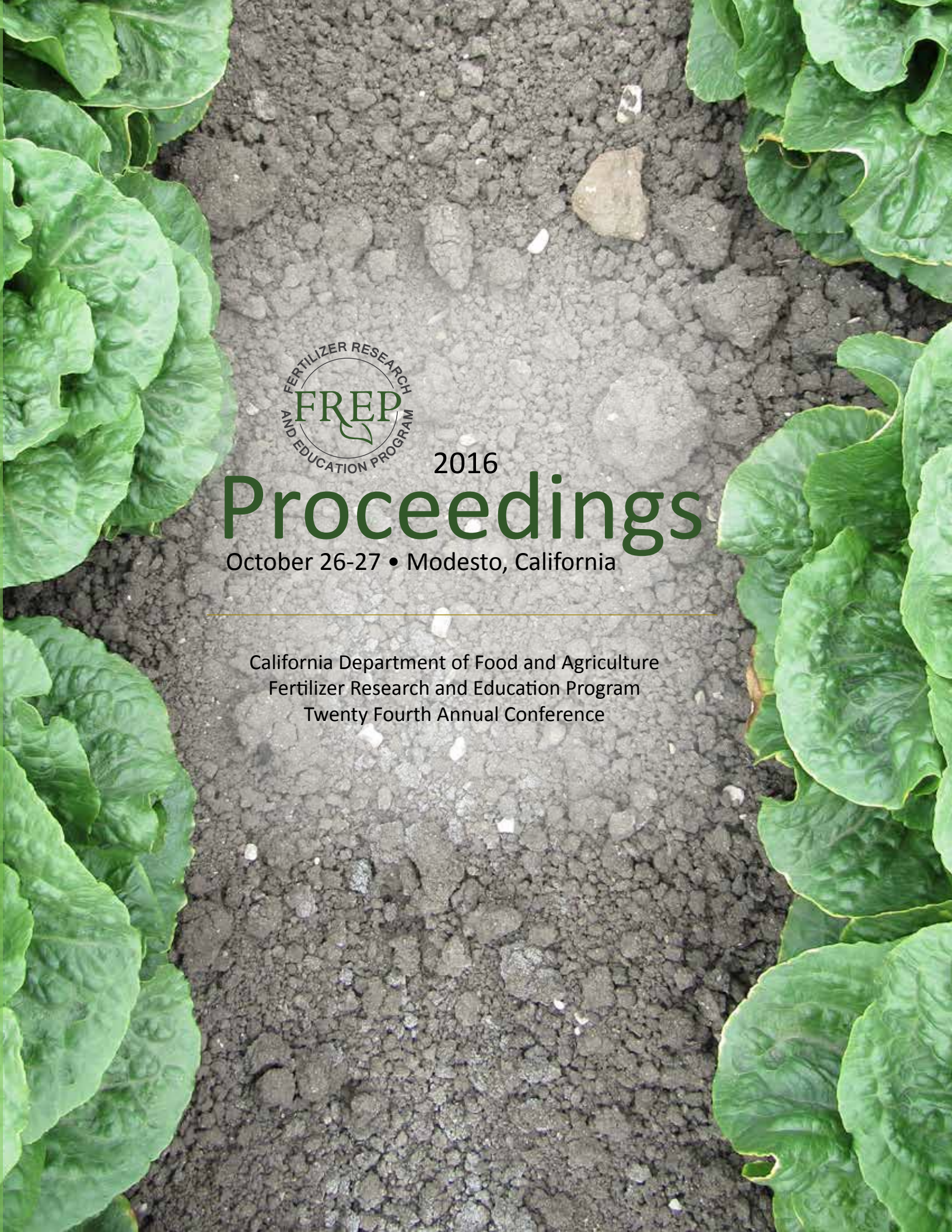

FERTILIZER RESEARCH AND EDUCATION PROGRAM
FREP

2016

Proceedings

October 26-27 • Modesto, California

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

2016

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Fertilizer Research and Education Program
Twenty Fourth Annual Conference

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INTRODUCTION

Fertilizer Research and Education Program

FOR 24 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.

2016 marks the eleventh year of collaboration between FREP and the Western Plant Health Association (WPHA). Our partnership allows the opportunity to extend our outreach to a broad audience of agriculturalists at multiple levels. This event brings together the agricultural community, from crop consultants to growers, public agency personnel, industry professionals to academic researchers. We gather to learn about the latest research and sound management of fertilizing materials.

This year's conference agenda includes information on nitrogen and irrigation management, as well as groundwater recharge, soil salinity, the role of nutrients in pest management, biochar, soil health, and more. Our conference speakers come from a variety of backgrounds, including academia, farm advising, public and private organizations, and industry. A poster session will close the first day of the conference, showcasing a dozen ongoing research projects regarding nutrient management across California.

Included in these proceedings are summaries of current FREP-funded projects, relevant research presented during the poster session of the conference, and completed FREP research projects.

FREP OVERVIEW AND NEW INITIATIVES

FREP has a mission to enable improvements in agricultural practices which will, in turn, enhance production of quality crops and protect the environment.

FREP funds and facilitates research, education, and outreach projects that improve the performance of fertilizing materials in agriculture and make new plant nutrient knowledge available to farmers and agricultural advisors (Figure 1). To date, FREP has funded 213 research and education projects, totaling over $15 million in financial support. FREP serves a wide range of agriculture community, such as growers, agricultural supply and service professionals, university extension and public agency personnel, and other interested parties.

FREP was established through legislation with support from the fertilizer industry. California Food and Agricultural Code Section

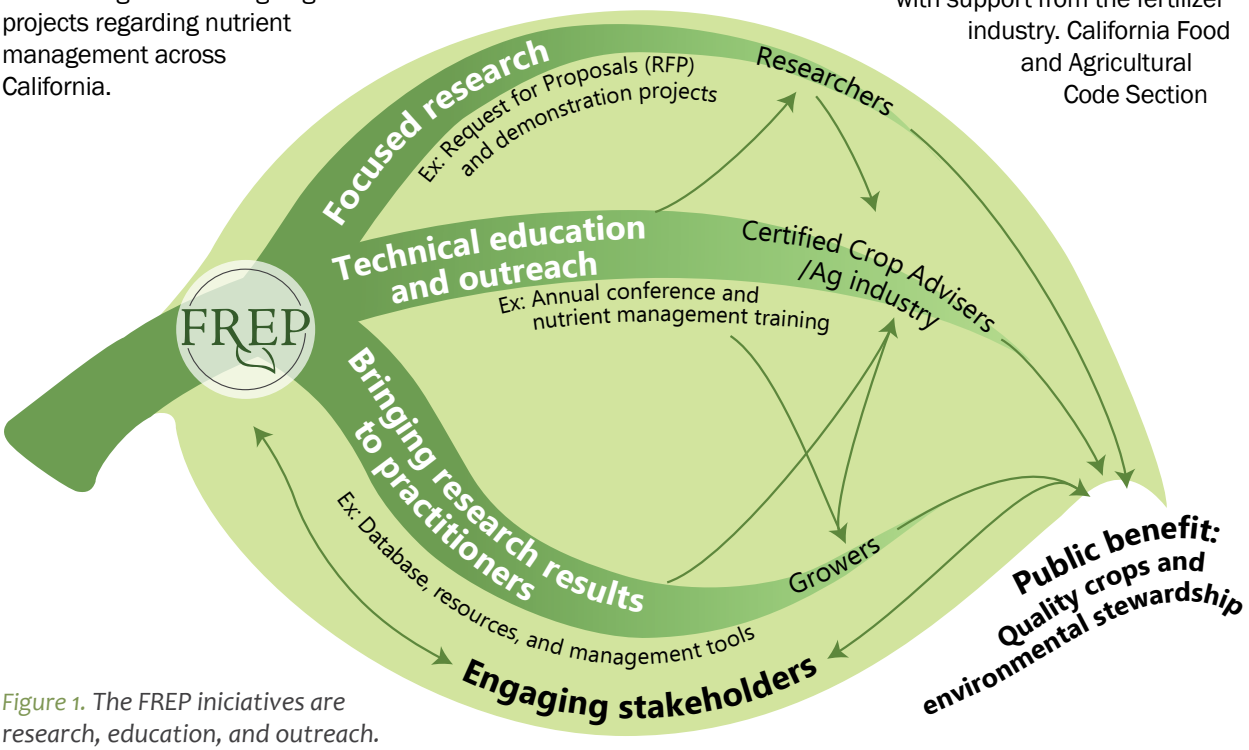


Figure 1. The FREP iniciatives are research, education, and outreach.

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.

To fulfill its mission, FREP has undertaken initiatives in the following three key areas: technical education, outreach, and research.

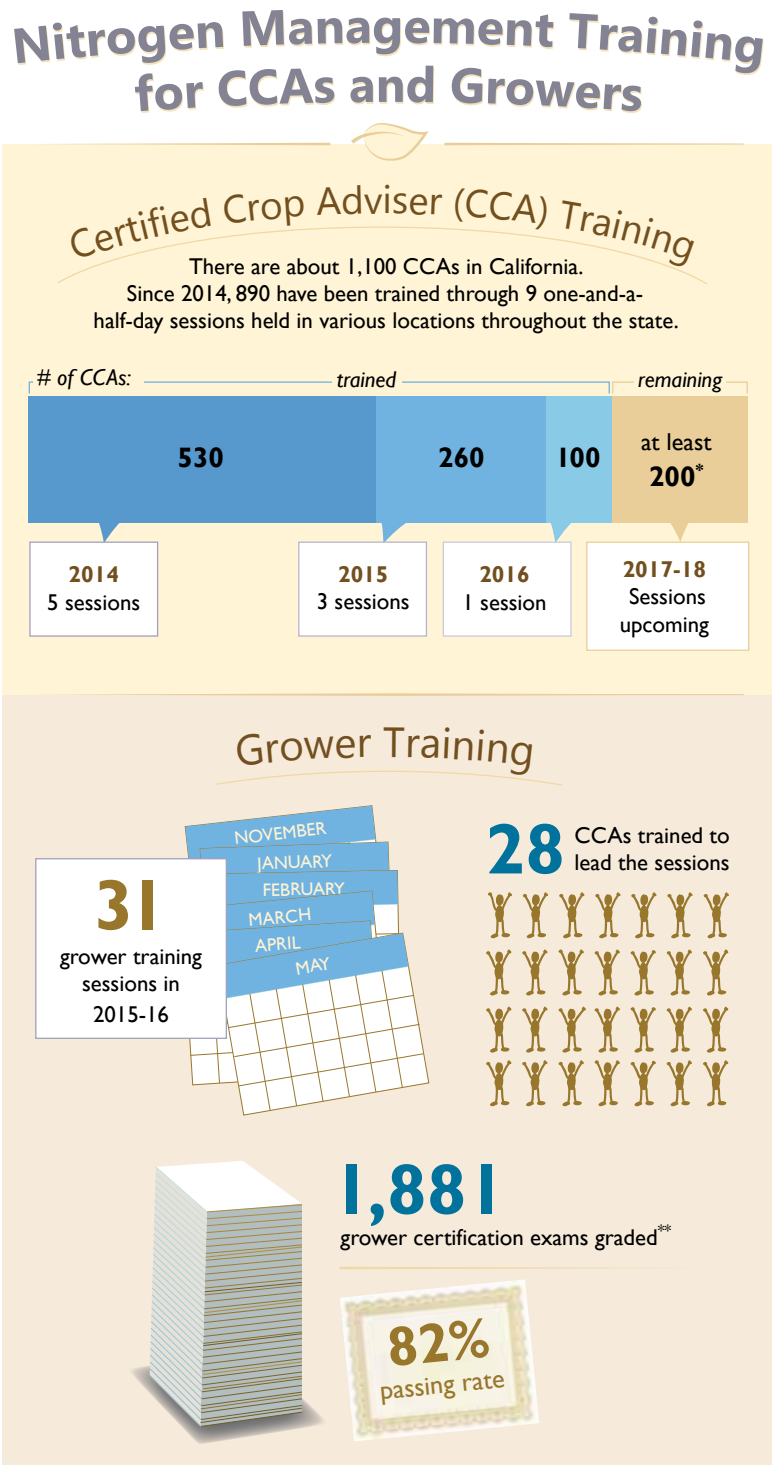
TECHNICAL EDUCATION

The annual conference provides a technical forum where new research and knowledge is discussed and disseminated among the agricultural community. Additionally, FREP provides growers and crop advisors with timely, technical education, including nitrogen management training.

The Nitrogen Management Training Program (NMTP) for CCAs and growers is a joint effort between CDFA, the University of California Agricultural and Natural Resources (UC ANR), the California CCA Program, the California Association of Pest Control Advisers (CAPCA), and the Coalition for Urban/Rural Environmental Stewardship (CURES).

The CCA curriculum facilitates 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 the Central Valley Regional Water Quality Control Board regulations.

Under the recent water quality regulations in the Central Valley region, growers are able to certify their own nitrogen management plans in areas that are at the highest risk for nitrate leaching to groundwater. In the grower training program, CCAs instruct growers on basic principles of crop nitrogen management and how to complete the Nitrogen Management Plans required by Central Valley Water Board regulations. Growers may self-certify their own nitrogen management plans if they



* As of February 2016. ** As of May 2016.

Sources: University of California Agriculture and Natural Resources (UC ANR), Coalition for Urban/Rural Environmental Stewardship (Cures), and California Association of Pest Control Advisers (CAPCA). Funding provided by FREP.

Figure 2. Nitrogen Management Training

participate in this CDFA training program and pass the exam. See Figure 2 for results of these trainings.

OUTREACH

FREP has sought to increase awareness of the safe and efficient use of fertilizer products by continuing to make research and crop fertilization guidelines, funded by the grant program, available online and at outreach events. Many decision-support tools that assist growers and advisors with their nutrient and irrigation management decisions are also available on the website.

In partnership with UC Davis Department of Land, Air, and Water Resources, FREP has developed:

A searchable database summarizing FREP-funded research projects - 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.

Crop fertilization guidelines - Based on a synthesis of peer reviewed journal articles and research reports, the crop-specific guidelines account for more than 70 percent of California irrigated agriculture. The guidelines are available at www.cdfa.ca.gov/go/FREPguide. New crops are being added to the guidelines on a continuous basis, and the crops included (currently 23) will double in the next few years.

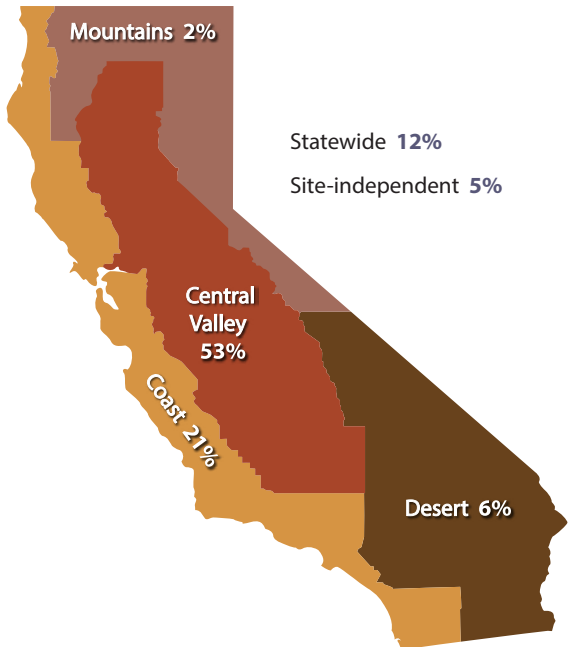


Figure 3. Locations where FREP projects have been conducted.

Figure 4. Nitrogen Management brochures for California crops are published by FREP.

Nitrogen management brochures for specific crops are published by FREP (Figure 4). Based on the guidelines, these outreach materials emphasize nitrogen management for common California crops. Irrigation maintenance checklists and tools are also available at events and on the FREP Resources page (www.cdfa.ca.gov/is/ffldrs/frep/Resources.html).

RESEARCH

The growing concern of nitrate present in ground and surface water from fertilizer sources prompts FREP-funded projects to address environmental, water, and air quality concerns as related to fertilizer use. FREP is helping to establish a baseline for efficient nitrogen fertilization for various crops and management practices that improve the performance of nitrogen fertilizers while minimizing environmental impact. Figure 3 illustrates the regional distribution of FREP funding. Figures 5 and 6 show, respectively, commodities and disciplines addressed by all FREP projects.

FREP continues to fund research to improve nutrient management practices through its competitive grants program. High-quality research and education projects go through a rigorous two-phase statewide competitive process, including independent peer review. Projects are typically funded at up to $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 possess technical and scientific expertise in the fields of fertilizing materials, agronomy, plant physiology, principles of experimental research, production agriculture, and environmental issues related to use of fertilizing materials. 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 2016, the Regular and Special RFPs.

REGULAR REQUEST FOR PROPOSALS

FREP research priorities for the 2016 Regular RFP were categorized into three major priority areas: improving input management, understanding soil-plant processes, and loss pathways.

1. IMPROVING INPUT MANAGEMENT:

Developing Integrated Decision Support Tools

As concern rises over shortages of fresh water and the potential environmental effects of California agriculture, a major challenge is to make the best use of fertilizers and water. New management tools are needed to help improve nutrient and irrigation management and to empower consultants and growers to make on-farm decisions that accommodate the complexities of agriculture.

Education and Outreach (Technical Education)

There is an increasing demand for applied technical trainings for agricultural workers at all levels. Development of educational and/or certification materials and methods to increase awareness and implementation of agronomically sound use of fertilizing materials and proper use and maintenance of irrigation systems is encouraged.

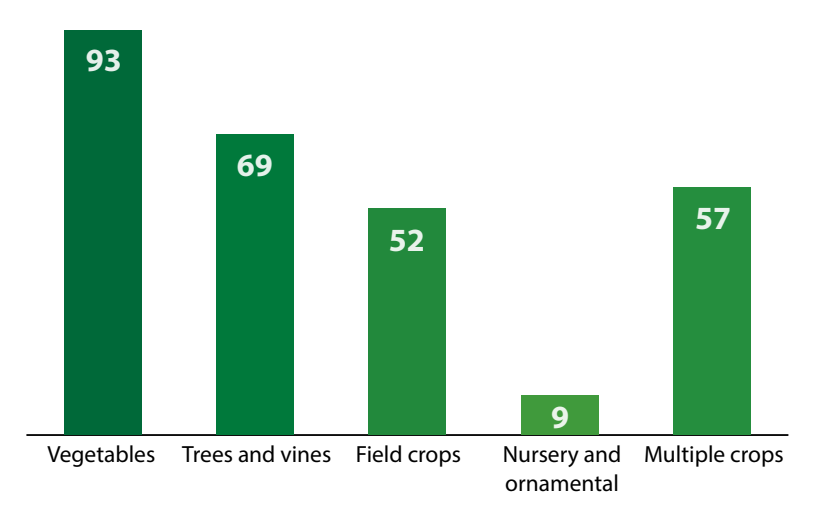


Figure 5. Distribution of FREP projects by commodity. Some projects address multiple commodities.

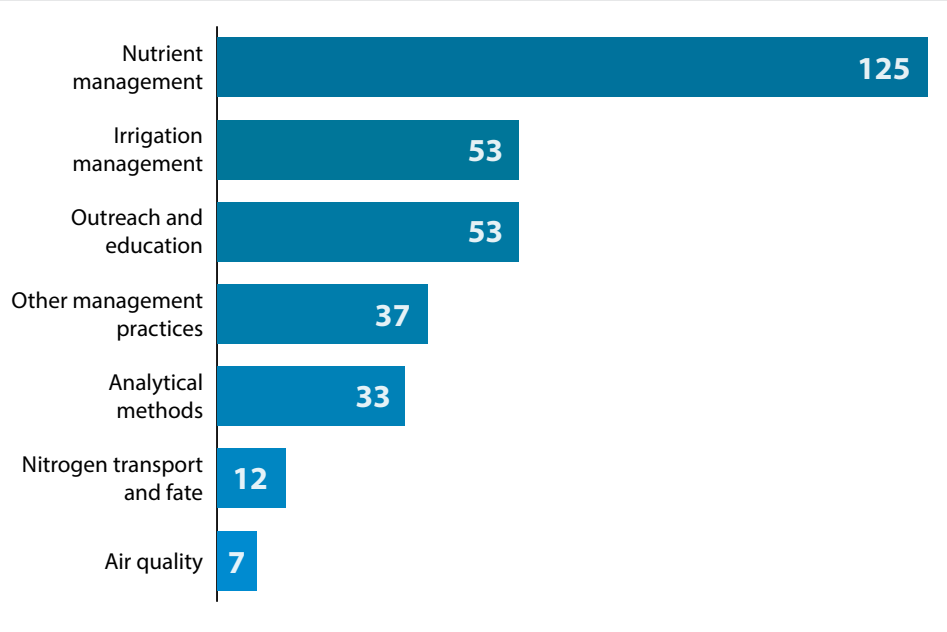


Figure 6. Distribution of FREP projects across different areas of study.

Promoting Adoption of Practices or Developing New Practices that Optimize Nutrient and/or Water Use Efficiency

Efforts to promote effective management practices and to help implement efficient nutrient management on grower's fields are of high priority. This priority area includes activities that:

- Promote adoption of existing decision support tools (e.g. CropManage)
- Support of peer to peer and community based learning
- Demonstrate recommended practices at the field scale
- Evaluate strategies to increase crop N use efficiency
- Promote practices that minimize nitrate movement below the root zone
- Promote practices that minimize nitrous oxide emissions related to fertilizer use

Addressing Challenges and Barriers to Adoption of Management Practices

A variety of management practices are available that can save money and time and improve environmental outcomes; however, many of these practices have not been adopted on a larger scale. Activities that improve our understanding of barriers to wider adoption of efficient management practices would include research that studies:

- The costs and benefits associated with adoption of various practices
- Economic thresholds
- Regulatory or institutional barriers
- Incentives or programs that might increase grower implementation of practices
- Human behavior, including studies that address fertilization and agricultural management decisions and the social, economic, and political variables driving adopting effective practices to improve fertilizer management.

2. UNDERSTANDING SOIL-PLANT PROCESSES:

Filling Knowledge Gaps for Nitrogen Management in Specific Crops

Certain crops have significant knowledge gaps that need to be explored concerning nutrient requirements or irrigation management. These crops include corn, pima cotton, processing tomatoes, baby lettuce, walnuts, citrus, and root crops.

The Role of Soil Organic Matter and Organic Fertilizing Materials on Nutrient Management in Soil

Across California, numerous organic materials are added to agricultural soils to improve soil physical, chemical and biological properties. These organic materials include, but are not limited to, biochar, soil amendments, manure-based fertilizing materials, cover crops and compost. Key issues to address the role that these materials have in nutrient and water management may include mineralization rates, agronomic rates, and impacts on nutrient management.

3. LOSS PATHWAYS:

Understanding and Quantification of Nitrate Movement in Deep Soil in Relation to Management Practices

There is a significant information gap in understanding nitrogen movement and distribution in soil as it moves below the root zone to groundwater. Studies of nitrogen movement can be conducted within any region of California.

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

Increasingly, growers are using a wide variety of sensors in their fields to help inform their decisions on irrigation and nutrient management. However, few growers have adequate tools to interpret sensor data. Development of easy-to-use and cost effective protocols to interpret sensor data is needed to effectively manage water and nitrogen use in agricultural operations.

Nitrous Oxide

Nitrous oxide is a greenhouse gas, one source of which is nitrogen fertilizer, that is significantly more potent than carbon dioxide. Comprehensive research has been completed on nitrous oxide emission factors for the top ten crops in California. The findings of this research can be used to test models that predict nitrous oxide emissions from different crops grown on numerous soil types under various irrigation/fertigation management practices in California. Research is needed to validate potential mitigation measures such as surface drip vs. buried drip, conventional formulations vs. nitrification inhibitors or controlled release formulations, surface fertilizer application vs. incorporation, fertilizer application timing studies,

fertilizer rate studies, crop and cover crop rotations, and irrigation timing relative to fertilizer application.

SPECIAL REQUEST FOR PROPOSALS

FREP priorities for the Special RFP were released after evaluation of the proposals for the Regular RFP. The were three priorities were: the effect of biochar on nutrient management, grower education and outreach, and challenges and barriers to improving nitrogen management.

The Role of Biochar in Nutrient Management of California Soil-Crop Systems

Biochar is considered to be a soil amendment that has the potential to simultaneously sequester carbon and improve soil physical, chemical and biological properties. Tree mortality in natural ecosystems, as well as tree prunings in orchards across California, are a potential feed stock for local biochar production. There is a need for better understanding of biochar for improved nutrient and water management in agricultural systems under California conditions. A better understanding of the economic feasibility of biochar use in California agriculture is crucial for better management of nutrients in croplands.

Education and Outreach (Technical Education)

There is increasing demand for applied technical training for growers and agricultural workers at all levels of farming organizations. Appropriately trained farm staff will employ irrigation and nutrient management practices that support efficient crop production and optimize environmental outcomes.

Potential training topics include nitrogen management for growers and irrigation and/or nitrogen management for agricultural workers at all levels. Trainings should build on (not duplicate) existing materials and resources, such as the growers Nitrogen Management Self Certification Workshop. They should feature new research, as well as outreach tools to optimize water and nutrient placement and timing for optimal environmental benefits and sustained yield (Crop Manage, for instance). Proposals should include metrics for evaluating the success of the outreach efforts (persons served, conservation practices implemented), potentially incorporating follow-up surveys to learn what impacts the trainings had on implementation rates of new management techniques.

Addressing Challenges and Barriers to Improving Management Practices

There is a variety of available management practices that can save money, time and improve environmental outcomes; however, many of these practices have not been widely adopted. Research on barriers to wider adoption or improvement of management practices would include studies that address fertilization and agricultural management decisions and the social, economic, and political variables driving implementation of effective practices that improve fertilizer management.

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 other agriculturalists. Proceedings from past annual conferences and pamphlets on various topics relating to fertilizing techniques are available by contacting FREP at FREP@cdfa.ca.gov or (916) 900-5022.

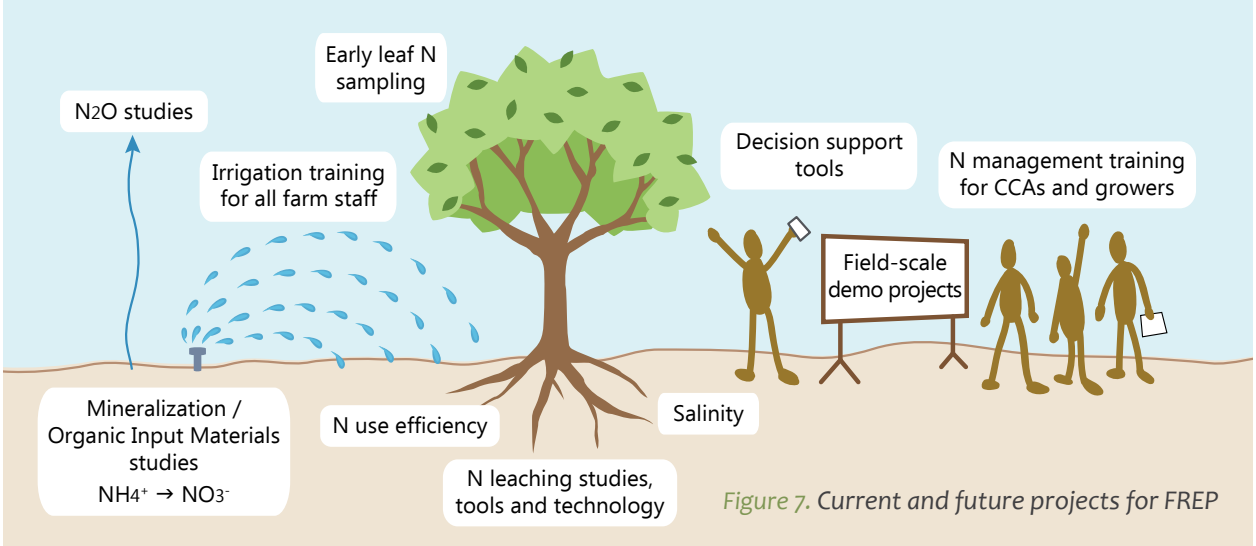


Figure 7. Current and future projects for FREP

FREP collaborates and coordinates with numerous other organizations to extend FREP research to agricultural advisors and growers. Agencies FREP partners 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 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 optimize fertilizer use efficiency.

There are more challenges facing the agricultural industry than ever before. FREP has maintained a commitment to outreach and education by continually seeking new ways of making scientific research accessible to a broad audience of agricultural professionals.

FREP annually releases research priorities in its calls for research and education proposals. Among those priorities, developing and improving decision-support tools for growers and consultants, as well as establishing education and outreach programs on nutrient and irrigation management, are of high importance. FREP encourages development of certificate programs designed for various target audiences including crop advisors, growers, and other farm staff. Other areas of interest include nitrogen mineralization from organic sources, nitrogen management of various crops, and nitrate leaching studies (Figure 7).

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 Dr. John Bushoven, Rex Dufour, Dr. Eric Ellison, Charles Hornung, DD Levine, Dr. Marc Los Huertos, Dr. Rob Mikkelsen, Dr. Barzin Moradi, Dr. Jerome Pier, and Steve Spangler 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, Ron Naven, 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; the former and current Inspection Services Division Directors, Rick S. Jensen and Natalie Krout-Greenberg; Dr. Amadou Ba, Environmental Program Manager II; Brooke Elliott, Research Analyst I; Dr. Doug West, Environmental Scientist; Dr. Barzin A. Moradi, Senior Environmental Scientist (Supervisory); Mark Cady, Senior Environmental Scientist (Specialist), and Natalie Jacuzzi, Environmental Scientist. In addition, special thanks to Dr. Daniel Geisseler, Extension Specialist, and Patricia Lazicki, Assistant Specialist, both with the UC Davis Department of Land, Air, and Water Resources, for their diligent work on creating and expanding the FREP research database and Crop Fertilization Guidelines.

CONFERENCE PROGRAM

Wednesday, October 26, 2016

Facilitator: *Mr. Steve Vasquez, Tessenderlo Kerley, Inc.*

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

9:20 – 9:45 **Agriculture and Groundwater Banking for Increasing Water Security**
Dr. Graham Fogg, Professor, UC Davis Department of Land, Air and Water Resources

9:45 – 10:10 **Salinity and the Threat to Productivity of Orchard Crops in the Central Valley**
Dr. Patrick Brown, Professor, UC Davis Department of Plant Sciences

10:10 - 10:35 **Evaluating Biochar's Potential in California Agriculture**
Dr. Sanjai Parikh, Associate Professor, UC Davis Department of Land, Air and Water Resources

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

10:50 - 11:15 **Status of the ILRP in the Central Valley**
Sue McConnell, Section Chief, Central Valley Water Quality Control Board

11:15 - 11:40 **CCAs and Compliance with Water Board Regulations**
Fred Strauss, Branch Manager, Crop Production Services

11:40 – 1:00 **Lunch**

1:00 –2:30 **Panel Discussion: Growers' Perspective on Challenges to Improving Nutrient Management and Irrigation Practices in California**
Moderator: Dr. Karen Lowell, Agronomist, USDA-NRCS

2:30 – 2:45 **Nitrogen Management Training for Growers**
Mark Cady, Senior Environmental Scientist, CDFA

2:45 – 3:00 **Break**

3:00 – 3:25 **Irrigation Scheduling Using ET-Based Methods**
Dr. Khaled Bali, Irrigation Management Specialist, UC Kearney Agricultural Research and Extension Center

3:25 – 3:50 **Investing in Your Soil: The Role of Organic Matter in Soil Function**
Rex Dufour, Manager, National Center for Appropriate Technology

4:15 – 5:30 **Poster Session**

Thursday, October 27, 2016

Facilitator: *Dr. Steve Petrie, Yara North America, Inc.*

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

9:05 - 9:30 **Soil Life, Soil Management: What Every Agronomist Should Know About Microbes**
Dr. Kate Scow, Professor, UC Davis Department of Land, Air and Water Resources

9:30 – 9:55 **The Role of Nutrients in Pest Management**
Dr. Lacey Mount, Agronomist, Dellavalle Laboratory, Inc.

9:55 – 10:20 **Ecological Approach to Nutrient Management for Soil Health**
Dr. Z. Kabir, Regional Soil Health Specialist, USDA-NRCS

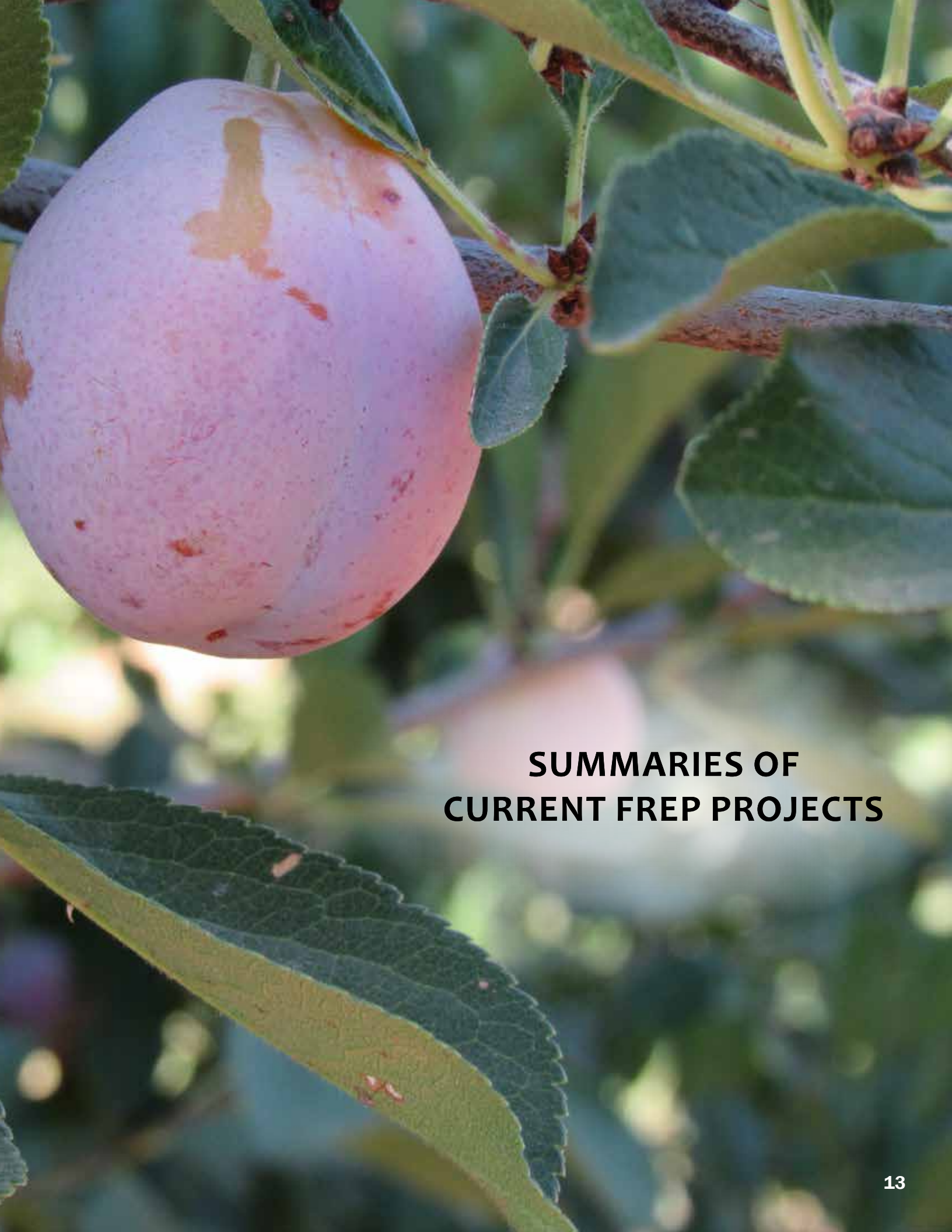
10:20 - 10:30 **Break**

10:30 - 10:55 **Deficiency to Toxicity: The Role of Boron in California Crop Production**
Dr. Sebastian Braum, Director of Technical Services, The Tremont Group, Inc.

10:55 - 11:20 **Nitrogen Budgets in California Rice Systems: What Do We Know and How Can We Improve?**
Dr. Bruce Linquist, UCCE Rice Specialist, UC Davis Plant Sciences

11:20 - 11:45 **Improving N Use Efficiency of Cool Season Vegetable Production Systems with Broccoli Rotations**
Richard Smith, UC Farm Advisor, Monterey County

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



SUMMARIES OF CURRENT FREP PROJECTS

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

Project Leaders:

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Cooperators

Matt McGuire
JV Farms

Steve Alameda
Top Flavor Farms

C. R. Waters
Duda Farm Fresh Foods Inc.

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 objectives of this project are to: 1. Develop economically viable and effective sampling protocols to generate prescription maps for the variable rate application of P, and 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, and 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 a 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 on 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 was 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 was harvested in early July, 2015.

Task 5. Field studies were repeated in fall-winter-spring 2015-2016. Studies included lettuce in Yuma, AZ and broccoli and spinach in Bard, CA. The lettuce was harvested March 1 and 2, 2016, the broccoli March 4, 5 and 6, and the spinach February 2. Two additional studies will be initiated with spinach in fall 2016. Economic analysis is under way and new data will be incorporated into this analysis.

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 four locations

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 and 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, 2014-2015, and 2015-2016 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 conclusions 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 2015 and 2016. Preliminary data collected during 2013-2016 showed potential economic and environmental benefits to VRT fertilizer management.

We have conducted a number of formal outreach activities during the 2013 to 2016 period. These included presentations at the SW Ag Summit in Yuma during 2014, 2015 and 2016, the Western Plant Health meeting in Yuma in 2014, the Desert Ag Conference in Chandler Arizona in 2014 and 2015, the Fall Pre-season Vegetable Workshop in Yuma in 2014, the FREP annual conference in 2015, and the CCA Nutrient Seminar in Ontario California in 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 spring 2017.

ACKNOWLEDGMENTS

We gratefully acknowledge support of the CDFA- FREP program for sponsoring this work and the cooperation of participating growers including Desert Mist Farms, JV Farms, Top Flavor farms, and the Ak Chin Native American Farm.

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

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INTRODUCTION

Intensive vegetable production in the southwestern U.S. receives large annual applications of nitrogen (N) fertilizers. Amounts of N applied range from 200 to 400 kg/ha and crop recoveries are generally less than 50%. There are numerous possible fates of fertilizer applied N in addition to the desired outcome of crop uptake. 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. 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.

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 and Polyon 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

Since most cool season desert crops were planted by 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 six experiment-demonstrations were initiated in the central coast with iceberg and romaine lettuce, spinach, and Mizuna.

Task 2c. Additional studies in low desert

In fall-winter-spring 2015-2016 six experiment-demonstrations were conducted across the desert. Experiment-demonstrations with spinach and romaine lettuce were conducted in the Coachella Valley, California. Experiment demonstrations with broccoli and spinach were conducted in Bard, California. Experiment-demonstrations with iceberg lettuce and spinach were conducted in Yuma and Maricopa, Arizona, respectively.

Task 2d. Additional experiment-demonstrations in the central cost.

Several more experiment-demonstration were initiated in the central coast during the summer of 2016. Data collection and analysis for these studies are on-going.

Task 2e. Additional experiment-demonstration in the desert.

Sites for these experiment-demonstrations have been negotiated with grower-cooperators and these will be initiated over the next 5 months.

RESULTS

Results with CRN continue to be favorable for many, but not all, crop production scenarios. There are interactions with soil, irrigation method, and season. Furthermore, in each demonstration we made modifications to accommodate the grower's comfort zone.

Two examples, selected from over 20 experiment-demonstrations conducted so far are shown below. One site was with desert spinach produced on a silty clay loam in Imperial County, CA. This experiment-demonstration had 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 in the desert. 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 typically outperforms CRN 90. Two growers that worked with us in 2014 and 2015 have implemented CRN products into their spinach N management programs.

Another example is with romaine lettuce in the central coast. The fertilizer treatments were applied in two ways: a post thinning application was made on July 12 by shanking the fertilizer between the seedlines using a Fairbanks small-plot dry fertilizer applicator; the remainder of all fertilizer treatments were applied through the drip system. The crop was sprinkler irrigated until after thinning when the drip tape was applied on July 12. The first drip irrigation and fertigation to the drip treatments was applied on July 13 and the second on July 29. See table 5 for treatments and rates. Each plot was 2 40-inch beds wide by 150 feet long and replicated 4 times in a RCBD. The field was sprinkler irrigated until thinning and then was irrigated with drip for the rest of the growth cycle. The drip system applications of liquid fertilizer were injected into the drip irrigation

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

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

Material[1]	App. Method[2]	1st app. N/A	2nd app. N/A	Total N/A	Fresh yield tons/A	Biomass %N	Biomass lbs N/A
Untreated	---	0	0	15	27.53	2.67	76.2
Standard	tractor	65	65	145	34.35	3.69	119.5
Moderate	tractor	40	20	75	31.62	3.11	93.0
Nitrapyrin 0.50 lb ai	tractor	40	20	75	34.06	3.06	97.5
Nitrapyrin 1.0 lb ai	tractor	40	20	75	31.58	2.94	89.7
Duration ST	tractor	40	20	75	33.75	3.07	102.1
Novatec	Drip	40	20	75	33.22	3.20	101.6
NSure/UN 32 (25:75)	Drip	40	20	75	34.47	3.11	102.1
NSure/UN 32 (25:75) NBPT	Drip	40	20	75	33.69	3.04	95.5

Table 2. Romaine Trial in central coast in summer 2015. Application timing, dates and rates (lbs N/A)

system by use of a multi-port manifold with backflow prevention valves which fed two inch layflat that provided water and fertilizer for each treatment. Injector ports in each layflat were used to inject the appropriate rate of UAN 32 liquid fertilizer. Battery powered pumps were used to inject fertilizer/ nitrification inhibitors mixtures into the layflat and injections were made during the middle third of irrigation events. Irrigation levels were managed at 140% of ET.

The main statistical differences were between the untreated and other treatments (Table 2). As was seen in trials 1 and 2, there are trends that indicate higher yield in the fertilizer technology treatments over the moderate nitrogen treatment. The exception was the nitrapyrin at 1.0 lb a.i./A which may have had some phytotoxicity. The nitrogen technology treatments did not have higher percent nitrogen in the tissue, but higher nitrogen uptake than the moderate nitrogen treatment was attributable to greater biomass. The same trends were evident in the tractor and drip applied nitrogen treatments. Yield increases in the nitrogen technology treatments over the moderate nitrogen treatments were typically around 2.0 tons/A.

ACCOMPLISHMENTS/PRELIMINARY FINDINGS

We completed laboratory incubations for all products in our inventory. These will continue as we gain access to more products. We continue to conduct experiment-demonstrations 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.

ACKNOWLEDGMENTS

We gratefully acknowledge support of the CDFA-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.

Optimizing the Use of Groundwater Nitrogen for Nut Crops

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INTRODUCTION

The purpose of this work was to fill in knowledge gaps, both at the academic and grower level for the "Pump and Fertilize" nitrogen (N) management practice. We examined N-mass balance under best management practices applying nutrient budget N management and to describe and contrast those practices with 'Pump and Fertilize' N management treatments. Prior to the beginning of the growing season the growers planned the N budget for the year based on the Almond Nitrogen Model http://fruitsandnuts.ucdavis.edu/Weather_Services/Nitrogen_Prediction_Models_for_Almond_and_Pistachio/. Pump and Fertilize (PandF) takes into account well water NO_3^- concentration in the N budget. N-fertilizer was applied as planned and leaf samples indicated that there was no need to modify the N-budget midseason.

Another major knowledge gap concerned estimating water and N losses below the root zone at the orchard scale. We used the agronomic Nitrogen Use Efficiency approach of monitoring the annual N-budget (applied-N minus removed-N) as a reference and compared this with our calculations and modeling exercises. We compared this mass balance with "Darcy flow" and inverse modeling, two approaches to estimating N and water flow through the vadose (root) zone.

OBJECTIVES

Overarching Objective:

The overarching objective being pursued under this investigation contributes to a multidisciplinary approach that will answer a number of key questions not only relevant to the "pump and fertilize" (PandF) approach to groundwater NO_3^- management but also for on farm monitoring of Nitrogen Use Efficiency in general. Specific objective included:

1. Establish research and demonstration orchards for "Advanced Grower Practice", High Frequency Low Nitrogen Concentration and "Pump and Fertilize" nitrogen (N) management in pistachio and almond orchards within two "Hydrogeologically Vulnerable Areas" (HVAs) as defined by the California Department of Water Resources (2000).
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 those practices with 'pump and fertilize' N management treatments.
3. Characterize key biological and physical parameters relevant to PandF concept (concentration dependent uptake, root distribution and activity, phenology of uptake, seasonal plant-soil N balance, soil NO_3^- movement etc).
4. Establish proof of concept for use of natural abundance stable isotopes of $\delta^{15}N$-NO_3^- as a tracer in N tracking under PandF practices.

5. Develop and ground validate decision support models (including online versions of HYDRUS) to assist growers with optimal management of groundwater N (mainly NO_3^-).

6. Demonstrate and proactively extend developed results, technologies relevant to on-site self-assessment and BMP's to growers.

DESCRIPTION:

The following outlined tasks were achieved during 2013-2016:

7. Almond orchard sites were located near Modesto with site characteristics (ground water depth of 25-35 ft., sandy and sandy loam soils) consistent with establishing connectivity between vadose zone N monitoring with first encounter of below root zone leachable NO_3^--N with groundwater (GW). Installation of the groundwater wells is anticipated for October-November 2016 and will be carried forward with support from the Almond Board of California (ABC).

8. We conducted nutrient budget N management, fertigations and early season leaf sampling and N-load adjustments to all three treatments in randomized complete blocks designs (Figure 1); including advanced growing practice (AGP), pump and fertilize (PandF) and high frequency low-N concentration (spoonfeed, HFLC) at two research orchards in Madera (pistachio and almond).

9. We collected samples from arrays of suction lysimeters (Figure 1) and analyzed them for nitrate (NO3-) and total nitrogen (TN) content. More than 100 pore water samples from the vadose zone (root zone) down to 300 cm below the ground surface (effective root zone). In addition we gathered soil samples from nine sites prior to the beginning of the 2014 growing season to evaluate changes in the soil N-pool between seasons.

10. We monitored temporal changes in the volumetric water content in the subsurface using continuous readings by 5TE sensors (Decagon Devises, WA USA) and bi-weekly readings by a neutron probe (Hydroprobe ,CPN, CA USA). To estimate the hydraulic gradient below the root zone we continuously monitored the matric potential using custom tensiometers established below the effective root zone (at 280 and 300 cm).

11. We estimated leaching under the orchards using gathered field data and compared it with modeling exercises using HYDRUS and RETC models with specific modifications. Simulations were compared to nutrient budgets and mass balances (Baram et al. 2016a; Baram et al. 2016b).

12. We presented the first results and experimental principles of project goals at grower and other stakeholder meetings where more than 3,000 growers and grower consultants (eg. CCAs).

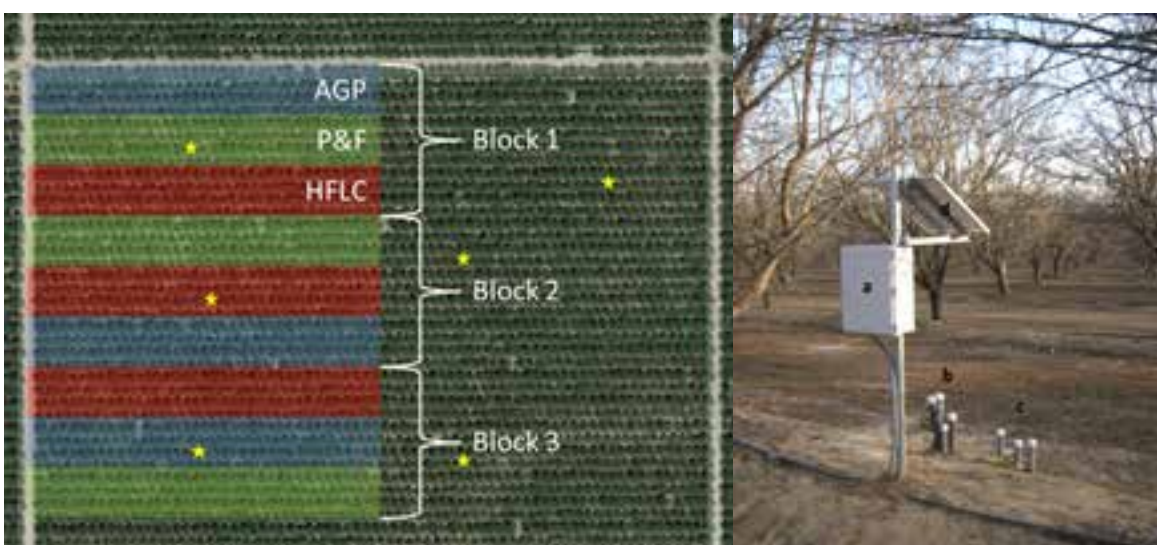

Figure 1. Basic experimental design (left) for both the almond and pistachio orchards with 4 rows of trees in each treatment and 3 replications each for AGP, PandF and HFLC. Sensor arrays (right).

Presentations have been ongoing since 2013 and through 2016, including The Almond Board Annual Conference on December 6th - 8th 2016.

13. We coordinated web-based and manuscript publications in peer reviewed journals. We prepared technical summaries for use by the supporting commodity boards (ABC and California Pistachio Research Board, CRPB), provided data to Central Valley Water Board, other agencies for perusal.

RESULTS AND DISCUSSION

Despite tremendous variability in soil NO_3^- concentration (Figure 2), the orchard average annual NO_3^--N losses were well estimated based on surface N-mass balance, vadose zone based water and N mass balance, flow calculations and HYDRUS (a water and NO_3^- infiltration model) modeling were all in the same order of magnitude at 80 – 240 kg-N ha^{-1} y^{-1}). All methods indicated that most of the N losses occur early in the growing season (February – May), when fertilizer is applied to wet soil profiles. Simple mass balance (i.e. N-load applied minus N-load removed) provided a good proxy of the annual N accumulation in the soil profile.

Good agreement between the annual N accumulation and the vadose zone based estimates of N losses below the effective root zone indicated that at this research site which we consider typical, eight vadose zone monitoring sites, representing different soil layering, were sufficient to capture the spatial variability in N loss at the orchard scale.

Yields did not differ between the AGP, HFLC and P and F treatments for 2014 and 2015 (*cf* Table 1 for 2014), thus indicating that P and F is a verifiable approach. Given the tremendous variability in pore water NO_3^- it is not certain that any of the N-loss numbers in Table 1 yet represent significant differences and investigation on this issue is ongoing (see Baram et al. 2016a).

RECOMMENDATIONS

All methods indicated most of the N losses occur early in the growing season (February – May), when fertilizer is applied to wet soil profiles. Thus, conservative N fertilization is recommended under this condition. Simple mass balance (i.e. N-load applied minus N-load removed) provided a good proxy of the annual N accumulation in the soil profile. Reduction of N losses at the orchard scale would require alternative fertigation and irrigation practices for long-term retention of water and N in the root zone.

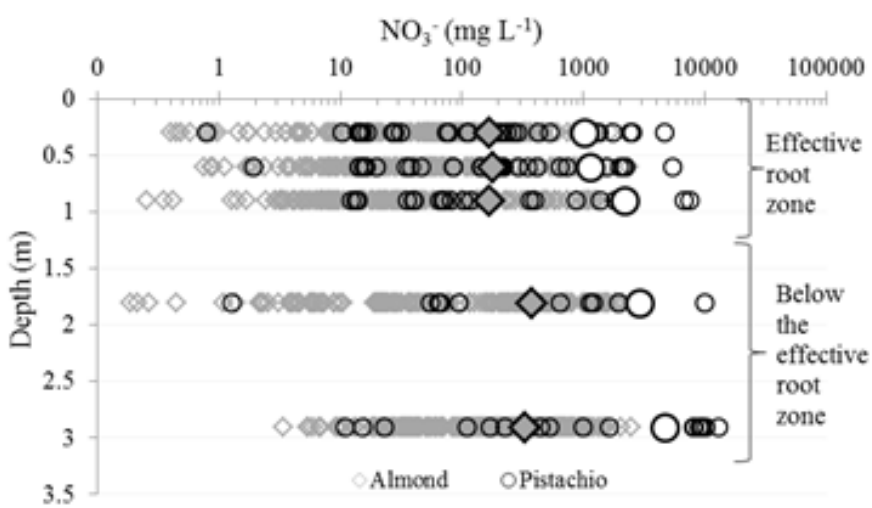

Figure 2. Nitrate concentrations in pore water samples taken throughout the monitoring period of 2014 – 2016.

Table 1. Total N-loads applied and lost from the orchards during the 2014 growing season.

	Almond (lb. acre^{-1})			Pistachio (lb. acre^{-1})		
	AGP	**HFLC**	**PandF**	**AGP**	**HFLC**	**PandF**
Yield (kernel)	2699	2869	2695	2837	2869	2695
[1]Groundwater N	73.8	73.8	73.8	14.3	14.3	14.3
[1]Fertilizer N	215	186	215	174	166	161
[2]N-in kernel	122	135	107	106	106	100
[3]N-in wood	25	25	25	25	25	25
[3]N-in hull and nut	5	5	5	5	5	5
N-loss	137	95	152	52	44	45

[1]Total cumulative load applied; [2]based on N-content measured in kernels; [3]based on data from previous investigations.

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

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

OBJECTIVES

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

DESCRIPTION

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

Procedures: Replicated field trials were conducted on the USDA Spence research facility near Salinas in 2013 and 2014 to address objective 1 for lettuce and broccoli. Irrigation water with N concentrations ranging from 2 to 42 ppm and were compared to an unfertilized control and a fertilized standard treatment (seasonal total of 150 lb N [AN20] applied in weekly fertigations). In addition, we included a treatment to evaluate crop N recovery from water dominated by NH_4-N. Water-powered proportional injectors were used to enrich all drip applied water to the target concentrations of treatments. Injected NO_3-N was a blend of $Ca(NO_3)_2$ and $NaNO_3$ to maintain the cation balance in the water. To observe the interaction of irrigation efficiency and crop nitrogen recovery, each N treatment was evaluated at two levels of applied water: 1. standard water rate equal to 110% of crop ET 2. High water rate of 160% to 180% of crop ET, which correspond to 40 to 50% leaching fractions. Lettuce (cv. Telluride), was seeded on 40-inch wide beds and germinated using overhead sprinklers. Water treatments were begun after the crop was thinned and cultivated, and the field was converted to surface drip. Plots measured 4 beds × 40 ft. Treatments were replicated 4 times and arranged in a split-plot randomized complete block design (water rate = main plot; nitrate concentration = sub-plot). Broccoli crops (cv. Patron) were also direct seeded, and followed the same experimental design and procedures as described for lettuce, with the exception that the fertilizer N treatment equaled 220 lbs N/acre.

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

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

RESULTS AND DISCUSSION

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

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

The second set of trials which directly compared crop N recovery from irrigation water and fertilizer, demonstrated similar NRE from water and fertilizer sources of N in lettuce (Figure 3) and broccoli (Figure 4). Regression lines were fit to the N uptake

response to the fertilizer treatments and the symbols represent mean N uptake response from the water N treatments. Crop N uptake from the water treatments was equal or greater than from corresponding fertilizer treatments. Crops were able to recover N from water with concentrations of nitrate as low as 14 ppm N. NRE was similar under high and standard water rates for lettuce but as found in earlier trials with broccoli, NRE declined for both the fertilizer and the water N treatments under the high water rate (Figure 4).

CONCLUSIONS

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

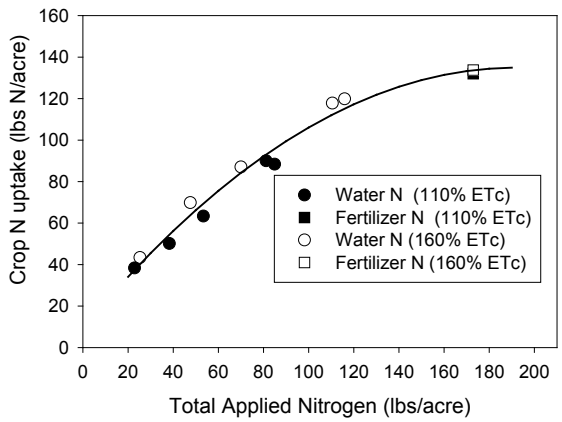

Figure 1. N uptake by lettuce (spring crop) from water and fertilizer sources of N at standard (110% ET) and high water rates (160% ET).

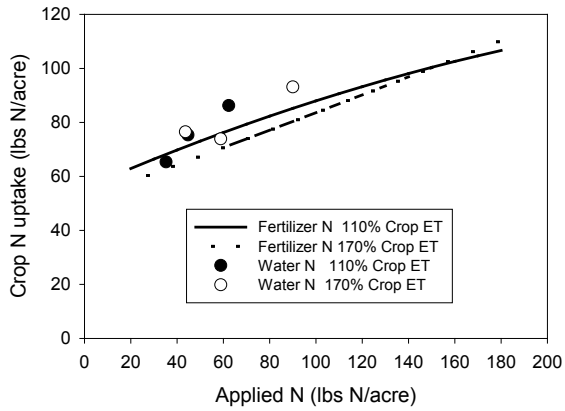

Figure 3. N uptake by lettuce from water and fertilizer sources of N at standard (110% ET) and high water rates (170% ET). Regression curves were fit to data from treatments receiving only fertilizer N. Symbols represent the means of the water N treatments.

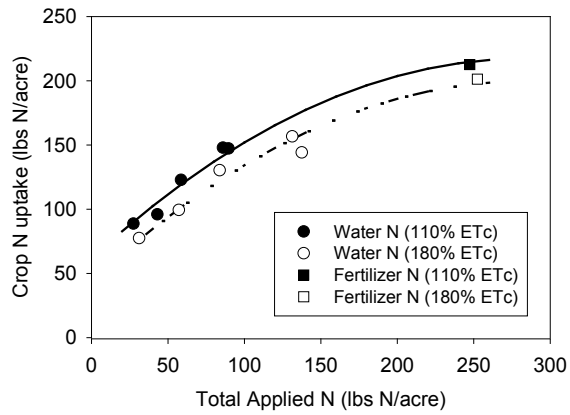

Figure 2. N uptake by broccoli from water and fertilizer sources of N at standard (110% ET) and high water rates (180% ET).

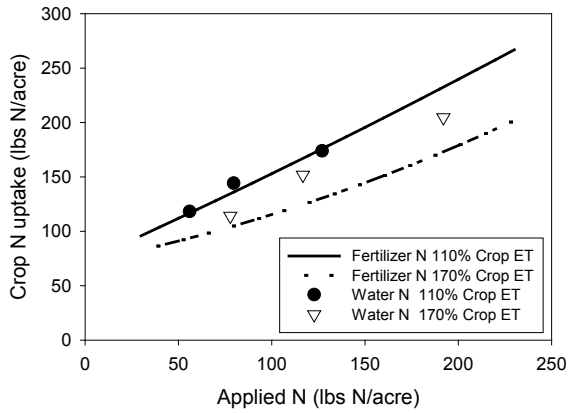

Figure 4. N uptake by broccoli from water and fertilizer sources of N at standard (110% ET) and high water (170% ET) rates. Regression curves were fit to data from treatments receiving only fertilizer N. Symbols represent the means of the water N treatments.

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

ACKNOWLEGEMENTS

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

Developing Nitrogen Management Strategies to Optimize Grain Yield and Protein Content and Improve Fertilizer Use Efficiency in California Wheat

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INTRODUCTION

Nitrogen (N) fertilizer management is a key determinant of the productivity and profitability of spring wheat. Wheat growers are paid not only for crop yield, but also for grain protein content, and achieving acceptable protein content is a continual challenge for California wheat producers. This challenge is more extreme in certain contexts, such as in the Intermountain area where there is often a discount for wheat with less than 14% protein compared to 13% in many California markets, as well as for particular types of wheat, such as durum wheat grown in the San Joaquin Valley.

Grain yield and protein content are often inversely related and influenced by the rate and application timing of N fertilizer. High rates of pre-season N fertilization can be attractive to growers due to the reduced cost of the pre-season forms of N and the ease of application. However, applying high rates of N pre-plant can also result in reduced grain protein content because average root-zone soil N levels available for plant N uptake may have declined once the crop reaches the grain filling stage, which is a critical time in determining grain protein. Additionally, very high early rates of N fertilization may cause excessive vegetative growth and lodging as well as increase N losses to the environment through pathways such as nitrate leaching.

For these reasons, over the past several seasons we have evaluated how the timing of N applications affects the yield and protein content of hard red and white spring wheats grown in diverse California environments. The goal of this work is to equip growers and crop consultants with a better understanding of the need for N at various stages of crop growth and to provide guidelines as to appropriate rates based on the use of in-field tests of the plant-soil environment.

OBJECTIVES

1. Measure the yield and protein content of popular hard spring wheat varieties grown using different N fertilizer rates and application timing to determine at which stages of growth fertilizer applications are most efficiently used by the crop for grain yield and protein.
2. Monitor relative changes in the plant-soil N status at critical phenological stages when growers might consider whether or not to apply a N fertilizer topdress.
3. Develop decision support tools using low-cost soil and plant diagnostic quick-tests that indicate whether a particular crop is likely to respond to a N fertilizer topdress.

DESCRIPTION

In experiments conducted over multiple years in the Intermountain Region, the Sacramento Valley, and the San Joaquin Valley, we applied N fertilizer in different proportions at four stages of the crop cycle: 1) pre-plant; 2) tillering-to-early-jointing 3) late-boot-to-early heading; and 4) flowering. For a given rate of N application, some treatments received all the N fertilizer pre-plant, whereas others received none until tillering, and still others received a portion at each of 2 or 3 crop growth stages. Urea was the fertilizer used and, for in-season applications, it was broadcast just

before rain or irrigation events both to ensure that the N was available in the crop root zone and that volatilization losses were minimized. Experiments were conducted on fields where the previous crop had been unfertilized to ensure low residual soil N concentrations and improve our ability to measure contributions to plant growth from fertilizer additions. We measured yield and protein content from grain harvested from plots 100 ft^2.

Prior to the start of the season, pre-plant soil samples were taken to 8 feet to assess baseline soil nitrate-N levels throughout the rooting zone. During the season, soil samples were taken from the top foot of the soil profile at critical stages of crop development from a subset of treatments that varied in N rate and application timing. These samples were analyzed for nitrate-N using both laboratory and quick-test methods. Finally, post-harvest soil samples were taken to 8 feet and analyzed for nitrate-N to assess the effect of N fertilizer application rate and timing on residual soil nitrate-N concentrations.

In addition to the soil monitoring, leaf and canopy reflectance (using an AtLeaf cholorphyll meter and a Greenseeker NDVI meter, respectively) were measured on a periodic basis throughout the season. Leaf tissue samples were also collected at critical growth stages in order to relate these proximal sensed measurements to a biophysical measurement. Statistical relationships between proximal sensed plant measurements, in-season soil measurements and wheat productivity were determined and used to delineate crop fertilizer demand throughout the season as well as the likelihood of crop response to a post-measurement fertilizer application.

RESULTS AND DISCUSSION

We found that crops receiving pre-plant fertilizer applications used N less efficiently than crops that received N applications at tillering and later (Figure 1). The reason is that, prior to tillering, the crop has relatively little demand for N. Then, between mid-tillering and the boot stage, the daily demand for N by the crop nearly triples, and this high rate of N demand continues through the flowering stage. Crop biomass is increasing rapidly during this period and grain formation is also occurring. As a result, N fertilizer applied at tillering and beyond, accompanied by enough water to move it into the root zone and stimulate crop growth and N uptake, results in higher yields and higher grain protein content (Figure 1).

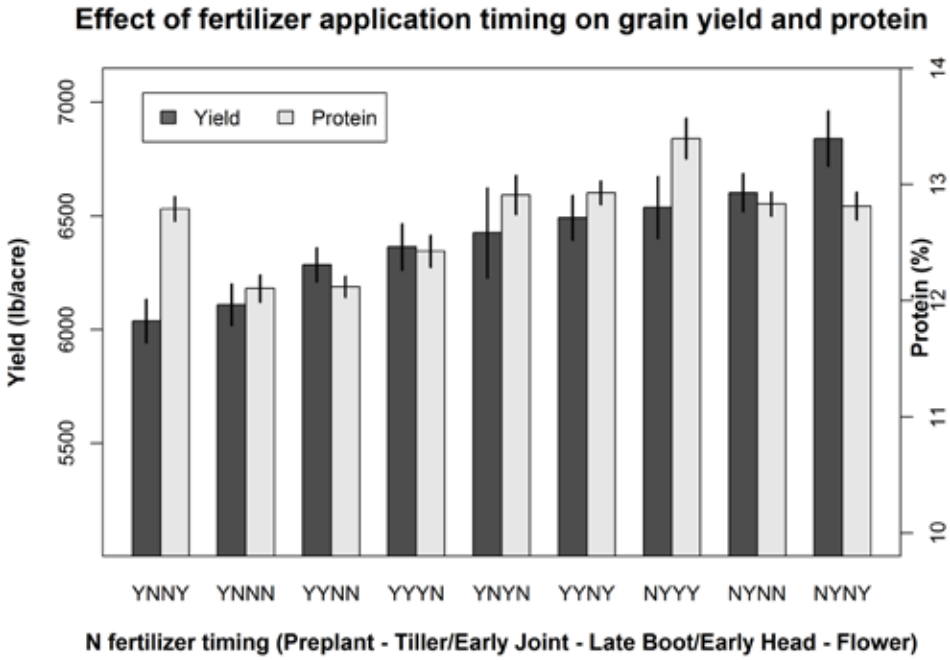

Figure 1. Wheat yield (left axis) and grain protein content (right axis) as a function of N fertilization application timing averaged across 5 site-years at rates of N fertilization for which there was a significant yield and/or protein response. "Y" and "N" indicate whether or not (Y for "yes" and N for "no") a crop received a N fertilizer application at one of the four stages indicated.

To further illustrate the relative value of in-season N fertilizer applications, Figure 2 depicts plants at mid-tillering in two of the experimental treatments at the Intermountain Region site in 2014. Treatment A received all of the N fertilizer as a pre-plant application. Treatment B received no N until the day this photo was taken, when it received 80% of its seasonal N; the remaining 20% was applied at flowering. Treatment B yielded 16% more grain than Treatment A and had more than 1 percentage point higher protein, despite its relative N deficiency at the tillering stage of growth. In the end, because so much more of the N uptake occurred after this stage of growth, the tillering-flowering applications better matched the overall timing of N demand by the crop and allowed it to stage a "come from behind" victory relative to the crop that received all of its N pre-plant.

The soil nitrate-N concentrations in the top foot of the soil profile as well as the leaf chlorophyll and canopy NDVI measurements recorded at tillering, late-boot/early-heading and flowering each provided unique information about the crop-soil N status and the likelihood of a post-measurement fertilization response. At the tillering stage, the soil nitrate-N was an important predictor of crop productivity, with 21 ppm soil nitrate-N in the top 12 inches of the soil profile serving as a threshold for predicting whether a crop was likely to respond to an N topdress at the tillering stage (Figure 3). As the crop transitioned into the reproductive growth stage, canopy NDVI and leaf chlorophyll measurements became relatively more important than soil nitrate-N for indicating productivity outcomes. When soil nitrate-N in the top 12 inches of the soil profile was measured in tandem with leaf chlorophyll and canopy NDVI, the combined information from these measurements predicted productivity outcomes with accuracy (R2 = 0.68, 0.67, and 0.70 for measurements made at the tillering, late-boot/early-heading and flowering staged, respectively). Figure 4 illustrates the value of this combined information at the tillering stage of growth, where plots with measurements that fell below the respective thresholds for the soil and plant diagnostic tools demonstrated a strong response to subsequent application of N fertilizer.

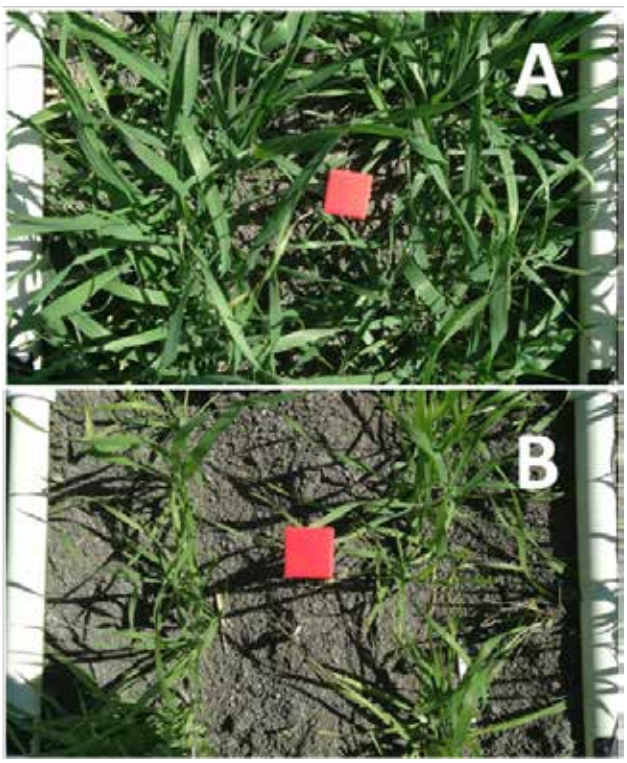

Figure 2. Comparison of Yecora Rojo growth at mid-tillering (5/22/14; 36 DAP) at the Intermountain Region site; 100% of seasonal N application pre-plant (A), and no N application until tillering (B).

TAKE HOME MESSAGE

Wheat yield and protein content are highest when more of the total N fertilizer application occurs in-season versus pre-plant. Growers should consider applying more N in-season and less pre-plant to improve yield and protein content. Soil nitrate-N and leaf and canopy proximal sensing devices provide valuable information about the likelihood of crop response to in-season N fertilization and the overall protein yield response to N fertilization in spring wheat. Used in tandem with in-season applications, growers can improve yield and protein content while using N fertilizers efficiently.

ACKNOWLEDGEMENTS

In addition to CDFA-FREP program project support, we are grateful for the continuing support of the California Wheat Commission in covering some ongoing costs for staffing, supplies and analytical costs of nitrogen fertilizer management work in wheat. We are thankful for the support of University of California staff through UC-ANR Cooperative Extension and the UC Davis Plant Sciences Department, and the excellent assistance, project support and use of use of University facilities and equipment in research at trial locations at the UC Davis Farm, and at the Intermountain, West Side and Kearney Research and Extension Centers.

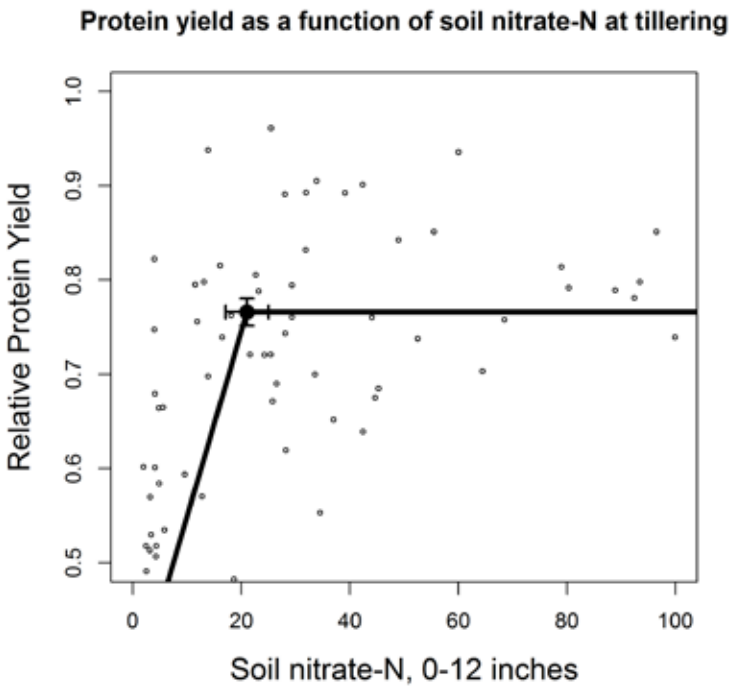

Figure 3. Soil nitrate-N concentration threshold for predicting wheat productivity response measured in the top 12" at tillering stage.

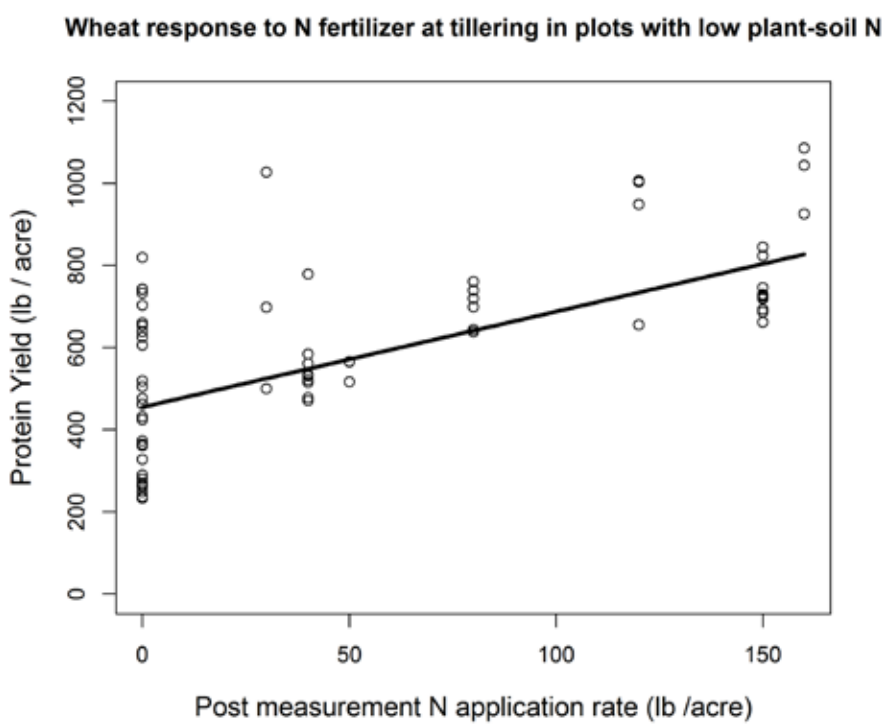

Figure 4. Protein yield as measured in plots where soil nitrate-N, leaf chlorophyll, and/or canopy NDVI were low and a subsequent application of N fertilizer was/ was not made at rates ranging from 0 to 160 lb / acre (Y = 2.33X + 455; P <0.001).

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. Coupled with differences in climate and management, this soil diversity complicates our understanding of the fate of nitrogen in the environment. Spatially explicit information is needed to help growers make informed decisions about nitrogen management practices.

The Nitrate Groundwater Pollution Hazard Index (HI) 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 it is also difficult to update, and does not directly provide growers with options to improve N management.

The overall goal of this project is to develop a data-driven nitrate hazard leaching index for every agricultural soil in California. Once completed, it will become an interactive decision support tool to 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 with 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 objectives of this project are to:

1. Develop an intrinsic nitrate leaching hazard ranking for all agricultural soils in CA.
2. Evaluate the effect of winter rainfall on leaching of residual nitrate agricultural soils in CA.

DESCRIPTION

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

A Ranking of Nitrate Leaching Potential

First, we created a simple nitrate leaching potential scenario for all soils in agricultural regions (cropland) of the State. This simple scenario was modeled to evaluate the soil's intrinsic susceptibility to nitrate leaching considering only soil properties. We ran HYDRUS 1-D for 5685 soil profiles. The simulation time was 1 year and we assumed constant rainfall of 1 cm/day and a nitrate pulse application of 1 Mu/day (Mu: mass unit) for 10 days. From this, we calculated solute travel times to a depth of 1.5 m, defined as

the time needed for the 95% of the total applied mass to reach the bottom of the profile.

Modeling Residual Nitrate Leaching Over Winter

Next, we investigated the effect of climate on nitrogen leaching to evaluate the fate of residual nitrate in soils after harvest. We defined seven climate zones in order estimate differences in evapotranspiration and precipitation across CA for the period of 1/1/2000 until 12/31/215. We conducted 39,795 Hydrus simulations (7 climate zones x 5,685 different soil profiles) for a 16-winter-year period. This exercise can be considered a scenario where winter precipitation drives the movement of residual soil nitrate after harvest when uptake is low. After conducting the simulations for the 16-year period we discarded the first 6 years as a model warm-up period. The following variables were calculated: annual deep percolation of water (in cm/year) beyond 1.5-m depth; annual solute mass (in Mu/year) lost beyond 1.5-m depth; and, annual Nitrate concentration (in Mu/cm^3) at 1.5-m.

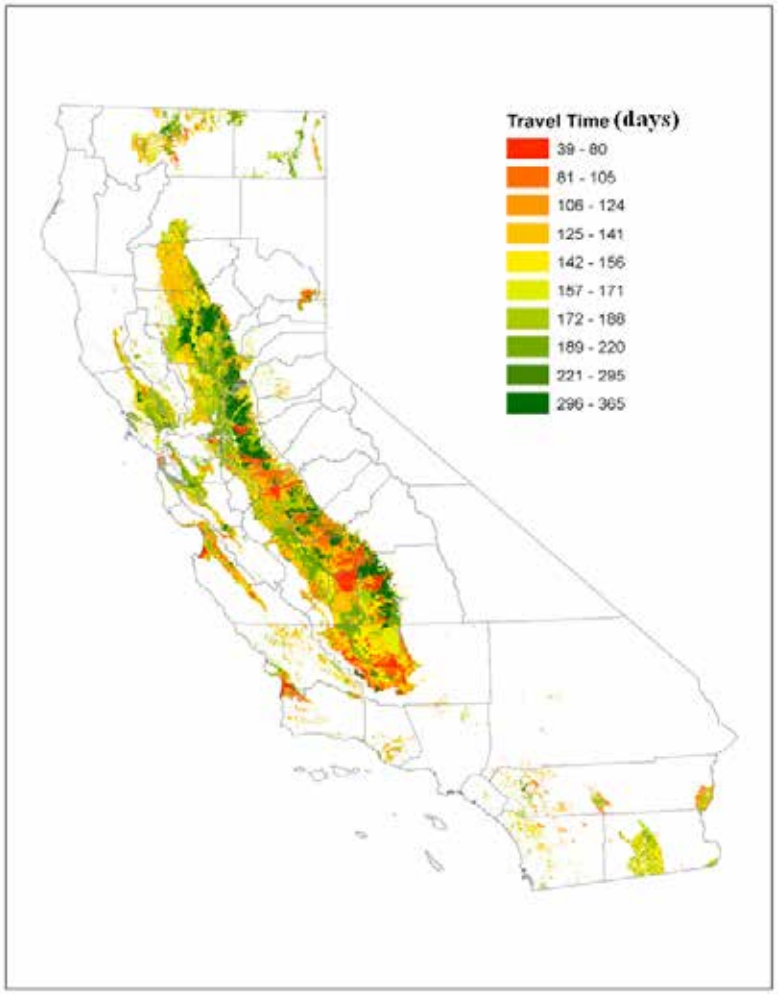

Figure 1. Spatial extent of nitrate leaching potential expressed as nitrate travel times.

RESULTS AND DISCUSSION

Figure 1 displays the spatial distribution of nitrate leaching potential expressed as nitrate travel times. This map represents the effect of soil properties such as texture, water retention and layering on nitrate leaching potential. Soils with long travel times (e.g. >189 days) are associated with hydraulically restrictive horizons such as claypans and cemented layers. Soils with the longest travel times, and thus, least prone to nitrate leaching, are concentrated along east side of the Central Valley. These soils contain impermeable cemented horizons. The map also depicts moderately long travel times (106 to 188 days) in uniformly clay-rich soils along the west side of the Central Valley. However, it is important to note that vulnerable regions with short travel times can be identified throughout the State (Figure 1). Areas of high nitrate leaching potential correspond with the coarser textured soils on recent alluvial fans.

Figure 2 (on the following page) shows the spatial distribution of annual nitrate mass leached beyond 1.5 m and annual nitrate concentration at 1.5m. As expected, the results show that climate strongly influences the movement of water and nitrate. The climatic zones we chose create sharp artificial boundaries rather than what are likely to be smooth transitions in climate. Vulnerable areas with values of higher mass leached are found in northern regions where precipitation is high (Figure 2a). However, areas with high nitrate concentration in pore water correspond with the dryer portions of the State (Figure 2b). The reason is that less mass is leaching from the soil profile and diluted by less water, which raises the concentration of nitrate in pore water. From a risk assessment point of view, this highlights the importance of nitrate pore water concentration in regions where groundwater recharge is low. As discussed earlier, this case represents a "winter scenario" and the inclusion of irrigation in our approach is expected to smooth out differences

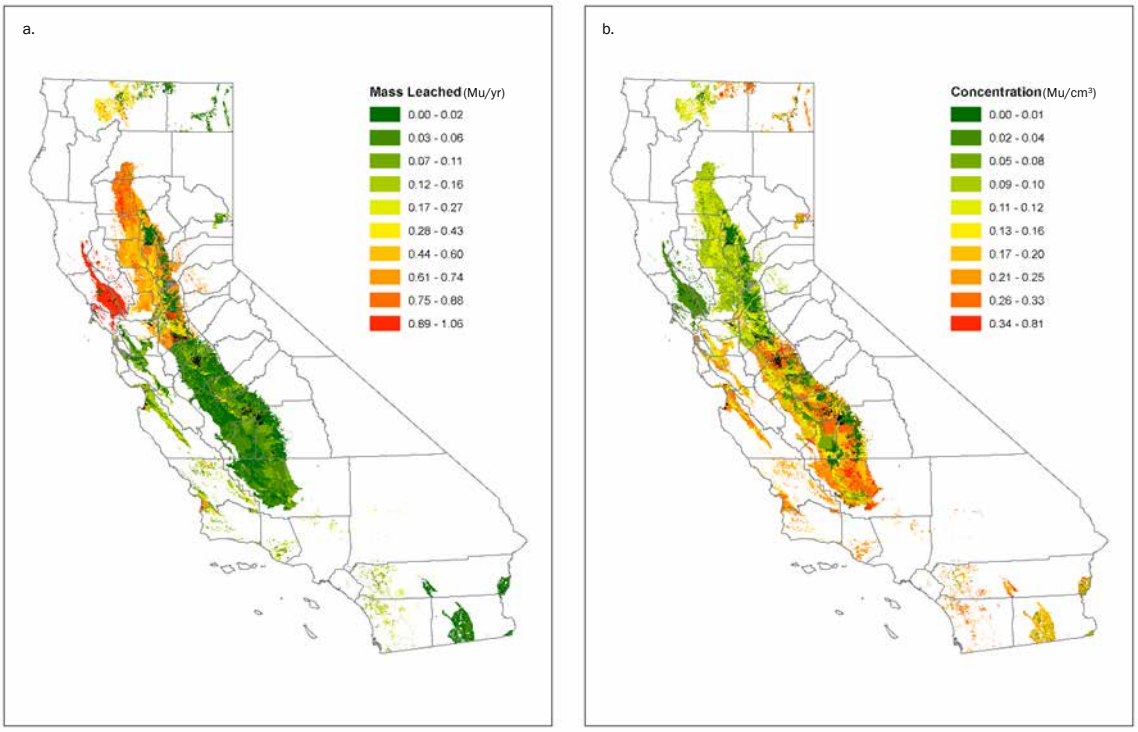

Figure 2. Extent of annual rates of nitrate mass leached (2a) and nitrate concentration (2b) in pore water at 1.5-m depth.

among climate zones. Moreover, cropping patterns and associated fertilizer management strategies will likely change these regional trends.

ACCOMPLISHMENTS

This study represents the first statewide map providing quantitative estimates of nitrate leaching potential for all agricultural soils in CA. These data, coupled with future scenarios that explore crop, fertilizer and irrigation scenarios can be used to evaluate management practices at local and regional scales. We expect this information will also be useful in developing Groundwater Management Plans in accordance with the Sustainable Groundwater Management Act.

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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 are challenged 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 professionals. It is essential, for the vitality of the industry and California, to prepare young people to make informed decisions about agricultural issues as they mature into adults.

With FREP funding, California Foundation for Agriculture in the Classroom (CFAITC) completed several educational resources focused on plant nutrients for elementary, middle, and high school classrooms. Comprehensive outreach will take full advantage of FREP's investment by promoting the resources and assisting teachers to incorporate the lessons into their curriculum.

OBJECTIVES

1. Engage marketing partners and a public relations agency to develop an outreach plan that encourages teachers to utilize CFAITC lessons in their classrooms.
2. Advertise educational publications.
3. Conduct evaluation of project.
4. Provide 60 educators throughout California with lab kits.
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 plant nutrients web page containing CFAITC developed and approved resources.
8. Participate in a minimum of three educator conferences to network with science, technology, engineering, and math (STEM) educators and to promote plant nutrient units.
9. Print an appropriate supply (over a three year period) of plant nutrient units.

DESCRIPTION

CFAITC is continuing to work with a marketing consultant to reach a broader audience with our Plant Nutrient curriculum. The resources have been promoted throughout social media from May 2015 through July 2016. The posts have reached and engaged audiences on Twitter, Facebook and Instagram, boosting awareness of the resources, see Figure 1. A summary of social media activity is shown in Table 1. In addition, the Plant Nutrients Pinterest board has attracted 35 followers.

CFAITC developed a *Learn About Ag... Plant Nutrients* webpage that includes all four units, fact sheets, and

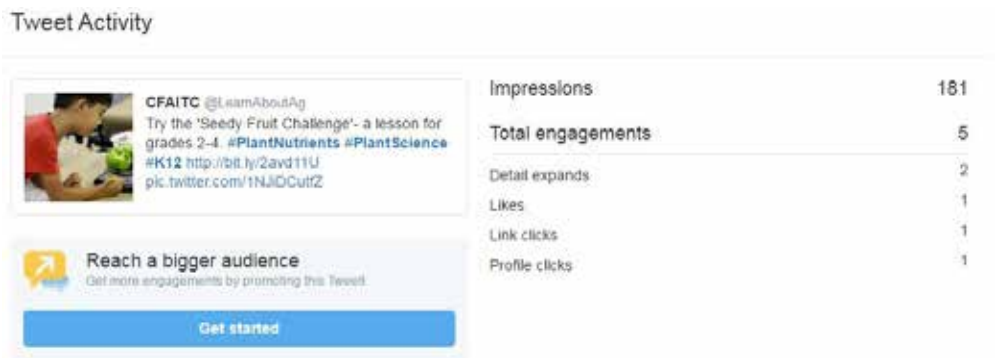

Figure 1. Social media twitter post (photo courtesy of Powerhouse Science Center).

the student newspaper, *What's Growin' On? Elements for Life* edition. Eighteen lessons from all four units of the curriculum are featured on the National Agriculture in the Classroom (NAITC) lesson plan matrix at agclassroom.org/teacher/matrix. See Table 2 for a summary of unique views. On the NAITC home page, *The Soil We Grow In,* lesson is a September featured resource.

A YouTube video was created that demonstrates each of the lab kits and is available for teachers to view as they receive their training. Our partnership with Powerhouse Science Center (PSC) has connected us with a new teacher base that will be trained to use our lessons this fall. PSC also held summer programs using our lessons for students, see Figure 2. Lab kits have been mailed out to science centers and teachers from the California Fertilizer Foundation Garden Grant Program and new teachers interested in using the curriculum.

Evaluations are online and teachers
and students are currently responding to the surveys as they complete their lessons. Downloads of the lesson plans from our website total nearly 2,000 since 2014. We have printed 3,500 copies total of the four units for teachers to order, with plans to print additional copies as needed.

RESULTS AND DISCUSSION

CFAITC is in its second year of a three-year work plan. In 2016, an evaluation of the outreach plan and classroom instruction will be completed. Sixty educators in school districts throughout California will have participated in the webinars and completed instruction using the lab kits that accompany the curriculum. Presentations featuring Plant Nutrients were conducted to teachers at the Soil Borne Farms Garden Symposium and to pre-service teachers from UC Davis. Plant Nutrient lessons will have been distributed through two regional science centers, Powerhouse Science Center and Fleet Science Center, and featured in four conference workshops that include regional and national levels. Conference workshops include the following:

1. National Agriculture in the Classroom Conference (June 2016)
2. REV Up After School Conference (September 2016)
3. California Foundation for Agriculture in the Classroom Conference (September 2016)

Figure 2. PSC Plant Nutrients Summer Program (photo courtesy Powerhouse Science Center)

Table 1. Summary of social media activity from CFAITC.

Social Platform	Date Posted	Impressions	Engagements	Engagement Rate	Link clicks
Twitter	July 31	181	5	2.8%	1
Facebook					
	May 12	489	6	1.2%	0
	June 24	535	11	2.1%	2
	July 20	623	7	1.1%	0
	July 31	917	2	.21%	1
Instagram					
	June 30	NA	14	NA	NA
	July 25	NA	11	NA	NA

4. California Science Teachers Association Conference (October 2016)

ACCOMPLISHMENTS

This project provides a comprehensive resource of the science and technology involved in modern agriculture. 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. The project is a means of connecting California students to the importance of plant health and the agricultural industry's efforts to protect our air, water, and soil quality. Many of these informed decision makers will provide future oversight to the industry, determine market trends, and continue to share the positive story of California agriculture. The benefits derived from this project go beyond the grant period.

ACKNOWLEDGEMENTS

This project was funded by a grant from the California Department of Food and Agriculture's Fertilizer Research and Education Program (FREP) and the Fertilizer Inspection Advisory Board.

Other project supporters include: CALAMCO, California Farm Bureau Federation, Powerhouse Science Center, and Western Plant Health Association.

Table 2. Data from NAITC matrix unique views.

California Plant Nutrient Lessons on the National AITC Matrix

Google Analytics Access Report
9/1/2015 – 9/8/2016

Lesson Title	Unique Page Views
Can We Have Too Much of a Good Thing?	268
Concentrate on the Solution	213
Digging Into Nutrients	390
It's a Dirty Job	319
Know Your Nitrogen	198
Let's Vote On It	75
Matter of Fact	100
One in a Million	202
People and Plants Need Nutrients	258
Photosynthesis and You	114
Plant Parts and Functions	269
The Right Diet for Your Plants	97
The Right Solution	74
The Soil We Grow In	316
Tropism Twist	46
Weather on the Farm	170
What's Your pH?	517
Where Did Your Hamburger Come From?	160

California Certified Crop Advisor Educational Project

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INTRODUCTION

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

CA CCA currently certifies over 1,000 professional advisors, and is the heart of competency certification for nutrient management professionals in California. The CA CCA educational project has grown significantly in recent years, and has as its goal to provide a needs-based mechanism for the educational credits and certification of qualified individuals to enhance the core base of fertilizer experts. The CA CCA program has developed awareness seminars for fertilizer 4R practices and conducted nutrient seminars to improve nutrient use and proper nitrate mitigation practices. This educational program has provided valuable outreach components to increase the number of CA CCAs while increasing awareness of proper fertilizer 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 and have professional and efficient program administration.

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 reviewed by the CA CCA Board of Directors (BOD) and shared with Project Manager and CDFA representative

DESCRIPTION AND ACCOMPLISHMENTS

- CA CCA directors, CAPCA CEO & S. Beckley & Associates have engaged in nitrogen education discussions with CDFA Staff, CA Regional Water Quality Control Board representatives and UC during the reporting period to identify best management practices and educational goals to improve total industry knowledge in addressing nitrate issues. CAPCA assisted UC and CDFA FREP in conducting two 1 1/2 day educational seminars. The seminars provided training

in efficient nitrogen management practices to more than 211 CCAs. CAPCA conducted 7 fertilizer focused seminars during the reporting period, with 9 planned for 2016.

- The CA CCA BOD conducted elections in November 2015 maintaining the diversity of the Board. The BOD solicited non-director volunteers to help expand the reach of the CCA program. CA CCA has established regional committees for 2016 to build towards sustainability. Regional Committees in the Desert of southern California and Arizona, the Central Valley and the Central Coast empower CA CCAs to get involved locally, provide relevant continuing education meetings, articles and marketing outreach. The Regional Committees also provide a mechanism to ensure regional representation on the CA CCA Board. The CCA Public Relations committee continues to attend many industry related meetings to articulate the best management practices for nutrient management.
- CAPCA as the grant Cooperator provided the professional management services guaranteeing responsible program administration and support to volunteer CA CCA directors. CA CCA BOD has engaged CAPCA staff to provide additional administrative and operational support for 2016 to handle the increased workloads. CAPCA ED has provided educational support and will manage a minimum of seven fertilizer seminars in 2016. CAPCA and the CCA BOD partnered with CDFA/FREP/UC to administer two educational outreach nutrient management seminars during the grant reporting period and one seminar for 2016.
- The CA CCA program has demonstrated a positive growth and retention trend due to awareness efforts and ground water regulatory requirements. The CA CCA BOD continues to offer exam study seminars and on-line practice questions to aide candidates in their test preparation. The BOD continues to solicit feedback and edits for a CA study guide for the California exam. The number of CA CCAs for 2015 was 1074 and the program has 1125 as of September 30, 2016. A total of 411 candidates tested for ICCA in 2015 with 195 passing the exam. Likewise, 484 tested for the CA exam with 197 passing the test.
- The mainstream communications tool for CCA awareness continues to be the CAPCA *Adviser* magazine (6 issues), with constant contact newsletter (2 issues) and social media as the electronic marketing tools. CAPCA staff supports candidates in both email and telephone inquiries. During this reporting period, CAPCA staff reviewed and processed approximately 760 CEU applications with over 2300 CEU hours.
- CA CCA BOD held its 7th annual meeting in conjunction with CA ASA Plant & Soil Conference in Visalia in February 2015.
- WPHA and CAPCA have included a CCA outreach/awareness effort in both the California University Student dinners and Pathway to PCA outreach programs whereby the message is conveyed to students to choose a career in agronomy, plant health and seek a professional license/credential to validate their expertise.
- CEU seminars covering urban and traditional agriculture have expanded CEU credits during the reporting period. The CCA BOD and ICCA work together to retain current CCA certificate holders.
- Dues paying membership of at least 1,000 has greatly assisted to make the CA CCA program self-sustaining. The CA CCA BOD is pleased that this membership goal has been reached and that normal administrative and operational support can be realized within the CA CCA program. The CA BOD and UC Project Leader continue to provide reviews and evaluations to CDFA/FREP. A CDFA representative attends all BOD meetings.

SUMMARY

CDFA-FREP support has enabled the CA CCA program to become a highly successful resource for fertilizer education and awareness, with significant growth over 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 1,100 Certified Crop Advisors in California.

For more information on the program please contact: CA CCA Program, Ruthann Anderson (916-928-1625 X 211) or correspond to CA. CCA 2300 River Plaza Drive, Suite 120, Sacramento, CA 95833. Fax 916-928-0705 www.cacca.org

ACKNOWELDGEMENTS:

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

CERTIFIED CROP ADVISER

Online Fertilization Guidelines for Agricultural Crops in California

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INTRODUCTION

For many crops, a comprehensive overview and synthesis of the current research on fertilizer use and management in California is missing. The FREP project 11-0485-SA, which started in spring 2012, has been closing this gap for some major crops. We created a user-friendly, web-based database of FREP-funded research and wrote crop-specific fertilization guidelines for 16 major crops grown in California. The guidelines consist of a summary of research data (from California, where possible) and UCCE farm advisor experience and present a general overview of nitrogen (N), phosphorus (P), and potassium (K) management. Micronutrients are also included for crops where their application is relevant. The aim of the current project is to update the contents of the database with information from new projects, expand the fertilization guidelines by an additional 12 major California crops, and make the website interface more interactive, user-friendly, and applicable to growers and crop advisers.

OBJECTIVES

The overall goal is to expand the information accessible through the FREP database and the fertilization guidelines and make the guidelines more interactive and user-friendly. The specific objectives are:

1. Keep database and guidelines up to date by entering new information.
2. Develop web-based nutrient management guidelines for an additional twelve crops grown in California.
3. Make the guidelines more interactive, user-friendly and widely relevant.
4. Increase the awareness level of the guidelines among potential users.

DESCRIPTION OF ACCOMPLISHMENTS

Updating the FREP database

We have entered all newly completed FREP projects into the database. In addition to the completed FREP projects, we have also summarized the proposals for all ongoing FREP projects, and indexed them in the database. The database is located at: https://www.cdfa.ca.gov/is/frep/. Currently, summaries of more than 180 FREP-funded projects can be accessed in the database.

Developing guidelines for an additional crops

In addition to the 16 crops mandated by our previous project, we have made available online guidelines for **prunes/plums, peaches/nectarines, potatoes, avocados, dry beans, onions, and celery** (Figure 1). The guidelines for **carrots** and **olives** have been written and are currently under review. For the stone fruits and avocados, we also included information about zinc fertilization since it is a standard practice. In addition, for each of the crops we have written an overview of the history of their cultivation in California, as well as a webpage presenting data on N uptake during the growing season, N partitioning in the plant and N removed with the harvested plant parts (https://apps1.cdfa.ca.gov/FertilizerResearch/docs/N_Uptake.html). In addition, we have written general instruction sheets for taking plant and soil

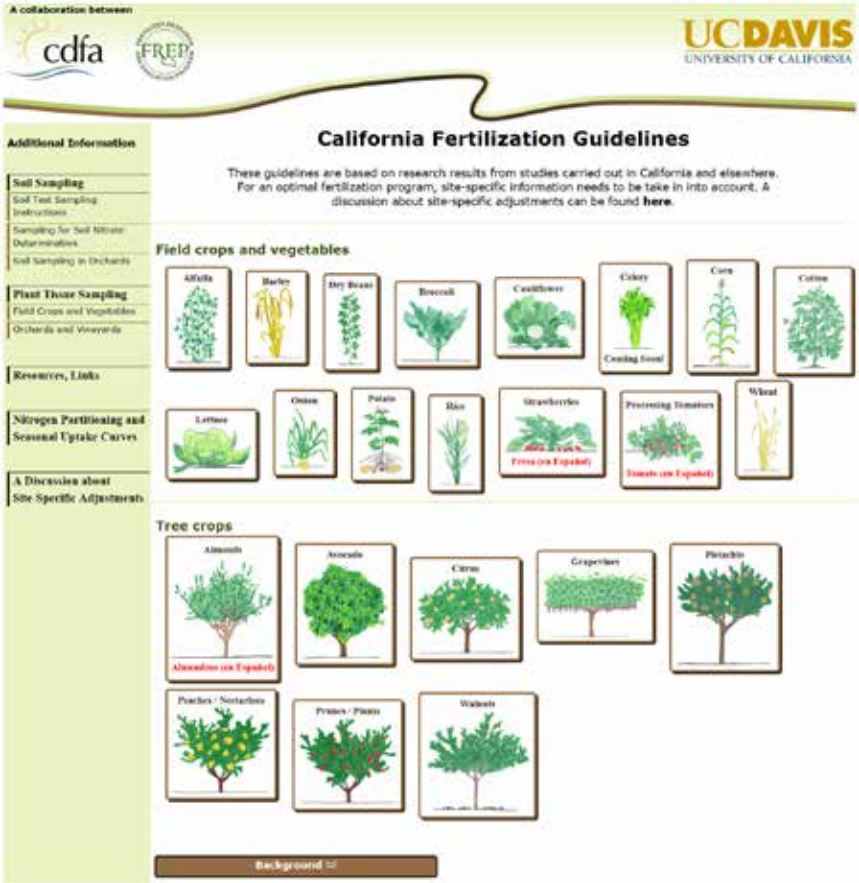

Figure 1. Screen shot of the start page for fertilization guidelines (left). Crop-specific guidelines can be accessed by clicking on one of the crops (online at https://apps1.cdfa.ca.gov/FertilizerResearch/docs/Guidelines.html*).*

samples in permanent and annual crops. These PDFs are linked to each guideline.

By July of 2017, we will have completed guidelines and supplemental information for the remaining three crops, namely: **melons, safflower** and **sunflower**.

Redesigning the guidelines

We redesigned the website to make it easier to navigate, and easier to use on tablets and smart phones (Figure 2). We also similarly redesigned the N uptake information page for each crop. While redoing the website, we reviewed each guideline, correcting errors and updating them with new information where necessary. We will continue to collect and incorporate new relevant research findings into the existing guidelines.

During the second half of the project, we will add quizzes so that users can test their knowledge about what they have just read in an interactive way. The quizzes will include a set of answers with an explanation and a reference to where the information can be found in the guidelines. Furthermore, case studies shall be added to highlight site-specific solutions.

Most nutrient management related studies have been conducted in the Central Valley and on the Central Coast. However, some important agricultural areas of California have unique soils and growing conditions, and the N application rates reported in the guidelines may not apply. To serve these regions, we will conduct region-specific case studies of nutrient management practices and outcomes. Case studies will be added in 2017.

Additional outreach activities

Between November 2015 and the present, we

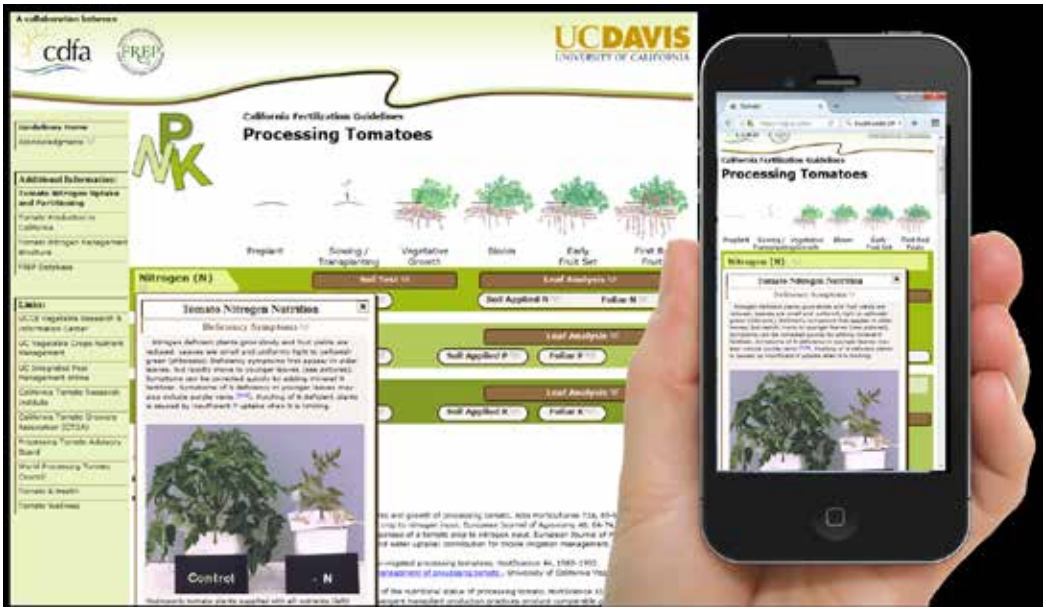

Figure 2. Screen shot of the guideline for processing tomatoes. All pages have now been redesigned for easy navigation and use on different devices.

presented the guidelines at numerous meetings and conferences. The guidelines have also been highlighted as a valuable resource at the N training for Certified Crop Advisers and the self-certification courses for growers. Furthermore, we are collaborating with FREP to produce brochures that contain a summary of key aspects of N management for specific crops. These brochures are very well received at meetings and field days. Currently the brochures for 10 crops are downloadable in PDF form from the FREP website. Two have been translated into Spanish.

The guidelines are generating several hundred page views per month. With regulatory pressure increasing, the need for research-based information on crop management will likely increase their popularity in the future.

ACKNOWLEDGEMENTS

Funding for this project was provided by the CDFA Fertilizer Research and Education Program.

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

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INTRODUCTION

Processing tomatoes are an important California crop grown on about 288,000 acres in 2014. Over the last 15 years, the wide adoption of drip irrigation by the tomato industry has resulted in a dramatic shift in production practices. During the same period, tomato yields increased from roughly 36 tons/acre to almost 50 tons/acre. This rapid shift from predominantly furrow irrigation to drip irrigation and the associated yield increase changed nitrogen (N) fertilizer management considerably, with fertigation through the drip system now being the most common practice.

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

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

OBJECTIVES

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

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

DESCRIPTION OF ACCOMPLISHMENTS

Creating a test version of CropManage for processing tomatoes

In a first step, we used data from published and unpublished research to develop equations and algorithms for the test version of CropManage for drip irrigated processing tomatoes, which is currently being developed by UC ANR programmers:

Nitrogen uptake. Based on 27 datasets from drip irrigated processing tomatoes grown in California, we calculated the average N content of tomatoes and the percent of the total aboveground N contained in the fruits. On average, tomatoes contained 2.83 lbs N/ton. Of the total amount of N in the aboveground biomass, 65% was in the fruits, the rest in in the vines. This N distribution is based on hand-harvested data. With machine harvest, the proportion of the total N removed with the harvested fruits may be lower (approximately 60%).

Comparing the calculated yield based on these values with the measured yields of the 27 datasets, we found that in some cases the difference was rather big. The field trials will focus on identifying other factors that affect the relationship between N uptake and yield to create a more accurate estimate for the final version of CropManage.

Nitrogen uptake curve. A sigmoid equation will be used to predict the seasonal N uptake curve. Based on 9 datasets available, we created a typical N uptake curve (Figure 1).

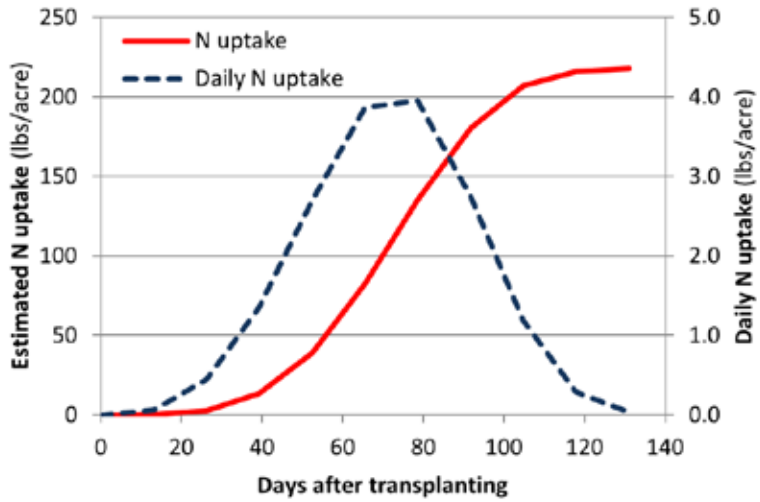

Figure 1. Modeled N uptake curve for a 50-ton crop.

Tomato uptake curves mainly differ in N uptake late in the season. The data collected in the field seasons shall help improve our ability to predict N uptake during the 4-6 weeks prior to harvest.

Collecting soil and plant related data in commercial fields

Field work for the project began in spring 2016. Six commercial fields were selected (Table 1). In each field we took preplant samples to 2 feet in 1-foot increment to determine soil moisture as well as ammonium and nitrate concentrations. The preplant nitrate-N concentrations ranged from 21 to 325 lbs/acre in the top foot and from 32 to 160 lbs/acre in the second foot of the profile (Figure 2). These values are based on an estimated bulk density of 1.2 g/cm^3. These differences highlight the need for a site-specific tool that takes into account residual soil nitrate.

Table 1. Location, soil type and transplanting dates of the six commercial fields included in the study in 2016.

Site	Coordinates (rounded to the nearest 5')	Soil type	Date transplanted
Yolo 1	38°45' N 121°45' W	Sycamore	April 12
Yolo 2	38°45' N 121°45' W	Maria silt loam	April 16
San Joaquin 1	37°55' N 121°10' W	Hollenbeck silty clay	May 16
San Joaquin 2	37°45' N 121°25' W	Capay clay	May 12
San Joaquin 3	37°55' N 121°25' W	Egbert silty clay loam	May 4
Fresno 1	36°15' N 120°05' W	Westhaven clay loam	May 9

In-season soil and plant samples are being taken in three-week intervals. Soil samples are analyzed for moisture content, ammonium and nitrate concentrations. The plant samples are used to determine total biomass and N, phosphorus and potassium concentrations. Vines and fruits are analyzed separately. In addition, canopy coverage is measured by infrared camera (Figure 3).

Canopy development is also measured in a variety trial in Solano County. The results will reveal whether one equation for canopy development can be used for all tomato varieties or whether different equations need to be developed.

At the time this report was due, sampling and sample analysis were still ongoing.

Outlook

Sampling in grower's fields will continue in 2017. In addition, a replicated trial will be carried out at UC Davis to evaluate CropManage for processing tomatoes. Outreach activities and training sessions for growers and consultants will start during winter 2017/18.

ACKNOWLEDGEMENTS

Funding for this project was provided by the CDFA Fertilizer Research and Education Program.

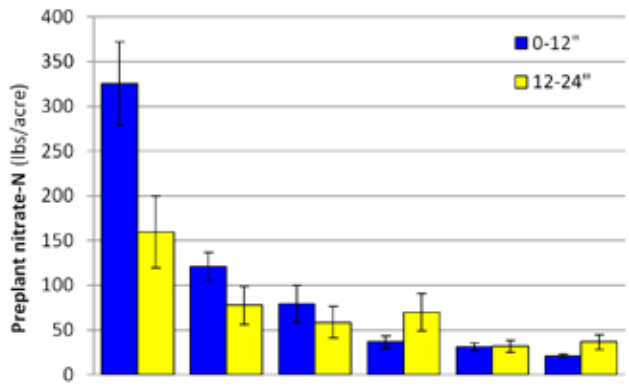

Figure 2. Preplant soil nitrate contents at the six sites in order of decreasing topsoil nitrate contents. Error bars represent standard deviations of the means (n=4).

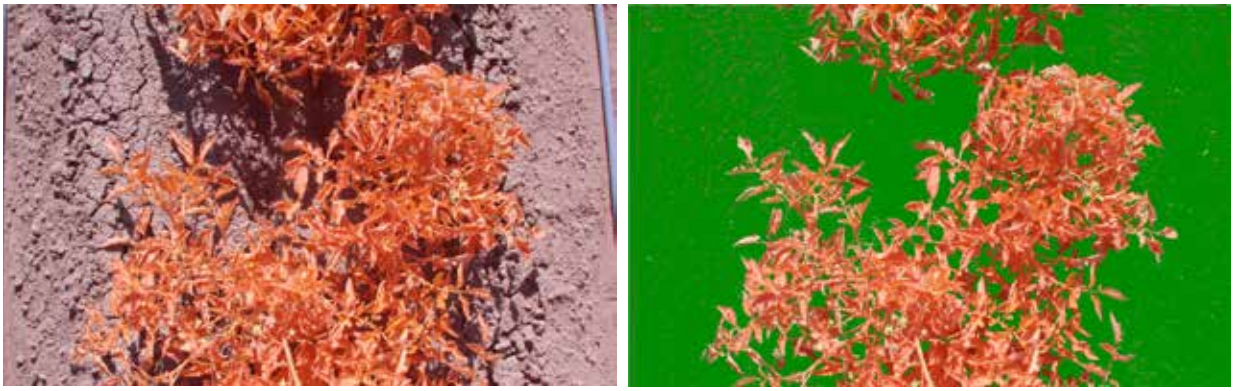

Figure 3. Infrared picture taken at the Yolo 2 site on May 27 (left). Using a specialized software, sieves can be set to distinguish between soil and plants (right). In the case above, the analysis resulted in a canopy coverage of 40%.

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

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INTRODUCTION

Nitrous oxide (N_2O) is 300 times more effective than carbon dioxide at warming the atmosphere, and the majority of N_2O in the U.S. is emitted by agriculture soils, mainly through N based fertilizer inputs and irrigation management. N_2O is produced by microorganisms that convert available (i.e. mineral, or inorganic) forms of nitrogen to N_2O gas as a byproduct of metabolic processes resulting in increased flux rates to the atmosphere. Direct N_2O emissions are a release of gas from the soil. Indirect emissions from row-crops occur when soil nitrate (NO_3^-) in water or leachate is transformed to gaseous N_2O in standing surface water, tile drain effluent or downstream aquatic environments, and are represented in current IPPC estimates via emissions factors based on cumulative NO_3^- leaching (De Klein et al., 2006).

There are economic, yield and environmental sustainability challenges associated with the nutrient intensive production of specialty crops, including strawberries and broccoli, grown in the Pajaro and Salinas Valleys. Nitrate-N fertilizer applications in excess of crop uptake may result in additional irrigation and fertilizer costs, N_2O emissions, and NO_3^- discharge in farm runoff and leaching to groundwater. We aim to address the lack of reliable N_2O flux monitoring studies that address both direct and indirect N_2O soil emissions for row cropped systems in the Central Coast of California. Our study is also evaluating the potential for evapotranspiration-based (ET-based) irrigation to mitigate direct and indirect N_2O emissions as a result of improved crop nitrogen uptake while simultaneously reducing groundwater nutrient loading, and reduced tile drain effluent.

CropManage (CM) is an online decision support tool developed by UCCE that relies on crop evapotranspiration (ETc) and N uptake models, which are modified based on residual soil and irrigation N composition. In this study, CM is being used in both strawberry and broccoli trials to provide irrigation and nutrient management recommendations and scheduling. Within each field demonstration trial, we are evaluating the N-cycle pathways to determine if there are any detectable yield quality or quantity differences between two different irrigation and nutrient management treatments. The overall goal of this study is to assist growers in optimizing water and fertilizer use in a way that reduces crop production costs while minimizing losses of excess N to the environment.

OBJECTIVES

1. Establish standard and alternative ET-based irrigation management treatments in a split-block design for strawberry and subsequent lettuce-broccoli crop rotations
2. Measure direct soil N_2O emissions and total applied water from these cropping systems
3. Estimate direct and indirect N_2O emissions in conjunction with NO_3^- leaching data
4. Quantify direct and indirect N_2O emissions in relation to yield quantity and quality differences, input costs and total water applied

5. Characterize N_2O emissions based on environmental factors
6. Analyze the pathway of N transformation in soil through physical NH_3 oxidation due to water and oxic/pH conditions

DESCRIPTION

Field trials for this study are currently ongoing and preliminary data analysis to date has been limited to objective 2.

Field sites have been selected from collaborating partner commercial growers working with CSUMB and UCCE on existing projects. We have been monitoring N_2O emissions simultaneously with nitrate vadose zone leaching to evaluate reductions in nitrogen losses from replicated randomized block strawberry plots. Irrigation treatments at 100% ETc; 100-N and 130% ETc; 150-N are being applied using CM. Similar work on broccoli is in the preliminary stages at the time of this report.

In each of the two replicated strawberry treatments we have been monitoring direct N_2O emissions using replicated soil cover chambers from which air samples are collected at regular time intervals over a 45-minute sampling period (Figure 1). Sampling occurs a minimum of twice per week, each time within 24 hours of an irrigation or fertigation event. Samples are being analyzed by gas chromatography. N_2O fluxes are determined using a hybrid of linear and non-linear regression analysis available through the HMR package on the R open-source statistical program.

Preliminary data for direct N_2O emissions from the beginning of the strawberry season in November 2015 to mid-July 2016 are presented in Figure 3. Mean daily N_2O fluxes ranged from 5.0 to 830 µg N m-2 h-1 in the 100% ETc treatment, and 3.9 to 670 µg N m-2 h-1 in the 130% ETc treatment. The highest N_2O fluxes were observed following fertigation and irrigation events during days with elevated soil temperature.

Upon completion of the strawberry production season in fall 2016, we will examine the relationships between emissions and both environmental and farm management factors, and will quantify scaled N_2O contributions based on yield and irrigation. Additionally, we will calculate indirect N_2O emissions from nitrate leachate concentrations sampled through lysimeters in each treatment, which is work funded by another study.

We will determine the role of soil O2 concentration in evoking discreet N_2O production pathways to understand how field irrigation and fertigation practices behave in a range of soil textures. We will differentiate the different ammonia oxidation and denitrification pathways leading to N_2O production (Zhu et al. 2013).

TAKE-HOME MESSAGE

At this time our field trials are still ongoing. Data will be analyzed following the end of the respective crop cycle for strawberries and broccoli, and will be presented in future reports. Our overall goal is to

Figure 1. Soil cover chambers placed between strawberry plants for direct N2O emissions measurements.

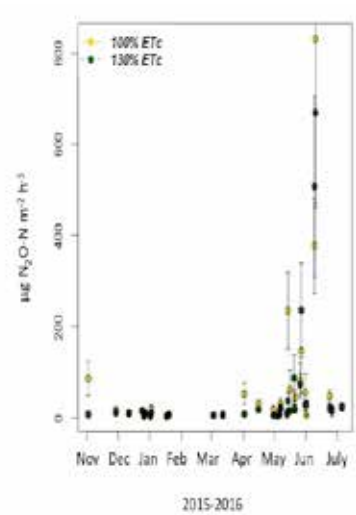

Figure 2. Mean daily N2O fluxes from each treatment. Line bars are standard error. n=4

provide data and analysis than can support improvement in overall N-cycle understanding by acquiring N_2O emission data in concert with studies of irrigation, fertigation, crop canopy development and vadose zone leaching data collected by other co-located studies.

This work will support the advancement of decision support tools and agronomically sound use of fertilizer and water by quantifying the benefits of reduced N and applied irrigation in terms of reducing N_2O emissions in conjunction with minimized NO_3- leaching. Findings are intended to support collaborative mitigation practices, which are beneficial, amenable, and environmentally and economically sustainable goals. Core project beneficiaries will be growers, RCD's, research extension specialist, other public and private entities interested in agronomic metrics, weather-based irrigation scheduling, and sustainability as a value added facet of their business model.

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Evaluation of the Multiple Benefits of Nitrogen Management Practices in Walnuts

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INTRODUCTION

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

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

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

OBJECTIVES

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

5. Disseminate results to growers of walnuts and develop outreach materials.

DESCRIPTION

The walnut orchards being utilized in this study are located near Ceres, CA. The management practices on both of the orchards include a combination of microsprinklers and flood irrigation. Fertilizer is applied by fertigation and pellets/granules amended into the soil. The orchards are approximately 5.8 acres and 4.0 acres. Each block is sectioned into a grid system containing 15 grid cells. Each grid cell is sampled by a combination of lysimeters to collect pore water, soil cores for nitrogen and carbon content, and moisture sensors to collect volumetric water content (Figure1 and Figure 2).

Prior to the beginning of the growing season, soil cores were collected from a random subset of grid cells in each orchard (Figures 1 and 2) to measure the immobile fraction of nitrogen. The concentration of nitrate in irrigation water was measured to determine the amount of nitrate applied via irrigation water. Lysimeters located below the root zone were used to evaluate amount of nitrogen moving past the root after fertigation and/or irrigation events. Soil samples will be collected to determine the amount

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

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

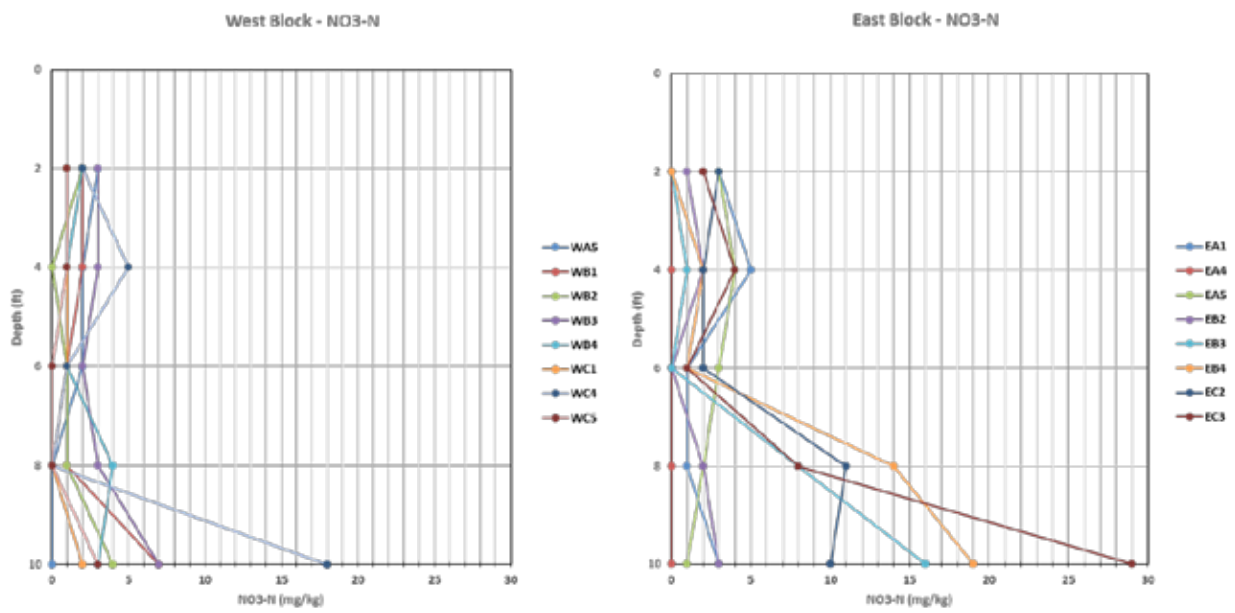

Figure 3. Mass of nitrogen in soil prior to fertigation in the west and east orchards.

of immobile nitrogen at end of the irrigation season. Nitrogen will also be measured in the walnuts prior to harvest to determine the amount of nitrogen removed from the orchards (date to be determined). Volumetric water content is being used to estimate the volume of water moving past the root zone. The data collected for this project will be utilized as input parameters for 1-D HYDRUS to model nitrogen fate and transport in the field.

RESULTS

To date, there have been 22 sampling events resulting in 167 pore water samples, 83 soil samples, 4 microsprinkler irrigation samples, 2 flood irrigation samples, and 1 water sample from the irrigation well. Preliminary results from the soil core samples indicate nitrogen levels remain relatively consistent between 2 feet and 10 feet (Figure 3) although some cores suggest that there is significant heterogeneity in the downward movement of nitrate. The project plans to interpret all of the results collected in year 1 after tissue samples are collected at the end of September.

ACKNOWLEDGEMENTS

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

A Nitrogen Management Training Program for Growers

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INTRODUCTION

Elevated levels of nitrates in groundwater in Central Valley locations are being attributed, in part, to inputs from farming practices. The Central Valley Water Board estimates approximately 3 million acres of irrigated lands overlay groundwater aquifers that have high levels of nitrate or are vulnerable to nitrate contamination. Approximately 25,000 landowners/operators, with a total of nearly 7 million acres of land in the Central Valley are affected by the Irrigated Lands Regulatory Program (ILRP) requirements to improve nitrogen application practices to protect groundwater. The ILRP requires Coalition Members to keep "on farm" a Nitrogen Management Plan (NMP) to track nitrogen fertilizer applications. If fields are located in high vulnerability areas, the NMP must be certified by an agronomic expert or the grower must be certified through an approved certification program. A NMP training curriculum developed by the University of California through a FREP grant and approved by Regional Water Board serves as a basis for this project entitled *A Nitrogen Management Training Program for Growers.* This program enables growers to self-certify their NMPs after they have passed a course taught by qualified trainers. The sessions have a secondary benefit of increasing the understanding of nitrogen fertilizer behavior, movement and distribution as it moves through the soil to groundwater. This knowledge should increase agricultural nitrogen use efficiency among growers and reduce nitrate leaching potential over the medium and long term in the Central Valley.

OBJECTIVES

1. Conduct outreach to attract potential trainers for the grower self-certification trainings.
2. Organize Train-the-Trainer sessions using the educational materials developed by UC to qualify trainers for the grower self-certification trainings.
3. Manage the interaction between organizations requesting a trainer for a grower training session and the trainer.
4. Provide grower testing, keep records of attendance, successful completion and conduct trainer evaluation.
5. Review and certify both content and trainers to conduct this activity.

DESCRIPTION

Approach

1. Outreach was conducted through mailings and emails to Certified Crop Advisor (CCA) contact lists to attract potential trainers for the grower self-certification trainings.
2. Train-the-Trainer sessions were conducted with the potential trainers using the Water Board-approved educational materials developed by UC for the grower self-certification trainings. Upon successful completion of the Train-the-Trainer sessions, a trainer would be considered qualified as a trainer for the grower certification program.
3. This project managed the interaction between those requesting a trainer for a grower training session—i.e. a coalition, grower group, private business, etc.—and the trainer. It operated like a "speaker's bureau" where a request came in and a list of trainers with the specific qualifications was provided. The group sponsoring the training selected the trainer.

4. The trainers were partnered with each of the coalitions requesting a grower self-certification session. CURES, through this project in conjunction with the coalitions, provided grower testing, kept records of attendance, successful completion and conducted trainer evaluation through post session grower program evaluation.

RESULTS AND DISCUSSION

CURES organized three CCA training meetings and assisted the water quality coalitions in hosting 31 grower self-certification meetings. In addition, coalitions organized 19 test retake sessions. CURES performed the test grading and distributed test scores to participants.

There are 28 CCAs who attended a 'train the trainer' course and returned the completed exam. Of these, 21 presented at one or more grower training meetings. Table 1 lists the dates of NMP training meetings, the venue locations, number of exams graded at each session and the percentage of test takers that passed the exam with a score of 70% or higher. As of September 1, 2016, 1,962 exams have been graded, with a passing rate of 82% and an average score of 79%. In addition, CURES created a guidance document for Central Valley Coalitions to reference when planning and holding a grower self-certification training meeting. The guidance document includes step by step instructions and optional advice compiled from lessons learned from completed trainings. Also included are instructions for planning in-office testing sessions and day of meeting responsibilities for coalition representatives.

Table 1. Grower training meeting results

Grower Trainings					
Meeting	**City**	**Total**	**Fail**	**Pass**	**PctPass**
11/9/2015	Modesto	48	9	39	81.25%
11/10/2015	Merced	49	8	41	83.67%
11/19/2015	Los Banos	89	15	74	83.15%
1/5/2016	Bakersfield	120	18	102	85.00%
1/7/2016	Stockton	68	12	56	82.35%
1/11/2016	Dixon/Solano	23	4	19	82.61%
1/12/2016	Stockton	73	16	57	78.08%
1/12/2016	Woodland	30	9	21	70.00%
1/20/2016	Stockton	132	37	95	71.97%
1/26/2016	Hanford	31	6	25	80.65%
1/27/2016	Dixon/Solano	17		17	100.00%
1/28/2016	Tulare	121	19	102	84.30%
2/2/2016	Woodland	30	4	25	83.33%
2/2/2016	Visalia	101	12	89	88.12%
2/9/2016	Fresno	44	5	39	88.64%
2/11/2016	Stockton	81	18	63	77.78%
2/16/2016	Elk Grove	21	3	18	85.71%
2/19/2016	Stockton	42	5	37	88.10%
2/23/2016	Woodland	26	6	20	76.92%
2/23/2016	Exeter	71	9	62	87.32%
2/24/2016	Colusa/Glenn	102	18	84	82.35%
3/1/2016	Stockton	29	3	26	89.66%
3/2/2016	Merced	54	7	47	87.04%
3/3/2016	Modesto	103	36	67	65.05%
3/4/2016	Hanford	39	4	35	89.74%
3/10/2016	Madera	84	16	68	80.95%
3/11/2016	Westley	46	15	31	67.39%
3/11/2016	Selma	71	14	57	80.28%
3/18/2016	Easton	66	11	55	83.33%
3/22/2016	Reedley	56	3	53	94.64%
5/25/2016	Chico	49	7	42	85.71%

Table 2. Office Retakes results

Office Retakes Results					
Meeting	**City**	**Total**	**Fail**	**Pass**	**PctPass**
2/2/2016	Coalition Office	3	2	1	33.33%
2/23/2016	Coalition Office-v1	1		1	100.00%
2/23/2016	Coalition Office-v4	1		1	100.00%
2/25/2016	Coalition Office	1		1	100.00%
2/26/2016	Coalition Office	2		2	100.00%
3/8/2016	Coalition Office	1		1	100.00%
3/10/2016	Coalition Office	2		2	100.00%
4/1/2016	Coalition Office	1		1	100.00%
4/11/2016	Coalition Office	1		1	100.00%
4/13/2016	Coalition Office	1		1	100.00%
4/20/2016	Coalition Office	6		6	100.00%
4/27/2016	Coalition Office	8		8	100.00%
4/27/2016	Coalition Office	1		1	100.00%
5/6/2016	Coalition Office	1		1	100.00%
5/12/2016	Coalition Office	1		1	100.00%
5/16/2016	Coalition Office	1		1	100.00%
5/17/2016	Coalition Office	12		12	100.00%
5/19/2016	Coalition Office	1		1	100.00%
6/1/2016	Coalition Office	1	1		

ACKNOWLEDGEMENTS

This project was funded by a grant from the California Department of Food and Agriculture's Fertilizer Research and Education Program (FREP) and the Fertilizer Inspection Advisory Board. We would like to thank University of California as well as the organizers from the following coalitions for their active participation, leadership and input with the implementation of this program: East San Joaquin Water Quality Coalition, San Joaquin County & Delta Water Quality Coalition, Sacramento Valley Water Quality Coalition, Westlands Water Quality Coalition, Kings River Water Quality Coalition, Kaweah Basin Water Quality Authority and Tule Basin Water Quality Coalition, Kern River Watershed Coalition Authority, Cawelo Water District, Westside San Joaquin River Watershed Coalition, Westside Water Quality Coalition, and Buena Vista Coalition.

New Fertigation Book

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INTRODUCTION

Farmers in California commonly apply a large percentage of fertilizers through irrigation water. Over the past few decades, there has been a gradual shift from gravity irrigation to drip/micro and sprinkler. Those pressurized irrigation methods now represent about 60% of the acreage in California, and are found on most of the intensively grown crops that need excellent fertilizer management.

There are many fertilizer books, and thousands of research articles on fertilizers and plant uptake. However, few of these resources focus on pragmatic chemical applications via irrigation water – especially in light of special California conditions. An older ITRC publication titled Fertigation has been an extremely important reference for practitioners in California. However, it is over 20 years old and was written at a time when fertigation was in its relative infancy, when organic farming was scarce, and when environmental regulations relating to fertilizers were few. Equipment and chemicals have both changed, as well as management practices.

The new Fertigation book, funded by FREP, will provide a valuable update that will hopefully serve California well for another 20 years.

OBJECTIVES

1. Improve the understanding of good fertigation practices by practitioners (i.e., farmers, foremen, farm managers). The improved understanding will hopefully result in farmers implementing better irrigation and fertilization practices. Those good practices will improve crop yields while protecting the environment.
2. Update the old Cal Poly ITRC Fertigation book to meet the primary objective. It has previously served as a valuable reference tool for practitioners, but is over 20 years old.

DESCRIPTION

The book will cover typical subjects such as commercial fertilizer properties, injection equipment, solubility, crop nutrient uptake patterns (lbs. vs. stage of growth), achieving good distribution uniformity with different irrigation methods, chemical maintenance of drip systems, and water amendments to improve infiltration rates. The book will also include many special current topics, including:

1. The A/R ratio that will likely be adopted by the California Regional Water Quality Control boards. This is the ratio of (Applied/Removed) nitrogen. Key new information will include typical nitrogen removal rates for crops (as a function of yield) and typical nitrogen application rates for those same crops.
2. Biostimulants
3. Special additives
4. Fertilizer mixes that are used for organic farming – including the analysis and comparison of a variety of commercial products.
5. New concepts in proportional dosing of chemicals.
6. New hardware
7. Oxygen injection into water

RESULTS AND DISCUSSION

Key actions that are completed include:

1. All of the major fertilizer and chemical injection

manufacturers who compete in the agricultural market were contacted, and information on their current products was obtained. Twenty manufacturers were identified as being major players.

2. Interviews were held with many of the manufacturers during the Irrigation Association trade show in Long Beach in November 2015. Of particular interest were their ideas on new controllers for proportional injection.

3. Visits were made to see new injection equipment at places such as the headquarters of Mazzei (Bakersfield) and Wonderful Farms (Lost Hills).

4. Hundreds of new photos were taken by ITRC employees showing existing equipment, chemicals, and installations.

5. An extensive search was conducted to locate vendors of organic fertilizer mixes. The search began by obtaining the CDFA database on approved organic fertilizer sources. Then the suppliers were contacted, literature obtained, etc. Finally, samples from what appeared to be nine common products were obtained. Those samples were analyzed for two things:

   a. The accuracy of the label contents (N, P, K). As can be seen in Table 1, what is promised is not necessarily what is obtained.

   b. The "pluggability" hazard if these materials are injected into drip/micro systems. Figure 1 shows that there is no good correlation between nutrient content and pluggability hazard.

6. Eight fertilizer dealers were visited and interviewed regarding their recommendations and the predominant fertilizers that they sell.

7. Specific fertilizer requirements, interactions, and timing recommendations were determined for major crops in California, including alfalfa, almonds, citrus, cotton, pistachio, grapes (table, raisin, and wine), tomato, walnuts, wheat, broccoli, cauliflower, lettuce, corn silage, and rice. Information came from literature searches, UC recommendations and programs, and some commercial laboratories.

8. Energy consumption as associated with nitrogen fertilizer manufacturing was documented.

9. Because biostimulants (e.g., humic and fulvic acids, protein hydrolysates, seaweed extracts, chitosan) are becoming quite popular for enhancing fertilizer uptake, these were examined, commercial sources identified, and characteristics cataloged. Biochar was also examined.

10. "Oxyfertigation" is an old concept of injecting oxygen into irrigation water, with the objective of improving root respiration – thereby enhancing crop growth. Proponents and literature were examined.

11. A short course was held in August 2016.

12. Writing of the book is in progress.

Sample ID	Percent Error		
	Nitrogen % N	**Phosphate % (P_2O_5)**	**Potash % (K_2O)**
6	2.3%	6.0%	16.7%
7	2.0%	15.3%	1.8%
8	54.3%	16.0%	20.0%
9	13.6%	26.5%	1204.3%
15	5.0%	32.7%	60.0%
16	4.2%	36.7%	60.2%
17	5.1%	35.6%	4.8%
19	38.5%	9.9%	19.4%
20	6.1%	62.4%	30.4%

Table 1. Percent error in label values

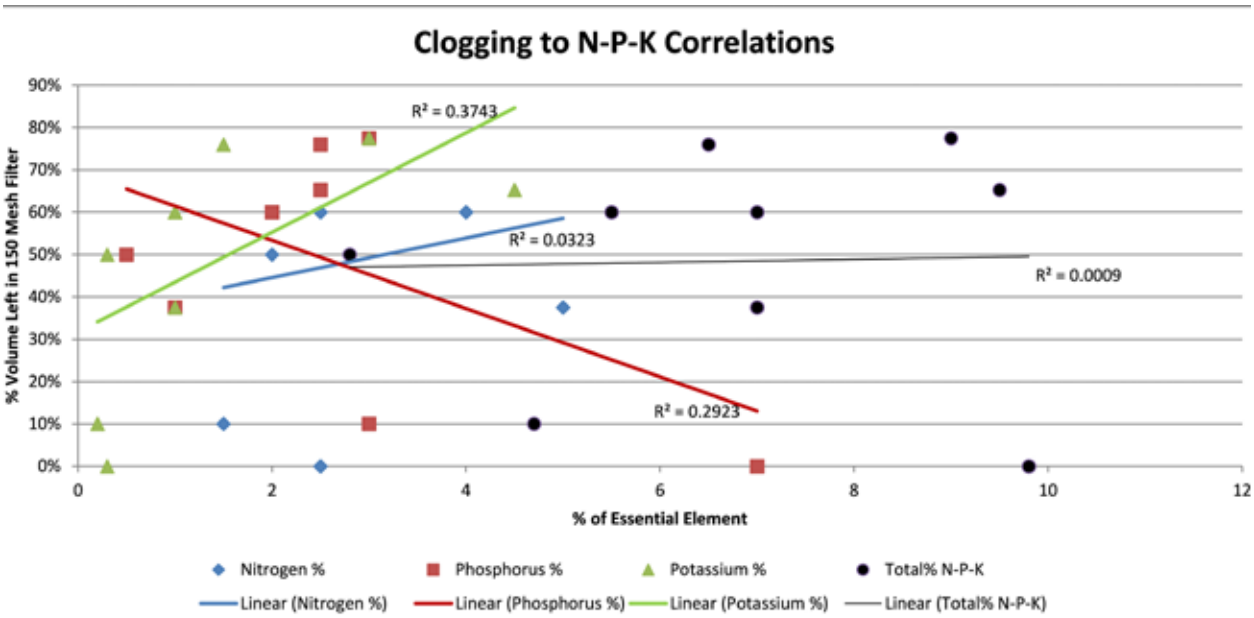

Figure 1. Correlations between nutrient content and pluggability for various materials

TAKE-HOME MESSAGE

This Fertigation book will serve as a valuable reference for California (and beyond) farmers, educators, and consultants.

ACKNOWLEDGEMENT

This project was funded by a grant from the California Department of Food and Agriculture's Fertilizer Research and Education Program (FREP) and the Fertilizer Inspection Advisory Board.

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

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INTRODUCTION

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

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

Similar to the work done in almonds and pistachios, this new FREP project aims to develop tools that can predict tree nitrogen status for commercially grown walnuts, prunes and pears. California growers of walnuts, prunes and pears are the primary audience that will benefit from this research. Commercial Analytical labs will also benefit by offering an improved product to their customers. The walnut, prune and pear industry will benefit by improving compliance with current and future N regulations as well as improving the quality of their products. Consumers and the general public will also benefit from an improved supply of healthy fruits and nuts with decreased environmental impacts.

Overview of the work accomplished to date and remaining work to be done: Team meeting was held in January. Detailed definition of the population of inference, sampling design, and sampling protocol was done in February. Design of the grower's survey was done in March. Orchard selection and data collection (survey interviews, leaf samples, and soil samples) were done from April to May. Data processing started in June. Remaining work for the current year involves summer leaf sampling, data processing, and web programing.

OBJECTIVES

This project is designed to achieve the following three objectives:

1. Objective 1: To develop a leaf nitrogen prediction model using spring collected samples to predict late summer tissue values. This will allow growers to better manage nitrogen in nut

(walnuts) and fruit (prunes, pears) orchards in California by sampling 30 representative orchards for each of three species during 2016 and 2017.

2. Objective 2: To create a user friendly online interface to help growers, extension specialists and consultants design nutrient plans based on early season leaf samples for walnuts, prunes and pears as well as pistachios and almonds (for which models have already been developed).

3. Objective 3: To promote the use of this tool, and an understanding of these models, to better manage nitrogen inputs at the right time in these nut and fruit trees.

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

Table 1. Criteria to define model scope (population of inference, sampling design, and sampling protocol.

Population of inference (Types of orchard that the model will work best)	Sampling design (Criteria to select each orchard)	Sampling protocol for leaf samples	Sampling protocol for soil samples
For prunes: Improved French Prune/M29C. Homogeneous management units that must be in their full productive years, and located from Red Bluff in the north to Visalia in the south. Avoid units that had strong drought problems, high heterogeneity in soil texture, or high pathogen infestation. **For walnuts:** Chandler/Paradox: Homogeneous management units that must be in their full productive years, and located in representative production zones that cover different regions of the central valley. Avoid units that had strong drought problems, high heterogeneity in soil texture, or high pathogen infestation. **For pears:** Bartlett/Winter Nelis*: Homogeneous management units that must be in their full productive years, and located in representative production zones (Sacramento/Yolo, Lake/Mendocino/Wheatland). Avoid units that had strong drought problems, high heterogeneity in soil texture, or high pathogen infestation.	Selection of five orchards per combination per each cultivar: • High nitrogen + Thinning • High nitrogen + No Thinning • Medium nitrogen + Thinning • Medium nitrogen + No Thinning • Low nitrogen + Thinning • Low nitrogen + No Thinning	**For prunes:** Collect leaves from 30 trees in one bag. Each tree sampled at least 30 yards apart. In each tree collect leaves, including petiole, around the canopy from at least four well exposed non fruiting spurs located between 5-7 feet from the ground of the four cardinal points. **For walnuts:** Same as in prunes, but from each tree collect at least four leaflets around the canopy from at least four well exposed non fruiting spurs located between 5-7 feet from the ground. From each spur, select the terminal leaflet of basal leaves only. This will result in one leaflet per spur. **For pears:** Same as in prunes, but in each tree collect leaves around the canopy. Select entire leaf, including petiole, from a mid-shoot position on current season's extension growth. Take 8 leaves from around the periphery of each tree (two from each cardinal point).	Collect one composite soil sample in an 'X' fashion following the method described by Geisseler and Horwath, 2013.

**Winter Nelis should be the preferred rootstock. However, you may sample orchards that are in other rootstocks*

RESULTS AND DISCUSSION

To date this project has focused on completing objective 1. During the first quarter, team meetings were held to define final criteria regarding orchard selection, sampling design and sampling protocols. This step was critical since the scope of the results is fixed to the established criteria utilized to collect the data. Special care was taken to include orchards that could represent a range of representative management practices in CA. Orchards with variable yield and variable nitrogen application rates were selected. In addition, important management data per orchard are being collected through surveys developed during the second quarter of this project. The data collected in the surveys will be used to check model outputs and improve results by management type (i.e. tree age), if needed. A summary of the criteria to define the model scope and an example of the surveys are shown in Table 1 and 2, respectively.

A visual inspection of the data variograms shows that the range of nutrient values in spring and summer seems to be adequate to correctly develop a statistical model that can predict different nitrogen concentrations. However, Figure 1 illustrates that simple regressions will not be sufficiently precise to predict leaf nitrogen in summer. This was a known potential difficulty given our previous experience in almonds and pistachios. To overcome this situation, a multi-dimensional model that includes more than one nutrient and possible other variables (i.e. weather and management data) will be built. Even though the principles and factors to build this model may be relatively complex, the user interface will be simple, requiring the input of few variables by the user.

Table 2. Survey developed for walnut growers. Similar surveys were developed for prunes and pear growers.

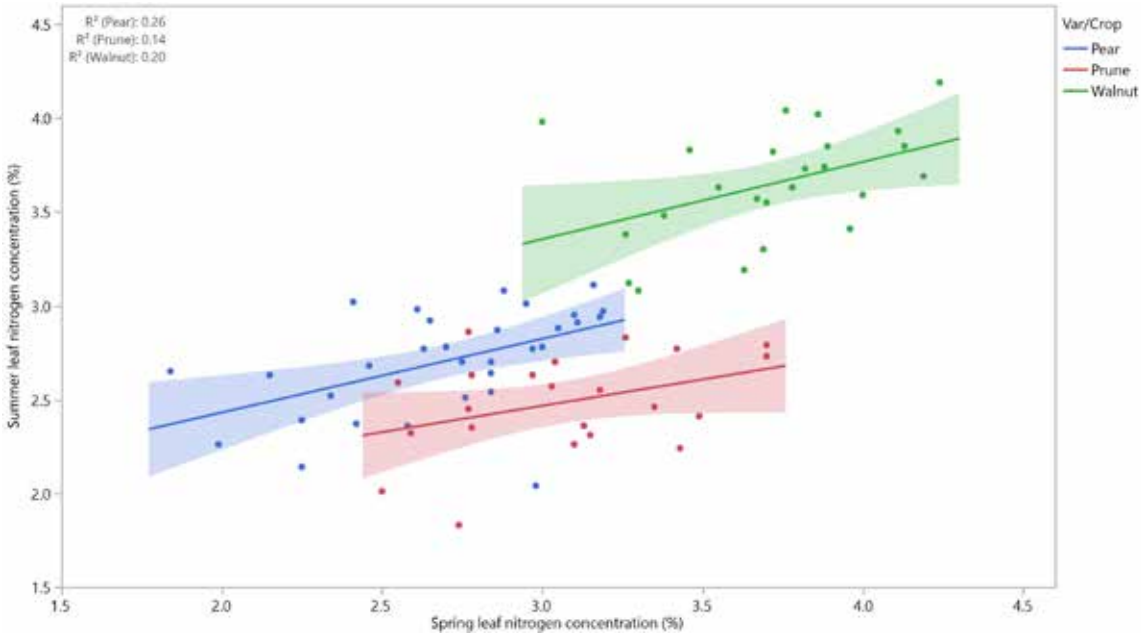

Figure 1. Simple linear regressions for spring versus summer leaf nitrogen concentration in Pears, Prunes, and Walnuts. While the range of leaf N concentrations will be adequate for subsequent model development it is clear from this figure that a simple regression of spring against summer N concentrations will not be sufficient to develop a viable predictive model. This will be addressed in year 2 of this project.

ACKNOWLEDGEMENTS

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

Evaluation and Demonstration of Nitrogen and Phosphorus Management in Organic Leafy Green Vegetables Production on the Central Coast

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INTRODUCTION

Organic vegetable production on the Central Coast (Monterey, Santa Cruz and San Benito Counties) was valued at $214 million in 2013. A wide variety of vegetable types are produced in this region but leafy greens vegetables comprise the majority of production. Large-scale organic production continues to expand given optimal climatic conditions and sale/shipping infrastructure that exists in the area. Little science-based information is available for managing nitrogen (N) in organic programs. Fertilizer practices vary widely among growers and residual soil nitrate or potentially mineralizable N is not commonly included in fertilizer decisions for crop N needs. The industry relies heavily on organic N fertilizers and amendments, mostly derived from animal by products that often have high phosphorus (P):N ratios. Surveys of soil P values in the Salinas Valley have shown that organic production fields can have soil P values comparable with conventional production. Management of P in organic production systems is an important challenge facing producers because it can adversely affect surface water quality.

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

OBJECTIVES

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

DESCRIPTION

Ten nitrogen mineralization trials were initiated with cooperating growers in commercial organic baby and romaine lettuce production fields. Field sites were located in diverse locations and soil types. Comparisons of unfertilized plots with the grower standard fertilizer program were established in each field and the following soil assays were conducted: total N content of the soil, organic matter content and mineral N in the top 12 inches of soil (weekly), nitrate in the water and water extractable N and C. Crop biomass N and soil mineral N were evaluated at harvest for each crop.

Table 1. Analysis of 4-4-2 fertilizer in polypropylene pouches buried 4 inches deep in soil in a baby spinach crop. Pouches removed at weekly intervals.

Weeks in soil	Wet wt. grams	Dry wt. grams	Carbon grams	Nitrogen grams	Phosphorus* grams	Potassium grams
Initial	20.00	18.03	5.14	0.75	0.29	0.36
1	17.10	15.70	4.08	0.52	0.39	0.20
2	15.95	14.55	3.56	0.41	0.39	0.14
3	15.25	14.05	3.28	0.40	0.39	0.11
4	14.20	13.10	2.85	0.39	0.39	0.07

** elemental P (not P_2O_5)*

Nitrogen and P inputs (compost, N in irrigation water, etc.) and output evaluations for lettuce and spring mix crops were conducted. Outputs include the biomass removed in the harvested product will be estimated by measuring the quantity of harvested biomass and its N and P content.

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

RESULTS AND DISCUSSION

An evaluation of the release of N, P and potassium (K) was conducted of the organic fertilizer 4-4-2; this is a commonly used fertilizer that is made from a combination of chicken manure and bone meal. The evaluation of this material was carried out by placing 20 grams in polypropylene pouches and burying them 4 inches deep in an unfertilized section of a baby spinach production field; pouches were removed weekly during the cropping cycle and the residual fertilizer was analyzed for N, P and K. Nitrogen content of the 4-4-2 granules declined rapidly for the first two weeks in the soil and then the decline slowed significantly thereafter (Table 1). Phosphorus content of the fertilizer increased in the prills, presumably because it did not move from the fertilizer prills while the weight of the prills declined. Potassium content of the prills declined each week. These results give an insight into the availability of N from this organic fertilizer under the conditions encountered in this field. Approximately 53% of the N contained in the prills mineralized over four weeks, however a considerable quantity of the N remained in the fertilizer material which can further complicate fertilization decisions by growers.

In a survey of 10 commercial organic vegetable production fields we observed a yield response to applied N in all fields. The magnitude of the yield responses varied indicating differences in the availability of residual soil N in the soils at each site. As we complete our analyses of the soil and mineralization of N from soil organic matter, we hope to better understand factors affecting the quantity and speed of N mineralization from soil. There is a good deal of interest by growers in this project because they have many question about organic fertilizer and the ability of soil to provide the N needs of their crops.

TAKE-HOME MESSAGE

Organic producers are in need of science-based information that can help them better manage N for crop production. Key organic fertilizers have high P:N ratios that may increase soil P levels beyond what is needed agronomically and potentially increase water quality issues. Through this project, we hope to better understand the mineralization of N from soil organic matter as well as organic fertilizers.

ACKNOWLEDGEMENTS

This project was funded by a grant from the California Department of Food and Agriculture's Fertilizer Research and Education Program (FREP) and the Fertilizer Inspection Advisory Board.

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

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INTRODUCTION

The majority of almond growers currently provide N fertilization in liquid form through micro-irrigation systems (MI) (drip and micro-spray) and increasingly growers are utilizing ground water that is saline. Irrigation strategies, fertigation management, nitrate leaching and salinity management are therefore linked and strategies must be developed that optimize productivity while minimizing nitrate leaching and avoiding salt-induced stress to almond trees. There has been very little research to explicitly co-optimize nutrient and water use efficiency and no research that we are aware of to guide irrigation strategies for the dual goal of managing both nitrate and salinity in almond trees. Perennial species and micro-irrigation impose unique challenges for salinity management and strategies developed for annual crops are not optimized for tree crops. Specifically, 1) almond is highly salt sensitive and as water quality diminishes greater leaching volumes will be required, 2) micro-irrigation results in local salt deposition at the lateral and vertical margin of the wetting pattern, water and nitrate within this high salt margin will not be available for uptake, 3) if not conducted properly, strategies that optimize salt leaching to the periphery of the rooted zone will simultaneously leach nitrate.

Almond is considered a salt-sensitive crop with a threshold EC of 1.5 dS/m, these values, however, was derived for Lovell rootstock under flood irrigation and are no longer relevant to modern almond systems. Rootstocks and cultivars of almond are known to vary dramatically in their sensitivity to salt induced water stress and vary in their susceptibility to the effects of toxic ions, Na and Cl.

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

For diverse reasons the most prevalent MI schedule in California is for growers to use long irrigation durations (commonly 24 hrs with occasional 48 hrs) and to apply nitrogen in 4 or fewer injected fertilizer applications during the year. This approach is in stark contrast to practices in Australia, Spain and Israel where MI and fertigation schedules are more commonly daily or even hourly. Spoon-feeding in this way has the potential to improve irrigation and consequently fertilizer management. While recent FREP funded research has provided clear biological rationale for the adoption of frequent spoon-feeding of nitrogen, this has not yet been widely adopted, possibly because of the added infrastructure and personnel costs that spoon-feeding may incur. The threat of salinity and the development of irrigation strategies to achieve the goal of minimal salinity and minimal leaching will serve as an additional impetus for the adoption of spoon-feeding approaches to irrigation and fertilization.

OBJECTIVES

1. To characterize the patterns of root nitrate uptake and plant response when plants are grown with roots in soils of different salinity status (as typically occurs under micro-irrigation).

2. To use HYDRUS to model solute transport, plant response (water and nitrate uptake) to salinity, and specific ions (Cl, Na, B) under a variety of irrigation scenarios and different conditions such as soil type, environment, timing, distribution, irrigation system, and water quality.

3. To use the information in objectives 1 and 2 to develop site and cultivar specific models and guidelines for nitrate sensitive salinity management and to produce a series of written and online grower guidelines and tools for irrigation design and scheduling.

4. To produce a robust modeling platform for the advanced grower, consultant, advisor, irrigation industry representative and researcher to develop novel and site specific irrigation design and scheduling practices for nitrate sensitive salinity management.

In this project we will evaluate the effect of irrigation management and soil type on the deposition pattern of salt within the root zone, and the consequent effect on N uptake by different rootstocks (salt-tolerant vs. salt-sensitive) of almond. Trees have been planted in 12 large lysimeter tanks and are now adapting to the new environment. The root zone will be instrumented to collect the required data on water, salts, nitrate and root growth to accomplish objectives of this project. The collected data will also be used to validate and calibrate an existing modeling platform, HYDRUS. The modeling platform was established and will be linked to an inverse modeling framework for estimation of known physical and biological parameters. Once the required parameters are obtained, this model will be used as an integrated water and nitrate management tool to develop alternative irrigation/fertigation methods to optimize nitrate uptake and minimize salinity effects for

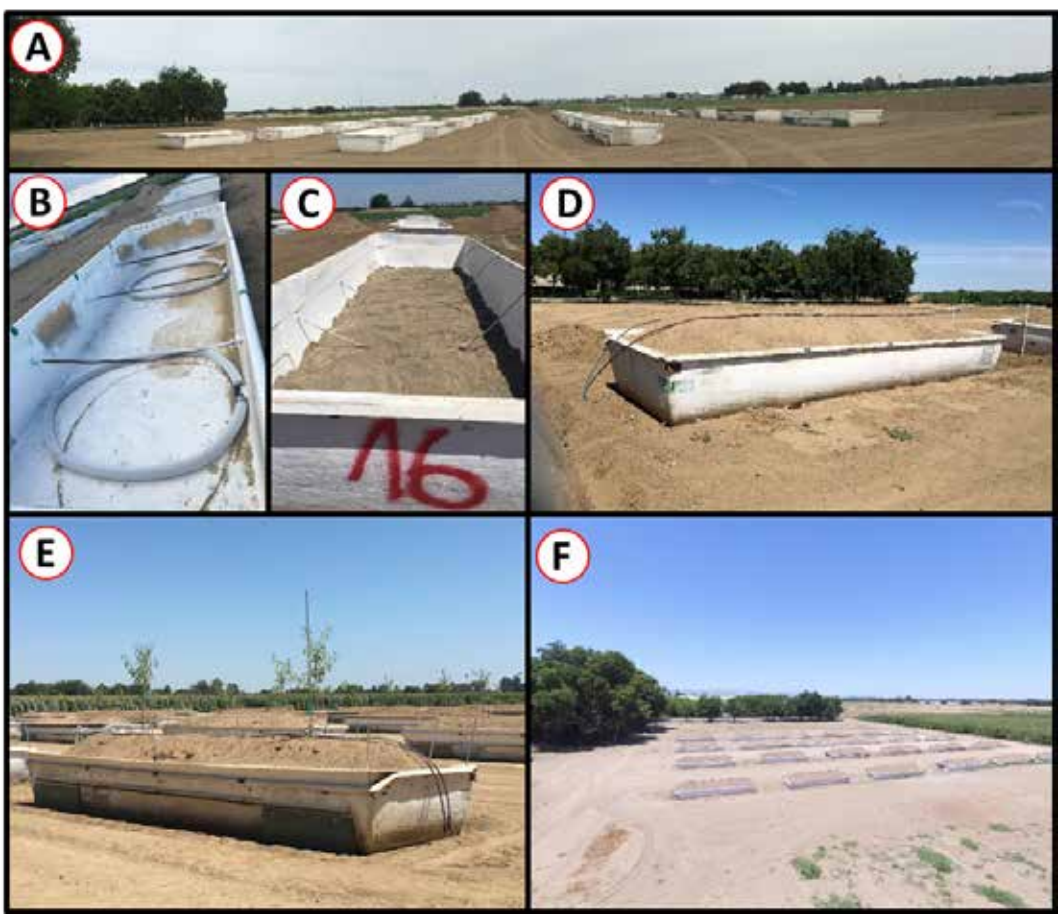


Figure 1. Process of establishing almond trees at the UCD Plant Sciences field research facility in large tomato truck bins. A- overview of bin layout in the field. B- Drainage pipe installed at the bottom of bins. C- Coarse sand covering the drainage pipe. D- Bin filled with soil. E- Almond trees planted in the bin. F- Top view of large bin's layout in the field.

different varieties of almond cultivar, soil types, and level of salinity. The ultimate goal of this project is to provide grower guidelines to minimize leaching of nitrate below the root zone while maintaining the growth and yield at optimum level and a balanced salt concentration in the root zone of the trees.

WORK DESCRIPTION

EXPERIMENTAL DESIGN AND INSTRUMENTATION

Experimental design:

Figure 1 shows the process of establishing almond trees at the UCD Plant Sciences field research facility in large tomato truck bins measuring 28 × 8 × 4 ft (L×W×D). Field ground was leveled with a slight slope allowing for movement of water toward the outlets of bins. Drainage pipe was installed at the bottom of each bin to facilitate the collection of leachate and was covered by coarse sand and then filled with loamy sand soil. Drip irrigation and fertilizer injection systems were installed and are operational. The experiment was designed for six treatments and four replicates for a total of 24 almond trees.

Six additional bins are being manufactured to be used as weighing lysimeters and be heavily instrumented using GS3 soil moisture sensors, solution samplers, tensiometers, and neutron probe and mini-rhizotron access tubes for both continuous (24/7) and alternating days monitoring of soil water, salinity, and nitrate status as well as leaching.

Instrumentation plan:

Once the soil in the bins is settled, all the bins will be instrumented with tensiometers, solution samplers, and neutron probe and mini-rhizotron access tubes for alternating day (bi-weekly for mini-rhizotron) monitoring. All the weighing lysimeters will be extensively instrumented using GS3 soil moisture sensors, solution samplers, tensiometers, and neutron probe and mini-rhizotron access tubes for both continuous (24/7) and alternating days

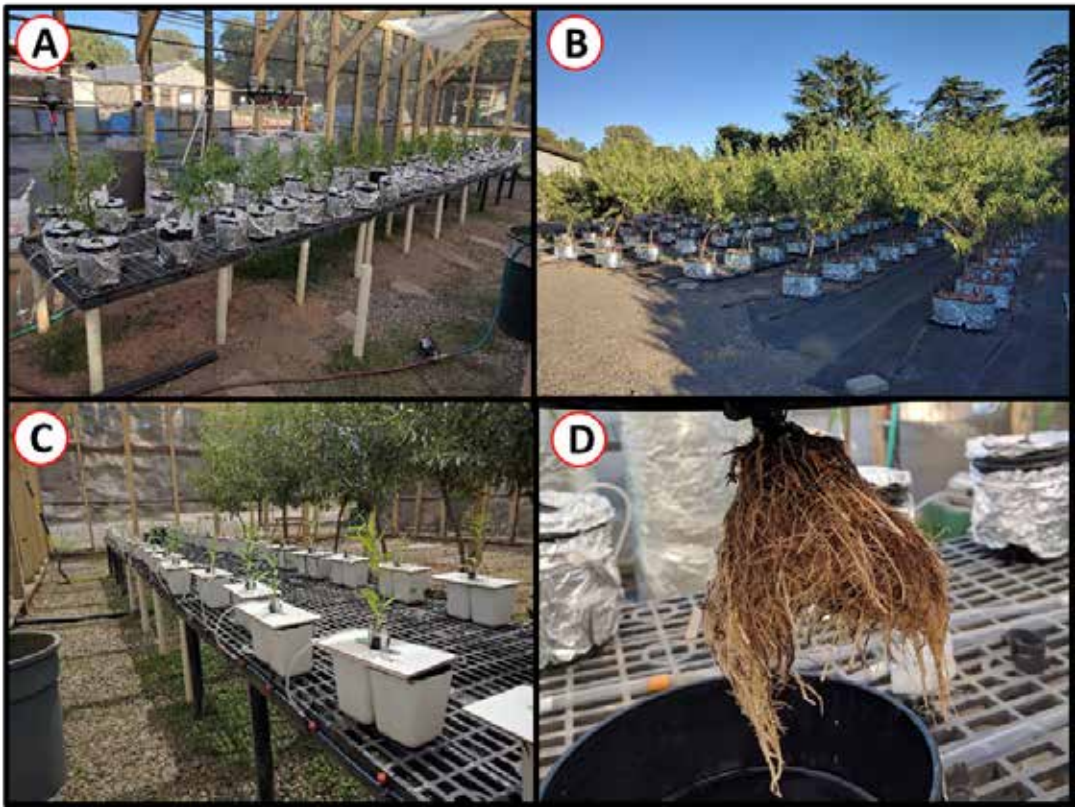


Figure 2. Greenhouse pot experiment to obtain biological parameters. A- Hydroponic experiment to determine nitrate uptake parameters. B- Split-root pot experiment to investigate root plasticity on water uptake. C- Split-root hydroponic experiment to investigate root plasticity on nitrate uptake. D- Almond roots grown under hydroponic condition.

monitoring of soil water, salinity, and nitrate status as well as leaching.

Soil hydraulic properties:

The soil hydraulic properties will be determined in the laboratory. (Will be accomplished during the winter period)

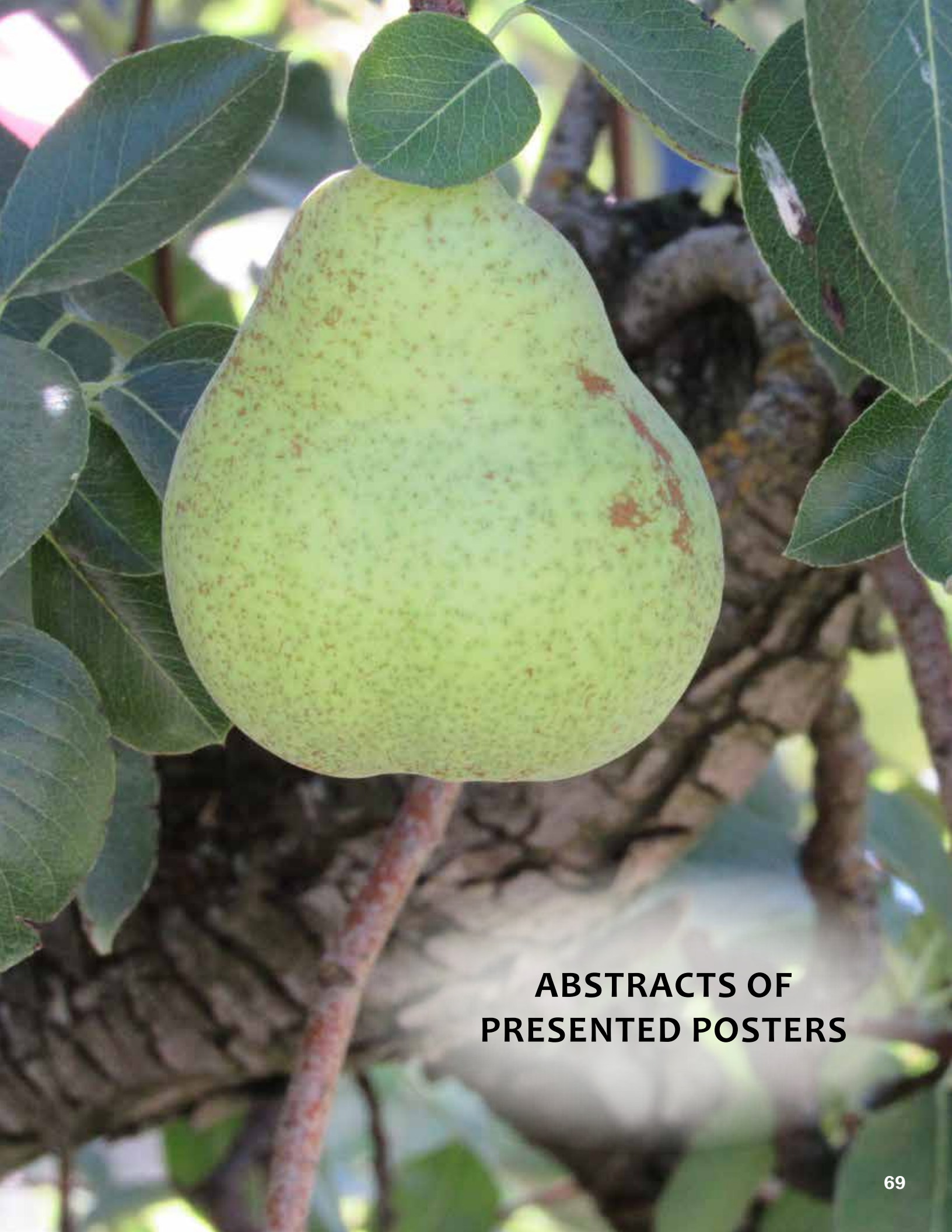
Modeling Scenario analysis:

HYDRUS calibration

The HYDRUS modeling platform was established and we are in the process of implementing the inverse modeling framework. The greenhouse experiment was established (Fig. 2) and we are in the process of data collection to be used for estimation of uptake parameters and root plasticity.

ACKNOWLEDGEMENTS

This project was made possible by support provided by the Fertilizer Research and Education Program, Almond Board of California, and ANR competitive grants program.



ABSTRACTS OF PRESENTED POSTERS

Adapting CropManage for Strawberry and Celery Production in Ventura County

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Successful berry and vegetable production cannot be achieved without proper irrigation and nitrogen (N) management. Applying the right amount of water and N fertilizers is only part of an effective irrigation and fertility program. The timing of their applications is equally important. By matching water and N fertilizer applications to the specific needs of the crop, growers can optimize yields and inputs and address environmental concerns related to water conservation and off-site movement of nitrate.

In order to help berry and vegetable growers with customizing irrigation and N management to the specific growth stage of their crops, the University of California Cooperative Extension created an online tool that makes water and N fertilizer recommendations on a field-by-field basis. CropManage (cropmanage.ucanr.edu) is a free web-based app that uses data from multiple sources to customize recommendations of water and N fertilizer for commercial fields. Data sources that drive CropManage include: plant developmental models from UC research (N uptake, canopy cover and root depth), soil nitrate samples, expected yield, evapotranspiration data from the California Irrigation Management and Information System (CIMIS), irrigation system characteristics and soil properties data from the NRCS national database.

The development of CropManage for a specific crop and region requires intensive data collection from multiple fields for at least one year in order to develop reliable plant growth models. Collaboration between UC and local growers and companies has enabled CropManage to be adapted for strawberries and celery production in Ventura County.

Two validation studies were performed in Ventura County in the last year in order to assess the effectiveness of CropManage's water and N fertilizer recommendations for strawberries and celery production. The studies were conducted in randomized complete block design with four replications in a commercial field (celery) and in a research station (strawberry). Yield, water and N fertilizer use were compared to the grower standard practice of the field where each study took place.

For the strawberry study, CropManage's recommendations resulted in 22% greater yields, 14% greater water use, and 34% greater N fertilizer use compared to the grower standard practices. For the celery study, CropManage's recommendations resulted in 5% greater yields (not statistically significant, $P = 0.286$), same water use, and 24% lower N fertilizer use compared to the grower standard practices. The use of significantly more water and N fertilizer in the strawberry study was most likely related to under-fertilization of the grower standard treatment.

These studies showed that recommendations from CropManage may result in greater or lower use of water and fertilizer depending on the comparison management practice. The fact that yields were the same or greater than the grower standard demonstrated that the CM recommendations do not reduce yields.

Strawberry Growth, Nitrogen Dynamics and Nitrate Leaching in Vermicompost-Amended Media

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The use of vermicompost is suggested as a method to reduce nitrogen losses in crop production; however, it is unclear whether and how vermicompost can affect water quality after a significant irrigation or rainfall event. The objectives of this experiment were to: a) determine the concentration of nitrate-nitrogen in drainage water from vermicompost-amended media planted with strawberry in a greenhouse setting and b) determine vegetative biomass of strawberry grown in vermicompost-amended media. Bare-root strawberry plugs were grown in one-gallon plastic pots. The treatments consisted of two media: 1) a peat:perlite soil-less mix and 2) a fine sand soil with three levels of dairy manure vermicompost addition: 0%, 10%, 25% by weight, and a biweekly synthetic fertilizer treatment of 150 mg N-P-K L^{-1} evaluated in a full factorial randomized block design. Drainage water from each plant was collected for 18 weeks and analyzed for NO_3^- concentration. High (1000-5000 mg l^{-1}) amounts of NO_3^- leaching in vermicompost -amended media were observed during the first two weeks of drainage collection relative to non vermicompost-amended media. Plants grown with vermicompost at 25% with synthetic fertilizer had the highest above-ground vegetative biomass (15.3 g) relative to plants with synthetic fertilizer alone (5.3 g). These data suggest vermicompost addition rates of 10% and 25% by weight promote high vegetative biomass in greenhouse strawberry but may facilitate high initial nitrate leaching, which can negatively affect water quality and environmental health.

Managing Drip Irrigation for Productivity and Sustainability in Organic Tomato Production

Jennifer E. Schmidt, Caitlin Peterson, Daoyuan Wang, Israel Herrera, Kate Scow, Amélie C.M Gaudin

Transitioning to drip irrigation in processing tomato offers a number of benefits, including improved yields and water use efficiency and decreased weed pressure and N greenhouse gas emissions. However, little information exists on nutrient dynamics and availability in drip irrigated organic systems, which rely on organic nutrient cycling and healthy soils for high yields. In fact, it is not clear how drip irrigation affects soil health and whether potential tradeoffs exist over the long term.

We will present results of a two-year field experiment (2015-2016) at UC Davis Russell Ranch comparing the impact of various irrigation strategies (single drip, double drip and furrow) on N mineralization, root distribution and N uptake, and soil health and microbial functions in a long-term organic processing tomato-corn rotation. Although maximizing water use efficiency through precise irrigation management is of critical importance given the current drought, our results suggest that organic growers and stakeholders may need to consider hidden tradeoffs of drip irrigation for soil ecosystem services. This research provides critical insight to reconcile productivity and sustainability goals and helps improve irrigation management to maximize organic N availability.

Regional estimates of nitrate leaching potential in California's agricultural soils

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Nitrate is recognized as one of California's most widespread groundwater contaminants. The fate of nitrate in soil, along with the risk of reaching groundwater is a function of several processes that occur over different temporal and spatial scales. Quantitative, soil-specific information is needed to predict nitrate leaching potential over this complexity of scales.

We simulated nitrate dynamics for all agricultural soils in California taking into account scenarios of climate, crop type, irrigation and fertilization. We quantified nitrate leaching potential using the Hydrus-1D model coupled with USDA-NRCS soil survey data. We also evaluated simple management options to reduce nitrate leaching.

The results of the simulations were validated against independent estimates of nitrate in harvest for 58 different crops. We calculated regional estimates of drainage rates of water under the root zone and nitrate concentrations in the drain water. We present maps for all agricultural soils in California to identify regions that may need improved management. Results indicate that adoption of simple irrigation and fertilization methods may significantly reduce nitrate leaching in vulnerable areas.

California Fertilization Guidelines

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California growers are facing increasing pressure to improve nitrogen (N) use efficiency in crop production to reduce nitrate leaching to the groundwater. For many crops, a comprehensive overview and synthesis of the current research on fertilizer use and management has long been missing. With support from FREP (projects 11-0485-SA and 15-0231), we have been closing this gap by writing online fertilization guidelines for major crops grown in California. Currently, guidelines for more than 20 major crops are freely available online at: cdfa.ca.gov/go/FREPguides.

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

Nitrate Storage and Usage in Wheat

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Background research in the three most widely propagated grasses, wheat (triticum durum), corn (zea maize) and rice (oryza sativa) has indicated nitrate storage in the stem. Over several season, electrochemical sensors implanted in the nodes of the corn stem have indicated the strong presence of nitrate in the lower part of the corn stem from pre-pollination to near harvest. Wheat is architecturally simpler than corn. It has a single stem for storage. The head at the top of this stem is the single reproductive sink for nitrate.

In wheat, a surface implanted in the lowest node of the stem can be used to determine the timing and magnitude of nitrate transfer from the soil into the stem. A surface simultaneously implanted in the node just below the head can be used to determine the timing and magnitude of nitrate transfer from the stem into the head. The two surfces can then be used to separate out storage and usage of nitrate.

Method

Three semi production wheat treatments (250 by 20 yards) were set up side by side in which nitrate was applied in the form of granular urea, low biuret foliar applied urea and UN32 to the respective treatments. A fourth treatment was used as control. The treatments were flood irrigated. Surfaces were implanted in sixteen plants in the four borders in the first node above the soil surface prior to boot phase (6 March 2016) and in the top node just below the head at boot phase (30 March 2016). The surfaces were monitored every ten minutes for sixty days. This led to the following five cardinal values every ten minutes:

- Extracellular fluid content in the vicinity of the surface
- Total Ion population in the extracellular fluid surrounding the surface
- Identification of the dominant Ion in the population, N or P or K.
- Changes in the ionic composition of the bulk fluid
- Changes in the energy level of the ions in the bulk fluid

Results

Nitrate moved strongly from the soil into the stem during irrigation periods, but not into the head. Nitrate moved precipitously into the head at a high rate during periods of unsettled weather characterized by a high value of vapor pressure. There was a slow uptake of nitrate into the head in the later stage of maturation. The form of the nitrogen movement was not significantly different in the four treatments.

Conclusions

Nitrate movement in the wheat plant has two distinct modes: 1) Movement of nitrate from the soil into the stem but not the head, 2) Movement of nitrate from the stem into the head. Mode 1 is a storage process. Mode 2 is a usage process. Mode 1 and Mode 2 are distinct and separate processes.

Usage of nitrate by the head was highly weather dependent insofar as Mode 2 correlated closely with high vapor pressure. But the correlation was not causal. The timing of nitrate movement into the head was similar to timing of nitrate movement observed in corn, almonds, pistachios, citrus, chili peppers and wine grapes using similar electrochemical instrumentation. This has led to the hypothesis that an underlying weather related agent exists in plants in general which triggers nitrate movement. This agent may be the atmospheric ion level and polarity.

Quantifying N2O Emissions from Different On-farm Irrigation and Nutrient Management Schedules in Strawberries

S. Kortman[1], K. Post[1,2], A. Conlen[1], D. Muratore[1], K. Prescott[1], R. Spellenberg[1,2], J. Toyoshima[1], I. Zaragoza[1,2], M. Cahn[3], R. Smith[3], F. Melton[1,2], and A. Haffa[1]

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The Pajaro and Salinas Valley are two of the most productive agricultural regions in the world, growing hundreds of different crops and providing an important share of California's $42.5 billion in cash farm receipts. As a result, the highly productive counties also share challenges associated with the nutrient intensive production of a diverse range of specialty crops including strawberries and broccoli; there is a need in both regions for cost-effective best management practices for irrigation and nutrients to protect water quality and improve agricultural sustainability without loss of crop yield or quality.

Sustainability includes economic success, and growers need validation that using low-cost decision support tools for integrated irrigation and nutrient management are beneficial. In collaboration with CSU Monterey Bay, NASA, and the UC Cooperative Extension of Monterey (UCCE), partner growers participated in field demonstration trials to evaluate the N-cycle pathways to better quantify the benefits of efficient irrigation and nutrient management.

The study used replicated irrigation treatments at 100% and 130% of crop evapotranspiration (ET) under which field scale nitrous oxide (N2O) emissions were simultaneously monitored with nitrate vadose zone leaching to evaluate reductions in nitrogen losses. Because N2O is 300 times more effective than carbon dioxide at warming the atmosphere, and 75% of N2O emissions in the U.S. are emitted by agriculture soil management, namely through nitrogen (N) fertilizer application, there is potential for low cost integrated irrigation and nutrient management practices to mitigate direct and indirect N2O emissions and nitrate loss below the rooting zone.

Results will allow us to quantify the benefits of ET-based irrigation and integrated in-field nitrate quick tests (NQTs) and irrigation water nitrogen accounting for reduction of nitrogen losses from agricultural systems. These results may then be incorporated into Crop Manage (CM), the online decision support tool developed by UCCE that assists growers by providing real-time irrigation runtimes and N-fertilizer recommendations. CM relies upon crop ET and nitrogen uptake models which are modified based on residual soil and groundwater N composition to better reflect applications residual nitrogen.

The overall goal of this study is to provide data and information than can assist growers working to optimize water and fertilizer use in a way that improves their bottom line while minimizing losses of excess nitrogen to the environment.

CDFA's State Water Efficiency and Enhancement Program (SWEEP)

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California Department of Food and Agriculture
Office of Environmental Farming and Innovation

IMPROVED NUTRIENT MANAGEMENT IS A SIGNIFICANT CO-BENEFIT OF THE PROGRAM

In 2014 CDFA was appropriated $10 million in emergency funding (through Senate Bill 103) to develop an incentive program to provide funds directly to farms to conserve water while also reducing greenhouse gas (GHG) emissions from irrigation systems. Historic drought conditions prompted the initiation of the program and funding has been continued through California Climate Investments, the proceeds of California's GHG Cap and Trade Program. Since the State Water Efficiency and Enhancement Program (SWEEP) was initiated, CDFA has received a total of $60 million to provide as grants.

Awarded SWEEP projects have taken on many forms. Applicants often combine several technologies and management practices to achieve water savings and GHG emission reductions, both of which are required in order to receive funding. The use of remote sensing technologies to improve irrigation management has been a very popular project type and is often in combination with the use of micro-irrigation, pump efficiency retrofits or the installation of renewable energy systems such as solar arrays.

The primary goals of the SWEEP program are to save water and reduce GHG emissions, but other co-benefits are achieved, including improved nutrient management. Projects that include the installation of micro-irrigation systems (including sub-surface systems) facilitate fertigation and nutrient management. Furthermore, soil moisture sensors and other scheduling tools assist farmers in preventing water and nutrient loss below the crop root zone. In these ways SWEEP projects may protect groundwater from nitrate contamination and reduce the emissions of nitrous oxide, a potent GHG.

The South San Joaquin Valley (Tulare Lake Basin) Management Practices Evaluation Program

John Dickey
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Casey Creamer
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The Management Practices Evaluation Program, or MPEP, was devised to complement other components of the Region 5 Irrigated Lands General Orders. This facet of the Orders contains most of the actions to actually protect water quality, along with the most rigorous performance demonstrations. This is where we go beyond simple metrics that might indicate a problem, and go through the steps required to solve problems.

Seven coalitions, representing about 1.85 million acres of irrigated land south of Fresno, are implementing a joint MPEP workplan. This workplan has been extensively discussed with State and Regional Board staffs and with technical partners at NRCS, CDFA, UC, and CSU. We have also reached out to other irrigated lands coalitions and the dairy industry to exchange ideas and promote consistent approaches.

Several MPEP activities combine to deliver what is needed. With the help of management practice literature and expertise (growers, farm and Certified Crop Advisers, researchers), we will compile known protective practices, relate them to circumstances where they can and should be applied, and reach out to our membership to raise levels of awareness, understanding, and implementation. This is the most practical way to rapidly reduce the mass of nitrate leaching from agricultural root zones.

At the same time, we will prioritize groups of crop, soil, and groundwater conditions, focusing on situations with the greatest potential to improve groundwater quality protection. We will identify weaknesses in our existing knowledge and barriers to adoption, and then develop, test, and verify new or revised, protective practices that feed into the next generation of outreach.

Outreach is how we facilitate and speed practice implementation by coalition members. Depending on the nature of the question, studies take the form of classic monitored field plots, monitoring of grower operations along with crop and soil conditions, surveys of grower operational preferences and barriers to adoption, or detailed assessment of existing knowledge on a particular issue (e.g., a literature review).

Our coalition members farm in diverse environmental and management settings, ranging from growers serving a locavore market on limited acreage with multiple vegetable crops per year, to extensive plantings of drip irrigated vines and fruit and nut trees. Although we are required to assess performance across the entirety of this area, we could not conceive of a soil and groundwater sampling program that, by itself, would produce such an assessment.

Fortunately, USDA and EPA have invested years and millions of dollars in modeling tools that, when properly calibrated, can be used to efficiently assess the environmental effects of farming, and the influence of projected changes in management. In this way, crop, soil, climate, and management information can be efficiently integrated to understand what is happening at the field and landscape scales, as required by the orders. We have developed initial model runs that will be refined over time to help the coalitions meet their performance assessment obligations and guide management.

Two other facets of the Orders provide management information: Farm Evaluations and Nitrogen Summary Reports. The Farm Evaluation tells us where protective practices are in use. The Nitrogen Summary Report allows us to relate nitrogen applied by growers (and removed by crops) to other management, crop, and soil information in our diverse landscapes. Together with monitoring data from focused field surveys and calibrated modeling results, these provide the feedback we need to assess and document progress in protecting groundwater quality.

Development of Leaf Sampling and Interpretation Methods for Pistachio and Development of a Nutrient Budget Approach to Fertilizer Management in Pistachio

Muhammad Ismail Siddiqui
UC Davis

The aim of the current project was to develop new approaches and interpretation tools that better quantify spatial and temporal variability, are sensitive to yield and provide for in-season monitoring and fertilizer optimization in pistachio orchards across different geographical locations in California. This work was done in collaboration with the California pistachio industry.

The overall goal of this research project was to develop integrated nutrient management practices for pistachio trees across different ranges of environments to provide growers with tissue sampling protocols and interpretation tools to better manage their crops. At present, leaf sampling and critical value analysis is widely used as a sole method for making nutrient management decisions in pistachio orchards in California. However, the use of leaf sampling as a nutrient management tool has limitations and when used as a sole management tool has the potential for negative environmental consequences. Concerns with leaf tissue testing are a poor correlation between tissue nutrient concentration and soil nutrient availability and a high degree of variability in tissue nutrient concentration in adequately fertilized crops within a single tree and within the same field. Also, the current practice of mid- summer sampling limits grower's ability to make in season fertilizer decisions for the current crop load.

Using data from three years and from four different counties in California, we have developed an early season sampling protocol. This early season sampling protocol allows the growers to determine the nutrient status of the trees early in the season and to make in season fertilizer adjustments for the current crop load.

We have developed and validated yield and phenology based nutrient budget curves across a range of environmental conditions and years for major nutrients including nitrogen, phosphorus and potassium as well as secondary macro-nutrients including calcium and magnesium. Results show that even the best-managed commercial pistachio orchards have substantial variability within and between years and this variability can compromise nitrogen use efficiency. The size of the crop determines the demand for N and provides the economic basis for fertilizer decisions, which, if implemented accordingly, can be used to optimize fertilizer use by synchronizing nitrogen applications with the actual tree demand.

The integration and implementation of the new management strategies developed by this project are expected to help growers to better monitor the nutrient status of their orchards and increase their profitability while protecting the environment.

Distributed Sensor Network Based Optimization of Agricultural Practices to Assess Nutrient Dynamics and Limit Nitrogen Losses

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The purpose of this project was to develop and deploy a distributed sensor network to track nitrate movement in vegetable crops. The objective was to build a system that could rapidly characterize nitrogen and water dynamics in agricultural fields. This system was programmable and employed various environmental and climatic sensors. The control system allowed for evapotranspiration based irrigation utilizing soil moisture sensors to measure water infiltration and leaching depth.

Methodology

The system was piloted and tested on a one-acre field of bell peppers over three growing seasons on the University Agricultural Laboratory at Fresno State. Using

current technology, the team deployed a Geonics EM-38 conductivity meter to measure soil texture and salinity. Decagon's 5TE probes were installed to measure volumetric water content, temperature, and electrical conductivity in the soil domain. A telemetry system was used to monitor, control, and record water and nutrient fluxes in the field. A vacuum system was utilized with ceramic tubes to gather nitrate samples within the soil.

Additionally, periodic soil samples were taken and analyzed by an independent lab. Water and nitrate samples were processed through the SCAN to ensure consistent data processing.

Findings & Conclusion

Current technology exists to develop and deploy nitrate sensing technology;

however, the technology is costly and has to be adapted from other industries for use in agriculture. CIT researchers were able to track nitrate in the soil after irrigation and fertigation events. Additionally, soil moisture sensors were utilized to trigger sampling as an automated system.

It is feasible to build and set up agricultural systems to monitor and take periodic sampling in fields. The current technology makes these types of systems costly and impractical for everyday use. However, with further development, this technology may allow growers more avenues to control and maintain fertilizer treatments in agricultural fields.

Measuring and Monitoring Nitrogen Dynamics in Central Valley Crops in Real Time to Control Nitrogen Leaching

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Groundwater pollution due to improper irrigation practices is a common issue all over the world. Improper irrigation and fertigation practices can lead to overuse of water and fertilizer and simultaneously result in leaching of soluble chemicals like nitrates below root zone. One third of tested irrigation and domestic wells of regions of Central Valley California like Tulare Lake Basin and Salinas Valley were found to exceed maximum containment level (MCL) of 45 mg/L (Boyle et al., 2012). It is with regard to this, this project was conducted to study nitrate leaching and factors contributing to it in real time so as to develop a control system of distributed sensor network that can deliver optimum amount of fertilizer and minimize leaching of nitrates in vegetable crops, while maximizing yield and water use efficiency.

Methodology

Three drainage lysimeters were installed to collect samples from six feet depth below the ground level. Two of them were installed on beds with 100% irrigation and fertigation treatments while the third one was installed on 80% bed. A fully automated collection system sampled and recorded nitrate-nitrogen readings. The system was setup at one of the 100% lysimeters area to keep track of nitrate-nitrogen leached in real time. For the remaining two lysimeters, manual collection of samples was done based on weekly schedule and nitrate-nitrogen readings were taken in laboratory using nitrate sensor. Soil moisture sensors were also used to keep track of water percolation at different depths in real time condition. Automated irrigation scheduling was based on ETo data obtained from CIMIS and corresponding ETc values from WATERIGHT website. A telemetry system was used to monitor and control real time irrigation data.

Findings & Conclusion

Analysis of Variance (ANOVA) was done using IBM SPSS Statistics version

24, and it was found that there was no significant difference between data obtained from automated 100% treatment bed and manual 100% treatment bed. This showed that automated system was equally good in tracking nitrate-nitrogen leaching in real time. The results also showed that there was a significant effect of treatments (irrigation and fertigation) on nitrate leaching with 100% treatment(irrigation and fertigation) resulting in higher nitrate leaching than 80% treatment. It was also found that nitrate leaching was higher with increasing temperature for 100% treatments (irrigation and fertigation) while it was lower with increasing temperature for 80% treatments.

LIST OF COMPLETED FREP PROJECTS

List of Completed FREP Projects

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

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

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

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

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

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

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

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

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

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

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

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

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

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

California Certified Crop Adviser FREP Educational Project • *Daniel H. Putnam*

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*

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*

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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*

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