2015

TWENTY THIRD ANNUAL

CALIFORNIA DEPARTMENT OF FOOD AND AGRICULTURE

FERTILIZER RESEARCH AND EDUCATION PROGRAM

PROCEEDINGS

Presented November 5-6, 2015
Seaside, California

FERTILIZER RESEARCH AND EDUCATION PROGRAM
FREP

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INTRODUCTION

Fertilizer Research and Education Program

FOR 23 YEARS, the Fertilizer Research and Education Program (FREP) of the California Department of Food and Agriculture (CDFA) has presented its pioneering fertilizer research at its annual conference.

2015 marks the tenth year of collaboration between FREP and the Western Plant Health Association (WPHA). Our joint effort creates an alternative conference concept, balancing FREP's scientific and technical research with a discussion of practical applications. This combination has provided FREP the opportunity to extend the program's outreach to a broader audience of agriculturalists at multiple levels.

The theme of the conference is "Nutrient Management: Challenges and Opportunities." Over one and a half days, presenters from academia, industry and agricultural consulting will provide general and technical information, current research data, and practical applications addressing statewide and regional nutrient management issues. The conference offers a unique opportunity for agricultural consultants, advisors, and governmental agency and university personnel to learn about FREP's cutting edge research findings, and to use these findings to inform their work and interactions with growers.

Included in these proceedings are summaries of FREP-funded projects, relevant research presented during the conference, as well as ongoing and recently completed FREP research projects.

FREP OVERVIEW AND NEW INITIATIVES

FREP has an ongoing mission to enable improvements in agricultural practices which will, in turn, protect the ground, the water, and the air of California. This mission has remained constant since the beginning of the program in 1990, and as knowledge is gained through research and collaboration, a sharper focus develops on better nutrient management practices and grower adoption of practices.

The persistence of the ongoing drought has led to a greater concern among growers and land managers for better water use efficiency. Improvements in irrigation practices are closely linked to better nutrient management through better timing and placement of fertilizer, and less potential for leaching losses beyond the root zone. FREP stands by the ongoing goal of continued fertilizer research and the application of best management practices in California agriculture.

FREP funds and facilitates research, education, and outreach projects to advance the environmentally safe and agronomically sound use of fertilizing materials. FREP serves a wide variety of agriculturalists, such as growers, agricultural supply and service professionals, university extension and public agency personnel, Certified Crop Advisors (CCAs) and Pest Control Advisors (PCAs), and other interested parties.

FREP was established through legislation with support from the fertilizer industry. California Food and Agricultural Code Section 14611(b) 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 current assessment is at one mill ($0.001) per dollar sales of commercial fertilizer, generating approximately two million dollars per year to support the program.

In 2012, the passage of Assembly Bill 2174 amended California Food and Agricultural Code Section 14611(b). As a result of this legislation, FREP's mission now encompasses promoting nutrient management practices, resulting in more agronomically sound use of fertilizing materials with the goal of minimizing the environmental impacts, including, but not limited to, nitrate in groundwater and emissions of greenhouse gases resulting from fertilizer use. To fulfill this mission, FREP has undertaken initiatives in the following three key areas: technical education, education and outreach, and research.

Technical Education

One of FREP's technical education efforts is the Nitrogen Management Training Program (NMTP) for CCAs, a voluntary nitrogen management curriculum. The Program is a joint effort between CDFA, University of California Agricultural and Natural Resources (UC ANR), and the California CCA Program. The

curriculum facilitates CCAs' understanding of sound nitrogen management practices. CCAs who take this training are qualified to create and certify nutrient management plans for growers, in compliance with Central Valley Regional Water Quality Control Board regulations. Between January 2014 and March 2015, 790 CCAs were trained across eight locations throughout California. One additional training program is scheduled for the first quarter of 2016.

Under recent water quality regulations in the Central Valley region, growers are able to certify their own nitrogen management plans in areas that are at risk for nitrate leaching to groundwater. In order to certify their plans, growers must first participate in a CDFA nitrogen management training program. FREP is helping to build this program by funding curriculum development, based on the CCA training materials, and a training program for CCAs who will ultimately train growers in the program. Agricultural water quality coalitions will offer the final training sessions to their grower members beginning in the late fall of 2015.

Education and Outreach

FREP has sought to increase awareness of the agronomically sound use of fertilizer products by continuing to make research, funded by the grant program, easily available online. In partnership with UC Davis Department of Land, Air, and Water Resources, FREP has developed a web-based, searchable database summarizing FREP-funded research projects, as well as interactive crop fertilization guidelines.

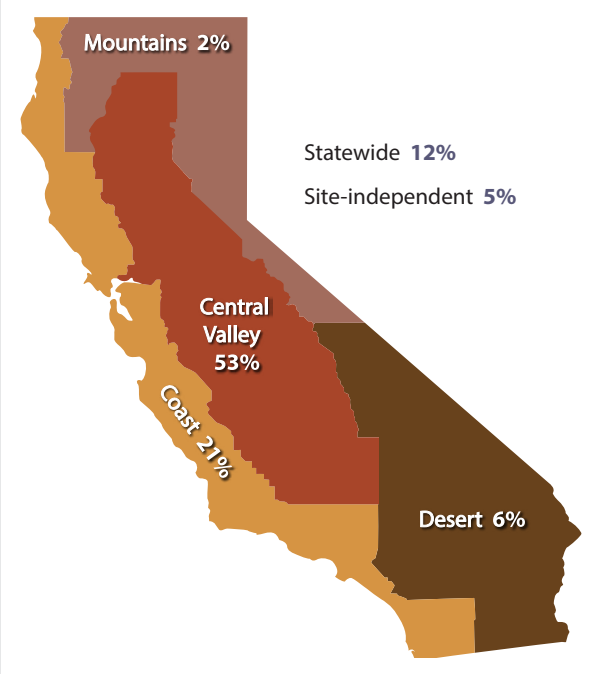


Figure 1. Locations where FREP projects have been conducted.

Figure 2. Nitrogen Management brochures for California crops are published by FREP.

The database makes the wealth of information contained in FREP research reports readily available, easily understandable, and convenient for growers and crop advisors to implement. Available at www.cdfa.ca.gov/go/FREPresearch, new records are continuously added as research projects are completed.

The Crop Fertilization Guidelines are based on a synthesis of peer reviewed journal articles and research reports. Currently, there are guidelines for 17 crops that account for more than 60 percent of California irrigated agriculture. The guidelines are updated regularly, and are available at www.cdfa.ca.gov/go/FREPguide. New crops are being added to these guidelines on a continuous basis, and there will be 12 new crops added over the next couple of years.

Nitrogen management brochures for specific crops are published by FREP (*Figure 2*). Based on the guidelines, these outreach materials emphasize nitrogen management for common California crops.

Research

FREP is focused on the growing concern of nitrate contamination in ground and surface water from fertilizer use. FREP-funded projects evaluate environmental water and air quality issues as related to fertilizer use. FREP's research funding has expanded to include agronomic efficiency in

the management of nutrients, along with many other factors that influence fertilizer use efficiency in California agriculture. Figure 1 illustrates the regional distribultion of FREP funding. Figures 3 and 4 show, respectively, commodities and disciplines addressed by all FREP projects.

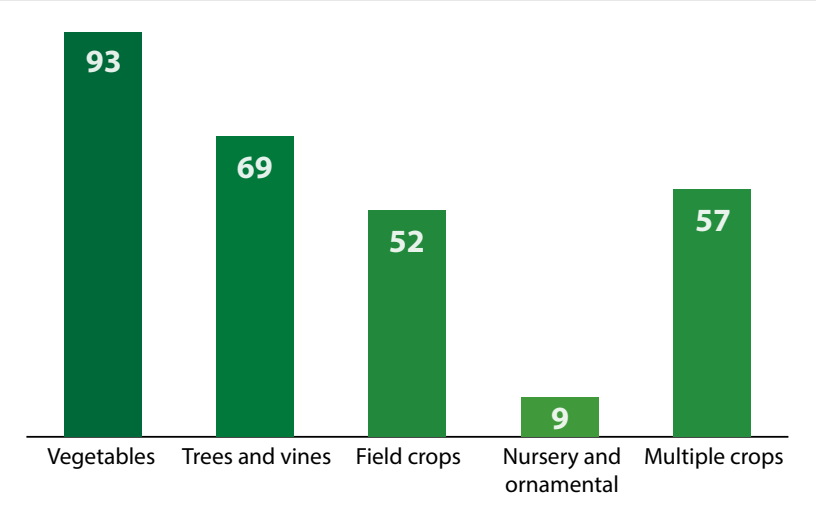


Figure 3. Distribution of FREP projects by commodity. Some projects address multiple crops.

FREP continues to fund research to improve nutrient management practices through its competitive grants program. FREP supports high-quality research and education endeavors that have gone through a rigorous two-phase statewide competitive process, including independent peer review. Projects are typically funded at $75,000 per year for up to three years; however, large, multi-disciplinary projects may be considered at higher funding levels.

The Technical Advisory Subcommittee (TASC) of the Fertilizer Inspection Advisory Board (FIAB) evaluates the scientific merit of all submitted project proposals. TASC members represent a cross section of the agricultural industry and possess technical and scientific expertise in the field of fertilizing materials, agronomy, plant physiology, principles of experimental research, production agriculture, and environmental issues related to fertilizing materials use. Based on the expert advice of the TASC, the FIAB recommends projects for funding to the CDFA Secretary.

Two Requests for Proposals (RFPs) were released in 2015, the Regular and Special RFPs.

REGULAR REQUEST FOR PROPOSALS

FREP research priorities for the 2015 Regular RFP were as follows:

Developing Integrated Water and Nutrient Management Tools

As concern rises over the shortage of fresh water and environmental effects of agriculture in California, a major challenge facing the agriculture industry is to optimize the use of fertilizers and water. New management tools should provide a platform for customizing management practices to local conditions on farms, as well as cope with drought.

Education and Outreach

Development of education and extension efforts to disseminate effective practices of fertilizing materials use, as well as to help implement nutrient management plans on grower's fields, are of high priority.

Developing New Best Management Practices (BMPs)

Innovative management practices must be developed that are compatible with sustainable agriculture and provide solutions to agricultural challenges in California. These include:

- Evaluating strategies to increase crop N use efficiency
- Minimizing nitrate movement below the root zone
- Minimizing nitrous oxide emissions related to fertilizer use

Field–Scale Demonstration of Recommended Best Management Practices (BMPs) Related to Fertilizing Materials

Demonstration projects are a key strategy to ensure results from basic experimental research trials are implemented and adopted by growers at the farm level. Effective management practices that are simple and have multiple benefits have a good chance of adoption by growers. Potential treatments include, but are not limited to:

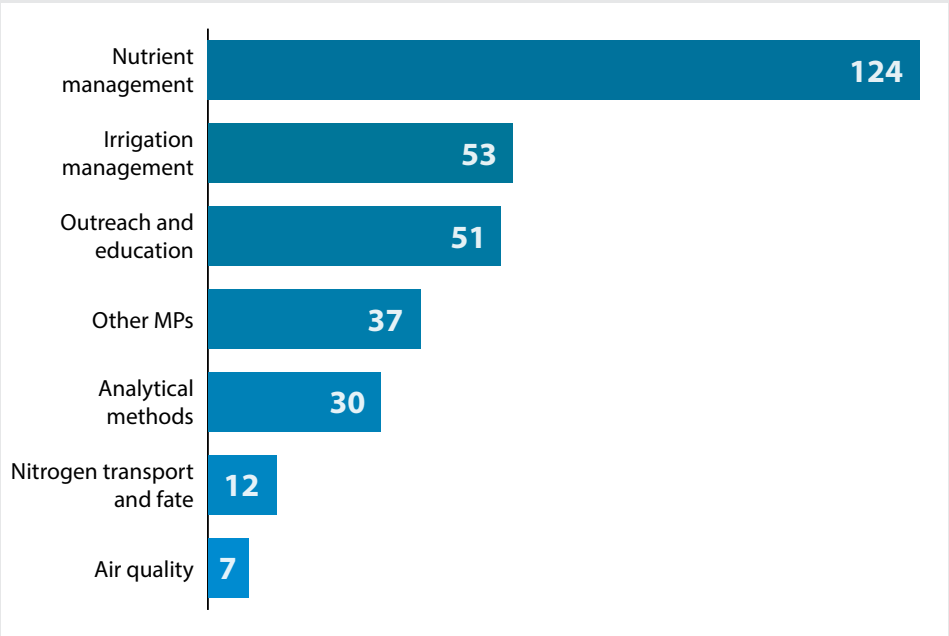


Figure 4. Distribution of FREP projects across different areas of study.

- Strategies in timing of fertilizer applications
- Leaf sampling to guide fertilizer recommendations
- Fertilizer sources and additives that enhance nutrient use efficiency
- Advanced irrigation management to improve nutrient use efficiency
- Comparison of irrigation technologies as related to nutrient use efficiency
- Nitrogen recovery and fixation with cover crops
- Soil organic matter effects on nutrient use efficiency

Filling Knowledge Gaps for Nitrogen Management in Specific Crops in the San Joaquin Valley

Better information is needed to improve nitrogen fertilizer efficiency in a range of California crops. For 2015, FREP requested proposals in corn, pima cotton, processing tomatoes, walnuts, citrus and root crops.

SPECIAL REQUEST FOR PROPOSALS

FREP research priorities for the 2015 Special RFP were as follows:

Nitrous Oxide Research

Nitrous oxide is a greenhouse gas from nitrogen fertilizers that is significantly more potent than carbon dioxide. Comprehensive research has been completed on nitrous oxide emission factors for the top 10 crops in California. Additional research is needed on N_2O to N_2 conversion rates, as well as N_2O emission under various fertilizer applications, to calibrate and improve the performance of current models.

Nitrogen Management Training Program for Growers

The Waste Discharge Requirements General Orders for the Central Valley Regional Water Quality Control Board allows growers to self-certify their own nutrient management plans if they attend a California Department of Food and Agriculture or other Executive Officer approved training program. CDFA has taken the lead on developing a grower training program based on the Certified Crop Advisor training funded by FREP. Additional funds are required to further develop the grower education component.

Demonstration Projects on the Multiple Benefits of Nitrogen Management Practices with Growers

Demonstration projects are a key strategy to ensure scientific research results are implemented and adopted by growers at the farm level. Demonstration projects must involve scientific experts from the University system, actual field plots, already completed FREP findings, or other well documented nutrient management research and close involvement of growers and other field professionals.

Understanding and Quantification of the Movement of Nitrate in Deep Soil

There is a significant information gap in understanding nitrogen behavior, movement and distribution from nitrogen fertilizers as it moves through the soil down to groundwater.

Development of Easy-to-Use Technologies for Field-Scale Management of Water and Nitrate Leaching

Increasingly, growers are using soil sensors in their fields to manage irrigation. However, some growers lack adequate tools to utilize sensor data to minimize water and nitrate leaching past the root zone. Development of easy-to-use protocols to interpret sensor data is needed to effectively manage water and nitrogen use and application in agricultural operations.

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

Objectives are:

- Demonstrate the new leaf sampling and nitrogen (N) application approaches in almonds in comparison to typical grower practices.
- Create a platform promoting widespread adoption of best nutrient management practices by almond growers throughout the region.

Demonstration of Advanced-Weather-Based Irrigation Management on California Tree Crops

Objectives are:

- Demonstrate advanced irrigation management to improve nutrient and water use efficiency in tree crops in California.
- Create a platform promoting widespread adoption of best irrigation management practices by tree crop growers.

BEYOND CONFERENCE PROCEEDINGS

One of FREP's key goals is to ensure that research results generated from the program are distributed to, and used by, growers and the fertilizer industry. Proceedings from past annual conferences and pamphlets on various topics relating to fertilizing techniques are available to interested members of the agricultural community by contacting FREP at FREP@cdfa.ca.gov or (916) 900-5022.

FREP collaborates and coordinates with numerous other organizations to extend FREP research to agricultural advisors, who in turn convey findings to growers. Agencies we partner with include the Western Plant Health Association, California Chapter of the American Society of Agronomy, California Certified Crop Advisor Program, USDA Natural Resources Conservation Service, California Water Boards, California Air Resources Board, California Energy Commission, California Resource Conservation Districts, and the California State University (CSU) and University of California (UC) systems. Growers have a vested interest in maintaining the viability of the resources that make farming possible and so successful in California. We at CDFA/FREP are keenly interested in funding new projects that offer growers alternative methods to address environmental issues and fertilizer use efficiency.

There are more challenges facing the agricultural industry than ever before. FREP has maintained its commitment to outreach and education by continually seeking new ways of making scientific research accessible to a broad audience of agricultural professionals. We are always interested to hear how we can improve FREP services and activities and encourage you to complete the conference evaluation form and contact us any time to offer your suggestions. Please contact FREP at FREP@cdfa.ca.gov

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 Jack Wackerman, Dr. Dennis Chessman, Rex Dufour, Dr. Eric Ellison, Charles Hornung, Dr. Marja Koivunen, Dr. Marc Los Huertos, Dr. Rob Mikkelsen, Dr. Jerome Pier, Steve Spangler, and Dr. Doug West 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, David McEuen, Melissa McQueen, Rachel Oster, Gary Silveria, and Steve Spangler.

We thank the Western Plant Health Association as a valued partner in the "Nutrient Management: Challenges and Opportunities" conference. The perspectives, input and support of Renee Pinel, President and CEO, and Callie Borror, 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 Rick S. Jensen; 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); and Mark Cady, Senior Environmental Scientist (Specialist), and Natalie Jacuzzi, Environmental Scientist. In addition, special thanks to Dr. Daniel Geisseler, Extension Specialist with the UC Davis Department of Land, Air, and Water Resources, for his diligent work on creating and expanding the FREP research database and Crop Fertilization Guidelines.

CONFERENCE PROGRAM

Thursday, November 5, 2015

Facilitator: *Dr. Jerome Pier*

9:00-9:30 **Welcome**
Renee Pinel, Executive Director, WPHA
Jim Houston, Undersecretary, CDFA

9:30 – 10:00 **Determination of Root Distribution, Dynamics, Phenology and Physiology of Almonds to Optimize Fertigation Practices**
Dr. Patrick Brown, Professor, UC Davis, Department of Plant Sciences

10:00-10:30 **Evaluation of a 24 Hour Soil CO_2 Test for Estimating Potential N-Mineralization to Reassess Fertilizer N Recommendations**
Dr. William Horwath, Professor of Soil Biogeochemistry, UC Davis, Department of Land, Air and Water Resources

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

10:50-11:20 **Development of Economical Variable Rate P Application Protocols for Desert Vegetable Production Systems**
Dr. Charles Sanchez, Professor, University of Arizona

11:20-11:50 **An Overview of Agricultural Regulatory Requirements in the Central Coast Region**
Chris Rose, Senior Environmental Scientist, Irrigated Lands Regulatory Program Manager, Central Coast Water Board

11:50 – 1:00 **Lunch**

1:00 – 1:30 **Water and Nitrogen Management: Recognizing and Adapting to Logistical Challenges at the Farm Field Level**
Dr. Marcus Buchanan, Agronomist, Buchanan Associates

1:30 – 3:00 **Panel Discussion: Challenges to the Implementation of BMPs on the Central Coast**
Moderator: Dr. Patrick Brown.
Panel: Dr. Michael Cahn (UCCE Monterey), Dr. Marcus Buchanan, Mark Mason (Huntington Farms), and Jocelyn Bridson (Rio Farms)

3:00 – 3:20 **Break**

3:20 – 3:50 **Improving Pomegranate Fertigation and Nitrogen Use Efficiency with Drip Irrigation Systems**
Dr. Claude Phene, Irrigation and Soil Physics Consultant, SDI+

3:50 – 4:20 **Assessment of Baseline Nitrous Oxide Emissions in Response to a Range of Nitrogen Fertilizer Application Rates in Corn Systems**
Dr. Martin Burger, Associate Project Scientist, UC Davis, Department of Land, Air and Water Resources

Friday, November 6, 2015

Facilitator: *Mr. Steve Vasquez*

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

8:30 - 9:00 **Optimizing the Use of Groundwater Nitrogen for Nut Crops**
Dr. David Smart, Professor, UC Davis, Department of Viticulture and Enology

9:00 – 9:30 **Developing Nitrogen Management Strategies to Optimize Grain Yield and Protein Content While Minimizing Leaching Losses in California Wheat**
Dr. Robert Hutmacher, Cooperative Extension Specialist and Center Director, West Side REC, and Mark Lundy, UC Davis, Department of Plant Sciences

9:30 – 10:00 **Fertilizer Sources and Nutrient Management**
Dr. Jerome Pier, Agronomist, North Valley Division, Crop Production Services

10:00-10:15 **Break**

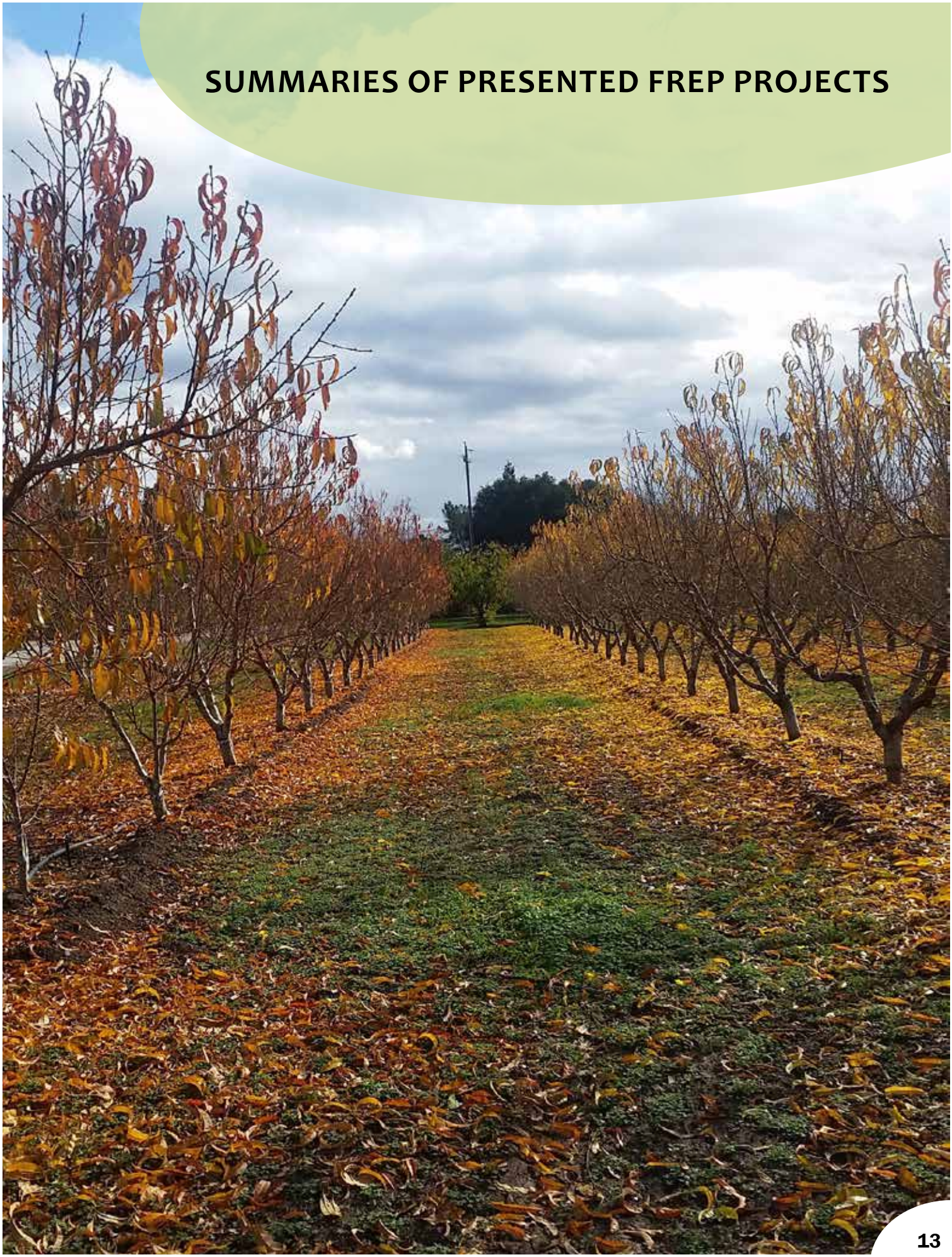
10:15-10:45 **Challenges in Developing an Organic Fertilization Program for Processing Tomatoes**
Gene Miyao, Farm Advisor for Vegetable Crops, UC Cooperative Extension, Yolo County

10:45-11:15 **Interpreting Soils – Old and New Techniques**
Keith Backman, Consultant Manager, Dellavalle Laboratory, Inc.

11:15-11:45 **Salinity Management in Strawberries and Caneberries**
Mark Bolda, Farm Advisor for Strawberries and Cane Berries, UC Cooperative Extension, Santa Cruz County

11:45-12:00 **Closing Remarks**

SUMMARIES OF PRESENTED FREP PROJECTS



Improving Pomegranate Fertigation and Nitrogen Use Efficiency with Drip Irrigation Systems

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INTRODUCTION

In 2009 pomegranate was a rapidly expanding crop in California due to the demand for juices with healthy bioactive compounds, mineral nutrients, and high antioxidant contents. Prior to this time no studies had quantified the water and nitrogen requirements of pomegranate that were irrigated with either high frequency (HF) surface drip (DI) or HF subsurface drip irrigation (SDI). Previous research has shown that well managed DI and SDI systems can eliminate runoff, deep drainage, minimize surface soil and plant evaporation, reduce crop transpiration, and significantly reduce fertilizer losses, thus protecting groundwater quality (Phene et al. 1989, Ayars, et al. 1999). Avoiding N deficiency or excess is critical to maintaining nitrogen use efficiency (NUE) and knowledge of the operation of DI and SDI, especially for deep placed SDI, is critical for effective management of N-fertigation. This project is determining the water requirements and nitrogen fertilizer efficiency for a surface and subsurface drip irrigated maturing pomegranate orchard.

OBJECTIVES

The objective is to optimize water-nitrogen interactions to improve fertilizer use efficiency (FUE) of maturing pomegranate.

Specific objectives are:

1. Determine the effectiveness of three nitrogen injection rates with DI and SDI on maintaining adequate N levels, plant growth and yield in maturing pomegranates.
2. Determine the effect on crop water use of automated high frequency DI and SDI irrigation, based on hourly lysimeter ET_c and develop crop coefficients (K_c) using CIMIS reference evapotranspiration (ET_o) for maturing pomegranate.
3. Develop fertigation management tools that will allow the growers to achieve objective "1" and present those results to interested parties at yearly held field days and seminars.

DESCRIPTION

The 1.43 ha pomegranate orchard (Punica granatum, L var. Wonderful) is located on the Kearney Agricultural Research and Extension Center (KARE). Trees were planted with a 5.79 m row spacing and a 3.66 m in-row spacing. The orchard is laid out in a complete randomized block with sub-treatments and 5 replicates. The main irrigation treatments are surface drip (DI) and subsurface drip (SDI) installed at 0.51-0.56 m-depth. Both systems have dual drip irrigation laterals, each 1.07 m from the tree row. The fertility sub treatments are 3 N treatments (estimated at 50% of adequate N (N1), adequate N (N2), based on biweekly tissue analysis and 150% of adequate N (N3), all applied by variable injection of N-pHURIC (10% N as urea, 18% S), AN-20 (10% NH4-N and 10% NO3-N). Potassium thiosulfate (K2T, 25% K from K2O and 17% S) and phosphorus (from H3PO4, PO4-P) are supplied by variable injection of P=15-20 mg/kg and K=50 mg/kg to maintain adequate uptake levels. The pH of the irrigation water is maintained at 6.5+/-0.5. Plant data include bimonthly plant tissue analyses,

fruit yield, and quality. A large weighing lysimeter (Phene et al. 1991) located in the field is used to determine crop water use for the fully irrigated SDI with adequate nitrogen (N2) treatment and to automatically manage the hourly irrigation schedule for the orchard. Water applied to the DI treatments is increased by 10% over the SDI amount to account for soil surface evaporation and water used by weeds. Orchard irrigations of DI and SDI were measured and recorded automatically with electronic flow meters and are based on hourly lysimeter measurements. The lysimeter tree is irrigated using a SDI system with the same number of emitters per tree as the rest of the orchard. The results will be analyzed using analysis of variance for the Randomized Complete Block Design (RBCD) with sub-samples.

RESULTS AND DISCUSSION

1. 2015 Water Balance. The yearly cumulative grass reference ETo (CIMIS ETo) and the orchard evapotranspiration (ETc) measured hourly by the weighing lysimeter were used to develop the irrigation requirement and crop coefficient (Kc) and were developed for grower's use (Phene et al. 1991). Water balance results for the last 6 years are shown in Table 1. Note that the water requirement increased to 848 mm in 2014 for the DI crop. There was no drainage recorded from the lysimeter during this period. A fifth order polynomial is used to characterize the crop coefficient, Kc = 3e-10x4 – 5e-5x3 + 3.0347x2 – 84013x + 9e8 where x is day of the year.

2. Soil Matric Potential (SMP) measurements and SMP Gradient Calculations in the SDI irrigated lysimeter. With the concern for transport of nitrate (NO3) to the groundwater it is essential to quantify the movement of NO3 through and below the crop root zone. In 2013 we installed heat dissipation soil water matric potential (SMP) sensors (Campbell Scientific Inc. CSI-229) two columns of 4 SMP sensors each at depths of 0.6 m, 0.9 m, 1.2 m and 1.5 m from the soil surface. These sensors provide the SMP status in the soil profile in the lysimeter and were used to calculate the SMP gradient to infer the leaching potential under high frequency SDI (Phene et al., 1989). The soil water gradients calculated from the SMP data indicate that there were no deep percolation losses from the SDI system since the installation. This is confirmed by the water balance data in *Table 1* that show no deep percolation losses during the project.

3. 2014 Yields, Water Use Efficiency and Nitrogen Use Efficiency. The yields were calculated based on the average per tree yield as follows, ((kg/tree) X (560.7 tree/ha) x (T/1000 kg)) which is equal to T/ha. Five trees were harvested in each of the five replicates and used to calculate an average yield for each treatment. The values from the individual nitrogen treatments for SDI and DI were averaged to obtain a single yield value for the SDI and DI treatments. The data show higher yields in the SDI irrigated plots than in the DI plots with 10% less applied water. This result carries through the water use and nitrogen use efficiencies such that each of these parameters is greater on average in the SDI treatments compared to the DI treatments.

Table 1. Water balance data for years 2010 to August 23 2015. No drainage was recorded by the lysimeter from 2011 until present.

Year	ET_o mm	Precipitation mm	DI Irrigation mm	SDI Irrigation mm	ET_c mm	Drainage mm
2010	1263.1	440.4	25.4	25.4	53.34	n/a
2011	1292.9	264.7	215.9	215.9	248.92	0.00
2012	1386.8	227.8	472.4	426.7	482.60	0.00
2013	1397.0	81.5	645.2	584.2	683.26	0.00
2014	1468.1	218.9	848.4	779.8	911.86	0.00
2015*	1002.3	89.5	662.0	603.2	665.69	0.00

*As of: Aug. 23 2015

Table 2. Average pomegranate yields in T/ha for SDI and DI in 2014 across all nitrogen treatments.

	SDI (T/ha)	DI (T/ha)
Prime	37.45	32.4
Subprime	9.80	11.7
Green	0.45	0.7
Total	47.7	44.8

Table 3. Pomegranate water use efficiency (WUE) T/ha of fruit divided by total applied water in m (T/m) in 2014.

WUE	SDI	DI
Prime	48.0	38.12
Subprime	12. 6	13.7
Green	0.6	0.9
Total	61.2	52.8

Table 4. Nitrogen use efficiency (NUE) calculated as T of fruit divided by total applied N in T/ha. (T Fruit/T applied N) in 2014.

NUE	SDI	DI
Prime	286.3	231.7
Subprime	82.5	92.4
Green	2.7	4.6
Total	371.5	328.7

ACCOMPLISHMENTS

The results from the past five years have demonstrated the potential of high frequency SDI to provide greater yields and WUE and NUE than the high frequency DI. While yields were greater in the SDI than the DI systems there was no statistical difference between the irrigation systems. High frequency SDI in the lysimeter also demonstrated the potential to maintain and minimize downward SMP gradient and eliminate drainage and NO_3 leaching for 5 years. Applied nitrogen in excess of 70.7 kg/ha did not affect the yield of pomegranate. The SDI system had fewer weeds on the surface than the DI. SDI represents a viable irrigation system for use in pomegranate.

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Determination of Root Distribution, Dynamics, Phenology and Physiology of Almonds to Optimize Fertigation Practices

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INTRODUCTION

Optimal fertilization practice can only be developed if knowledge of the 4 R's (right source, right rate, right place, and right time) are explicitly developed for the almond production context. In this project we provide essential information on root growth and development, root distribution phenology and uptake parameters for nitrate by roots. The effect of irrigation type (drip or fan jet) and fertilization rate and timing on root growth was also determined. This information was then integrated with data developed in related projects in which information on tree nutrient was derived. The overall goal is to use information derived from this project (root phenology and root uptake), with information from associated projects (tree demand and N movement in soils) to improve the design of fertigation systems and to optimize the application (volume, distribution pattern, rate, timing etc.) of fertilizers.

OBJECTIVES

1. Determine almond root growth and phenology and characterize root distribution and nutrient uptake activity as influenced by tree nitrogen status, irrigation source, yield and plant characteristics.
2. Determine the patterns and biological dynamics (K_m, V_{max}, C_{min}) of tree nitrogen uptake and the relationship to tree demand and phenology.
3. Integrate root phenology and uptake data with data on tree demand and utilize HYDRUS 2D and DNDC models to help interpret and extend findings.
4. Publication and extension of results.

DESCRIPTION

The orchard used was a high producing 11-13 year-old Nonpareil/Monterey planting located south of Lost Hills in Kern County. Four nitrogen treatments (125, 200, 275, 350 lbs N acre) and two irrigation systems (drip and fan-jet) were imposed in 1/3 acre complete replicated plots. Twenty minirhizotron access tubes were installed to follow root phenology (root flushes, root lifespan, growth, etc.) over multiple seasons under four fertilization regimes. Root images were taken over two complete seasons (2012 and 2013) on a 2-week basis and images were analyzed for number of roots, color, diameter and length. Root nitrate uptake parameters were determined in excised roots from a total of 80 root bags. Data on yield and nutrient accumulation in annual and perennial tissues was determined by multiple tree excavation and sampling over 4 years in a coordinated project conducted at this same orchard.

RESULTS AND DISCUSSION

Objective 1: Root images were collected during the 2012 and 2013 season every 2 weeks. Images were analyzed for number of roots, color, diameter and length and distribution of roots with depth. Data is presented as new root production (new white roots *Figure 1*), active root presence (total of white and light brown roots, *Figure 2*), root distribution with depth (*Figure 3*).

In both years a consistent pattern was observed with the majority of new roots being produced from mid-March to June and a much smaller root flush in

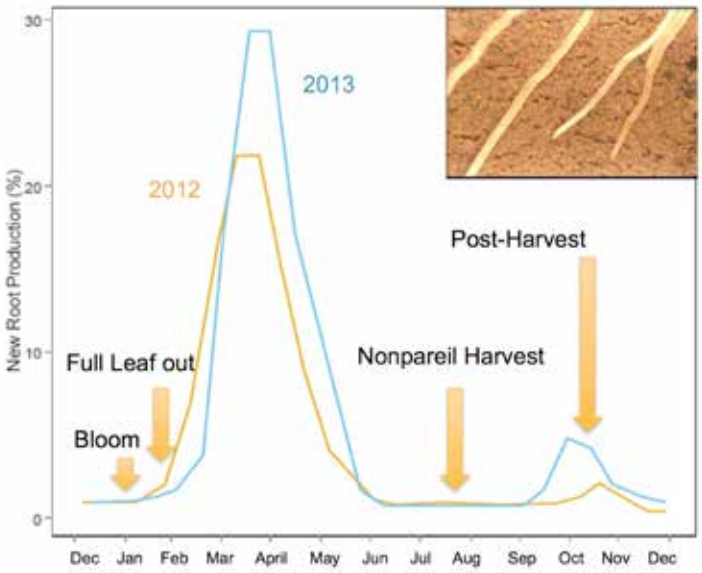

Figure 1. New root production (young white roots as shown in photograph) expressed as the percentage of total annual roots produced at each date. Data for two years is shown.

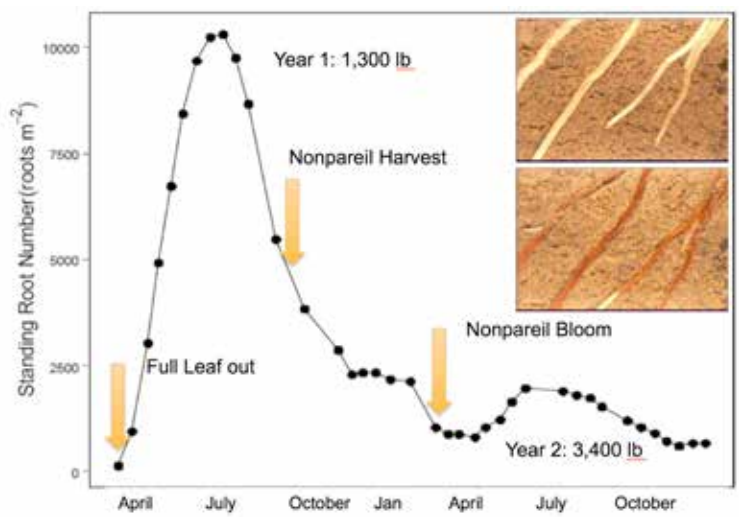

Figure 2. Standing biomass of active roots (see inset picture) over two growing seasons. While the pattern of root production is similar from year to year the amount of roots produced in the low yielding year 1 (2012) was 8x greater than in high yielding year 2 (2013).

fall from mid-September to December. New root growth was very limited from Jun through September when maximal carbon demand for growing nuts occurred (*Figure 4*). There was very little root growth prior to leaf out with the predominant root growth period occurring after full leaf out. The pattern of new root growth did not vary from year to year or between irrigation or fertilization treatments.

While the timing of new root production during the year did not vary between years (*Figure 1*) the total amount of roots produced was dramatically different between the two years (*Figure 2*). Yield in 2012 was exceptionally low (1,300 lbs.) while root growth was exceptionally high, while in 2013 yield was high (3,400 lbs.) and root growth was low. These results suggest that competition between shoots and roots defines the rate of root growth and that current fruit load influences root growth by limiting carbohydrate supply to actively growing roots.

The distribution of roots with depth was determined in both years and under nitrogen and irrigation treatments. In all years and treatments the majority of roots were produced in the 0-0.6 m depth (0-24 in.) and there was no significant effect of treatment or year (*Figure 3*).

Objective 2. Roots from 200, 275 and 350 lb N acre treatments were exposed to a variety of nitrate concentrations from 0.05 to 7.5 mmol·l-1 of N-NO_3 (0.42 to 14.0 ppm of N-NO_3) and the parameters (Km, Vmax, Cmin/max) determined (*Table 1*). Km and Cmin values were not influenced by pre treatment while roots from the high N pretreatment did exhibit a lower Vmax suggesting that uptake was down regulated when N was in excessive supply.

Objective 3. As part of the objective to integrate these findings with collaborative projects the pattern of nitrogen accumulation in perennial and annual tissues was determined by sequential harvesting of entire trees followed by partitioning and determination of N in all organs. Data for 2011 is shown in *Figure*

Table 1. Nitrate uptake parameters. (Column values with same superscript do not differ)

Pre treatment N Rate (lb N acre^{-1})	Vmax (nmol g^{-1} s^{-1})	Cmin (mmol L^{-1})	Km (mmol L^{-1})
200	1.8^{a}	0.04^{a}	0.04^{a}
275	1.75^{a}	0.1^{a}	0.07^{a}
350	1.2^{b}	0.06^{a}	0.04a

4. This experiment was repeated in 2012 and 2013 with fewer replications and a nearly identical pattern of N uptake was observed. In January of 2011 (11 year old trees) the entire N biomass in all tissues (perennial and annual, above and below ground) was 450 lbs N acre^{-1}. By mid-March, trees had flowered, fruit were ½ inch and leaves were 75% of final leaf size. During the period January through mid-March total orchard N acre^{-1} did not increase suggesting that all N required for plant growth until mid-March was supplied by remobilization of N from perennial tissues which decreased in N content by an estimated 30 lbs N. Net N uptake from soil commenced in Mid-March, increased dramatically through late July, then diminished as nuts reached maturity. To support the N demand of the 5,000 lb yield in this orchard was 340 lbs N, while 30 lbs was allocated to new growth and N storage for the subsequent year. At years end the total orchard N content was 485 lbs acre^{-1}, 35lbs greater than at the commencement of the season which may suggest a small uptake of N from the soil post-harvest.

TAKE-HOME MESSAGE

Data on tree nitrogen demand (*Figure 4*) and root growth patterns (*Figures 1, 2, 3*) demonstrates that root and leaf development occur simultaneously in early March. Prior to this date there is both an absence of above ground N demand and a lack of viable roots to facilitate nutrient uptake. The primary period of active root growth and accumulation of nitrogen in annual and perennial tissues occurs between April and August with a smaller root flush during the late postharvest period. Roots are primarily located in the 0-24 inch root zone. Root growth is markedly diminished in trees with a large crop suggesting that above ground competition for resources determines root growth. Collectively these data provide biological guidance for nitrogen fertilizer practice suggesting that N fertilizers should be concentrated during the period of greatest N demand and targeted to remain in the 0-24 inch active root zone.

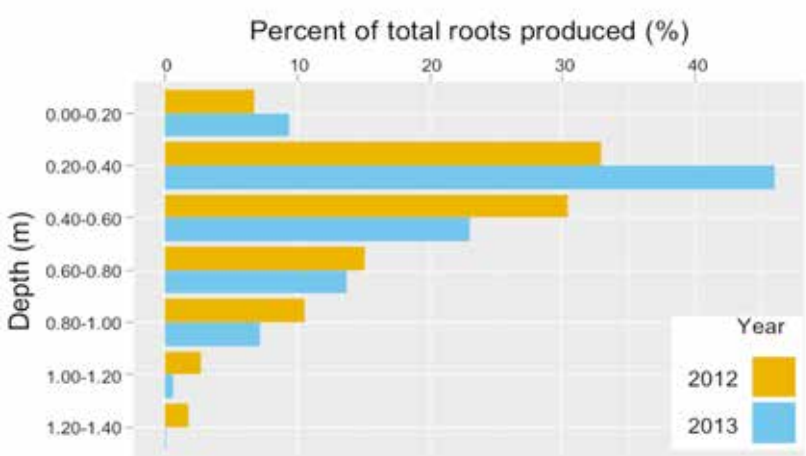

Figure 3. Distribution of roots with depth over two production years. 80% of all root length is present in the 0-0.6 m depth (0-24 inches).

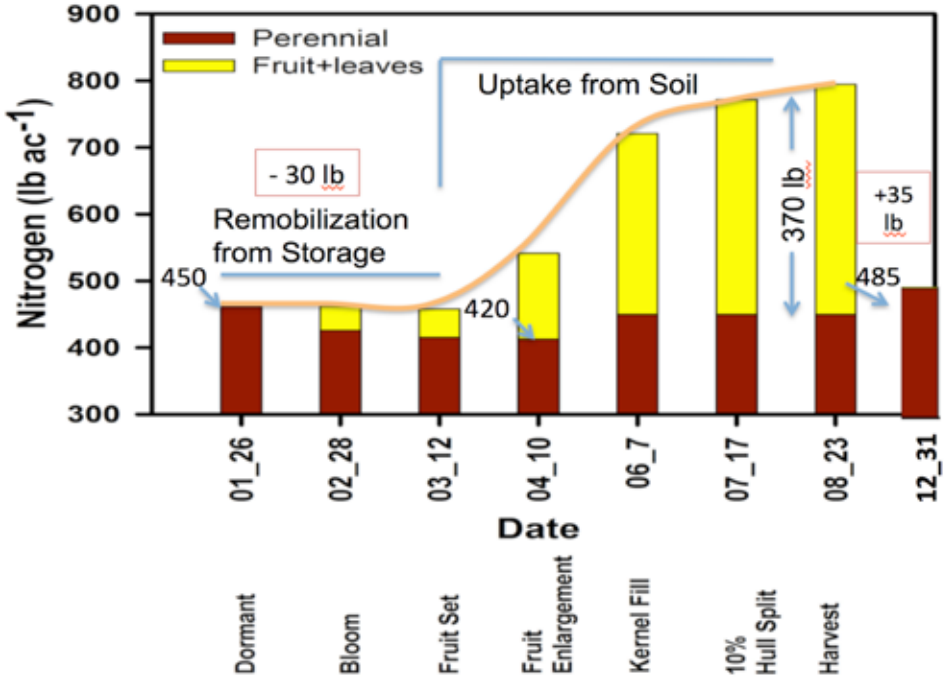

Figure 4. Total nitrogen in all plant organs at the commencement of 2011 through December 31 of 2011. Periods and quantity of N remobilization and uptake were determined by measurements of total tree N contents at each date and allocation to perennial and annual tissues.

ACKNOWLEDGEMENTS

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Assessment of Baseline Nitrous Oxide Emissions in Response to a Range of Nitrogen Fertilizer Application Rates in Corn Systems

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INTRODUCTION

Nitrous oxide (N_2O) contributes about 24% of the total greenhouse gas (GHG) emissions from California's agriculture sector (California Air Resources Board, 2015). Quantifying N_2O emissions from different cropping systems is a prerequisite to address the goals of the Global Warming Solutions Act (Assembly Bill 32) of bringing GHG emissions to 1990 levels by 2020 and develop effective mitigation practices and strategies. Among California's field crops, corn has the largest acreage (610,000 acres), and to-date, the effect of N fertilizer levels on N_2O emissions in irrigated corn production in California has not been investigated.

Nitrous oxide (N_2O) is produced in soil by microorganisms as by-product of nitrification [conversion of ammonium (NH_4^+) to nitrate (NO_3^-)] and denitrification [conversion of NO_3^- to atmospheric nitrogen (N_2)], primarily under oxygen limitation (Zhu et al. 2013). Therefore, the production of N_2O depends to a large degree on the availability of N in mineral form in the soil. However, soil water content and carbon availability also play important roles in regulating N_2O emissions. Soil moisture affects microbial activity, as well as gas content and transport in the soil, and carbon availability stimulates microbial processes that consume oxygen.

Meta-analyses based on over 1000 studies found that fertilizer nitrogen (N) application rates have significant effects on N_2O emissions (Bouwman et al. 2002). Moreover, studies in other regions found that N_2O emissions increase sharply in response to N additions that exceed crop N needs (Van Groenigen et al. 2010). Management practices that increase nitrogen use efficiency (NUE) can be expected to also reduce N_2O emissions because applied N taken up by the crop is not available to the soil processes that generate N_2O. Presently, few data of corn N use have been collected in California, and N fertilization guidelines for corn production in California are based mostly on recommendations from other regions. Thus, data on both N fertilizer use by the crop and N_2O emissions are needed. The present study takes a systems approach evaluating N_2O emissions, crop performance, N use efficiency, and potential environmental impacts with various levels of N fertilizer applications. The over-arching goal is to develop best management practices that minimize N_2O emissions without sacrificing corn yield potential.

OBJECTIVES

1. Assess annual N_2O emissions in response to a range of N fertilization rates in an irrigated corn cropping system;
2. Calculate yield-scaled N_2O emissions and N_2O emission factors for each N fertilizer level;
3. Determine the N use efficiency of and optimum N application for the corn crop;
4. Identify key environmental conditions affecting N_2O emissions.

DESCRIPTION

Emissions of the greenhouse gas nitrous oxide (N_2O), were measured during two growing seasons and one post-harvest (winter) season in furrow-irrigated corn fertilized at five different nitrogen (N) rates (*Figure 1*).

Figure 1. Appying UAN fertilizer at five different rates.

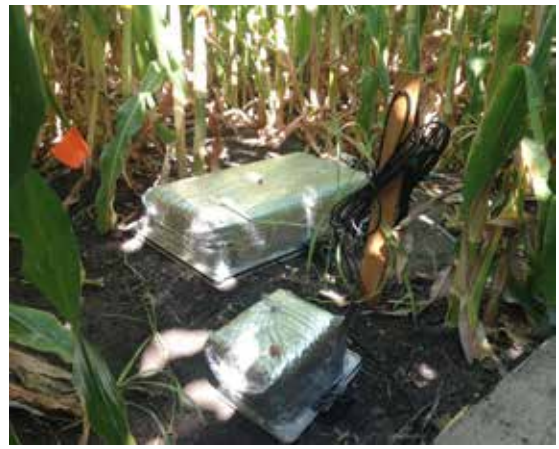

Figure 2. Soil cover chambers used for N2O flux measurements.

The trials were conducted in a grower's fields in San Joaquin County in soil classified as Stockton clay. The N fertilizer bands (two bands per row of plants) were in the bed and shoulder locations. In 2013, the corn was harvested for grain, but in 2014, silage was produced.

The N_2O flux measurements were made by placing soil cover chambers in the field for short durations (<one hour) and collecting air samples from the chambers at timed intervals (*Figure 2*). The air samples were analyzed by gas chromatography. The N_2O fluxes were calculated, using ideal gas relations, from the change in N_2O concentrations over time, chamber air temperature, chamber volume and area covered by the chamber. The daily N_2O fluxes were measured on the beds, the shoulders of the beds, and the furrows. To calculate the daily fluxes and seasonal emissions per area, the N_2O fluxes from beds, shoulders, and furrows were weighted at 65, 25, and 10%. The cumulative N_2O emissions were

Table 1. Pre-plant nitrate levels, mean annual nitrous oxide (N2O) emissions and standard errors (±), emission factors (EF), and yield-scaled N_2O emissions in 2014 and 2013. Values designated with the same letters are not significantly different (P<0.05). n = 3.

Fertilizer N treatments	Pre-plant NO_3^-	N_2O-N	EF	N uptake-scaled N_2O	Yield-scaled N_2O
	kg N ha^{-1}		%	g N_2O-N kg^{-1} N	kg CO_2 equiv. Mg^{-1}
2013					
11	72	0.25 ±0.03 a			
139	72	0.82 ±0.32 b	0.6±0.2	4.06 ±1.74 a	40 ±17 a
226	72	0.73 ±0.33 b	0.3±0.1	3.49 ±1.36 a	40 ±14 a
270	72	1.52 ±0.67 b	0.6±0.2	5.87 ±2.04 a	71 ±28 a
342	72	1.94 ±0.30 b	0.6±0.1	6.95 ±1.61 a	77 ±19 a
2014					
75	94	1.08 ±0.18 a	1.4 ±0.2	4.61 ±0.41 a	40 ±7 a
164	94	3.41 ±1.26 b	2.1 ±0.4	12.24 ±3.21 ab	113 ±24ab
254	94	4.23 ±1.04 bc	1.7 ±0.4	14.38 ±4.25 b	151 ±37 b
344	94	6.14 ±0.68 c	1.8 ±0.1	16.50 ±1.57 b	205 ±13 b

Table 2. Mean corn grain yield, biomass N, grain N, and apparent N fertilizer use (FUE) and N use efficiencies (NUE) and standard errors (±) in 2014 and 2013. Means designated with the same letters within each column and year are not significantly different (P<0.05). n = 3.

Fertilizer & pre-plant N	Corn grain (SE)	Biomass N	Grain N	FUE (minus control)	NUE
kg N ha^{-1}	Mg ha^{-1}	kg N ha^{-1}	kg N ha^{-1}	kg kg^{-1}	
2013					
80	4.2 (1.2) c	115 ±11	64 ±15 a		
211	10.8 (0.4) ab	207 ±8 a	157 ±4 b	0.66 ±0.06 a	0.98 ±0.04 a
298	9.6 (0.5) b	197 ±11 a	147 ±5 ab	0.36 ±0.05 a	0.66 ±0.04 b
342	10.2 (0.8) b	229 ±33 ab	167 ±25 b	0.42 ±0.12 a	0.67 ±0.10 b
414	13.8 (1.7) a	288 ±35 b	226 ±5 b	0.51 ±0.10 a	0.70 ±0.09 b
2014					
169	12.5 ±0.3 a	233 ±24 a		n.d.	1.39 ±0.15 a
258	14.1 ±0.6 a	287 ±33 ab		n.d.	1.12 ±0.13 ab
348	13.1 ±0.2 a	301 ±13 ab		n.d.	0.87 ±0.04 b
438	14.0 ±0.5 a	377 ±30 b		n.d.	0.86 ±0.07 b

calculated by linearly interpolating between daily flux estimates. Differences between treatments were assessed using analysis of variance and standard mean separation procedures. Yields and the total N in grain and corn biomass were measured, and the yield-scaled N_2O emissions (N_2O-N divided by grain-N per unit area) were calculated. The emission factors were calculated as the amount of N_2O-N divided by the amount of fertilizer N applied (per unit area). The apparent N use efficiency was calculated as total N uptake by the corn crop divided by the amount of the total of pre-plant inorganic N and applied N (per unit area).

RESULTS AND DISCUSSION

In both years, substantial amounts of nitrate (72 and 94 kg N ha-1 in 2013 and 2014, respectively) were measured at planting (*Table 1*). Most of the N_2O was emitted in spikes following each of the first six irrigation events, whereas N_2O emissions after harvest and through winter were low.

In the first year, there were no significant differences in N_2O emissions among the fertilized treatments, but in the second year the N_2O emissions increased significantly with increasing N fertilizer rates from about 1 kg N ha^{-1} in the 75 kg N ha^{-1} treatment to about 6 kg N_2O-N ha^{-1} in the 344 kg N ha^{-1} treatment. The yield-scaled N_2O emissions did not differ among fertilized treatments in 2013, but in 2014, yield-scaled N_2O emissions were significantly lower in the 75 than in the 254 and 344 kg N ha^{-1} treatments and similar among 164, 254, and 344 kg N ha^{-1} treatments. In the U.S. corn belt, where the average N applied is 138-157 kg N ha^{-1}, average N_2O emissions were 3.8 (standard deviation 5.2) kg N ha^{-1} (Decock 2014). In 2014, the N uptake- and yield-scaled N_2O emissions (Table 3) in the 75 kg N ha^{-1} treatment were significantly lower than in the two treatments that received the highest N applications, supporting the hypothesis that N_2O emissions increase non-linearly when fertilizer N is applied in excess of crops' need (Van Groenigen et al. 2010). According to a meta-analysis comprising 19 different sites from all over the world, the mean EF was 1.06% and yield-scaled N_2O emissions were 185 kg CO_2 equivalents Mg^{-1} (Linquist et al. 2012). In both years, yields did not differ between the highest and lowest N application treatments. This seems to indicate that N was not limiting in any of the fertilized treatments and that adding 75 and 139 kg N ha^{-1} as fertilizer N would have been sufficient in 2013 and 2014, respectively (Table 2). Mineralization of soil organic matter likely contributed N for crop uptake, but N in the (surface) irrigation water was low (1 mg NO_3^--N L^{-1}).

Assuming a yield potential of 14 Mg ha^{-1} at this site, the corn N requirement based on recommendations from other regions (Virginia, Pennsylvania) would

be 248 – 304 kg N ha^{-1}, which corresponds approximately to the 226 kg N ha^{-1} treatment (fertilizer + pre-plant N 298 kg N ha^{-1}) (Alley et al. 2009; Beegle and Durst 2003). In 2013, the N removal by the harvested crop in this treatment was 147 kg N ha^{-1}, leaving approximately the same amount as surplus. In 2014, an N rate of 164 kg N ha^{-1} (+94 kg residual NO_3^--N ha^{-1}), which resulted in a yield of 14.1 Mg grain ha^{-1}, would have been an appropriate recommendation.

TAKE-HOME MESSAGE

Assessing pre-plant nitrate levels and adjusting N fertilizer applications to not exceed the N required for achieving the site specific yield potential increases N use efficiency and potentially lowers yield-scaled N_2O emissions.

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Development of Economically Viable Variable Rate P Application Protocols for Desert Vegetable Production Systems

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INTRODUCTION

Vegetable crops produced in the desert receive large annual applications of phosphorus (P) fertilizers. Amounts of P applied to vegetable production systems often approach and exceed 200 kg P/ha and crop recoveries of P fertilizers are generally less than 25%. While much of the added P is converted to insoluble forms in the calcareous soils of the region, some of it is carried in runoff and drainage water into receiving surface waters having adverse ecological effects. Further, erratic fertilizer pricing over the past several years has created incentives for improved efficiency. Approximately three years ago, the costs of mono-ammonium phosphate (MAP), a formulation widely used for desert vegetable production, exceeded $1,200.0 per ton. Although costs have since declined, rapid increases are anticipated as the world economy recovers and resource demand in the developing world regains momentum. In addition, world P reserves are rapidly declining and there is concern that a shortage of P fertilizers will ultimately result in large fertilizer P price increases and ultimately compromise world food production.

In studies we have shown most cool seasons vegetables produced in the desert will respond to P fertilizers up to a sodium bicarbonate P soil test level of 30 to 35 mg/kg. As pre-plant soil tests approach these critical soil test P levels, the probability of crop response to P fertilizer drops dramatically. However, P fertilization based on a composite soil sample from a production unit assumes relatively uniform fertility within the unit which is inconsistent with our findings. In high resolution sampling of vegetable production fields in the desert we have found large in-field variability in soil test P levels within production units (CVs from 18 to 90% usually exceeding 50%). Thus, if we made adjustments in pre-plant P recommendations to minimize economic losses due to under-fertilization, we would have to over-fertilize a large portion of the field. This not only has economic consequences, it can result in very high available P levels over part of the field and adverse consequences such as P induced micronutrient deficiency (particularly Zn).

The prospect of variable rate pre-plant P fertilizer application has not been extensively evaluated in desert vegetable cropping systems

OBJECTIVES

The objective of this project is to 1. Develop economically viable and effective sampling protocols to generate prescription maps for the variable rate application of P, 2. Compare variable rate P application to current methods and evaluate alternative economic outcomes. In the first phase of the project we will test alternative sampling schemes. Sampling schemes evaluated will include grid sampling at various resolutions, samples schemes which seek to define zones directed by other indices of in-field variability. In the second phase we will evaluate the efficacy and economic returns to variable rate P application. Project success will be the development of economically viable protocols for the implementation of variable rate P application technologies.

DESCRIPTION

Task 1. Evaluate alternative sampling schemes including various resolutions of grid sampling and zone sampling based on soil properties that may serve as covariates.

During 2013-2014 four research sites were established. One was iceberg lettuce in Imperial County, CA (Bard), one was broccoli in Riverside County CA (Coachella Valley), one was romaine lettuce in Yuma County AZ, and one was potato in Pinal County AZ. In September 2013 we performed soil EC surveys at the first three sites as a basis for zone sampling. The last survey for potato was performed in late January 2014. The Veris 3100 soil apparent electrical conductivity (ECa) sensor is simple to operate and user-friendly for producers but the EM-38 being a research-grade instrument gives higher resolution map. It is one of our objectives to evaluate these two systems as alternatives for deriving zone-based sampling schemes.

Each production field was divided into three equal areas. For one, prescription fertilization maps would be developed based simple grid based sampling, for another they would be developed based on zone sampling, and for the third, P fertilizers were applied based on the growers normal practice. ECa measurements were processed using the USDA-ESAP program to locate soil samples for the zone sample method based on natural variability of the soil. Immediately after these surveys, we collected soil samples for both grid and zone based fertilizer application comparisons.

The samples were analyzed for P and salinity in our laboratory. The salinity data was used to statistically distinguish salinity and soil texture as sources of variation in the electronic surveys. The P soil tests were used to develop P soil test maps and corresponding prescription maps. Applications of P fertilizer were carried out with a 4-row frame retrofitted with metering and driving equipment for variable-rate applications of both liquid and granular materials. The grower in the Coachella Valley had a preference for liquid P fertilizer so we used liquid P at this site. The growers in Yuma, Bard, and Maricopa preferred dry P sources so we used dry fertilizer in these sites.

Task 2. Field testing of VRA and standard grower practice.

Field testing of VRT and grower practices were conducted during the fall-winter –spring period in 2013-2014. The sites in the Coachella Valley, Yuma, Bard, and Maricopa were planted to broccoli, romaine lettuce, iceberg lettuce, and potato respectively. The romaine and broccoli were harvested in January. The iceberg lettuce was harvested in February, and the potato were harvested in June.

Tasks 3. Repeated evaluation of alternative sampling schemes including various resolutions of grid sampling and zone sampling based on soil properties that may serve as covariates.

During 2014-2015 we established four more additional sites. One site was broccoli in the Coachella Valley (Riverside County CA), one was iceberg lettuce in the Yuma Valley (Yuma County Arizona), one was iceberg lettuce in Bard (Imperial County CA), and one was potato in Maricopa (Pinal County, AZ). As in the previous years, the survey for the lettuce and broccoli were completed in September and October. The survey for the potato was completed in January. As in the previous year, we compared zone and grid based sampling schemes.

Task 4. Field testing of VRA and standard grower practice.

Field testing of VRT and grower practices were repeated during the fall-winter –spring period in 2014-2015. The broccoli in Riverside County and the lettuce in Yuma were harvested in January. The lettuce in Imperial County was harvested in March, 2015. The potato were harvested in early July, 2015. These data are currently being analyzed.

Task 5.

Field studies are being repeated in fall-winter-spring 2015-2016. We will conduct economic evaluations after we collect a third set of data in 2015-2016.

RESULTS

During 2013 the following was accomplished. We built and tested a combined platform for soil apparent EC measurements with Veris 3100 and EM-38. Hardware included GPS for data geo-referencing. We set up instrumentation supported by a CAT II tractor. This included a Trimble FMX display with integrated GPS receiver and variable-rate function unlocked, Field IQ, VRT Rawson controller and associated harnesses and power connections. We also built a 3-point hitch frame to support tank, hoppers, drive shafts, pumps, soil-engaging tooling and other

hardware for precise application of both liquid and granular P fertilizer.

We performed soil ECa surveys at three locations in 2013, four locations in 2014, and one location in 2015. Sites were located in Imperial County, CA (Bard), Riverside County CA (Coachella Valley) Yuma County AZ and Pinal County, AZ. Processed EC measurements in USDA-ESAP was used to locate soil samples for zone sample method based on natural variability of the soil. Immediately after these surveys, we collected soil samples for both grid and zone based fertilizer application comparisons. Fertilizer applications were made using these prescription maps.

In 2013 we collected all yield data by hand on a 0.5 acre or less resolution. However, by fall 2014 we started working on the design and construction of an electronic yield monitor system for in-field evaluations. We developed a system whose basic components consisted of: a) GPS receiver to generate positioning data. We used a variety of Trimble systems with differential correction for sub-meter accuracy (typically within 12 in); b) box counting hardware which consisted of either a handheld button assembly to generate counts manually, or a sensor-based approach that used laser sensors (Keyence model LR-ZB240CB) for automatic counting of boxes moving along the machine conveyers; and c) Field-ready electronic data acquisition (Campbell Scientific CR3000 and CR 1000) with serial and analog ports to accommodate GPS string data, pulses from handheld manual counters, and differential voltage generated by the laser sensors. This was a customized solution and therefore we wrote CR-basic code with specific instructions for the logger to handle the data inputs and integrate it on 10 sec intervals, which corresponded to about 9 inches in the direction of machine travel. Three units were set up to account for the possibility that multiple machines were used in the field under study.

Yield data collected 2013-2014 and 2014-2015 show that, although we did not improve yield consistently, there was a potential for reduced P fertilizer use in desert vegetable production systems due to variable rate P fertilizer management. In most cases both Grid and Zone based soil sampling, reduced total P application compared to grower standard practice. There were no consistent differences between Grid and Zone based samples and final conclusion concerning sampling protocol will have to await economic analysis at project conclusion.

ACCOMPLISHMENTS/PRELIMINARY FINDINGS

In early 2013 considerable effort was directed toward building and testing equipment for surveys and variable rate fertilizer applications. In fall 2013 field tests were implemented. In 2013 we collected all yield data by hand. However, by fall 2014 we started working on the design and construction of an electronic yield monitor system for in-field evaluations. These systems were used in 2014. Preliminary data collected during 2013-2015 showed potential economic and environmental benefits to VRT fertilizer management.

We have conducted a number of formal outreach activities during the 2013 to 2015 period. These included presentations at the SW Ag Summit in Yuma during 2014 and 2015, the Western Plant Health meeting in Yuma in 2014, and the Desert Ag Conference in Chandler, Arizona, in 2014 and 2015. In addition to these field days we have worked with growers and crop consultants from local chemical companies in the field on demonstration and training with respect to the variable-rate technologies developed and deployed. Additional outreach activities are scheduled for fall 2015 and spring 2016.

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EVALUATION OF A 24-HOUR CO_2 TEST FOR ESTIMATING POTENTIAL N-MINERALIZATION TO REASSESS FERTILIZER RECOMMENDATION

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INTRODUCTION

In order to make accurate fertilizer N recommendations, including the contribution of soil organic matter to plant-available N is essential. The breakdown of soil organic matter, commonly referred to as mineralization, makes these nutrients available for plant and microbial metabolic processes. The mineralization of soil organic matter has been shown to account for over 50% of total plant N uptake in a growing season in California (Kramer et al., 2002; Doane et al., 2009). Despite this substantial ability of the soil to provide crop N, many fertilizer recommendations ignore this contribution, only considering preplant N levels, leading to overfertilization of N. The prediction of the in-season mineralization has proved difficult due to the fact that it is a biologically-driven process, which can vary widely among and between sites.

To account for this variation, biologically-based tests have been proposed and tested. However, they are often time-, space-, and labor-intensive, leading to low adoption rates by commercial soil test labs. Some of these tests have been shown to work better than current chemical extraction methods, but as of yet, none have proven robust enough to provide replicable results across a broad range of soil characteristics. One of these biological tests that has recently been utilized to predict N mineralization is the flush of respiration upon the rewetting of air-dried soil (Franzluebbers 1999; Franzluebbers et al., 2000; Haney et al., 2001; Haney et al., 2008), which will be investigated here.

OBJECTIVES

This study seeks to fill the previously discussed knowledge gap and provide growers, PCAs and commercial soil test labs with a viable test for the assessment of soil N mineralization potential in California. Specifically, the objectives of this project include:

1. Evaluate whether the flush of CO_2 from soils can predict growing season soil N mineralization across a range of soils that vary in fertilizer N requirements, soil amendments (crop residues and manures and composts), organic matter contents and other agronomic practices.
2. Develop correlations to other tests such as total soil N, total soil organic matter, crop N uptake and pre-crop nitrate levels to predict soil N mineralization potential with the main goal of reassessing fertilizer N applications for important California crops.
3. Evaluate the cost-effectiveness of implementing biologically based soil assays and procedures in commercial soil test labs.

DESCRIPTION

Agricultural soils were gathered across varying management strategies and growing regions within California, including several major crops: processing tomatoes, corn, almonds, sorghum, lettuce, and cotton. Management strategies were grouped according to the presence or absence of a winter cover crop preceding sampling.

These soils also represented a range of inherent soil qualities, such as soil organic C and texture. Cumulative respiration upon the rewetting of the air-dried soil (CMIN), measured at 6, 24, and 72 hours, and permanganate-oxidizeable carbon (POXC), which is known as "biologically-active carbon" (Weil et al., 2003), were utilized as measures of soil biological activity. Three distinct chemical fractions were examined: measure total soil C and N on combustion, 0.5M K_2SO_4-extractable organic C and N (DOC and DON), and water-extractable organic C and N (WEOC and WEON). These biological and chemical indicators were then analyzed in relation to the net N mineralization ($NMIN_t$) of incubated soil samples, where $NMIN_t$ was defined as the increase in inorganic N (NO_3^- + NH_4^+) at a given time, *t*= 28, 56, or 105 days, after rewetting of the soil. Thus, the net N mineralization is a measure of the rate of release of plant-available N throughout the growing season.

RESULTS AND DISCUSSION

Relating Biological and Chemical Indicators to N Mineralization

Net N mineralization increased throughout the incubation, with significant differences between management at each date. This translated to 43.5-75.3 lbs N/ac, 44.5-72.4 lbs N/ac and 52.6-88.2 lbs N/ac released by the soil for plant uptake for $NMIN_{28}$, $NMIN_{56}$, and $NMIN_{105}$, respectively, across all fields. Cover cropped fields had higher NMIN values than non-cover cropped fields throughout the season, although they showed a similar trend in release dynamics. On average, fields with cover crops supplied 7-8 lbs N/ac more than non-cover cropped fields.

Chemical indicators show that C:N ratios have no significant ability to predict N mineralization, but individual C and N fractions do. However, this predictive ability is much higher in cover cropped fields than in either non-cover cropped fields or when all the fields are pooled

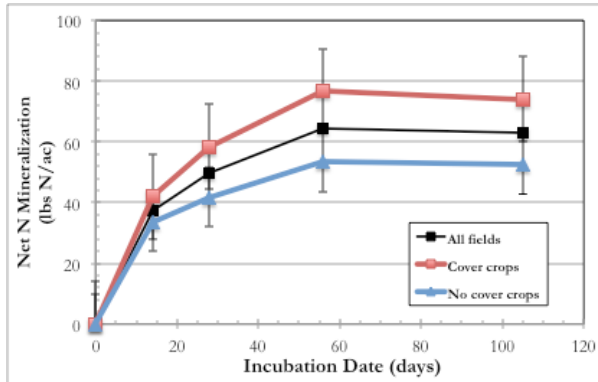

Figure 1. Net N Mineralization during the incubation, by management. Error bars are standard error.

together. Total C and N of the soil is the strongest predictor of N mineralization from the three studied chemical fractions and was the only fraction to have a strong, statistically significant relationship across all fields, whether they were pooled or separated by management. Total N accounted for a maximum of 32% of the variation in N mineralization across all fields, 24% in cover cropped fields, and 27% in non-cover-cropped fields.

Biologically-based predictors of N mineralization varied in their ability to predict net N mineralization values. The main source of variation was the management strategy, with significant relationships only occurring in fields that had received cover crops. In the cover cropped fields, POXC had stronger correlations with NMIN than any of the respiration measurements in $NMIN_{28}$ and $NMIN_{105}$. In $NMIN_{56}$, $CMIN_{0\text{-}72}$ had the best predictive power. Of these three biological predictor variables, POXC serves as a better estimator of N mineralization than its corresponding chemical estimator for both $NMIN_{28}$ and $NMIN_{105}$.

Combining Indicators for Increased Accuracy of N Mineralization Predictions

The lack of significant relationships between biological indicators and measures of net N

	POXC		$CMIN_{0\text{-}24}$		$CMIN_{0\text{-}72}$	
	Adjusted R^2	Normalized RMSE	Adjusted R^2	Normalized RMSE	Adjusted R^2	Normalized RMSE
$NMIN_{28}$	0.457	0.266	0.405	0.273	0.327	0.247
$NMIN_{56}$	0.293	0.302	0.266	0.301	0.258	0.253
$NMIN_{105}$	0.445	0.243	0.425	0.248	0.359	0.225

Table 1. A comparison of models integrating water-extractable C and N (WEOC/N) with the three best biological indicators to estimate net N mineralization (NMIN).

mineralization in non-cover cropped fields suggests that biological indicators do not offer any increased predictive abilities when used in conjunction with chemical indicators. In these cover cropped fields, $CMIN_{0-72}$ provided a modest improvement in prediction of N mineralization over POXC, when combined with WEOC and WEON (Table 1). Although there is a slight increase in predictive abilities using $CMIN_{0-72}$, POXC may ultimately be more favorable in a soil test lab due to a shorter processing time and its utilization of commonly used lab equipment.

TAKE-HOME MESSAGES

The breakdown of soil organic matter is a substantial portion of plant-available N that is unaccounted for. The prediction of the amount and timing of release of these nutrients is a biological process, which makes it difficult to predict. The method of prediction of this release varies substantially according to management. In fields that did not receive a winter cover crop, net N mineralization is best predicted by total soil N, which is still a relatively poor predictor (24% variability explained). In fields with a winter cover crop preceding, a combination of chemical and biological indicators predicted N mineralization best. The water-extractable organic C and N were the best chemical predictors, when paired with a biological indicator. $CMIN_{0-72}$ and POXC provided a comparable level of confidence in prediction, but POXC may be the preferred predictor, given its increased utility in a soil test lab setting.

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Developing Nitrogen Management Strategies to Optimize Grain Yield and Protein Content while Minimizing Leaching Losses in California Wheat

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INTRODUCTION

The primary goal of this study is to evaluate the impacts of timing and rate of nitrogen fertilizer application on optimization of wheat grain yield and protein content while reducing the potential for N losses. The study focuses on hard and durum classes of spring wheat grown in multiple regions in California, and is planned as a multiple year, three region study. Growers of hard and durum wheat are paid not only for crop yield but also for grain protein content. These factors can be inversely related and strongly influenced by the rate and timing of nitrogen (N) fertilization. The goals of nitrogen (N) management research in wheat include improved understanding of interactions of N application timing and rate choices, and resulting productivity and protein content responses. Past research has estimated that the amount of total available N required for acceptable yields and protein ranges for hard red spring wheat are at least 1.6 lbs of total available N per bushel at lower yield levels and over 2 lbs total available N per bushel (or about 3 lbs of N per 100 lbs of grain yield) at higher yields. Achieving acceptable protein content is a continual challenge for wheat producers throughout California. It can be difficult under certain conditions and types of wheat, such as Durums in the San Joaquin Valley or in the intermountain area where many growers market grain in the Pacific Northwest where there is a discount for wheat with less than 14%, compared with 13% for California markets. Higher protein levels can be difficult to achieve, especially in high yielding irrigated fields. Primary production factors impacting protein content are cultivar selection and N fertilizer rate and timing decisions.

Over and above yield and grain protein responses to N management, the cost of fertilizers and application costs provide growers with additional incentives to limit the amount and number of fertilizer applications while attempting to get the most from each unit of applied N. A specific focus, then, of more recent research on California wheat nitrogen management is to evaluate what proportion of total fertilizer nitrogen should be applied at different growth stages to get the most benefit? Currently, there remains a wide range of N fertilization strategies across locations and growers, with some growers applying all or nearly all of the nitrogen as a preplant application and others doing a wide range of application amounts and timing of split applications. Results from recent wheat studies done by the authors have indicated that split applications can be beneficial and more successful in providing acceptable grain protein levels in combination with good yields. In multiple cases, it has been seen that high rates of N are not necessarily needed at preplant in order to achieve high yields and acceptable protein levels, and that tillering may be closer to being one of the key times to apply nitrogen for maximum yield benefit, likely because this is the beginning of the period of peak N uptake by wheat plants. Additional research in California conducted as part of this FREP-funded study will provide multi-site evaluations of the impacts of split nitrogen fertilizer rate and timing options.

OBJECTIVES

1. Compare yield and protein content of popular hard red, hard white, and durum spring wheat varieties in response to a range of N application treatments to determine their N-use-efficiency.

2. Evaluate N management schemes utilizing different rates and split applications of N to determine the effectiveness of pre-plant applications versus delayed applications, with evaluations done in three different wheat production regions (San Joaquin Valley, Sacramento Valley, and Intermountain region).

3. Determine the concentration of nitrate-N at different depths in soil profiles at the end of the season as a function of N rate and application timing for three trial locations/soil types as a means of evaluating potential treatment (rate, timing) impacts on soil nitrate movement and zones of accumulation or loss.

4. Measure the effect of N application timing and rate on flag leaf total N to determine if tissue N can be used to indicate needs for late-season N applications to achieve desired grain protein. Compare with other indices of plant N status at one or more locations.

5. As information is developed in the study, present information to appropriate grower groups, consultants and industry to give opportunities for feedback and to refine concepts of workable changes in N management approaches.

DESCRIPTION

In the first year of current work (2013-2014), five trials were implemented across three experimental regions (San Joaquin Valley at the University of CA West Side and Kearney Research and Extension Centers, a Sacramento Valley site at the UC Davis Farm, and in the Intermountain Region at the University of CA Intermountain Research and Extension Center). The first year trials included: (1) variety by nitrogen management trials at the Intermountain Region and the San Joaquin Valley; and (2) trials with multiple N application rates [0-300lb/acre], and multiple splits [pre-plant, tillering, boot, and flowering]) at all three locations. In 2014-2015, the variety by N management trial was only conducted at the Intermountain REC site, while the multiple rate: split timing trials were conducted at all three experimental regions as in the first year. All trials had four replications of each treatment. Fertilizer N applications were made using granular urea, followed by irrigations within a short time period following applications. Irrigation methods and amounts differed between the sites according to local conditions and irrigation water requirements to be a non-limiting factor. Some basic details on the conduct of the trials are included in the Results and Discussion section, by region. Efforts were made to select experimental sites with low pre-plant soil NO3-N, and pre-plant soil sampling was conducted to 8 feet to assess soil nitrate levels. Soil samples were also collected post-harvest to a depth of 8 feet in one foot increments between 0 and 4 feet depth and in two foot increments from 4 to 8 feet depth. Yields were determined at each site using a plot harvester, and grain subsamples were collected for protein analyses. Soil sample data from each site is still in the process of being analyzed and summarized, and impacts of fertilizer N rates and timing on distribution of soil nitrate-N will be discussed in future reports.

RESULTS AND DISCUSSION

Sacramento Valley

During the 2013-14 and 2014-15 seasons, we grew 2 varieties of hard red and 1 variety of hard white spring wheat at 2 separate locations (4 site-years) and under several N rates and application timings in the Sacramento Valley. The trials were carried out on soils with low levels of pre-plant N and demonstrated strong yield and protein responses to N fertilizer applications. At the various periods of the crop cycle when fertilizer applications were made (pre-plant, tillering, boot, and flowering), we measured the soil-plant N status on subsets of the treatments: pre-plant soil sampling to 8 ft depth; soil samples to 1 ft at tillering, boot, and flowering; post-harvest sampling to 8ft depth; plant tissue sampling; and proximal colorimetric sensing of the leaf and canopy. From these data we are beginning to understand the timing and quantity of N fertilizer demand for irrigated spring wheat grown in the Sacramento Valley and the degree to which the in-field soil and plant measurements can indicate N sufficiency/deficiency at various points of the crop cycle. At the Sacramento Valley site, we have found that crops receiving pre-plant applications of fertilizer use N less efficiently than crops that receive N applications at tillering and later. The apparent recovery of applied fertilizer N at a high yielding site in 2013-2014 in the Sacramento Valley for the four stages of crop growth when N was applied was determined by the difference between the grain N content in the unfertilized and fertilized plots expressed as a percentage of the total fertilizer N applied. Applications occurring at tillering and later resulted in greater than a 40% increase in apparent N recovery relative to pre-plant applications.

In the first year work, for N rates split between

preplant and tillering (the most common current management practice), yields increased up to 150 lb N/acre, protein yields increased up to 225 lb N/acre, and protein increased up to 300 lb N/acre. It is important to note that the combination of higher than average yields and extreme soil N deficiency at this trial site in 2013-2014 created conditions for N responses at rates higher than are typically used for wheat in the Sacramento Valley. Therefore, we should not necessarily conclude that the absolute rates reported here are advisable under normal management conditions. Interactions were measured between the timing of N and the absolute N application rate/amount, suggesting that higher or lower N rates would be required, depending on the application timing. As more site-years are added at this and other sites, it may be possible to better discern the consistency of N and protein responses to N rate by timing management practices.

San Joaquin Valley

The varieties for the SJV site variety by N management trial in 2013-2014 included: Volante Durum, Summit 515 and a hard white variety Blanca Grande. Research in 2014 indicated applying N at planting, tillering, boot, and flowering on newer varieties had potential to increase yield and protein in some combinations. Yields at this site ranged from about 3800 to over 5000 lbs/acre with no supplemental N fertilizer, and ranged from 5400 to over 8200 lbs across other treatments. Multiple treatments with comparable higher yields were achieved at the 230, 280 and 300 lb applied N rates. Boot and flowering stage applications had significant impacts on protein levels but there were also interactions between application amounts and split application timing. The West Side REC study indicated in multiple cultivars that split applications that included mid and later season N applications consistently had higher protein and in some cases, also higher yields in these newer varieties. Mid and higher N rates that produced higher (>13%) protein levels in some of the types of wheat (Blanca Grande and Summit 515) did not necessarily achieve protein levels over 13% in the durum wheat cultivar.

In 2014-2015, the rate by timing study was done using hard red wheat Summit 515, planted December 11 and sprinkled up with 2 inches of water. Yield results indicated no treatment differences in grain yields across treatments ranging from no supplemental N through 300 lbs N/acre, with yields only ranging from a low of about 7000 to a high of nearly 8100 lbs/acre. Several 225 lbs N/acre total nitrogen treatments had the highest yields numerically but were not significantly different. There was a trend toward consistently higher proteins (approximately 0.4 % higher) with treatments that had urea applied at either the boot or flowering stages at the 150 or 225 lbs N/acre total nitrogen rates. Soil nitrate quick tests were tested 6 times during the growing season (including within 2 weeks prior to harvest) across five treatments and will be compared with soil nitrate test results from samples sent through the UC Davis analytical lab. Total above ground plant dry matter was collected at two growth stages (flowering, pre-harvest) and analyzed for total N to be able to calculate above ground plant N uptake as a function of treatment at these two stages. Soil cores from the surface to 8 feet depth were collected during August and will be analyzed for nitrate-N to evaluate treatment effects on nitrate-N profiles and to help assess reasons for lack of major yield responses to applied N rates and timing at this site in 2015.

Intermountain Region

The wheat varieties evaluated in the variety by N management trial both years were Yecora Rojo, Hank, WB9668, and WB9518. In the first year (2013-2014) wheat yields in these trials were lower than average, similar to trends seen in the Klamath Basin as a whole. Yecora Rojo was the lowest yielding variety at every N rate, with yields 0.5 to 1 ton/acre lower in the higher yielding treatments. The cultivars Hank and WB 9518 had similar yield. WB 9668 tended to be the highest yielding cultivar especially at the highest N rate. Nitrogen had a dramatic effect on grain yield for all four cultivars, with yield more than tripling in higher N rate treatments compared to unfertilized controls. The field was somewhat moisture stressed after tillering as a result of the drought and the irrigation needs of the crop were underestimated. Based on this situation, it appeared that moisture stress may have an even greater effect on severely nitrogen deficient plants than on plants with adequate N. There was no yield increase beyond the 225 lbs N/acre rate for the lower-yielding Yecora Rojo or with the cultivar Hank, but yield increased slightly for the WB varieties as N rate was increased to 300 lbs N/acre.

In the 2013-2014 study, N rate had significant impacts on grain protein levels. For Yecora Rojo, protein content increased two full percentage points at the 300 lbs N/acre rate compared to the unfertilized. Surprisingly, protein content was significantly higher for unfertilized plots for some cultivars compared with the 150 lbs N/acre rate,

likely because yields in these plots was so low that more of the N was allocated to grain. The variety Hank tended to have the lowest protein content at all N rates. Both WB cultivars had higher protein content and the protein content of WB 9518 was comparable to Yecora Rojo at many of the N rates. In general, yield tended to increase with increasing N rate, but not always, showing some dependence on N application timing. Yield did not increase when N rate went from 225 to 300 lbs/A for any of the treatments that received an application at tillering stage, but did for both N fertilization regimes when most N was applied preplant. It appears, in agreement with previous studies at Intermountain REC, that tillering stage applications can be especially efficient and important. Averaged over all N rates, the highest yield occurred when N was split between tillering and preplant and the overall highest yielding treatment was when no preplant N was applied and most N was applied at tillering. A preplant application of N alone was not sufficient to meet the 14% protein standard, but came close at the 300 pound per acre N rate. Significantly higher protein concentrations occurred when less N was applied preplant and more was delayed until the flowering stage. Protein goals were met by all treatments where total applied N was 225 pounds or greater and an application was made at flowering.

The 2014-2015 crop was only recently harvested so yield or quality data will not be discussed at this time. Soil samples to 8 feet will be collected in mid-September or early October and will be processed for NO3-N content.

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Optimizing the Use of Groundwater Nitrogen for Nut Crops

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INTRODUCTION

The problem of reactive nitrogen (mainly NH_3, NH_4^+, NO_2^-, NO_3^-, NO_x and N_2O) loss to air and water is currently one of the most important challenges to environmental sustainability for California agriculture. Information is needed to inform and satisfy impending regulatory demands and to provide growers with improved management tools. Nitrate (NO_3^-) is the primary contaminant of well waters as a consequence of agricultural activities in California's Central Valley (Viers et al. 2012), in particular the application of synthetic fertilizers to irrigated crops. Previous studies have shown NO_3^- in groundwater (GWN) is a potential source of N for crop use, and may reduce fertilizer costs, lower N concentrations in soil pore space water and hence reduce environmental nitrogen (N) loading (King et al. 2012). The goal of this project is to validate, demonstrate and optimize the utility of GWN using the 'pump and fertilize' (P&F) approach for integrated N management in almonds and pistachio. The project is being carried out as a multidisciplinary project. The P&F approach is being contrasted with high frequency low-N concentration fertigation (HFLC, spoon feed) approach (20 growing season N fertilizer injections) and Advanced Grower Practice (AGP); https://www.sustainablealmondgrowing.org, accessed 20 Aug. 2015) which consists of split-applications targeted to tree N demand.

OBJECTIVES

1. Establish research and demonstration orchards for AGP and P&F N management in pistachio and almond orchards within two Hydrogeologically Vulnerable Areas (HVAs)
2. Utilize and validate recent developments in yield and nutrient budget N management, early season sampling and yield estimation to describe best management practices and contrast these practices with P&F N management treatments.
3. Characterize key physical parameters relevant to P&F concept including root distribution and activity, phenology of uptake, seasonal plant-soil N mass balance, soil NO_3^- and water infiltration for movement of NO_3^- below the rooting zone)

DESCRIPTION

1. Use completely randomized block experiments to evaluate efficacy of P&F contrasted with AGP and HFLC (*Figure 1*) in two almond and one pistachio orchards located in two HVAs (Turlock and Madera).
2. Eight locations in each of one almond and one pistachio orchard were instrumented with tensiometers suction lysimeters (solution samplers) and soil moisture sensors, for intensive hydrologic monitoring of individual trees during 2014 and 2015. The selected sites represented different subsurface layering in the orchards.

3. Applications of fertilizer were based on the Almond Nitrogen BMP, adjusting for early season leaf N analysis

4. Gathering of soil samples was to evaluate changes in NO_3^- and total N-loading in the soil profile between the different fertigation approaches, and to compare with pore water samples

5. Generated N mass balances and in-situ retention curves to estimate water and N losses from the orchard soils.

RESULTS AND DISCUSSION

N-fertilizer was applied to the three orchards according to the Almond Nitrogen Model accounting for groundwater NO_3^--N concentration (https://www.sustainablealmondgrowing.org, accessed 20 Aug. 2015) Spring leaf N concentrations indicated there was no need to modify the N-budget. Nitrate-nitrogen concentrations ([NO_3^--N]) below the root zone at the almond and pistachio orchards ranged from <1 mg L^{-1} to over 550 mg L^{-1} and up to 2500 mg L^{-1}.

The mean concentrations below the effective root zone of the almond and pistachio orchards were almost one and two orders of magnitude, respectively, higher than the drinking water EPA standard of 10 mg/L NO_3^--N (*Table 1*). This is likely a consequence of long-term drought.

During the 2015 growing season N-fertilizer (UAN 32) was applied at the end of irrigation while during 2014 it was applied midway through irrigation. During 2014 sharp increases in NO_3^--N were observed at a depth of 1.8 m across many sites, and at 2.9 m in some locations. In contrast, during 2015 minimal increases in [NO_3^--N] were observed at the depths of 1.8 and 2.9 m (*Figure 2*). Gärdenäs et al. (2005) observed similar differences in [NO3--N] and reinforces that N fertigation at the beginning to middle of an irrigation cycle tends to increase seasonal NO3--N leaching, while N injection at the end of the irrigation cycle reduced potential for NO3- leaching. In AGP, HFLC and P&F practices, N injection at the end of irrigation led to lesser deep losses, apparently caused by

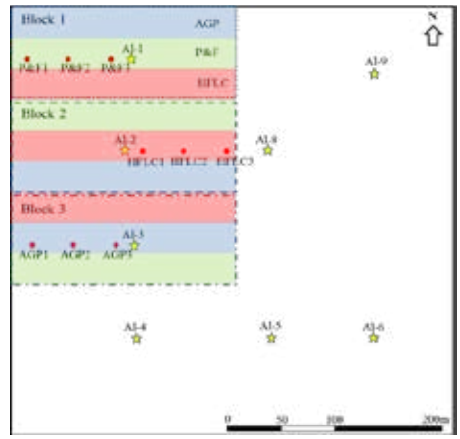

Figure 1. Monitoring setup at the almond and pistachio orchards. Each block has twelve rows of trees, four in each fertigation regime. Al-sites (stars) represent monitoring stations. P&F1-3, HFLC1-3 and AGP1-3 (circles) represent sites where only porewater was sampled from depth of 2.9 m.

longer (≥ 24 h) successive irrigation events, longer residence times of fertilizer N in soil and by less lateral movement of fertilizer N by capillary forces, as suggested by Cote et al. (2003). These observations suggest minimizing NO3--N leaching, N injection at the end of the fertigation and irrigation event and short consecutive irrigations would retain water and N in the active root zone (<1 m depth), as suggested for almond by Phogat et al. (2011).

Pre-bloom and post-harvest flood irrigation led to deep infiltration (>1.8 m) and downward flushing of NO_3^--N deeper into the vadose zone (*Figure 2*). Comparison of the total N loads in the soil profile based on soil extractions down to a depth of 3 m, prior to the beginning of the 2014 and 2015 growing seasons, suggested minimal, if any, N uptake from the deep profile (>1.5 m). Soil N extractions indicated the persistence of high N concentrations in the subsurface. Differences were observed between soil extractions and the porewater samples from similar sites, suggesting that there were two main N-phases in the soil, a mobile N pool and an immobile pool.

Table 1. Mean ± standard deviation of porewater NO_3^--N concentration by depth and tree crop.

	Sampling depth (cm)				
	30	60	90	180	290
Almond	37 ± 59	40 ± 78	38 ± 67	85 ± 116	73 ± 77
Pistachio	148 ± 229	142 ± 257	235 ± 498	322 ± 661	917 ± 1046

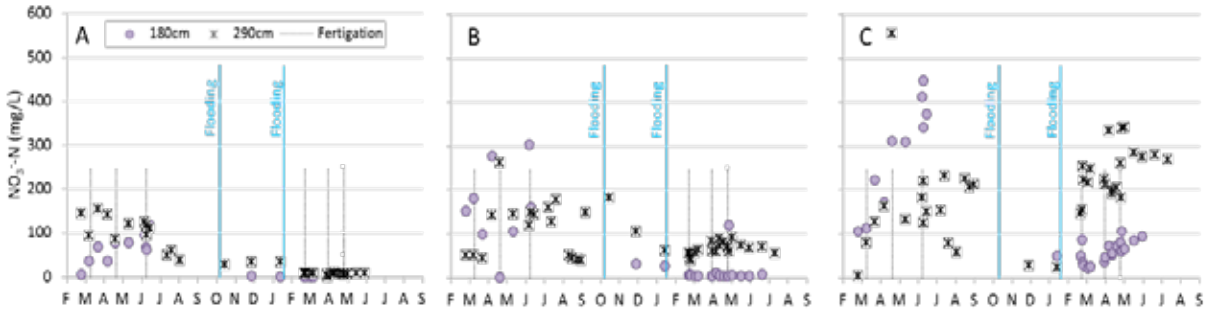

Figure 2. Temporal trends in NO_3^--N concentrations in the pore-water samples from depth of 180 and 290 cm. Results from three monitoring sites in the almond orchard.

Differences between the two sampling methods indicated that most applied N-fertilizer stayed in the mobile phase and therefore was more likely to propagate through the vadose zone and contaminate groundwater.

Principal component analysis (PCA) was used to evaluate the correlations between [NO_3^--N] at a depth of 2.9 m (427 water samples) and the principal factors that may affect it. For all fertigation approaches [NO_3^--N]s were positively correlated with the timing of fertilizer application within the duration of the irrigation/fertigation event and time length of irrigation while negatively correlated with the presence of and thickness of hard pan in the subsurface and flood irrigation. These correlations emphasize the need for fertilizer application towards the end of an irrigation event, and the need for short consecutive irrigations to keep the fertilizer and water in the active root zone (<1 m). The presence depth and width of the hard pan, the time of fertigation and the length of the irrigations following the fertigation events had the highest contribution to the variability in the data.

TAKE-HOME MESSAGE

Our results have indicated little if any loss of yield when irrigation water N was accounted for in the fertigation budget. Nonetheless, there was not a clear reduction in potential leachable NO_3^- or emissions of nitrous oxide (a greenhouse gas with 300 times the radiative forcing potential as CO_2). The study demonstrated the most viable way to minimize the potential for NO_3^--N leaching to groundwater from commercial orchards is by transitioning to fertilizer application at the end of an irrigation event followed by short consecutive irrigations, irrespective of application strategy.

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ACKNOWLEDGEMENTS

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SUMMARIES OF OTHER PROJECTS

Fertilizer Sources and Nutrient Management

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Increased scrutiny of groundwater quality and nitrate pollution is causing California growers to focus more attention on nitrogen management. Best fertilizer management practices follow guidelines of the International Plant Nutrition Institute 4R Nutrient Stewardship Program, which states that sustainable farming should focus on applying the Right Source of fertilizer at the Right Rate, Right Time and Right Place. This presentation emphasizes the importance of choosing the Right Source of nitrogen fertilizer in the context of the other three R's.

Nitrogen is one of the most challenging nutrients to manage. Crops require nitrogen in large quantities. Nitrogen rates have a major impact on crop yield and quality. Applications of soluble nitrogen fertilizer can produce a pronounced visual response, so growers equate nitrogen fertilizer with crop health. The low cost of nitrogen fertilizers compared to the high potential net returns for the specialty crops grown in California has led to growers frequently over-applying nitrogen. Nitrogen bio-geo-chemical dynamics are complex and there are few simple methods for accurately measuring available nitrogen in the soil. Over-application of nitrogen and water can leach mobile nitrate-nitrogen below crop roots, eventually contaminating groundwater.

All soluble nitrogen fertilizers are derived from ammonia. Pressurized liquid ammonia (82-0-0) is the most concentrated and lowest cost per unit nitrogen fertilizer, but it is dangerous to handle and it must be injected below the soil surface to prevent gaseous losses. With the increased use of pressurized micro-irrigation in California, anhydrous ammonia applications have declined. Ammonia injected into water raises the pH and precipitates calcium and magnesium carbonates, which plugs drip emitters and sprinkler nozzles, making anhydrous ammonia inappropriate for pressurized fertigation.

Urea (46-0-0) is the next most concentrated form of nitrogen fertilizer, after ammonia. Urea is most commonly applied to soils as a dry prilled material. Urea is converted in one to two days, via urease enzymes, to ammonium carbonate. The conversion of urea to ammonium-nitrogen increases the pH the soil solution, which may cause potential losses by ammonia volatilization, especially when soils are dry, have a basic pH and the air is warm and moving over the soil surface. Urea is mobile in the soil solution, similar to nitrate, until it is converted to ammonium. Ammonium ions are mono-valent cations that can adsorb to negatively charged clay and organic matter surfaces, minimizing the potential for leaching loss. Injection of liquid fertilizers containing urea should be handled similar to nitrate sources to limit leaching losses.

There are several strategies for reducing potential losses from urea fertilizers. One method is to add nitrogen stabilizers, which inhibit the function of the urease enzyme, which prevents the rapid conversion of urea to ammoniacal-nitrogen. Nitrogen stabilizers are good at limiting ammonia volatilization from surface applied urea. Another method is to apply porous polyurethane coatings to urea prills to control the release of urea-nitrogen

into the soil solution. Coated urea products are considered controlled release fertilizers. Finally, by polymerizing urea molecules into long chain methylene ureas or urea formaldehydes, microbial action slowly releases nitrogen into the soil. All these strategies add to the cost of the fertilizer, but the added costs are balanced by the improved environmental benefits provided by reduced nitrogen losses.

Ammonia gas dissolved in water forms ammonium hydroxide solution, also known as Aqua (20-0-0). Aqua is less dangerous to handle than anhydrous ammonia and is commonly applied pre-flood in rice in the Sacramento Valley. Rice grown under flooded conditions requires reduced forms of nitrogen, so Aqua is widely used for rice production, but some rice growers are now banding urea solutions (20-0-0), which is considered an ammoniacal source.

Urea ammonium nitrate (32-0-0), the most widely used liquid nitrogen fertilizer, is not appropriate for rice, however, since one-quarter of the nitrogen is nitrate, which is leached below the root zone during the flood or denitrified when checks are drained. Nearly all other crops grown in California grow best with a mix of ammoniacal and nitrate sources.

Other ammoniacal nitrogen fertilizers are: ammonium sulfate (21-0-0-24), ammonium thiosulfate (12-0-0-26), ammonium polyphosphate solution (10-34-0), mono ammonium phosphate (11-52-0), ammonium phosphate sulfate (16-20-0-13S) and ammonium polysulfide (20-0-0-45S). All ammoniacal fertilizers generate acidity during the microbially mediated oxidation reaction to nitrate. Some crops can take up a small amount of ammoniacal-nitrogen by diffusion. Warm, moist soil conditions stimulate the microbially mediated conversion of ammonium to anionic nitrate-nitrogen, a reaction that is completed in less than a week. Nitrate is highly mobile in the soil solution, which allows this form of nitrogen to move by mass flow to the rhizosphere where uptake is passive. Thus, even when a fertilizer contains mostly ammoniacal-nitrogen, the majority of nitrogen uptake is in the form of nitrate. The same soil mobility that makes nitrate the dominant form for plant nutrition also causes nitrate to be vulnerable to leaching losses when excess water is applied.

Nitrogen fertilizers high in nitrate are: calcium ammonium nitrate solution (17-0-0-8Ca), calcium nitrate liquid (9-0-0-11Ca) or dry (15.5-0-0-19Ca) and dry potassium nitrate (13-0-45) or liquid (3-0-11). These fertilizers are ideal for those crops that grow best with mainly nitrate nitrogen. Nitrate based fertilizers also tend to raise or have minimal effect on soil pH so they work well in drip irrigated sandy soils that have a low buffering capacity. Fertigation with nitrate fertilizers should take place near the end of an irrigation set to reduce to potential for leaching nitrogen past the root zone.

There are many choices of nitrogen fertilizers available. Choosing the Right Source depends upon the crop, soil type and chemistry and cropping system as well as the cost and availability of the product.

Water and Nitrogen Management: Recognizing and Adapting to Logistical Challenges at the Farm Field Level

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Jacksonville, OR

Commercial production of vegetables and small fruits in the Central Coast region presents unique management and environmental challenges. Water and nitrogen (N) management practices must optimize growth and market quality of product, while increasingly growers face regulatory challenges to demonstrate that practices also minimize impact to surface and groundwater quality. Today there is an emphasis on identification and implementation of improved or 'best practices' for 'source control' to reduce field N losses. In some cases, growers must develop and implement irrigation and nutrient management plans. Concurrently new research-based information, in field monitoring tools, and technology-based decision making tools are available.

At the same time, new management practices or tools are inevitably adopted incrementally by growers in light of perceived or real economic limitations and risk. On the ground, growers may have unique constraints of available time, cost, crop types, existing infrastructure, trained personnel, as well as different site specific conditions that can limit what is immediately practical, relatively easy to implement, and effective.

During the past 15 years I have worked with public agencies (Irrigation and Nutrient Lab Programs) and independently with a range of Central Coast warm and cool season crop growers with the objective of optimizing irrigation and nitrogen (N) management. This began with a successful collaborative proposal to CDFA-FREP in partnership with a grower organization to demonstrate the potential of the soil nitrate quick test to improve N fertilization decision-making and minimize N losses in selected cool and warm season crops. We now conduct field-level assessment and monitoring of irrigation systems and scheduling, soil, water, and/or crop nutrient status as a basis for practice evaluation that can identify specific opportunities to improve water and fertilizer use efficiency.

However, in our experience these evaluations and recommendations have had limited value without follow up and when possible, an ongoing 'boots on the ground' approach. At its best this involves working directly with managers and/or other personnel and the constraints and variables present at the field level. I will briefly summarize a few 'case study' examples to illustrate how practice monitoring, evaluation, training, and follow up has assisted to improve a grower's water and N management efficiency.

Challenges in Developing an Organic Fertilization Program for Processing Tomatoes

Gene Miyao
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A review of key research reports provided the basis for summarizing practical nutrient management strategies. For canning tomato production in California's Central Valley, animal manures are the mainstay for supplying the bulk of the NPK needs with some minor supplemental applications of other materials on occasion. The concern with continued use of high rates of animal manure is the excessive phosphorus and potential salt buildup from years of repeated applications while trying to meet the crop nitrogen requirement.

My own applied field research effort centers on supplemental applications of composted poultry manure and off-season leguminous cover crops in a conventional tomato production system that will add to the discussion.

Salinity in Strawberries and Caneberries

Mark Bolda
Farm Advisor for Strawberries and Caneberries
Cooperative Extension, Santa Cruz County

Salinity in strawberries and caneberries has become more of an issue during the recent years of drought because of reduced winter rainfall and lower quality of well water in the summer. Berry growers on the Central Coast of California have encountered a number of salinity issues, including those of excess nitrate, sodium and chloride. The presentation will address these issues both through research results and evidences collected from farm calls.

An Overview of the Agricultural Regulatory Requirements in the Central Coast Region

Christopher Rose
Regional Water Quality Control Board
Central Coast Region

The Conditional Waiver of Waste Discharge Requirements for Discharges from Irrigated Lands (Agricultural Order No. R3-2012-0011) was adopted by the Central Coast Water Board on March 15, 2012. As a result of a petition against the Agricultural Order, the State Water Resources Control Board adopted order WQ 2013-0101 on September 24, 2013, which largely upheld the Agricultural Order, with modifications.

The Agricultural Order requires growers engaged in commercial irrigated agriculture to electronically enroll their ranches for permit coverage. Once enrolled, the ranch is assigned one of three tiers, denoting the probable threat to water quality. The higher the tier, the greater the threat to water quality; tier 1 ranches are the lowest threat to water quality and tier 3 ranches are the greatest threat to water quality. Agricultural Order requirements are proportional to the threat to water quality. Therefore, tier 3 ranches are assigned more regulatory requirements than tier 1 and tier 2 ranches. There are currently over 1,750 operations with 4,300 ranches enrolled in the Agricultural Order. Each ranch is required to submit data and information to the Central Coast Water Board.

The presentation outlines Agricultural Order requirements and summarizes some of the information reported to the Central Coast Water Board.

Interpreting Soils - Old and New Techniques

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An agronomist looking at a soil sample result sees a single piece of data for each analytical result. Has it ever been as simple as deciding if it is adequate/deficient? 40 years ago this was not really the case in most situations because of variable situations. Tissue analysis was always the best way to evaluate the nutrient or salt situations affects on the plant as it pertained to your crop, variety, root stock, soil type, weather conditions, etc, etc.

In 2015 new farming techniques and regulatory situations have added more variables in the picture. In the 70's a grape vine gathered its nutrients and salts from a root zone that was 12' by 14' by 5' deep. Now it forages an area maybe 30" in diameter and 36" deep under the single dripper. This tiny area is what it relies on for its sustenance during the hot summer. Techniques and critical levels for determining if a soil level is adequate, and how long it will take to be depleted, has totally changed.

Tissue tests are still the best evaluation system for a plant during the growing season. For soil tests the value is to determine what nutrients and salts are in the root zone and indicate if changes are needed at the start of the season. The Agronomist needs to have a 3-dimensional concept of the root zone to understand its variables and nutrient content.

SUMMARIES OF ONGOING FREP PROJECTS

Assessment of Plant Fertility and Fertilizer Requirements for Agricultural Crops in California

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INTRODUCTION

Over the years, a large number of research projects have investigated different aspects of fertilizer management for crops grown in California. The California Department of Food and Agriculture's Fertilizer Research and Education Program (FREP) alone has funded more than 200 projects since the early 1990s. For many crops, however, a comprehensive overview and synthesis of the current research on fertilizer use and management is incomplete and or missing.

In a collaborative effort between FREP and researchers at the University of California Davis, this obstacle to information access is being addressed by making the wealth of information from crop nutrient management studies accessible online in a user-friendly searchable database and with crop-specific fertilization guidelines. The database and guidelines shall support growers and crop advisers evaluating nutrient management programs and improving nutrient use efficiency in crop production.

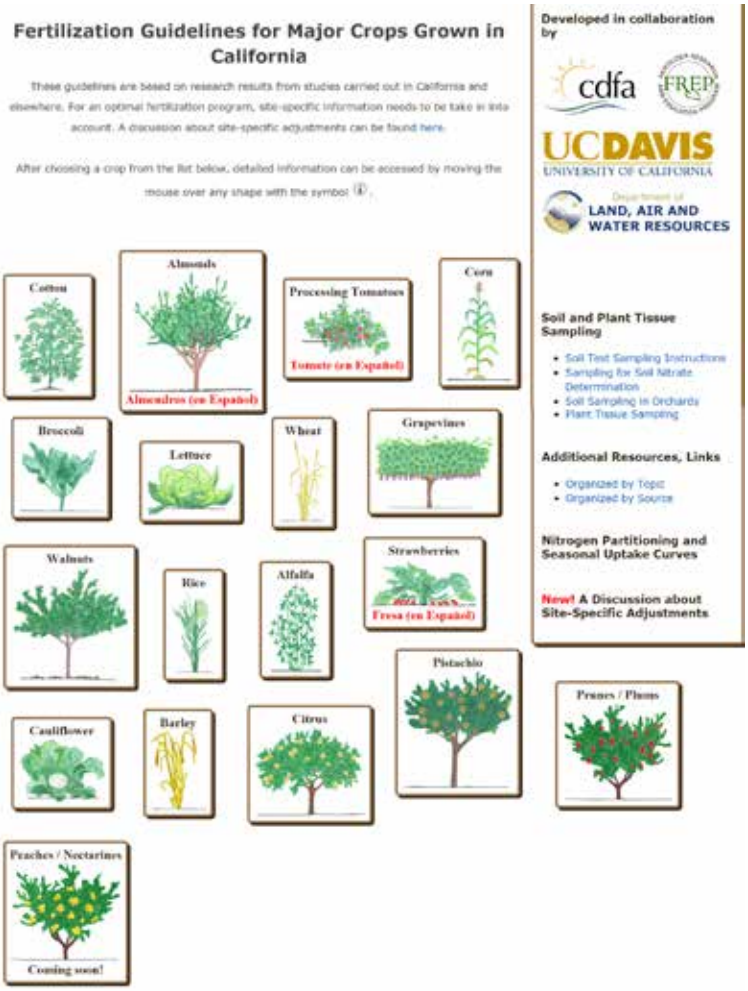

Figure 1. Screen shot of the start page for fertilization guidelines. Crop-specific guidelines can be accessed by clicking on one of the crops (online at http://apps.cdfa.ca.gov/frep/docs/guidelines.html).

OBJECTIVES

The two main objectives of the project are:

1. Make technical research data and findings from FREP-funded projects available to growers and crop advisors through a user-friendly, web-based database.
2. Synthesize information from peer-reviewed journal articles and research reports for major crops grown in California and make the summaries available online.

ACCOMPLISHMENTS AND ACTIVITIES

FREP Database

Objective one was addressed by creating a searchable online database, which can be accessed at www.cdfa.ca.gov/go/FREPresearch. Key information from approximately 150 final reports is currently available through a user-friendly interface. Users can search for specific topics by either entering a keyword or choosing a crop type, a county, or a date range from a drop-down menu. Links to the final report, FREP proceedings, and external sites closely related to the project are also provided. Additional projects are added to the database when the final reports are submitted to FREP.

Fertilization Guidelines

The guidelines present accurate and current crop nutrient information in a user-friendly, visually interactive interface. Fertilization guidelines for 17 major crops grown in California are currently available online at www.cdfa.ca.gov/go/FREPguide (Figure 1). Some of them are also available in Spanish. Guidelines for additional crops will be uploaded to the web page on a flow basis, and existing guidelines will be updated as new research emerges. The guidelines consist of a summary of research data and UCCE farm advisor experience and present a general overview of nitrogen (N), phosphorus (P), and potassium (K) management. Information on selected micronutrients is included for crops where deficiencies are common. The guidelines provide a basis for in-depth discussions with local farm advisors or fertilization experts.

Key information for major crops is summarized in brochure form and distributed at grower meetings.

DISCUSSION

California growers are facing increasing pressure to improve N use efficiency in crop production. Stricter regulatory and reporting requirements are being implemented. The database and guidelines provide research based information which assists growers and crop advisers to improve nutrient use efficiency and meet regulatory requirements.

Plan and evaluate nutrient management programs

The database and the guidelines contain a wealth of information from research trials predominantly carried out in California. Information about application rates, time of application, fertilizer placement and types of fertilizers is included. In addition, deficiency symptoms are described. These resources help plan and evaluate fertilization programs and suggest potential improvements.

Use of soil and plant tissue samples as decision support tools

Crop specific sampling instructions for soil and tissue analyses are integrated in the guidelines for each crop, while general instructions for representative sampling are provided in the form of printable files. Soil and tissue analyses are important tools for site-specific nutrient management.

Pre-plant or pre-fertilization soil nitrate tests reveal how much of the crop's N requirement can be met by residual soil nitrate. The nitrate present in the rooting zone is a pool of crop available N and needs to be considered in the N budget. Care must be taken when sampling to get a representative and meaningful result. Instructions for soil P and K tests are also included.

Plant tissue analyses provide a means to evaluate the nutrient management program and make corrections either during the current season or for next season.

Nitrogen uptake and removal rates

Nitrogen budgets require input on the crop's N requirement and the amount of N removed with harvested crops. We added a number of pages to the website with N removal rates for major crops grown in California. The sites can be directly accessed here:

http://apps.cdfa.ca.gov/frep/docs/N_Uptake.html

The values reported were determined in field trials

Figure 2. Screen shot of the page providing information about non-fertilizer N sources (online at http://apps.cdfa.ca.gov/frep/docs/Adjustments.html).

Overview:

Nitrogen from non-fertilizer sources
- **Residual soil nitrate**
- **Nitrate in irrigation water**
- **Legume cover crop N credits**
- **Alfalfa N credits**
- **Crop residues N credits**
- **Nitrogen mineralized from soil organic matter**
- **Manure N credits**
- **Atmospheric N deposition**

Fertilizer use efficiency
- **Leaching losses**
- **Ammonia volatilization**
- **Denitrification**

References

Field-Specific Nitrogen Fertilization Adjustments

By Daniel Geisseler, Patricia Lazicki and William R. Horwath*

The fertilization guidelines on this website are based on results from studies carried out predominantly in California. However, for an optimal fertilization program, growers need to make field-specific adjustments, which depend on expected yield, soil properties, local weather conditions and crop management (see Fig. 1). These factors affect crop nitrogen (N) uptake, non-fertilizer N inputs and potential N losses. The major factors affecting soil N availability are discussed in the following sections.

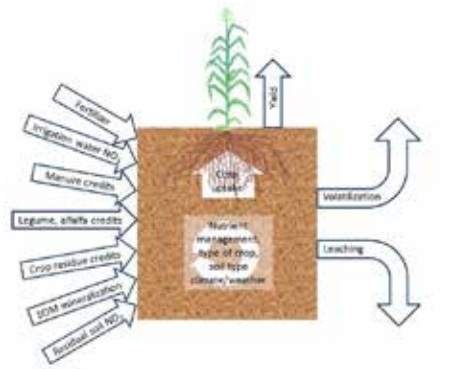

Fig. 1: Overview of the most important site-specific factors affecting crop N availability.

carried out predominantly in California. While removal and N uptake rates are useful tools to estimate N requirements by crops, and to plant N application rates, the amount of N taken up and removed with harvested plant parts is site-specific and depends on a number of factors including variety, N application rate and N availability from non-fertilizer sources.

Nitrogen supplied from non-fertilizer sources

A discussion on N supplied from non-fertilizer sources and the factors affecting the amount of N available has been added to the guidelines and can be found in Figure 2.

http://apps.cdfa.ca.gov/frep/docs/Adjustments.html

Sources of non-fertilizer N include residual soil nitrate-N, N from the irrigation water and N mineralized during the growing season from organic sources, such as soil organic matter, crop residues and organic amendments. The contribution of these sources is field-specific and may vary from one year to the next. They need to be taken into account to achieve high N use efficiency in crop production.

Links to additional information

An extensive list of links to sites with nutrient management related information, organized by topic, is available for users who cannot find the information they are looking for on the website:

http://apps.cdfa.ca.gov/frep/docs/resources_Topic.html

SUMMARY

The present project aims to make research data about fertilizer use in crop production in California readily available to growers and crop advisers. The products of the project include a database of FREP-funded studies and fertilization guidelines for major crops grown in California. Both the database and the guidelines are available online. The web pages are interactive and user-friendly and new information can be added easily.

Links to all the sites mentioned in this report can be found on the start page for the guidelines:

www.cdfa.ca.gov/go/FREPguide

New crops and additional contents are constantly added. This site contains valuable information for growers, crop advisers and anybody interested in nutrient management of crops in California; a site worth being bookmarked.

A Data Driven Nitrate Leaching Hazard Index and BMP Assessment Tool

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INTRODUCTION

California's agricultural regions have an incredible diversity of soils that encompass a range of properties possibly found in no other agricultural area of similar size in the United States. This soil diversity complicates our understanding of the fate of nitrogen (among other nutrients) in the environment. Spatially explicit information is needed to help growers make informed decisions about nutrient management practices. The Nitrate Groundwater Pollution Hazard Index (HI) http://ciwr.ucanr.edu/Tools/Nitrogen_Hazard_Index/ is a valuable tool used by growers and regulatory agencies to understand the potential for nitrate contamination of groundwater (Wu et al., 2005). The tool rates 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, which is subject to bias, but also in that it is difficult to update, and does not directly provide growers with management 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. Specifically, this interactive geospatial decision support tool will evaluate the likelihood of nitrate loss beyond the root zone in consideration of soil properties, crop characteristics and irrigation schemes. The tool will be developed by linking digital soil survey data to HYDRUS 1-D, a process-based hydrological model capable of predicting nitrate leaching over infinite scenarios of soil variability. In addition to soils, the modeling will include crop-, nitrogen- and irrigation-management scenarios and couple nitrate leaching hazard ratings with relevant BMPs to promote improved nitrogen management.

OBJECTIVES

The specific objectives of this project are to:

1. Create a state-wide, digital database of soil survey information for modeling purposes.
2. Model nitrate leaching using HYDRUS 1-D for agricultural soils in California for different crop classes, best management practices and irrigation types.
3. Develop an online interactive app in Google Maps that enables users to navigate and obtain nitrate leaching hazard ratings for any agricultural soil for major crops and irrigation scenarios.
4. Extend the science and educate the public using model outcomes to demonstrate the effectiveness of place-based best management practices that limit nitrate loss via leaching.

DESCRIPTION

Our progress to date has been limited to objectives 1 and 2.

1 Database development

A soil survey database was constructed for the State from the USDA-NRCS Soil Survey Geographic Database (SSURGO). Initially our goal was to run the HYDRUS model directly from SSURGO data, however, we found that older soil surveys did not have adequate resolution of soil property information to accurately run the model. To remedy this shortcoming, we decided to run the model with point data from the National Cooperative Soil Survey Soil Characterization Database http://ncsslabdatamart.

sc.egov.usda.gov/, which contains measured soil properties for most soil types. Any soil types that are missing from this point dataset will be run from SSURGO data. Ultimately the results from this modeling will be linked with SSURGO in a GIS to generate maps of nitrate leaching potential.

Some soil surveys in the region are outdated with respect to alterations by deep tillage, a common practice in the establishment of tree crops and vines. This is because most of CA's agricultural soils were surveyed decades ago, and tree and vine crop expansion is more recent. Thus, an updated soil disturbance dataset was created using geospatial analysis. A map of orchard and vineyard crops was created using DWR land use maps (issued between 2001 and 2011) and aerial imagery from the National Agricultural Imagery Program (NAIP) and Google Earth™ (2012 to 2014). This file was overlain in a GIS with a map of soils with water restrictive horizons. We assumed that any tree or vine crop planted on soils with restrictive soil layers have been modified by deep tillage. Modifications to the soil survey data were made in instances where the spatial intersect of perennial crops and soils with water restrictive horizons occurred to generate an updated map of modified soils. To reflect the mixing of soil horizons, the depth weighted average of sand, silt, clay, and saturated hydraulic conductivity was obtained for the entire soil profile to reflect the mixed condition.

2 Modeling Nitrate Travel Times

To date, we modeled nitrate travel times in roughly 100 different soil types with HYDRUS 1-D. Nitrate travel time was modeled across a 1-m vertical distance assuming a constant 1-cm head of water maintained at the soil surface. We created a scenario where nitrate was applied at the surface with no nitrate existing within the soil initially. The model failed for soils that contained water restrictive horizons, such as hardpans and claypans. We plan to work with the model developer to address this problem.

RESULTS AND DISCUSSION

Given that this project is in its initial phase, all findings described below should be considered preliminary and subject to change. As demonstrated in Figure 1, modeled nitrate travel times in HYDRUS generally had good agreement with the original HI ratings. Soils rated as high risk by HI (e.g. HI values 4 or 5) display relatively short mean travel times of less than 95 hours. Soils ranked as lower risk (HI values 1-3) have longer travel times but also greater variability. In part, this variability is a result of our inability (at this time) to account for denitrification, which is a process that converts nitrate to nitrogen gas in poorly drained conditions.

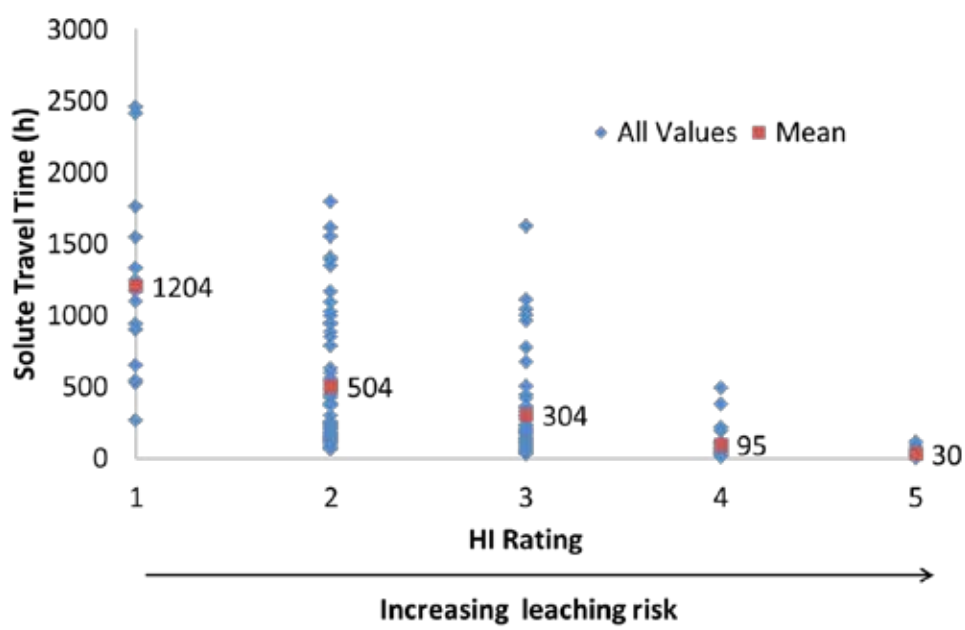

Figure 1. Correlation between nitrate travel times modeled in HYDRUS with the Nitrate Leaching Hazard Index (HI). Higher HI values indicate greater risk of nitrate leaching.

Figure 2 depicts the spatial distribution of modeled nitrate travel times for select soil types. Soils with long nitrate travel times are present along the west side of the Central Valley where soils are clay-rich. Soils with short nitrate travel times are present in the southern part of the Central Valley and along the east side where soils are coarse textured. Soils with claypans and hardpans, which are expected to have very long nitrate travel times have not been modeled yet, and are not included in this map.

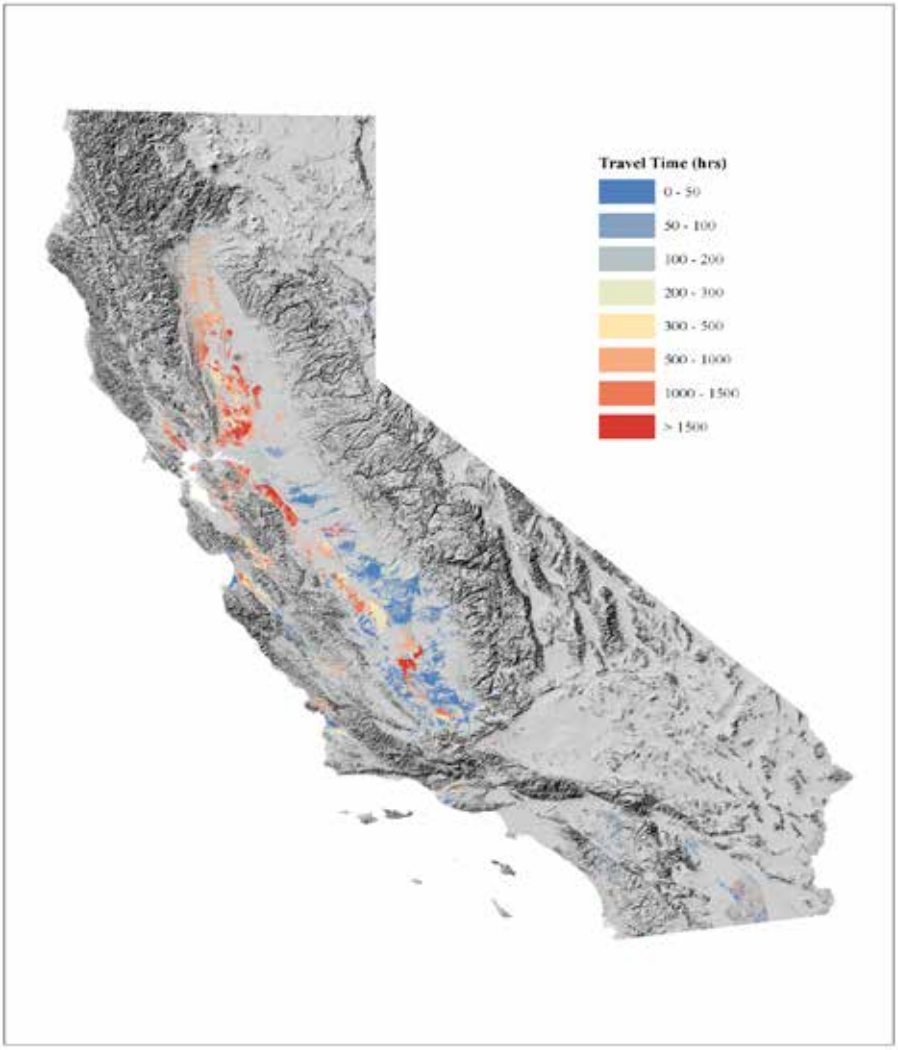

Figure 2. Spatial extent of modeled nitrate travel times (hours) for select soil series in California.

ACCOMPLISHMENTS

These preliminary findings suggest that the HYDRUS model appears to be a suitable way to document the fate of nitrate in soil, assuming we can accurately account for the process of denitrification. This information can be used in a variety of ways. Once our study is completed, a map of intrinsic nitrate leaching potential will be available. Modeling nitrate leaching under different scenarios of climate, irrigation and crop class will provide place-based estimates of the fate of nitrate across the State.

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ACKNOWLEDGEMENTS

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Plant Nutrient Education Materials for Elementary through High School Classrooms from California Foundation for Agriculture in the Classroom

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INTRODUCTION

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.

With FREP funding, CFAITC has recently completed several educational resources focusing on plant nutrients for use in elementary, middle, and high school classrooms. A comprehensive outreach plan is needed to take full advantage of FREP's investment in these resources by promoting them and helping teachers incorporate the lessons into their curriculum.

OBJECTIVES

1. Engage marketing partners and public relations agency to encourage teachers to utilize CFAITC lessons in their classrooms.
2. Advertise educational publications.
3. Conduct evaluation of project.
4. Provide 60 educators in the Bay Area and Southern California with grade appropriate lab kits for use with plant nutrient lessons.
5. 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.
6. Identify science centers to supply with lab kits and plant nutrient units.
7. Establish a web page containing CFAITC developed and approved resources relating to plant nutrients.
8. Participate in a minimum of three educator conferences to network with science, technology, engineering, and math educators and to promote plant nutrient units.
9. Print an appropriate supply (over a three year period) of plant nutrient units.

DESCRIPTION

Teachers and students alike will develop a greater knowledge base of plant nutrients, best management practices, and the science that goes into producing our abundant food supply. This project will provide a significant resource for the thousands of California educators who are either uninformed or misinformed about the science and technology involved in modern agriculture.

The proposed project will serve as a powerful means of connecting California students to the importance of plant health, as well as the agriculture industry in general and will greatly benefit growers by providing a unified message on behalf of all California farmers and ranchers. Growers throughout the state will reap the benefits of increased student understanding of the essential role of plant nutrients in agriculture

production and enhanced student appreciation of the agriculture industry's efforts to protect our air, water, and soil quality. Over time, many of these informed decision makers will provide oversight to the industry, determine market trends, and continue to share the positive story of California agriculture. The benefits derived from this project will go beyond the grant period.

RESULTS AND DISCUSSION

In 2015, California Foundation for Agriculture in the Classroom was in the first year of a three year work plan. By the end of 2015 a marketing firm will have been selected to plan strategies and promotion will have begun. Sixty educators in the urban school districts in San Francisco and Los Angeles will have been selected to receive instructional webinars and lab kits to accompany the curriculum. Plant nutrient lessons will have been distributed at one regional science educator conference.

ACKNOWLEDGEMENTS

California Farm Bureau Federation

Fertilizer Research and Education Program

Western Plant Health Association

Powerhouse Science Center

CALAMCO

California Certified Crop Advisor Educational Project

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INTRODUCTION

The California Certified Crop Advisor (CA CCA) program currently certifies over 1,000 professional advisors, and is the heart of competency certification for nutrient management professionals in California. The CA CCA educational project 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. This program has grown significantly over the past 5 years, as the need for informed nutrient and crop management in California has intensified.

These grass roots professionals 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.

The Fertilizer Research and Education Program (FREP) funding for this educational program has provided valuable outreach components to increase the number of CA CCAs while increasing awareness of proper fertilizer practices. The CA CCA program has developed awareness seminars for fertilizer 4R practices and conducted nutrient seminars to improve nutrient use and proper nitrate mitigation practices.

In response to regulatory requirements during the reporting period of this grant placed on growers by Regional Water Quality Control Agencies, CA CCAs have embraced this responsibility consulting growers to manage nitrate contamination in ground water. The University of California and CDFA/FREP established nitrate mitigation training to assist CCAs in their understanding of the challenge ahead.

The CA CCA program is a voluntary, non-profit certification body that represents the Certified Crop Advisors who provide nutrient recommendations to private applicators, agricultural producers such as the dairy industry, and governmental agencies tasked with the stewardship of the state's natural resources. Its purpose is to credential new applicants under the leadership of the American Society of Agronomy and provide continuing education to maintain current fertilizer knowledge and practices.

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 to improve the educational opportunities of California agriculture related to fertilizers, farm management and agricultural sustainability and enabled the Cooperator to provide the administration for the CCA program.

OBJECTIVES

The objectives of this project are to:

1. Provide responsible program administration, leadership and CCA outreach awareness for CA fertilizer industry
2. Strengthen CA CCA program certifications through communications, marketing, recruitment techniques identifying the value for having a CCA certification
3. Implement a workable plan towards sustainability as an organization
4. Efficiently administer the CA CCA program on a day to day basis providing services to ICCA,

CDFA/FREP and all CA CCA certificate holders or candidates

5. Project management evaluation and deliverables will be viewed at each CA CCA BOD and shared with Project Manager and CDFA representative

DESCRIPTION AND ACCOMPLISHMENTS

The FREP-funding assisted the program for the California CCA to fulfill its outreach and educational objectives. These include:

- The number of CCAs in California for 2014 was 975 with CA continuing to demonstrate the largest US growth. The program as of August 2015 has 1,065 members with over 100 candidates submitting credential materials.
- CA CCA program approved 975 Continuing Education Classes for approximately 3005 actual CEU hours for CCAs and supported the introduction of online CEU registration.
- The ICCA/CA CCA Exams were held the first Friday in February and August, 2014. Test sites were located in Sacramento, Ventura, Salinas, Yuma and Tulare with two proctors located at each exam site. The CA CCA program tested 400 new applicants with a pass rate of approximately 55%.
- Pre exam training sessions were offered for both exam periods to individuals prior to each exam testing date. Sessions were held in Sacramento.
- The program maintained a CA CCA Fan Page on Facebook. Updates to the page regularly made with information that is relevant to CCAs. This page allows communication with current and potential CCAs; also it allows communication with other state CCA programs as many representatives of those programs are fans. The page is at http://www.facebook.com/#!/pages/California-Certified-Crop-Advisers/272373776767?ref=ts.
- CA CCA Annual Meeting was held in February in Fresno in conjunction with California Plant and Soil Conference.
- Fertilizer articles were published in Western Farm Press and the CAPCA Adviser magazine providing CA growers current and valuable nutrient information.
- The CA CCA candidate program was promoted to agricultural students that qualify for the program, but do not have the necessary experience. Career day outreach and CAPCA's Pathway to PCA program all contributed to career opportunities in the fertilizer industry.
- Representatives of the CA CCA program participated in the Western Plant Health Association (WPHA) Student Dinners at UC Davis, CSU Chico, CSU Fresno, UC Riverside, Cal Poly Pomona and Cal Poly San Luis Obispo.
- The CA CCA program attended and/or exhibited at the following events: California Association of Pest Control Advisers Annual Conference, CA Weed Conference, Central Valley Grape Expo, Pacific Nut Expo, Fresno Raisin Grape Expo, CA Agricultural Teachers Conference, Southwest Fertilizer Conference, Yuma Southwest Ag Summit and CA Organic Fertilizer seminars in Tulare, Chico, Fallbrook, San Mateo, and Cloverdale, Western Alfalfa and Forage, and the Eco Farm Conference.
- Nutrient management presentations were made at 30 CAPCA ED seminars including an additional three fertilizer

Figure 1. Dr. Rob Mikkelsen and Dr. Tim Hartz at the Nitrogen Management Training Program

only seminars with a total of 350 CCAs attending, CAPCA Chapter CE seminars and the WPHA Nutrient Management Series by CA CCAs encouraging attendees to take the exams and be more aware of fertilizer stewardship responsibilities.

- CA CCA representatives held discussions with representatives of California Fertilizer and Ag retail industry on benefits of program and value of the CCA. The CA CCA program is experiencing tremendous support from agricultural retailers as noted by the continuous increase in number of candidates testing and becoming a CCA.
- The program outreach and regulatory requirements from regional CA Water Quality Control Boards are having a positive impact on CCA program growth.
- News releases were prepared and distributed on the CA CCA program, nutrient seminars and upcoming exam opportunities.
- The program has maintained and updated CA CCA website www.cacca.org.
- CA CCA supported CDFA/FREP/UC leadership to develop stakeholder involvement in Nitrogen Management Training program. The CCA program leadership actively supported the CDFA/FREP outreach activity to assist growers and agricultural organizations to address nitrate residual concerns in drinking water for two seminars.
- CA CCA Board developed final steps to cultivate other sources of financing, including increasing exam fees, introducing pre-exam training fees and setting options for seminar sponsorship opportunities. Notwithstanding, growth of CCA numbers in the program are the most optimum opportunity to work towards less dependence on CDFA/FREP financial support. 2017 has been identified as the goal for CA CCA program to be self-sustaining.
- CAPCA as the cooperator coordinated activities with ICCA program, including participating in the ICCA Board Meetings. Current CA CCA member Mike Huffman is a board member of ICCA.
- Electronic newsletters were distributed to CA CCA members. Subjects include program status, upcoming meeting and other relevant information.
- CAPCA as cooperator on this grant provided daily and efficient administration for the CEU approval and member/Board communications. The Cooperator's participation in the support of the CA CCA program is dependent upon grant funding.
- CAPCA coordinated with ICCA on all announcements and coordinates the exams.
- CAPCA completed the interim and annual report for the project leader for the CDFA/FREP grant.

SUMMARY

The CDFA FREP-supported CCA program has enabled this program to become a highly successful resource for fertilizer education and awareness, with significant growth over the past 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. This program is heavily invested in the educational component of the FREP objectives, and developing long-term basic expertise and competency embodied in the more than 1,065 Certified Crop Advisors in California.

The program grant has provided training on new issues faced by the state's crop advisors, including organic production, water nitrate contamination, and manure management. The CA CCA program has conducted vigorous outreach efforts to assure the growth and sustainability of the program. CA CCA has expanded its certification program to include nutrient management training for those developing nutrient management plans and nutrient seminars to raise the educational knowledge and stewardship for advisors. The continued success of the CA CCA program serves the agricultural industry and the general public by assuring that agricultural practices are environmentally sound and economically feasible.

For more information on the program please contact:

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Characterizing N Fertilizer Requirements of Crops Following Alfalfa

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INTRODUCTION

Likely over 400 million pounds of nitrogen is produced via N_2 fixation in California's alfalfa crop each year, and a portion of this may be available to subsequent crops in rotation. Reducing fertilizer use to account for alfalfa's N contributions could prevent over-fertilization and protect groundwater, and could also help improve farm profitability (Bundy et al., 1997).

Figure 1. Strips of alfalfa and wheat-sudangrass rotations were established to compare the effects of legume vs. non-legume on a subsequent wheat crop planted after both systems (Photo Tulelake, CA).

The quantity of N from alfalfa that remains for use by a subsequent crop depends on alfalfa stand duration and vigor; stand density at plow-down; soil type; and environmental conditions. This contribution can be substantial. Two to five-year-old stands of alfalfa have been found to supply nearly all the N needs of subsequent corn crops, especially in Midwestern rain-fed cropping systems (Yost et al., 2014). In seeding year alfalfa, estimates of alfalfa's N contribution have ranged from 30 to 75 lb N ac^{-1} (Kelner et al., 1997), and up to 175 lb N ac^{-1} (Harris and Hesterman, 1980; Hesterman et al., 1987) for older stands. Irrigated systems may be different. In an irrigated semiarid system in Spain, alfalfa was estimated to contribute 140 lb N ac^{-1} to a subsequent corn crop (Ballesta and Lloveras, 2010). Another study under irrigation found that corn following alfalfa required 0 to 103 lb N ac^{-1} under sprinkler irrigation and 105 to 175 lb N ac^{-1} under flood irrigation (Cela et al., 2011).

California's wide range of environments, soils, and

management strategies could affect alfalfa's N contributions to subsequent crops. We used the difference method, comparing N response curves for wheat grown after alfalfa and non-legumes at three locations over two year cycles to develop recommendations for N credits for California.

OBJECTIVES

Our overall objective is to understand the impacts of rotation with alfalfa on the N fertilization needs of a non-legume crop. Specific objectives are to:

1. Quantify the N available to a subsequent wheat crop provided by rotation with alfalfa.
2. Develop an N-credit recommendation for crops following alfalfa.
3. Differentiate other rotational benefits or disadvantages that may be attributed to crop rotation following alfalfa, as distinct from N benefits.

DESCRIPTION

The project consists of two rotation treatments: alfalfa-wheat, and grain-wheat, with wheat used as a 'bioassay' to estimate the N effects from the legume. At each location, we grew irrigated wheat in small plots within larger replicated strips that previously had either (1) alfalfa for 2.5+ years or (2) sudangrass-wheat rotation for 1.5+ years. Neither the previous alfalfa nor the sudangrass-wheat strips received N fertilizer prior to the wheat, but were otherwise grown using standard farming practices. The experiment was replicated at three locations in California: Davis (Solano County), Kearney/Parlier (Fresno County), and Tulelake (Siskiyou County). Soils in Davis and Tulelake are clay loams, and in Parlier, a sandy loam. To determine the effect of the preceding crop (alfalfa vs. sudangrass/wheat) on wheat N requirement, we applied N fertilizer rates to the wheat ranging from 0 to 250 lb N ac-1. When the wheat reached the soft dough stage, plots were harvested to determine aboveground biomass. Subsamples were taken for determination of plant moisture and N content. At maturity, wheat grain was harvested, and grain yields, grain moisture content, and grain protein content were determined. The experiment was repeated in 2014 and again in 2015. Here, the 2014 data are discussed.

CURRENT FINDINGS

Alfalfa was found to have a significant effect on the N nutrition of the subsequent wheat crop, compared with a grain-wheat rotation. Both wheat forage yields and wheat grain yields as well as grain protein were improved by rotation with alfalfa. Soil nitrate-N levels (0-12 inch depth) in the fall before the 2014 production year were 5-7 ppm NO_3-N in plots that had just been in alfalfa and 0.5-4 ppm in plots following the sudangrass-wheat rotation. This soil nitrate difference between the two rotations was consistent across the three locations.

In plots receiving no N fertilizer, wheat whole-plant above-ground biomass was higher following alfalfa than following sudangrass-wheat at all locations (Figure 2), indicating that the alfalfa contributed more plant-available N than the sudangrass-wheat rotation did. At Davis, wheat biomass following alfalfa was the

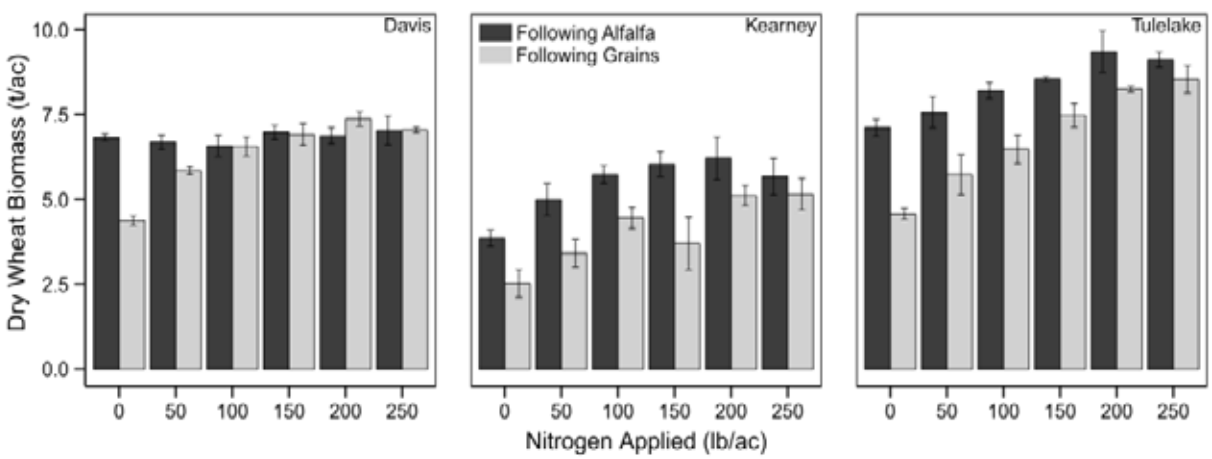

Figure 2. Response of wheat to N rate as affected by previous crop in rotation. Wheat yield expressed as above-ground plant biomass (dry weight) at soft dough stage, 2014. Error bars represent standard errors of the mean.

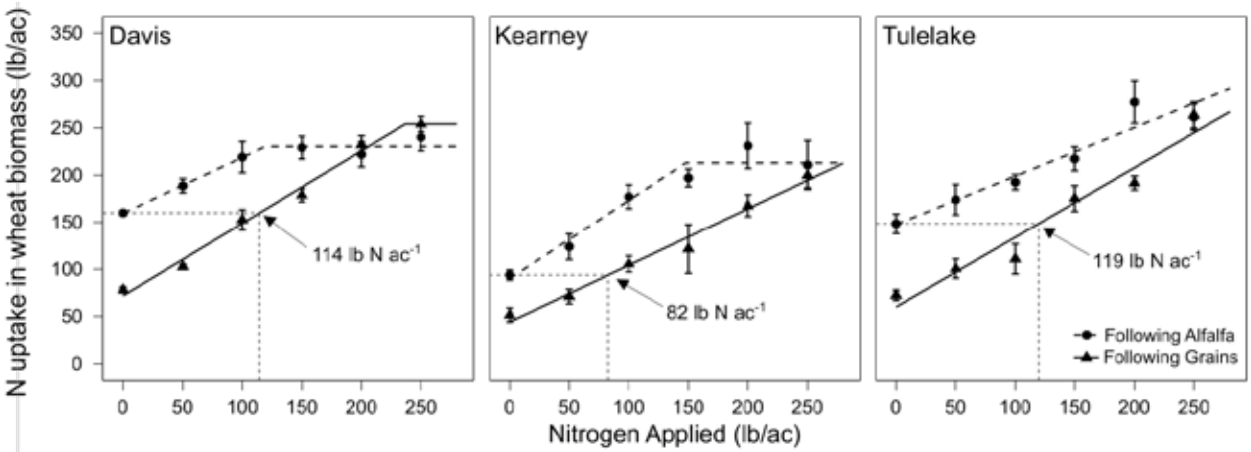

Figure 3. Total nitrogen uptake of wheat grown with 6 N rates after alfalfa and following sudangrass-wheat (grains) at the three locations. Error bars represent standard errors of the mean. Regression curves (dashed and solid lines) represent linear-plateau models. Dotted lines and arrows indicate the amount of fertilizer N required for wheat following sudangrass-wheat to take up the same amount of N as unfertilized wheat following alfalfa.

same regardless of N fertilization levels, indicating that alfalfa likely satisfied a nearly all of the wheat's N needs there.

Nitrogen uptake data from the wheat biomass suggest that, in plots at Davis receiving no N fertilizer, wheat following alfalfa assimilated 80 lb ac^{-1} more N than wheat following sudangrass-wheat (Figure 3). In order to sequester this additional 80 lb N ac^{-1}, the wheat following sudangrass-wheat needed about 114 lb N ac^{-1} fertilizer (Figure 3). Similarly, for 0 N plots following alfalfa, 119 lb N ac^{-1} were required for wheat following sudangrass-wheat at Tulelake to achieve similar levels of N uptake, and at Kearney, 82 lb N ac^{-1} were required. From these N uptake data, alfalfa's N contribution might range from 80 lb N ac^{-1} at Kearney, up to 120 lb N ac^{-1} at Davis and Tulelake.

Wheat grain yield and protein content

Wheat grain yield responded differently to N fertilization in the alfalfa and the sudangrass-wheat rotation, similar to the total biomass response (Figure 2). At Tulelake, grain yields following alfalfa plateaued beyond the 100 lb N ac^{-1} rate, but grain protein continued to increase beyond that N rate (Table 1). Others (Heldin, 1957) have found similar responses. Since considerable economic benefits are often accrued due to wheat protein content, the value of alfalfa rotations to wheat profitability should be considered. This is likely due to the greater availability of organic N mineralized late in the crop growth periods, benefitting grain development.

SUMMARY

In these studies, alfalfa was found to have a significant effect on the N nutrition of a subsequent non-legume crop, in some cases reducing the need for N fertilizers to near zero. In 2014, alfalfa's N contribution ranged from about 80 lb N ac^{-1} at Parlier to about 120 lb N ac^{-1} at Davis and Tulelake, but there was evidence of contributions above 120 lb N ac^{-1} at Parlier and Tulelake. These results correspond well with results from research in Spain for irrigated crops in a climate similar to California's (Ballesta and Lloveras, 2010; Cela et al., 2011), but indicate a higher N credit than previous 'thumbnail' estimates of 40-80 lb N ac^{-1} (Pettygrove and Putnam, 2009). After summarization of the 2015 data, which replicates the 2014 data, this study will be completed in 2016.

Table 1. Mean and standard deviation of grain yield and protein from wheat plots following alfalfa and following grain, fertilized with 0 to 250 lb N ac^{-1} (2014 data).

	Davis				Tulelake			
	Following Alfalfa		Following Grain		Following Alfalfa		Following Grain	
lb N ac^{-1}	Yield	Protein	Yield	Protein	Yield	Protein	Yield	Protein
0	4.11 t ac^{-1} (s = 0.34)	10.45 t ac^{-1} (s = 0.3)	2.25 t ac^{-1} (s = 0.66)	8.02 t ac^{-1} (s = 0.13)	3.48 t ac^{-1} (s = 0.11)	8.03 t ac^{-1} (s = 0.56)	2.31 t ac^{-1} (s = 0.23)	7.6 t ac^{-1} (s = 0.12)
50	4.2 t ac^{-1} (s = 0.17)	11.07 t ac^{-1} (s = 0.44)	3.5 t ac^{-1} (s = 0.22)	9.3 t ac^{-1} (s = 1.65)	4.19 t ac^{-1} (s = 0.27)	8.22 t ac^{-1} (s = 0.38)	3.2 t ac^{-1} (s = 0.27)	7.3 t ac^{-1} (s = 0.39)
100	4.28 t ac^{-1} (s = 0.41)	11.96 t ac^{-1} (s = 0.62)	3.63 t ac^{-1} (s = 0.2)	8.83 t ac^{-1} (s = 0.24)	4.44 t ac^{-1} (s = 0.28)	8.98 t ac^{-1} (s = 0.39)	3.84 t ac^{-1} (s = 0.15)	7.67 t ac^{-1} (s = 0.36)
150	4.15 t ac^{-1} (s = 0.24)	12.43 t ac^{-1} (s = 0.24)	4.15 t ac^{-1} (s = 0.2)	10.31 t ac^{-1} (s = 0.15)	4.28 t ac^{-1} (s = 0.24)	9.65 t ac^{-1} (s = 0.35)	3.94 t ac^{-1} (s = 0.71)	8.07 t ac^{-1} (s = 0.21)
200	4.4 t ac^{-1} (s = 0.34)	12.62 t ac^{-1} (s = 0.59)	4.1 t ac^{-1} (s = 0.14)	10.94 t ac^{-1} (s = 0.63)	4.22 t ac^{-1} (s = 0.08)	10.47 t ac^{-1} (s = 0.33)	4.51 t ac^{-1} (s = 0.21)	8.97 t ac^{-1} (s = 0.61)
250	4.01 t ac^{-1} (s = 0.26)	12.9 t ac^{-1} (s = 0.69)	4.31 t ac^{-1} (s = 0.25)	11.86 t ac^{-1} (s = 0.17)	4.44 t ac^{-1} (s = 0.28)	11.25 t ac^{-1} (s = 0.24)	4.74 t ac^{-1} (s = 0.36)	9.78 t ac^{-1} (s = 0.46)

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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, 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 (Bauder et al., 2011, Hopkins et al., 2007, Vavrina et al., 1998) 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 will develop 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 have been 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 will have 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 NO3/NH4 in irrigation water to the online irrigation and N management tool, CropManage, as well as a downloadable spreadsheet tool for making similar calculations.

Objective 1 trials: Replicated field trials for head lettuce and broccoli were conducted on the USDA Spence research facility near Salinas in 2013 and 2014 to address objective 1. Nitrogen treatments ranged from 2 to 42 ppm $NO_{3-}N$ and were compared to an unfertilized control and a fertilized standard treatment. 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 (Figure 1). 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: approximately 110% and > 170% of crop evapotranspiration.

Figure 1. Manifold and injection system for simulating irrigation water with different concentrations of nitrate

Objective 2 trials: Four replicated field trials were conducted for head lettuce and broccoli on the USDA Spence research facility near Salinas in 2014 and 2015 to address objective 2. All trials using methods similar to objective 1 trials to simulate irrigation water with vary concentrations of N. Water treatments with varying levels of N were compared to treatments where N was fertigated 3 to 4 times during the crop cycle. Fertigated N treatments ranged from 0 to 150 lbs N/acre for lettuce and 0 to 250 lbs N/acre for broccoli. Irrigation water $NO_{3-}N$ concentration varied from 3 to 43 ppm $NO_{3-}N$. A subset of the treatments were compared under applied water amounts that had low (110% of ETc) and high (> 170% of ETc) potential to leach nitrate.

RESULTS AND DISCUSSION

Results of objective 1 trials in lettuce and broccoli demonstrated that the concentration of nitrogen in the irrigation water significantly affected plant size, N content of tissue, biomass yield (Figure 2), and confirmed that a significant portion of the N in the irrigation water was taken up by the lettuce crops and broccoli crops. Even relatively low concentrations of $NO_{3-}N$ in the irrigation water were utilized by the crop.

For lettuce, the response of biomass yield, plant weight, and plant N uptake to N concentration of the water treatments was greater during the summer than the fall, presumably because the N demand of the crop was greatest during the summer when growth was most rapid. Average N recovery was determined for each trial from the slope of a linear plot of the amount of N applied by water and crop N uptake (Figure 3). For lettuce, crop recovery of N from the water treatments averaged 86% during the summer and 41% during the fall trials. For broccoli, crop recovery of N from the water treatments averaged 100%. The higher recovery for lettuce during the summer reflects the fact that the crop was growing more vigorously than during the fall. The high rates of N recovery for the spring lettuce and broccoli also reflects that the total N applied in these treatments was significantly less than required for attaining maximum yield.

The volume of water applied to the crops did not affect the recovery of N from the water treatments, demonstrating that all of the applied water could be credited as having N value to the crop.

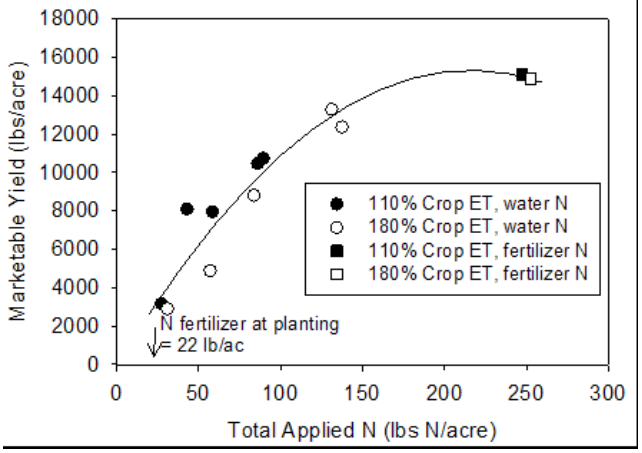

Figure 2. Effect of N in water on broccoli yield

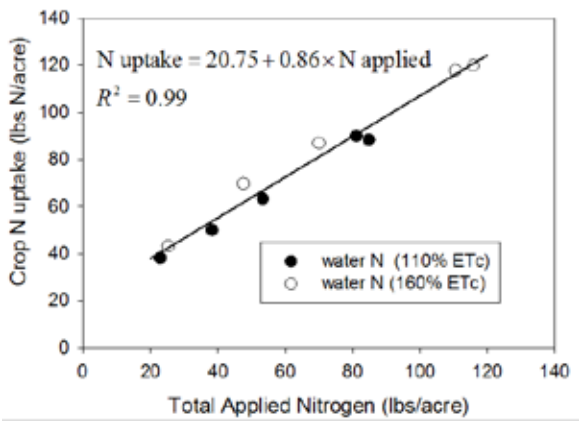

Figure 3. Crop N uptake from water sources of varying N concentrations for summer harvested lettuce

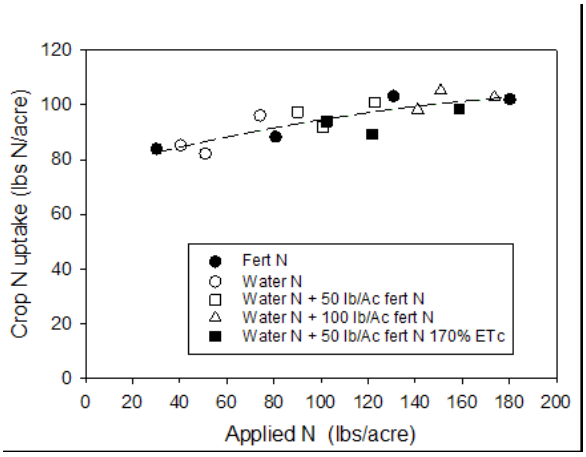

Figure 4. N recovery from water and fertilizer sources of N for fall harvested lettuce.

The source of N in the irrigation water (NH_4 vs NO_3) also had no significant effect on N recovery by lettuce and broccoli crops.

Although the N rate of the fertigation treatment was higher than the N rates of the water treatments, the data from all treatments fit the same quadratic response curve (R2 = 0.99, p < 0.0001) which would suggest that the crop recovery of N from the water and fertilizer would likely be similar at the same N rates.

Objective 2 field trials were conducted in 2014 for lettuce (summer and fall harvested) and 2015 for lettuce and broccoli. Preliminary analysis of the data confirmed that crops had similar yields and N recovery whether the N source was from the water or from fertilizer treatments (Figure 4).

Take Home Message

The results of series of replicated field trials demonstrated that ambient N in irrigation water has fertilizer value for shallow rooted vegetable crops such as lettuce and broccoli, even when the N concentration in the water was low (< 20 ppm N). The trials also showed that the source of N (NH_4 vs NO_3) did not affect crop recovery. Presumably NH4 would quickly transform to NO_3 when added to the soil. Also, the volume of water applied did not affect the recovery rate of N, suggesting that all water applied containing N had fertilizer value to the crop. These results were attained under a well- managed drip irrigation system, with a high application uniformity and irrigations were frequent (2 to 3 times per week) so that irrigation volumes were small, which likely minimized leaching losses, even under high ET applications rates. 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.

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AKNOWLEDGEMENTS

We thank CDFA-FREP for financial support of this project, and USDA-ARS staff in Salinas CA for their assistance with the field trials.

Irrigation and Nitrogen Management Web-based Software for Lettuce Production

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INTRODUCTION

Vegetable growers on the Central Coast of California are under regulatory pressure to reduce nitrate loading to ground water supplies. Additionally, over pumping of ground water for agricultural production has contributed to seawater intrusion into coastal aquifers, which may be accelerated during the current drought. Two tools available to farmers for improving nitrogen and water use efficiency are the soil nitrate quick test (SNQT) (Hartz et al. 2000) for monitoring soil mineral nitrogen levels and weather-based irrigation scheduling for estimating water needs of crops (Cahn and Smith, 2012, Johnson et al. 2013). Under a previously awarded CDFA FREP grant we developed the web-based software application, CropManage (CM) (ucanr.edu/cropmanage), to facilitate the implementation of both tools for lettuce, and subsequently through additional CDFA-FREP funding, for cole crops and leafy greens (Cahn and Hartz, 2012, Cahn et al. 2013a, 2013b). Users can access the software through a web browser on their smart phones, tablet and desktop computers. The software allows growers to quickly determine a fertilizer N rate based on the SNQT and N uptake curves for cool season vegetables. In addition, the software estimates the water requirement of the crop using evapotranspiration data from the California Irrigation Management Information System (CIMIS) and models of canopy development. Preliminary field testing of the software in commercial fields indicated that growers can significantly reduce N fertilizer and water use without reducing crop quality and yield. Large-scale field trials comparing the CM fertilizer N recommendation with grower standard practices resulted in similar yields using an average of 32% less N fertilizer. Replicated trials resulted in a 25% to 40% savings in water by following the irrigation schedule of the online tool compared to the grower standard practice, and equal commercial yields between treatments (Johnson et al. 2013).

Since CM was first launched in 2011, the decision support tool currently has more than 650 registered users and more than 200 registered ranches. Some of these users represent large vegetable and berry farming companies on the Central Coast that are interested to adapt CM practices for their operations. Despite recognition by these growers that CM can help them efficiently use nitrogen fertilizer and water for their crops, they have been challenged to integrate the CM tool into their daily farming practices. Many growing operations needed to hire and train new personnel to sample fields and to test soil nitrate levels before applying fertilizer, and to record and to monitor irrigation applications, as well as to oversee the input of data into CM. Growers have also invested in tools such as soil moisture sensors and flow meters, to verify that changes made in their management are not risking yield and quality of their crops.

OBJECTIVE

The overall goal of this project is to demonstrate how to efficiently manage nitrogen fertilizer and irrigation water for the production of cool season vegetables using CropManage (CM), an online decision support tool. Specific objectives are:

1. Assist growers, consultants and industry representatives to implement CM on commercial vegetable operations.
2. Evaluate improvements in nitrogen and water use efficiency of cool season vegetables using the CM decision support tool.

Figure 1. Water applications to lettuce fields are automatically recorded using flow meters and uploaded to CropManage so that growers can compare their water management to weather (ET) based recommendations.

DESCRIPTION

This project supports efforts of growers and the agriculture industry representatives to implement CropManage into commercial farming operations to improve the efficiency of nitrogen and water management while sustaining yield and quality of crops. Our approach is to work with growers currently implementing CM into their farming operations, and provide one-on-one consulting and small group training. We also provide field support for monitoring commercial fields and to document improvements in management. Finally we provide cross-training to consultants, agency personnel, and commercial companies interested in building capacity to help growers integrate CM practices into their operations.

In collaboration with major vegetable shippers we identified two growers on the Central Coast and one grower in the Imperial Valley that are currently implementing or desire to implement best management practices (BMPs) for nitrogen and water in their farming operations using CM. We provided training for personnel who will be participating in the project including, grower operators, farm managers, farm management staff, and associated consultants. Participating growers identified two to three vegetable fields of the same commodity (either lettuce, broccoli, cabbage, or cauliflower) for monitoring current water and N use practices. Each field was equipped with a flowmeter (Figure 1) for recording applied water volumes and sensors for monitoring soil moisture (Figure 2). Fields were evaluated for residual soil nitrogen at planting, before each fertilizer N application, and after harvest. All collected information was maintained using the online CM decision support tool. Biomass was sampled near harvest to estimate total N uptake of the crop. Participating growers provided commercial yield data for the fields. Opportunities to improve management will be identified by comparing the amount of N fertilizer and water applied to the CM recommended amounts. During the second phase of the project, participating growers identified an additional two to three vegetable fields of the same commodity for evaluating CM recommendations for nitrogen and water applications. The same procedures were followed as described above, with the exception that the CM recommendations for nitrogen fertilizer and water were followed as closely as the grower can practically accomplish. Grower practices were compared with the recommended values to estimate the improved efficiency for nitrogen and water management.

RESULTS AND DISCUSSION

Monitor Current Nitrogen and Water Management Practices in Lettuce

Two growers were identified who were interested to implement CM decision support for their vegetable farming operations in the Salinas Valley during the 2014 season. Each growing operation annually farms more than 2000 acres of vegetables. Growers selected three commercial lettuce fields for monitoring current nitrogen and water management practices. Fields were equipped with a flowmeter for recording applied water volumes and sensors for monitoring soil moisture. Data were automatically updated in CM using cell phone and radio modem communications. Fields were evaluated for residual soil nitrogen at planting, before each fertilizer N application, and after harvest. All collected information was maintained using the online CM

Figure 2. Tensiometers readings are automatically recorded to a datalogger and uploaded to CropManage through radio and cell phone communications.

decision support tool. Biomass was sampled near harvest to estimate total N uptake of the crop. Opportunities to improve management were identified by comparing the amount of N fertilizer and water applied to the CM recommended amounts. Preliminary results indicated that applied N could be reduced by 40% to 50% and applied water by 20% to 30% without harming marketable yields.

In Imperial County, a vegetable operation near Bard CA participated in a demonstration trial with CropManage. All procedures used for demonstration fields in the Salinas Valley were followed in this field, including beginning and ending soil nitrate levels. We determined that the main cause of low soil nitrate in the soil was caused by applying excess water during the sprinkler phase of the crop, which likely leached a substantial portion of the residual nitrogen in the soil profile.

Implement BMPs for Nitrogen and Water Management in Lettuce

During the second phase of the project, each participating grower selected an additional group of lettuce fields where the fertilizer N and irrigation were adjusted during the season following the guidance of the CM decision support tool. Because of the interest of one of the participating growers, we monitored an additional 3 lettuce fields during the 2014 season following the guidelines of CM. The combination of improving water management and testing the soil for residual nitrate before fertilizer applications, reduce fertilizer N by an average of 40% (100 lbs N/acre) for these 3 fields. Similar demonstrations were continued in 5 lettuce fields during the 2015 season.

Provide trainings on CropManage

Growers participating in the demonstrations received continuing support on using the CM decision support tool either weekly or biweekly. We assisted these growers in navigating and learning to use CM as well as with interpreting recommendations. Additionally, we presented on CM at various educational meetings, including industry meetings, and academic meetings. Finally we conducted four in-depth workshops on CropManage in Monterey, Imperial, Ventura, and Santa Barbara counties. These four-hour workshops provide an opportunity for growers, consultants, and industry reps to get hands-on training in using the online tool for managing water and nitrogen fertilizer.

ACCOMPLISHMENTS

This project assisted three large vegetable growing operations identify strategies to reduce N fertilizer inputs by minimizing losses due to leaching. Improving both water management and monitoring soil nitrate levels during the cropping cycles was an effective approach to using fertilizer N more efficiently. The online decision support tool, CropManage, was an efficient method to maintain records of fertilizer and water use patterns, and to quickly determine appropriate amounts of water and fertilizer to apply to their crops on a field-by-field basis. This project has also been successful in training growers and crop consultants from most of the major cool season vegetable production regions in California to use CropManage.

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AKNOWLEDGEMENTS

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

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Cooperators

Cooperators included vegetable producers in California and southern Arizona and manufactures of controlled release technologies. We have worked with Ocean and Desert Mist Farms, A. Duda & Sons, Top Flavor Farms, Pasquinelli Produce Sabor Farms, J. V. Farms, Agrium Advanced Technologies, Koch Industries, and J. R. Simplot Company.

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 objective of this project is to conduct experiment-demonstrations with CRN technologies in vegetable producing areas in California with a wide range of CRN technologies available. Experiment demonstrations will all occur with grower-cooperators and CRN management will be compared to their standard practices. Success will be discerned by data collected, grower interest, and grower implementation. We will compile data on grower participation, interest, and adaptation.

DESCRIPTION

Task 1. Release rates for a range of products

Release rates for ESN (Agrium), and number of Duration products (Koch Industries), and two Gal-Xe products (JR Simplot) were completed. Others will be conducted as we obtain additional products form manufactures. Based on release rates and our model, we have identified products that will release 90% at 45 (CRN 45), 90 (CRN 90), 120 CRN 120), and 180 (CRN 180) days at 20 degree Celsius. We have reconciled these with planting curves and selected preliminary products for field testing for crops and season.

Task 2a. Preliminary experiment-demonstration in desert spring window

Since most cool season desert crops were planted by

Table 1. Yield response of spinach to N management in winter-spring 2015.

Treatment	Yield (MT/ha)
GSP (315 lbs N/A as UAN 32)	34.5
CRN-45 (75 lbs N/A) plus 105 lbs N as UAN 32	29.7
CRN-90 (75 lbs N/A) plus 105 lbs N as UAN 32	33.4
CRN 45 (150 lbs N/A)) plus 105 lbs N as UAN 32	29.6
CRN 90 (150 lbs N/A)) plus 105 lbs N as UAN 32	34.1
LSD(0.05)	4.2

initiation of this contract on January 1, 2015 we were limited on what could be done in the desert in spring 2015. We completed broccoli, celery, and romaine lettuce demonstrations initiated with funding from other sources and we initiated new spinach experiments after January 1, 2015.

Task 2b. Experiment-demonstrations in central coast

During the summer two experiment-demonstrations were initiated with spinach and two with romaine lettuce. One additional demonstration will be conducted before the season terminates in this area.

Task 2c. Additional studies in low desert

The desert season is just beginning as of this writing. We have already arranged for experiment-demonstrations with broccoli, spinach, lettuce, and onions.

RESULTS

As of this writing, the data from the Central Coast is not available so our discussion is limited to data from the desert at this time. Prior to FREP funding we began some trials with industry funding. We have continued these studies with FREP funding as of January 1, 2015. Results continue to be favorable and for many crop production scenarios. There are interactions with soil, irrigation method, and season. Furthermore, in each demonstration, we make modifications to accommodate the grower's comfort zone. One example with spinach is shown below.

This site was a silty clay loam in Imperial County, CA. This experiment-demonstration has a wet date of February 15 and was harvested March 26, 2015. The treatments compared grower standard practice to programs that included reduced rates of N as CRN. We used one CRN 45 and one CRN 90 at two rates applied pre-plant and power-mulched into the beds. The GSP received three applications of UAN32 of 30 gal/A (approximately 315 lbs N total per acre) spaced throughout the season. The low and high rates of CRN received one application of 30 gal UAN 32 late in the season (approximately 180 and 255 lbs N/A total, respectively). Overall, both the high and low rates of CRN 90 produced yields similar to the grower practice at considerably lower N rates. Overall, these results are similar to others we collected. We wish to note that although the CRN 90 outperformed the CRN 45 in this particular spinach experiment, for spinach experiments conducted during the cooler part of the season the CRN 45 outperformed CRN 90. Two growers who worked with us in 2014 and 2015 have implemented CRN products into their spinach N management programs.

ACCOMPLISHMENTS/PRELIMINARY FINDINGS

We completed laboratory incubations for all products in our inventory. These will continue as we gain access to more products. We began studies in the low desert and the Central Coast production areas. Results continue to show CRN management will produce favorable results in many vegetable crop production scenarios. Some of the growers we worked with have incorporated CRN products into their N management programs. Demonstrations are on-going.

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 including Desert Mist Farms, JV Farms, Top Flavor farms, and Pasquinelli Produce.

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Nitrogen Management Training for Certified Crop Advisors

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INTRODUCTION

The Nitrogen Management Training and Certification Program is a joint effort between the California Department of Food and Agriculture; University of California, Agricultural and Natural Resources; California Certified Crop Advisor Program of the California Association of Pest Control Advisors; and the Regional Water Boards to develop and implement a voluntary nitrogen management curriculum specifically targeted for California Certified Crop Advisors. The effort is being coordinated by the UC California Institute for Water Resources. The curriculum addresses the management of nitrate to reduce unintentional emissions in waters throughout the state.

OBJECTIVE

The objective of this program is to facilitate California Certified Crop Advisors understanding of sound nitrogen management practices and increase their ability to make informed recommendations to growers, thereby improving environmental performance relative to nitrogen management for crop production.

DESCRIPTION

This project involves curriculum development, website development and maintenance, trainings, and publications. The project is being carried out in two phases with deliverables provided in stages.

Phase I: (January 1, 2013 – December 31, 2014)

This phase involved curriculum development and an initial round of trainings. All deliverables in this phase have been completed.

Curriculum Development. The initial curriculum was developed by small teams (5-15 people). A team leader organized each team. Participants were involved in curriculum development with in-person meetings in Davis and subsequent collaboration taking place largely via conference call and email.

Trainings Sessions. The course was developed to be one and a half days in length. Team members led training sessions. Logistics for the training sessions were provided by the California Association of Pest Control Advisors. The dates and locations for the first set of trainings took place as follows:

1. Modesto – January 14-15, 2014
2. Woodland – February 18-19, 2014
3. Fresno – February 25-26, 2014
4. Salinas – March 5-6, 2014
5. Tulare – March 11-12, 2014

Phase II: (October 1, 2014 – December 31, 2016)

This phase involves curriculum modification based on what was learned during the first set of trainings, a second round of trainings, and development of publications and other outputs from the curriculum that can be used for additional outreach.

Curriculum Modification. The curriculum used in the first round of trainings was reviewed based upon feedback from evaluations during those trainings. Modifications to the curriculum have been implemented. This task has been completed.

Training Sessions. Three additional training sessions were held in early 2015 as follows:

1. January 13-14, 2015: Fresno, Ramada Inn
2. February 24-25, 2015: San Luis Obispo, Courtyard by Marriott
3. March 10-11, 2015: Sacramento, Scottish Rite Temple

Publications. A total of 11 publications (see list below) are being created from the training materials, lessons learned from the training sessions and from additional research. They will be available as individual modules or can be assembled into a single publication, both of which will be available on our current website. The current intent is to produce publications for the University of California, Agriculture and Natural Resources peer reviewed 8000 series. This task is in process and on track to be delivered by the stated deadline.

Publications:

1. Nitrogen cycle principles, fertilizer management, nitrogen budgeting
2. Irrigation and nitrogen management
3. Cole crops and leafy greens
4. Wheat
5. Corn – silage and grain
6. Strawberry and cane berries
7. Tomatoes and melons
8. Cotton
9. Nuts
10. Citrus and avocados
11. Deciduous fruits and grapes

RESULTS AND DISCUSSION

The first phase of this project was to plan and develop the curriculum for the CCA training, create a website for training materials, and complete eight training sessions. This has all been accomplished. The training materials were created by the first training session and subsequently modified for later training sessions based on the feedback received from participants in their evaluation forms. The curriculum for the trainings is as follows:

Day 1: Nutrient Management

9:00 am	Module 1: Objectives
9:30 am	Module 2: Nitrogen Cycle in Crop Production Systems
11:15 am	Module 3: Nitrogen Sources
1:00 pm	Module 4: Irrigation and Nitrogen Management
2:00 pm	Module 5: Nitrogen Budgeting
3:00 pm	Module 6: Tools and Resources
3:45 pm	Regional Board Update
4:30 pm	Questions/summary/check-out
5:00 pm	Adjourn

Day 2: Annual and Permanent Crops (Participants chose a crop type track)

8:00 am	Current practices and BMPs
10:30 am	Nitrogen management planning exercise
12:00 pm	Evaluations/Sign-out/certificate of attendance

At this time, training materials and videos are available on the web at ciwr.ucanr.edu/NitrogenManagement. We have developed fully updated, annotated presentations for the Day 1 curriculum to make the material more accessible for participants across trainings (the Day 2 annotated presentations will be available by October 2015).

Figure 1. Participants at the first nitrogen training event in Modesto, January 2014.

Figure 2. Doug Parker, director of the California Institute for Water Resources, and Terry Stark, executive director of the California Association of Pest Control Advisers, at the Modesto training in January 2014.

ACCOMPLISHMENTS

This project has resulted in a strong curriculum in nitrogen management that has been used to train over 700 Certified Crop Advisors.

ACKNOWLEDGEMENTS

Our project has been supported by Fertilizer Research and Education Program.

Table 1. The reach of the training program in numbers of Certified Crop Advisers participating to date:

Training Date	Location	Completed	No Shows	Partial Hours	Total Registered
1/14/14 – 1/15/14	Modesto	113	0	0	113
2/18/14 – 2/19/14	Woodland	89	1	0	90
2/25/14 – 2/26/14	Fresno	111	4	1	116
3/05/14 – 3/06/14	Salinas	104	0	3	107
3/11/14 – 3/12/14	Tulare	112	7	4	123
1/13/15-1/14/15	Fresno	67	4	3	75
2/24/15-2/25/15	San Luis Obispo	68	0	7	76
3/10/15-3/11/15	Sacramento	74	5	4	94
	TOTALS	738	21	22	794

Evaluation of N Uptake and Water Use of Leafy Greens Grown in High-Density 80-inch Bed Plantings and Demonstration of Best Management Practices

Project Leaders

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INTRODUCTION

The Central Coast Regional Water Quality Control Board (CCRWQCB) began collecting information from growers on the quantity of nitrogen (N) that they apply to their crops; regulations could follow for growers who apply greater quantities of N to crops than is taken up. Crops such as baby lettuce, cilantro, spring mix (mizuna, representative spring mix crop evaluated in this study) and spinach are grown on 80-inch wide beds that are seeded in 14 to 32 seedlines; they are considered high density plantings because they are planted to cover the entire bed top and are irrigated exclusively with sprinkler irrigation. Nitrogen uptake and water use of these crops was not well understood, and this project was initiated to evaluate their nitrogen uptake and water use. Understanding the quantity of N taken up by these crops is basic to understanding the efficiency of current fertilizer practices and devising improvements in N use efficiency. In addition, understanding the quantity of water applied during the crop production can help to better understand typical water application patterns relative to crop demand (crop ET). The nutrient uptake and water use information developed by this project is being used to develop algorithms in CropManage, an online tool that is designed to assist growers in managing both nitrogen and irrigation management in cool season vegetables.

OBJECTIVES

1. Document the quantity and pattern of N uptake pattern over the life cycle of baby lettuce, cilantro, spring mix (e.g. mizuna) and spinach
2. Evaluate quantities of irrigation water applied to these crops over the course of the growth cycle
3. Evaluate the rooting depth of the crops over the growing season
4. Evaluate fertilizer additives such as urease and nitrification inhibitors with pre/at-planting fertilizer applications to improve N use efficiency

DESCRIPTION

The research for this product was conducted on commercial vegetable production fields. Ten nitrogen uptake evaluations were completed for each of the following crops grown on high density 80-inch wide beds: baby lettuce, cilantro, mizuna and spinach. Biomass samples were collected from two to four times during the crop cycle and evaluated for total N uptake. At harvest, total N, P and K in the biomass was measured as well at the total N in the commercial harvested portion of the crop and in the residue that remained in the field.

Six nitrogen technology fertilizer trials were conducted in commercial fields. Soil mineral N was measured over the crop cycle, as well as total N uptake and yield at harvest.

Flow meters were installed in two fields of each commodity each year and infrared photographs were taken to measure crop growth and development. Total water applied was quantified for each field that was evaluated and compared with crop ET. Rooting depth evaluations were conducted on selected fields.

Table 1. Yield and nitrogen uptake evaluations of cilantro (n=7), baby lettuce (n=10), mizuna (n=10) and spinach (n=7)

Crop	Dry Biomass Lbs/A	Solids %	N content %	N total uptake lbs/A	N in harvested Product lbs/A	N in residue lbs/A	N fertilizer lbs/A	N applied/ uptake ratio
Cilantro	2054.8	11.5	5.1	104.0	57.3	46.7	208.0	2.0
Baby lettuce	1388.7	6.1	5.2	70.0	46.0	23.9	170.0	2.4
Mizuna	1722.8	7.1	5.8	99.2	58.3	40.9	179.7	1.8
Spinach	2204.4	7.1	5.7	126.2	86.1	40.1	180.0	1.4

Table 2. Phosphorus and potassium uptake evaluations

Crop	P content %	P total uptake lbs/A	K content %	K total uptake lbs/A
Cilantro	0.3	6.7	6.9	141.1
Baby lettuce	0.5	7.1	7.8	105.2
Mizuna	0.6	9.5	5.3	96.7
Spinach	0.7	15.0	9.3	202.9

RESULTS AND DISCUSSION

Cilantro had the longest average crop cycle (47.1 days); spinach and baby lettuce were harvested on average at 32.8 and 30.8 days, and mizuna at 24.9 days. Days to harvest varied by the time of year, but these data give a relative comparison of the length of the crop cycle of these crops. Mizuna and spinach had the greatest rate of growth of the four crops (69.2 and 67.2, lbs biomass/acre/day, respectively). Spinach and cilantro had the highest overall dry biomass of the four high-density crops (Table 1). Spinach had the highest total N uptake of all the crops, followed by cilantro, mizuna and lettuce. Fertilizer N application to N uptake ratios ranged from 1.4 (spinach) to 2.4 (baby lettuce). The percent of the crop biomass that was harvested ranged from 41% for mizuna to 68% for spinach. These ratios can vary significantly due to a variety of market and production conditions, but they provide an estimate of nitrogen-rich crop residues that remain in the field after harvest. Cilantro, spinach and mizuna return the greatest quantity of N in the unharvested crop residue. The nitrogen concentrations in crop tissues were high with mizuna and spinach having the greatest concentration in the tissue at 5.8 and 5.7%, respectively. Potassium uptake was greater than N uptake for all crops except mizuna (Table 2).

Six fertilizer nitrogen fertilizer trials have been conducted on spinach. Materials evaluated in the project include: nitrapyrin (Instinct®), Super U® (DCD + urease inhibitor impregnated on prills of urea), Novatec (ammonium sulfate treated with DMPP), triazone (NSure®), and polymer coated urea (D45®). These materials were compared with a standard application of ammonium sulfate. Fertilizer technologies were applied at a suboptimal rate with and without the fertilizer technologies and compared with the standard fertilizer rate. Trials were conducted on commercial farms in the north and south end of the Salinas Valley. These trials have been difficult to conduct on commercial fields over the past three years due to the prevalence of high levels of residual soil nitrogen during the drought years (little nitrate leaching in the winter). As a result, in these studies, we have observed that the use of nitrogen fertilizer technology resulted in modest improvements in yield in high-density crops.

The total volume of water applied to high density leafy green crops was monitored using flow meters and rain gauges. The initial data showed that total water (irrigation water and rainfall) applied to a crop ranged from 2.5 to 10 inches (Table 3).

Crop coefficients for high density leafy greens were developed by monitoring canopy development during the crop cycle of commercial fields using an NDVI multispectral camera. Data were fit to the equation

Table 3. Total water applied to high density leafy green crops.

Crop	Irrigation water applied	Rainfall	Total applied water (AW) inches	Crop ET	Reference ET	AW/ETc %
Baby Lettuce	12.5	0.0	12.5	4.3	5.9	283
Cilantro	5.3	0.6	5.8	3.7	5.6	156
Mizuna	3.5	0.6	4.1	3.1	4.6	148
Spinach	7.4	0.3	7.7	3.1	5.2	245

Table 4. Parameters of canopy models for high density leafy green crops.

			model coefficients			
Bed width	Crop	Sites	Gmax	A	B	R^2
inches			%			
80	cilantro	4	72.8	6.629	-11.799	0.95
80	mizuna	4	79.5	5.968	-10.379	0.95
80	baby lettuce	4	72.0	6.506	-11.002	0.99
80	baby spinach	10	80.0	5.058	-10.268	0.80

based on the canopy model of Gallardo et. al. (1996) for estimating evapotranspiration of lettuce (Table 4).

Rooting depth of high-density leafy green crops was monitored in commercial fields at weekly intervals (Figs. 1-3). Rooting depth of baby spinach and mizuna reached 18 inches by harvest (30 days), while roots of cilantro reached deeper than 30 inches by harvest (46 days). However, the active roots of clipped spinach were concentrated in the zone from 4 to 8 inches deep and this was the most active depth of nitrogen uptake. This data emphasizes the need for good water management to keep highly mobile nitrate in the root zone of a short-term crop like spinach.

RECOMMENDATIONS

Data from these evaluations indicate that the high-density crops take up moderate amounts of N, but over a short crop cycle. N applied:N uptake ratios were highest for baby lettuce and lowest for spinach. Nitrogen technologies provided an inconsistent benefit for improving nitrogen use efficiency in these crops. High density crops are exclusively sprinkler irrigated and the applied water data indicate that, in some fields, improvements in water use efficiency can help improve nitrogen use efficiency. Date from these trials has been used to enter algorithms for spinach and include it in the crops covered by CropManage, the web based program to assist growers in improving applied water use efficiency.

ACKNOWLEDGEMENTS

Funding for this project was provided by CDFA's Fertilizer Research and Education Program and the California Leafy Greens Research Board.

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

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INTRODUCTION

Water quality regulations implemented by the CCWQCB are challenging growers to evaluate and implement practices to improve the efficiency of applied nitrogen to vegetable crops. The cool season vegetable production areas of the Central Coast of California frequently grow more than one crop during the cropping season. Fertilizer applications to cool season vegetables vary widely, but often exceed uptake of the crop; in addition, the quantity of N that remains in the field from unharvested crop residue can be significant. In a prior FREP funded project, broccoli was shown to take up more nitrogen (N) from the soil than is typically applied as fertilizer. In essence, it is scavenging N from the soil. Broccoli was also shown to be deep rooted and capable of capturing nitrogen from deeper in the soil profile. All of these characteristics indicate that broccoli may play a useful role in capturing nitrogen from prior rotations, bring it back to the soil surface where it is utilized and/or made available for subsequent crops. This project evaluates the role that broccoli rotations can play in reducing nitrate leaching in the cool season vegetable system.

OBJECTIVES

1. Determine the effective rooting depth of broccoli for removing residual N from the soil profile though direct evaluation of rooting pattern and replicated field trials
2. Adapt soil nitrate quick test for broccoli to guide N fertilizer applications by evaluating factors including soil sample depth, threshold of soil nitrate sufficiency, and crop stage.
3. Conduct commercial field trials evaluating the efficiency that broccoli can 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
5. Conduct an outreach program to growers and consultants on the results of the study and how to utilize the nitrogen scavenging attributes of broccoli to improve nitrogen utilization in the cool season vegetable production system

DESCRIPTION

Evaluations of the ability of broccoli to capture residual soil nitrate were conducted in commercial broccoli fields and in a research station study. Evaluations included surveys of the amount of nitrate taken up by a broccoli crop following a lettuce crop. Evaluations were made of the initial quantity of residual nitrate-N in the top three feet and during the broccoli cropping cycle. Biomass evaluations were made to measure the quantity of N taken up by the broccoli and rooting depth evaluations were also made. A field study was initiated in which drip tape was injected into the soil at 12, 18 and 24 inches deep and the response of broccoli to nitrogen applied at these depths was made. Nitrogen mineralization studies were conducted to evaluate the timing and quantity of mineral N that is released from broccoli residue following harvest.

Table 1. Analysis of total N available from residual soil N and fertilizer and broccoli N uptake and its impact on N utilization and nitrate leaching

Site	Initial residual soil mineral N[1] lbs/A	Total N fertilizer Applied lbs/A	Total available mineral N lbs/A	Total N uptake by 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 water applied /ET	Total N potentially leached[2] lbs/A
1	146.4	178.0	324.4	313.4	97.0	8.9	322.3	1.53	32.1
2	372.1	178.0	550.1	370.0	67.3	132.6	502.6	1.25	77.5
3	134.3	190.0	324.3	268.1	82.6	19.2	287.3	1.48	67.0
4	183.6	190.0	373.6	369.6	99.0	48.0	417.6	1.13	-14.0
5	257.4	240.0	497.4	220.5	44.3	92.1	312.6	2.02	214.8

1 – total N in the top three feet of soil; 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/A as part of the total available mineral N)

RESULTS AND DISCUSSION

A survey of broccoli fields following a crop of lettuce was conducted. The initial quantity of residual soil nitrate-N in the top three feet of soil varied from 134.3 to 372.1 lbs N/A (Table 1). Fertilizer applications varied from 178 to 240 lbs N/A. The total of these two parameters result in the total available nitrate-N in the soil to range from 324.4 to 550.1 lbs N/A. Crop biomass was generally from 4.37 to 4.76 tons/A except for site 5 which was 3.53 tons/A. Site 5 was a loamy sand soil texture and was a challenging site to manage N. The broccoli biomass took up from 67 to 99 percent quantity of the residual N found in the soil; site 5 was the exception and the broccoli only took up 44% of residual soil N. The quantity of potentially leached N ranged from no leaching (site 4) to 77 lbs N/A except for site 5 which potentially leached 214 lbs N/A. Site 5 also received the greatest amount of water relative to crop demand which facilitated pushing nitrate beyond the root zone; growing crops on loamy sand soils are more difficult to manage with sprinkler irrigation. These data indicate the tremendous potential for broccoli to capture nitrate from the soil profile, utilize it for crop growth and reduce nitrate leaching. It is interesting to note that on the site with the highest amount of available N (site 2) the broccoli biomass had the highest percent of biomass N (4.2%) indicating that broccoli has some ability to take up luxurious amounts of N into the tissue beyond what is needed for maximum growth.

The rate of mineralization of nitrate from broccoli crop residue was dependent on the temperature, the concentration of N in the crop tissue and the amount of N added to the soil. Rates of N release from residue generally peaked by 4 weeks following the initiation of the incubations. Soil type did not have as big an effect on mineralization. 125 ppm N in the tissue mineralized a greater quantity of N than residue with 108 ppm N. Increasing the temperature from 15 to 25 C increased N mineralization at the two-week evaluation date, but not after 4 weeks of incubation.

RECOMMENDATIONS

These evaluations indicate that broccoli residue is capable of taking up substantial quantities of residual soil nitrogen from the soil from the proceeding crop. Broccoli is moderately fertilized and from the research station evaluation, it is clear that sufficient N needs to be present at the beginning of the crop cycle to allow the broccoli crop to develop sufficiently to take advantage of N deeper down in the soil profile. The quantity of N mineralized from broccoli residue can be substantial and needs to be accounted for in the crop grown subsequent to the broccoli.

ACKNOWLEDGEMENTS

Funding for this project was provided by CDFA's Fertilizer Research and Education Program and the California Leafy Greens Research Board.

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 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.

Developing Testing Protocols to Assure the Quality of Fertilizer Materials for Organic Agriculture • *William Horwath, 13-0023*

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

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

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*

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

Updating Prior Curriculum for Grades 5-8 • *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*

Improved Methods for Nutrient Tissue Testing in Alfalfa • *Orloff, 09-0580*

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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*

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