use efficiency. A field trial is being conducted at California State University, Chico Farm to investigate the effect of Quickroots® (Monsanto BioAg, MO), BioOrganics TM Endomycorrhizal Inoculant (Bio OrganicsTM, PA), and a mixture of these two inoculants on root characteristics, growth, and yield of corn. Corn seeds were inoculated with the products and sown directly into an Almendra Loam soil following a fababean cover crop. Leaf nitrogen is estimated using a SPAD chlorophyll meter, root characteristics (thickness and surface area) are being quantified using WinRhizo (Regents Instruments, Quebec, Canada), and arbuscular mycorrhizal (AM) fungi infection was quantified as the percentage of root colonized by AM fungi.

Preliminary results suggest that microbial inoculants had little effect on corn growth (plant height), leaf chlorophyll concentration (SPAD values) and silage yield. On average corn produced 28% and 24% more silage in response to Quickroots® and Endomycorrhizal Inoculant than the control, respectively; however, the differences were not significant. Similarly, variations of leaf nitrogen, plant height, and root parameters due to the treatments were not significant. Interestingly, root infection by AM fungi was minimal across all treatments. Absence of AM fungi from the roots might be associated with high levels of available P in the soil. These results suggests that in addition to cultural practices such as tillage that disturb soil microorganisms and lower their benefits, nutrient management can also impact the benefits of soil microorganisms in cropping systems. A pot experiment is being conducted to test the effects of these products on corn root parameters and yield in a low P soil mix. Additional studies needed to quantify the presence and effect of AM fungi on crop yield under various cropping systems and nutrient managements.

Water Stress Preconditioning:
An Ancient Technique for Reducing Irrigation Water and Improving Heat and Drought Tolerance in the Field Crops

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Deficit irrigation aims to save water while minimizing adverse effects of drought on crop yield and crop revenue. Knowledge of plant physiological responses to drought (and other forms of abiotic stress) can help planning deficit irrigation strategies that save water and maintain a high yield. Drought preconditioning (DP), which is the exposure of young plants to drought, has been shown to improve the plant drought tolerance later in the season. Preconditioned plants use various mechanisms to lower their evapotranspiration, and avoid substantial yield loss when exposed to stress at the sensitive stages of flowering and grain filling.

A field trial has been established at California State University- Chico Farm to investigate the effects of DP on the drought tolerance of corn and sorghum. Plots were established under four treatments of

1. fully irrigated control,
2. preconditioned only,
3. preconditioned plus stress at flowering, and
4. stress at flowering only.

Root surface area and root thickness, stomatal conductance, plant growth, plant NDVI, and leaf area expansion have been monitored throughout the season. Preliminary results confirm that exposure of young plants to drought reduces the height, NDVI and leaf area, and affects the stomatal conductance and carbon exchange rates. Interestingly, we found that PD plants tolerate heat stress compared to fully irrigated plants. When temperature exceeded 40°C, DP plants were able to keep their stomata open and maintain higher CO2 exchange than fully irrigated plants. These preliminary results align with the previous findings that recommend DP can improve plant tolerance to heat and cold stresses. Results will be presented in more detail including plant biomass, plant leaf area, stomatal conductance, and root parameters in response to the treatments.

LIST OF COMPLETED FREP PROJECTS

List of Completed FREP Projects

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

European Pear Growth and Cropping: Optimizing Fertilizer Practices Based on Seasonal Demand and Supply with Emphasis on Nitrogen Management • *Kitren Glozer & 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, & Lyn Hyatt, 10-0010*

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Uniformity of Chemigation in Micro-irrigated Permanent Crops •*Larry Schwankl & 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 & 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, & Henry Krusekopf, 97-0365 M97-03*

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Determining Nitrogen Best Management Practices for Broccoli Production in the San Joaquin Valley • *Michelle Lestrange, Jeffrey Mitchell, & 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, & Laosheng Wu, 95-0519*

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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