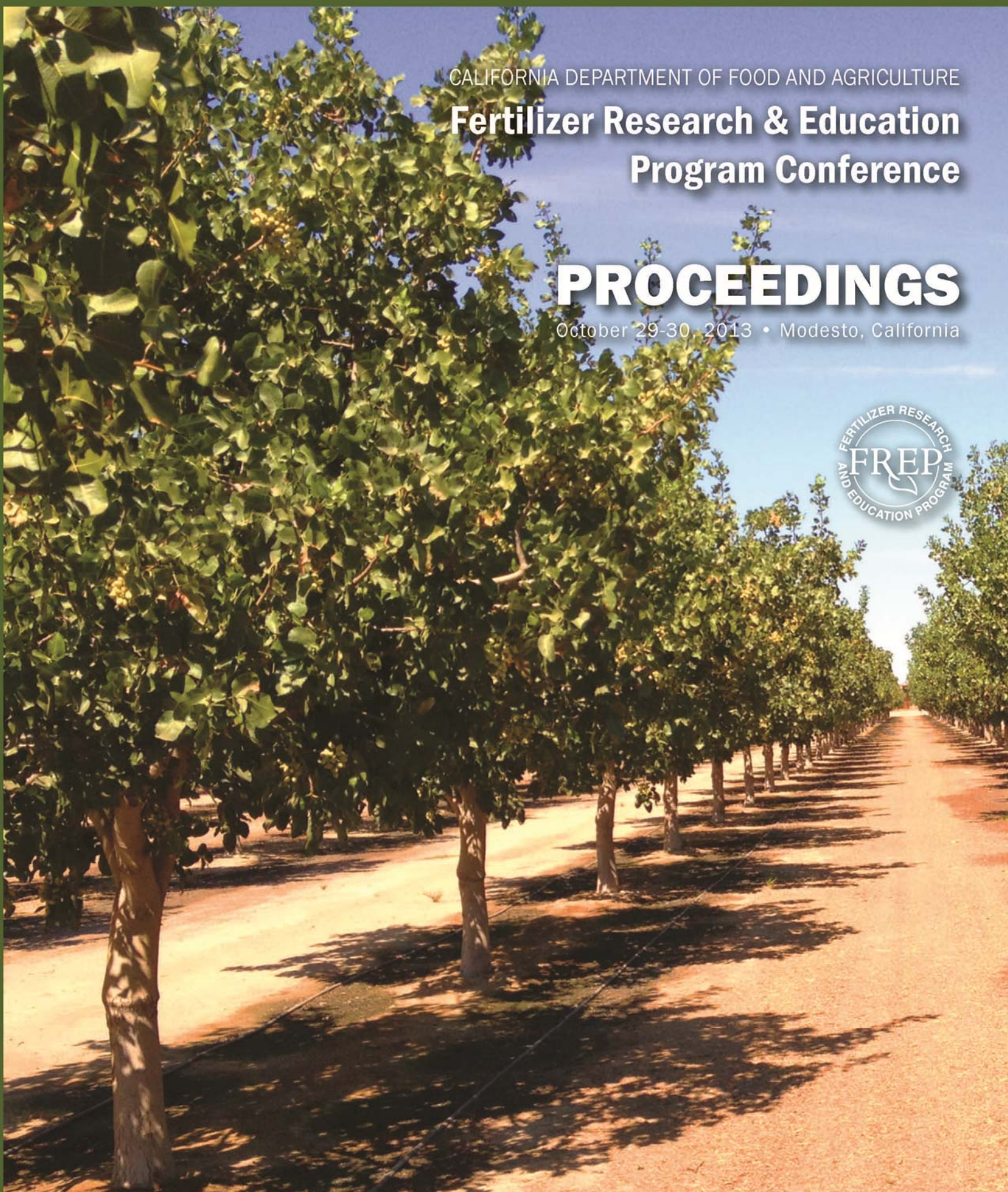
Twenty-First Annual



CALIFORNIA DEPARTMENT OF FOOD AND AGRICULTURE

Fertilizer Research & Education Program Conference

PROCEEDINGS

October 29-30, 2013 • Modesto, California

FERTILIZER RESEARCH AND EDUCATION PROGRAM
FREP

Twenty-First Annual

CALIFORNIA DEPARTMENT OF FOOD AND AGRICULTURE

Fertilizer Research & Education Program Conference

PROCEEDINGS

October 29-30, 2013 • Modesto, California

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Pistachio orchard used in FREP project *Optimizing the Use of Groundwater Nitrogen for Nut Crops*; Madera, CA
L. Douglas West, Ph.D., July 2013

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Matt Read of UC Davis uses a back hoe to open a soil pit and determine root depth distribution using the trench wall profile approach. | Madera, CA

Fertilizer Research and Education Program

FOR 21 YEARS, the California Department of Food and Agriculture's (CDFA) Fertilizer Research and Education Program (FREP) has presented its pioneering fertilizer research at an annual conference. Since 2007, FREP has collaborated with the Western Plant Health Association (WPHA) to create an alternative conference concept that balances FREP's scientific and technical research with a discussion of practical application techniques. This combination has allowed FREP to convey its research findings in the context of topic overview and practical application, thus extending its outreach to a broader audience of agriculturalists at multiple levels.

This year's conference offers another integrated agenda. Aptly titled, "Managing Agricultural Nutrients: Challenges, Opportunities, and the Future," the 2013 event combines the 21st Annual FREP Conference with WPHA's Central Valley Regional Nutrient Seminar. Over one and a half days, presenters from academia, industry and agricultural consulting will provide general and technical information, current research data, and practical applications addressing statewide and regional nutrient management issues. The Conference offers a unique opportunity for agricultural consultants, advisors, and governmental agency and university personnel to learn about FREP's cutting edge research findings, and in turn pass them on to growers.

Summaries of FREP funded projects presented during the conference as well as other ongoing and recently completed FREP research projects are included in these proceedings. FREP is excited to announce that beginning this year, we will spotlight an ongoing FREP-funded project by featuring project photos on the cover and section dividers of our annual conference proceedings. The inaugural edition of this new effort features photos of *Optimizing the Use of Groundwater Nitrogen for Nut Crops*, led by David Smart, Jan Hopmans, Patrick Brown, and Thomas Harter of UC Davis. FREP would like to thank the project leaders for inviting our staff to visit the project site and agreeing to participate in this new effort.

FREP OVERVIEW AND NEW INITIATIVES

The Fertilizer Research and Education Program (FREP) funds and facilitates research, education, and outreach projects to advance the environmentally safe and agronomically sound use of fertilizing materials. FREP serves a wide variety of agriculturalists such as growers, agricultural supply and service professionals, university extension and public agency personnel, certified crop advisers (CCAs) and pest control advisers (PCAs), and other interested parties.

FREP was established in 1990 through legislation with support from the fertilizer industry. California Food and Agricultural Code Section 14611(b) authorizes an assessment not to exceed one mill ($0.001) on the sale of fertilizing materials to provide funding for research, education, and outreach regarding the use and handling of fertilizing materials. The current assessment is at one mill ($0.001) per dollar sales of commercial fertilizer, generating approximately two million dollars per year to support the program.

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

Technical Education

One of FREP's technical education efforts is the Nitrogen Management Training Program (NMTP) for CCAs currently being developed. The Program is a joint effort between CDFA, University of California Agricultural and Natural Resources (UC ANR), and the California CCA Program to develop and implement a voluntary nitrogen management curriculum specifically targeted for California CCAs. The curriculum will address the management of nitrates from plant nutrients to reduce unintentional emissions throughout the state. The goal of the Program is to facilitate CCAs' understanding of sound nitrogen management practices and increase their ability to make informed recommendations to growers, thereby improving environmental performance relative to nitrogen management for crop production.

Research

FREP has remained true to its original mission by continuing to fund research to improve nutrient management practices. In addition to the annual request for proposals, in 2012 FREP released its first-ever Special Request for Proposals. The purpose of this Special

RFP was to specifically address the issue of nitrates in groundwater in environmentally sensitive areas of California. The Special RFP called for proposals focusing on research that utilized the "pump and fertilize" method in concert with nitrogen budget worksheets to show proof-of-concept. The following two projects were selected for funding:

- *Optimizing Groundwater Nitrogen Use by Nut Crops* will examine nut crops in the Central Valley and is being led by David Smart, Jan Hopmans, Patrick Brown, and Thomas Harter of UC Davis
- *Determining the Fertilizer Value of Ambient Nitrogen in Irrigation Water* will examine lettuce and broccoli on the Central Coast and is being led by Michael Cahn and Richard Smith of UC Cooperative Extension and Tim Hartz of UC Davis

The goal of these two projects is to demonstrate if the "pump and fertilize" is an effective method in reducing use of nitrogen fertilizer based on the nitrates available in the ground water, and subsequently reduces nitrate levels in groundwater aquifers. You can read more about these projects on pages XX and XX of this publication.

Education and Outreach

In the past year, FREP has worked to increase our education and outreach efforts beyond our annual conference. In June 2012, FREP partnered with the UC ANR Institute for Water Resources (CIWR) to hold a series of forums titled "Managing Agricultural Nitrogen." Held in Sacramento and Tulare, the forums were free and open to the public and were geared toward growers, dairy operators, agency representatives, agricultural commissioners, policymakers, and other concerned community members. The goals of these forums were to discuss the role of policy in nitrogen management, explore solutions to nitrate in groundwater, and cover the need for additional research and education.

In addition, FREP has sought to increase awareness of the agronomically sound use of fertilizer products by continuing our effort to make FREP research easily available online. In partnership with UC Davis Department of Land, Air, and Water Resources, FREP has developed a web based information portal consisting of a searchable database of FREP research projects coupled with interactive crop fertilization guidelines. Phase I of the project, the database, aims to make the wealth of information contained in FREP research reports readily available, easily understandable, and convenient for growers and crop advisors to implement. The database was completed in July 2012 and is available at http://www.cdfa.ca.gov/is/frep/Default.aspx; new records will continue to be added as FREP research projects are completed. Phase II of the project includes the creation of crop fertilization guidelines based on a synthesis of peer reviewed journal articles and research reports. The guidelines are being uploaded on a flow basis and are available at http://apps.cdfa.ca.gov/frep/docs/Guidelines.html. You can read more about this effort on page XX of this publication.

FREP COMPETITIVE GRANTS PROGRAM

Each year, FREP solicits suggestions for research, demonstration, and education projects related to the use of fertilizer materials. FREP strives for excellence by supporting high quality research and education endeavors that have gone through a rigorous two-phase statewide competitive process, including independent peer review. Projects are typically funded at $75,000 per year for up to three years; however, large, multi-disciplinary projects may be considered at higher funding levels.

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

Specific research priorities for FREP in 2013 were:

Demonstrating Agronomically Sound Uses of Fertilizing Materials at the Field Scale: Demonstrate results from basic experimental research trials (prior FREP research, etc.) with organic and conventional fertilizers at the field scale.

Managing Agricultural Nitrogen: Research the agronomically sound use of nitrogen fertilizing materials, including:

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

Developing Best Management Practices (BMPs): Development of nutrient BMPs and educational materials for agriculture and urban landscapes.

Education and Outreach: Development of educational materials to increase awareness of agronomically sound use of fertilizing materials. Extension efforts to implement best management practices.

Since its inception, FREP's research focus has been the growing concern of nitrate contamination in ground and surface water from fertilizer use. FREP-funded projects continue to evaluate environmental water and air quality issues as related to fertilizer use. In recent years, FREP's research funding has expanded to include agronomic efficiency in the management of nutrients, as well. The following figures illustrate the geographical regions, commodities, and disciplines covered by FREP projects over the past two decades.

Figure 1 lists FREP projects by location; 56% of FREP projects have been conducted in the Central Valley, 21% statewide, 13% on the Central Coast, 5% on the South Coast, 4% in the desert, and 1% in other locations.

Figure 2 lists the distribution of FREP projects by commodity; 25% of FREP projects have been conducted on multiple crops, 21% on vegetable crops, 20% on fruit crops, 19% on field crops, 9% on nut crops, 3% on nursery and horticulture crops, 1% on turfgrass, 1% on fruit and nut crops, and 1% on soil.

Figure 3 lists the distribution of FREP projects by discipline; 31% of FREP projects focus on nutrient/soil testing, 19% on irrigation and fertigation, 15% on fertilizer practices, 14% are educational projects, 6% on precision agriculture, 3% on compost and cover crops, 3% on pest interactions, 2% on air quality, 1% on heavy metals, and 6% on various other topics.

PROCEEDING BEYOND CONFERENCE PROCEEDINGS

One of FREP's key goals is to ensure that research results generated from the program are distributed to, and used by, growers and the fertilizer industry. Proceedings from past annual conferences, videos, DVDs, and pamphlets on various topics relating to fertilizing techniques are available to interested members of the agricultural community at low or no cost by contacting the FREP office.

FREP collaborates and coordinates with other organizations with similar goals to extend FREP research to agricultural advisors who in turn will convey findings to farmers. Our partners include: Western Plant Health Association, California Chapter of the American Society of Agronomy; California Certified Crop Adviser Program; University of California Cooperative Extension Program; University of California Sustainable Agriculture Research and Education Program; State Water Resources Control Board Interagency Coordinating Committee; California Air Resources Board; California Energy Commission; and Monterey County Water Resources Agency.

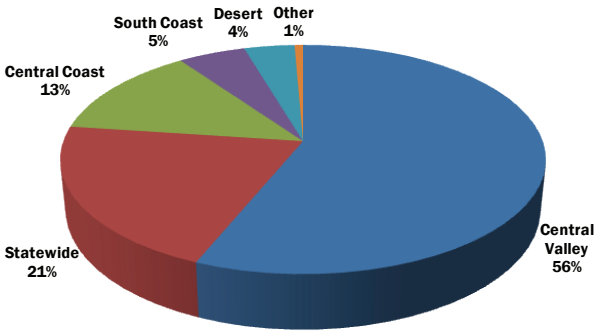

Figure 1. FREP Projects by Location, 1990-2012.

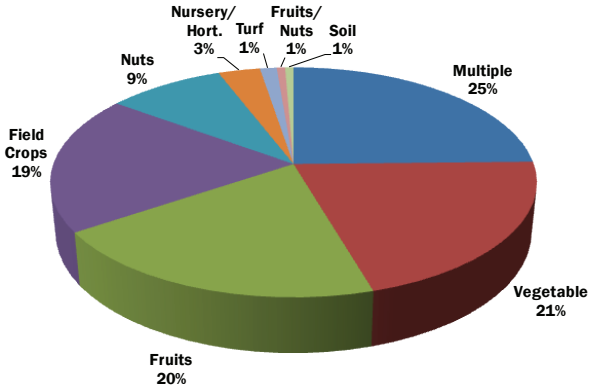

Figure 2. FREP Projects by Commodity, 1990-2012.

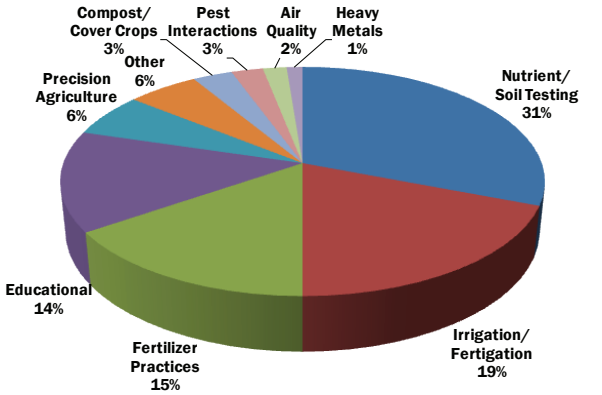

Figure 3. FREP Projects by Discipline, 1990-2012.

Growers have a vested interest in maintaining the viability of the resources that make farming possible and so successful here in California. We at CDFA/FREP are keenly interested in funding new projects that offer farmers alternative methods to address environmental issues and fertilizer use efficiency.

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

ACKNOWLEDGEMENTS

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

We recognize the members of the Fertilizer Inspection Advisory Board's Technical Advisory Subcommittee who review and recommend projects for funding. The professionalism, expertise, and experience of Jack Wackerman, Tom Gerecke, Dr. Michael Cahn, Dr. Dennis Chessman, Dr. Eric Ellison, Dr. Marja Koivunen, Dr. Holly Little, David McEuen, Dr. Rob Mikkelsen, Dr. Jerome Pier, and Dr. Doug West have provided FREP with direction to ensure the program achieves its goals. In addition, we thank the members of the Fertilizer Inspection Advisory Board for their continued support of the FREP program: S. Jay Yost, Brad Baltzer, Jake Evans, Andrew Godfrey, Doug Graham, David McEuen, Rachel Oster, John Salmonson, and Steve Spangler.

We thank the Western Plant Health Association as a valued partner in the "Managing Agricultural Nutrients: Challenges, Opportunities, and the Future" conference. The perspectives, input and support of Renee Pinel, President and CEO, and Mary Junqueiro, Director of Programs, have led to greater outreach and dissemination of FREP research findings.

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

Special recognition also goes to the leadership at the California Department of Food and Agriculture, including Secretary Karen Ross; Science Advisor Dr. Amrith Gunasekara; Inspection Services Division Director Rick S. Jensen; Dr. Asif A. Maan, Environmental Program Manager II; Erika A. Lewis-Ortega, Research Analyst I; Dr. Doug West, Environmental Scientist; and Edward J. Hard, Research Program Specialist II. In addition, special thanks to Dr. Daniel Geisseler, Post Doctoral Researcher with the UC Davis Department of Land, Air, and Water Resources for his diligent work on creating the FREP research database and crop fertilization guidelines.

Francisco Acevedo creates a soil platform on the side of a trench wall profile to gather samples used to measure soil bulk density. | Madera, CA

Tuesday, October 29, 2013

Facilitator:	*Dr. Jerome Pier, Crop Production Services*
9:00-9:30	**Welcome**
	Renee Pinel, Executive Director, WPHA
	Karen Ross, Secretary, CDFA
	Dee Dee D'Adamo, Board Member, California State Water Resources Control Board
9:30-10:00	California Certified Crop Advisor Nitrogen Management Training Program *Dr. Doug Parker, Director, California Institute for Water Resources, UC Agriculture and Natural Resources*
10:00-10:30	FREP Crop Fertilization Guidelines *Dr. Daniel Geisseler, Post Doctoral Scientist, UC Davis Department of Land, Air, and Water Resources*
10:30-10:45	**Break**
10:45-11:15	Irrigation and Nitrogen Management Web-based Software for Lettuce Production *Dr. Michael Cahn, Farm Advisor, UCCE Monterey County*
11:15-12:00	Panel: Grower Perspective/Response to Decision Tools
12:00-1:00	**Lunch (provided)**
1:00-1:30	Remediation of Tile Drain Water Using Bioreactors *Dr. Timothy K. Hartz, Extension Specialist/Agronomist, UC Davis Department of Plant Sciences*
1:30-2:00	New Leaf Sampling and Nutrient Budgets for Almond and Pistachio *Dr. Patrick Brown, Professor, UC Davis Department of Plant Sciences*
2:00-2:30	Scheduling and Conducting Tissue Sampling *Mike Buttress, Staff Agronomist, A & L Western Agricultural Laboratories*
2:30-2:45	**Break**
2:45-3:15	Towards Development of Foliar Fertilization Strategies for Pistachio to Increase Total Yield and Nut Size and Protect the Environment *Dr. Carol J. Lovatt, Professor, UC Riverside Department of Botany and Plant Sciences*
3:15-4:15	Fertigation Injection and Irrigation Equipment Live Demonstration *Bill Green, Education Specialist, Fresno State Center for Irrigation Technology*

Wednesday, October 30, 2013

Facilitator:	*Dr. Jerome Pier, Crop Production Services*
8:15-8:30	**Welcome and Recap**
8:30-9:00	Plant Nutrient Education Materials for Elementary through High School Classrooms *Judy Culbertson, Executive Director, and Shaney Emerson, Curriculum Coordinator, California Foundation for Agriculture in the Classroom; Haley Clement, Ag Chemistry Teacher, Liberty Ranch High School*
9:00-9:30	California Certified Crop Adviser Educational Project *Terry W. Stark, CEO/President, California Association of Pest Control Advisers*
9:30-10:00	Optimization of Organic Fertilizer Schedules *Dr. David Crohn, Associate Professor, UC Riverside Department of Environmental Sciences*
10:00-10:15	**Break**
10:15-10:45	Improved Methods for Nutrient Tissue Testing in Alfalfa *Steve Orloff, County Director/Farm Advisor, UCCE Siskiyou County*
10:45-11:15	European Pear Growth and Cropping: Optimizing Fertilizer Practices Based on Seasonal Demand and Supply with Emphasis on Nitrogen Management *Dr. Kitren Glozer, Associate Project Scientist, UC Davis Department of Plant Sciences*
11:15-11:45	Emerging FREP Resources *Dr. Robert Mikkselsen, Director, Western North America, International Plant Nutrition Institute*
11:45-12:00	**Closing Remarks**

Safety reinforcement in soil pit used to delimit rooting zone for test of pump and fertilize approach to nitrogen management. | Madera, CA

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

PROJECT LEADERS

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INTRODUCTION

Over the years, a large number of research projects have investigated different aspects of fertilizer management for crops grown in California. The California Department of Food and Agriculture's Fertilizer Research and Education Program (FREP) alone has funded approximately 160 projects over the past 20 years. For many crops, however, a comprehensive overview and synthesis of the current research on fertilizer use and management is missing.

In a collaborative effort between FREP and researchers at the University of California Davis, this obstacle to information access is being addressed by making the wealth of information on crop nutrient management accessible online in a user-friendly searchable database and with crop-specific fertilization guidelines.

OBJECTIVES

The two main objectives of the project are:

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

DESCRIPTION OF ACCOMPLISHMENTS AND ACTIVITIES

FREP Database

In a first phase of the project, key information from more than 130 final reports of FREP-funded projects has been entered into a database. The database can be accessed online at: http://www.cdfa.ca.gov/is/frep/Default.aspx.

On the website, users can search for specific topics by either entering a keyword or choosing a crop type, a county, or a date range from a drop-down menu (**Figure 1**). From the list of projects that meet the search criteria, users can access summaries of specific projects. In addition to the summary, the page also provides links to the final report, FREP proceedings, and external sites closely related to the project, such as articles written by the project leaders that are available online. Additional projects are added to the database when the final reports are submitted to FREP. Researchers are now asked to submit a fact sheet together with the final report to facilitate entering the key information into the database.

Fertilization Guidelines

In a second project phase, results from research projects, including FREP-funded studies, are being synthesized to create web-based fertilization guidelines for specific crops grown in California.

The guidelines present accurate and timely crop nutrient information in a user-friendly, visually interactive interface (**Figure 2**). Information about application rates, time of application, fertilizer placement and types of fertilizers is included. In addition, deficiency symptoms are described and the use of soil and plant tissue analysis is discussed and instructions for representative sampling are provided (**Figure 3**). Currently, the guidelines provide information about nitrogen, phosphorus, and potassium fertilization. An extensive list of references and links to sites with additional information complement the guidelines.

An initial ten priority crops were identified by considering acreage and nitrate sensitivity of the area

in which they are grown. Guidelines for almonds, processing tomatoes, broccoli, and lettuce are now available online at: http://apps.cdfa.ca.gov/frep/docs/guidelines.html.

Guidelines for cotton, rice, corn, wheat, grapes and walnuts are being written or are under review and will be uploaded to the web page on a flow basis. The guidelines are a general overview of fertilization practices based on research and shall provide a basis for in-depth discussions with local farm advisors or fertilization experts about site-specific adjustments.

SUMMARY

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

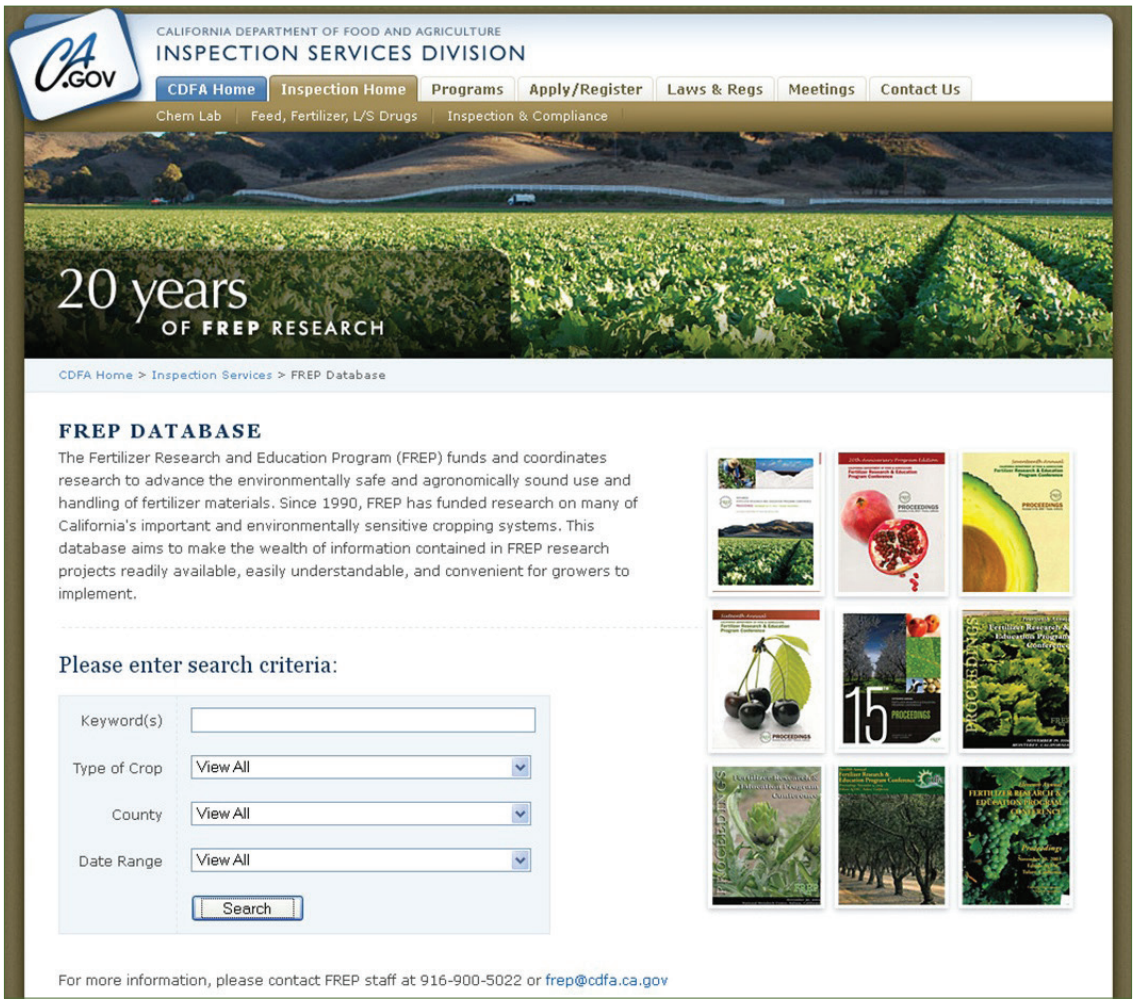

Figure 1. Start site of the FREP database allowing the user to search the database using keywords or specific search criteria (online at http://www.cdfa.ca.gov/is/frep/Default.aspx).

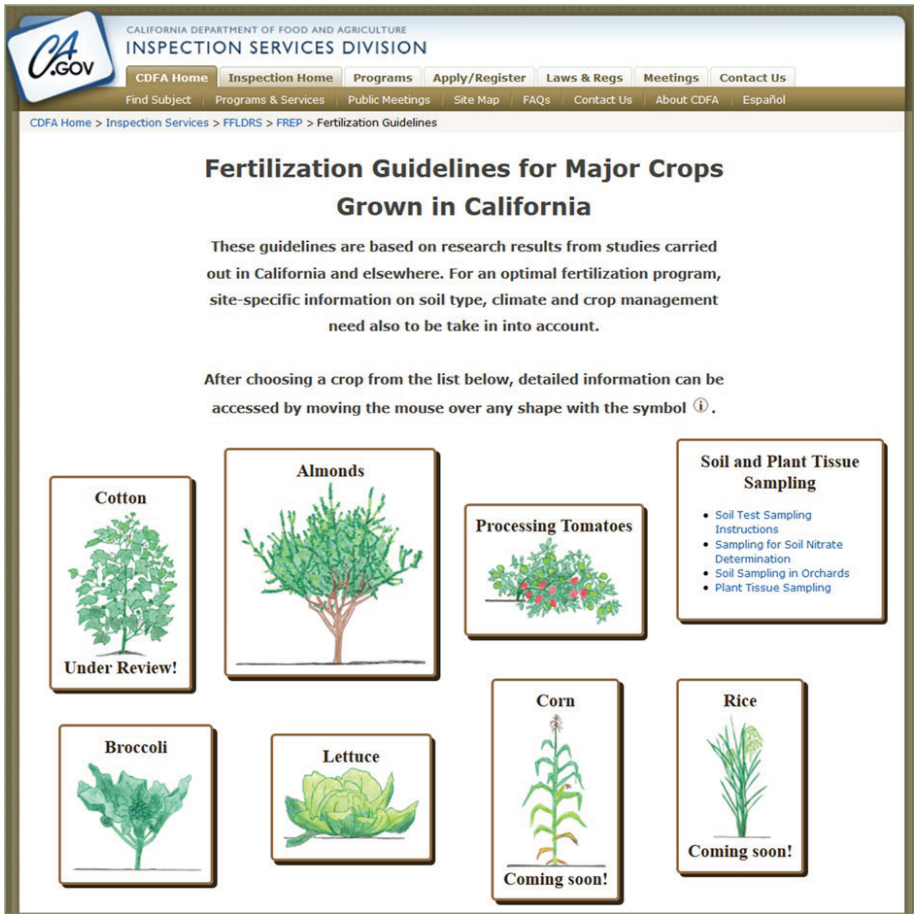

Figure 2. Screen shot of the start page for fertilization guidelines. Crop-specific guidelines can be accessed by clicking on one of the crops (online at http://apps.cdfa.ca.gov/frep/docs/guidelines.html).

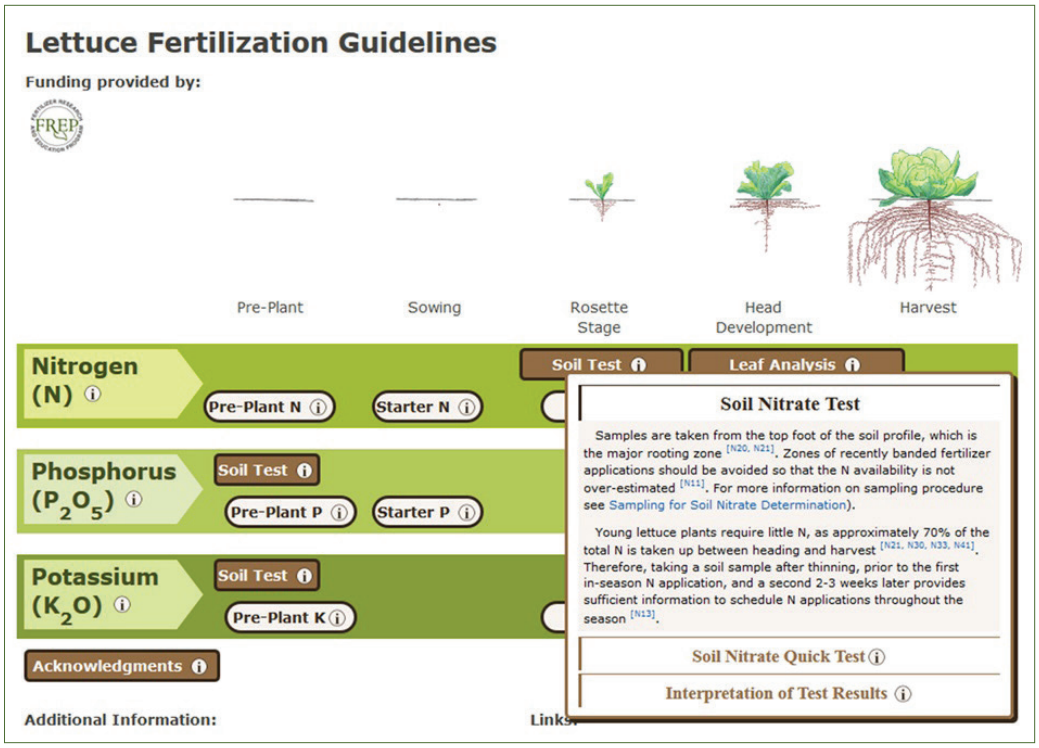

Figure 3. Screen shot of the web page for lettuce fertilization guidelines. Detailed information can be accessed by moving the cursor over the different shapes. For the screen shot, the curser was places over the 'Soil Test' box.

Irrigation and Nitrogen Management Web-based Software for Lettuce Production

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INTRODUCTION

Commercial lettuce production requires significant inputs of water and nitrogen (N) fertilizer to maximize yield and quality. Changes in water quality regulations on the Central Coast and higher fertilizer prices in recent years have prompted grower interest in increasing efficiency of nitrogen fertilizer use in lettuce. By improving water management and matching nitrogen applications to the uptake pattern of the crop, growers could potentially reduce fertilizer use and address water quality concerns. Two tools available to growers, the quick nitrate test and evapotranspiration (ET) data from the California Irrigation Management Information System (CIMIS), have been shown to help lettuce producers better manage water and fertilizer nitrogen. However, adoption of these practices has not been wide spread. One reason is that these techniques can be time consuming to use, and many farm managers have several hundred fields for which they need to make irrigation, fertilization, and pest control decisions during a single season.

The overall goal of this project is to develop a web-based software tool that will aid growers in optimizing water and nitrogen fertilizer applications in lettuce. The software employs established guidelines to recommend the amount of fertilizer and water to apply during upcoming irrigation and fertilizer applications. The software also helps growers track irrigation schedules and nitrogen fertilizer applications on multiple fields and allows users from the same farming operations to share data. Use of this tool may help growers reduce production costs by applying less fertilizer and water, and minimize water quality impacts of vegetable production on surface and ground water supplies.

OBJECTIVES

The principal goal of this project was to develop a web-based software tool that will aid growers in optimizing water and nitrogen fertilizer applications in lettuce, thereby saving production costs and minimizing water quality impacts. Specific objectives of the project were to:

1. Develop irrigation and nitrogen management software.
2. Evaluate irrigation and nitrogen management software in commercial lettuce fields.
3. Conduct educational trainings and develop a user guide for the software.

DESCRIPTION

The goal for the first year of the project was to develop a preliminary version of the web-based software. This included developing a relational database that stores information about fields, crops, and ranches, developing algorithms used for irrigation and fertilization recommendations, automating downloading of CIMIS reference ET data, designing a user interface, and finally testing the software. The second year of the project was dedicated to updating and testing new versions of the software using a core group of growers and conducting evaluations and trials in commercial lettuce fields. During the final year of the project we have continued improving the software and conducting evaluation trials. We have also conducted educational training on using the software and developed a help section to support users.

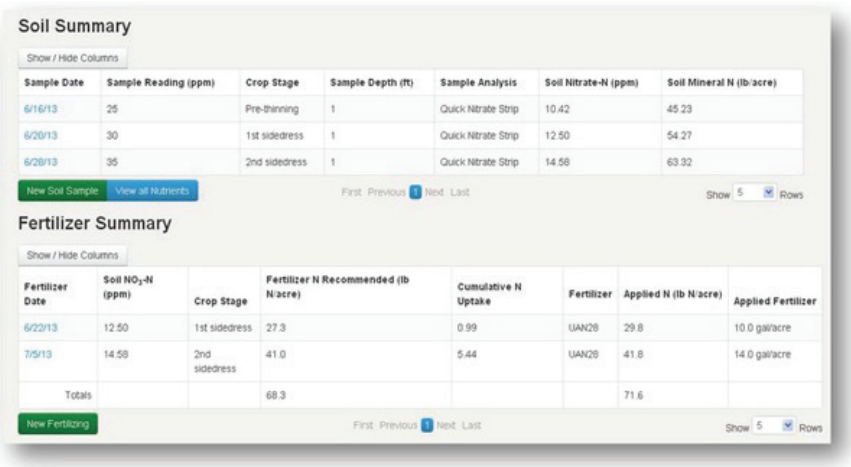
ACCOMPLISHMENTS

Software Development Overview

In collaboration with UC Agriculture and Natural Resources, Communication Services, we launched a preliminary version of the irrigation and nitrogen management software for lettuce (ucanr.edu/cropmanage) on September 1, 2011. The software is accessible from most web-browsers using personal computers, tablet computers, and smart phone screens. The user is required to login before viewing their personalized list of ranches/farms. By selecting a ranch, the user can view all fields currently planted. A database stores ranch information, such as total farmable acres, well names and associated water quality, nearest CIMIS weather stations, and information about individual fields, such as acres, soil type and soil physical properties.

The user can enter the ranch information following the new ranch link. Once the database information is entered for a ranch, the user can add new plantings to a field, which requires inputting information on lettuce type, first irrigation and harvest dates, planted acres, bed spacing, and irrigation system characteristics. The planting "home" screen displays summaries of soil tests, fertilizer applications (**Figure 1**), and watering schedules (**Figure 2**). As the user enters intended dates to fertilize and/or irrigate, the summary tables are updated with recommended water volumes and fertilizer N rates.

Multiple users can view and edit data for a planting, which can facilitate sharing of information within the same farming operation. The ranch owner has authority to assign users access to view and/or edit plantings within a ranch.



Soil Summary

Show / Hide Columns

Sample Date	Sample Reading (ppm)	Crop Stage	Sample Depth (ft)	Sample Analysis	Soil Nitrate-N (ppm)	Soil Mineral N (lb/acre)
6/16/13	25	Pre-thinning	1	Quick Nitrate Strip	10.42	45.23
6/20/13	30	1st sidedress	1	Quick Nitrate Strip	12.50	54.27
6/28/13	35	2nd sidedress	1	Quick Nitrate Strip	14.58	63.32

New Soil Sample | View all Nutrients | First Previous 1 Next Last | Show 5 Rows

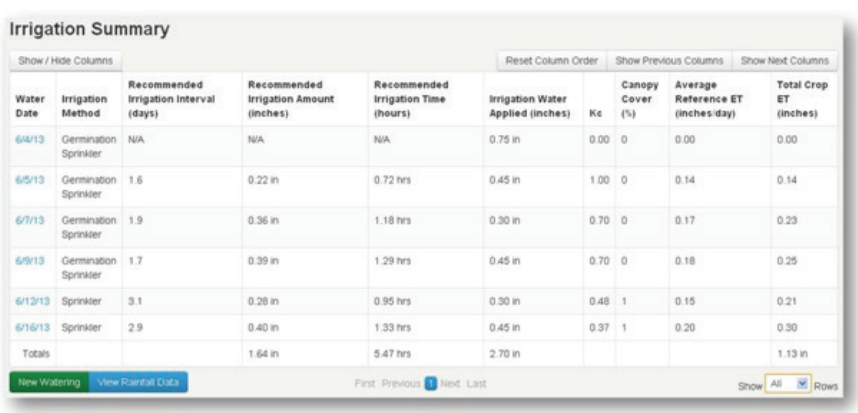
Fertilizer Summary

Show / Hide Columns

Fertilizer Date	Soil NO_3-N (ppm)	Crop Stage	Fertilizer N Recommended (lb N/acre)	Cumulative N Uptake	Fertilizer	Applied N (lb N/acre)	Applied Fertilizer
6/22/13	12.50	1st sidedress	27.3	0.99	UAN28	29.8	10.0 gal/acre
7/5/13	14.58	2nd sidedress	41.0	5.44	UAN28	41.8	14.0 gal/acre
Totals			68.3			71.6	

New Fertilizing | First Previous 1 Next Last | Show 5 Rows

Figure 1. Example display of the soil test and the fertilizer summaries for a romaine lettuce crop.



Irrigation Summary

Show / Hide Columns | Reset Column Order | Show Previous Columns | Show Next Columns

Water Date	Irrigation Method	Recommended Irrigation Interval (days)	Recommended Irrigation Amount (inches)	Recommended Irrigation Time (hours)	Irrigation Water Applied (inches)	Kc	Canopy Cover (%)	Average Reference ET (inches/day)	Total Crop ET (inches)
6/4/13	Germination Sprinkler	N/A	N/A	N/A	0.75 in	0.00	0	0.00	0.00
6/5/13	Germination Sprinkler	1.6	0.22 in	0.72 hrs	0.45 in	1.00	0	0.14	0.14
6/7/13	Germination Sprinkler	1.9	0.36 in	1.18 hrs	0.30 in	0.70	0	0.17	0.23
6/9/13	Germination Sprinkler	1.7	0.39 in	1.29 hrs	0.45 in	0.70	0	0.18	0.25
6/12/13	Sprinkler	3.1	0.28 in	0.95 hrs	0.30 in	0.48	1	0.15	0.21
6/16/13	Sprinkler	2.9	0.40 in	1.33 hrs	0.45 in	0.37	1	0.20	0.30
Totals			1.64 in	5.47 hrs	2.70 in				1.13 in

New Watering | View Rainfall Data | First Previous 1 Next Last | Show All Rows

Figure 2. Example display of an irrigation table for a head lettuce crop. Hyperlinked values link to additional information.

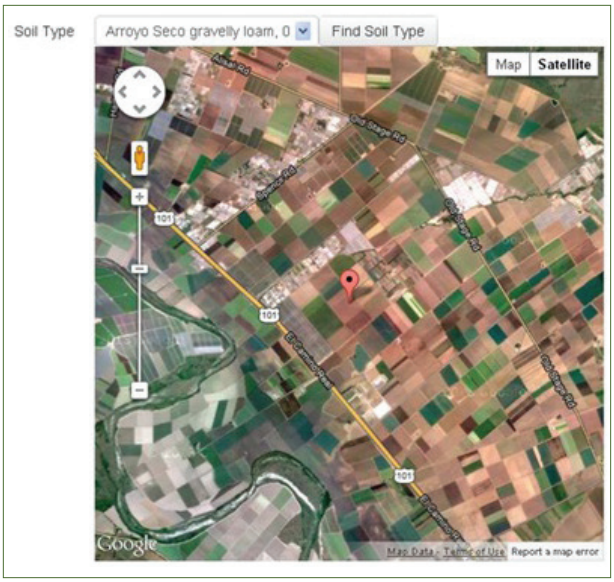


Figure 3. Soil selection tool is used to determine soil type and physical properties of each field within a ranch.

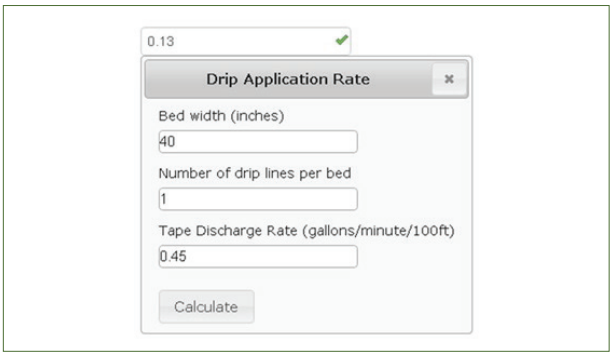


Figure 4. A calculator for determining application rate of drip systems has been integrated into the "new planting" interface.

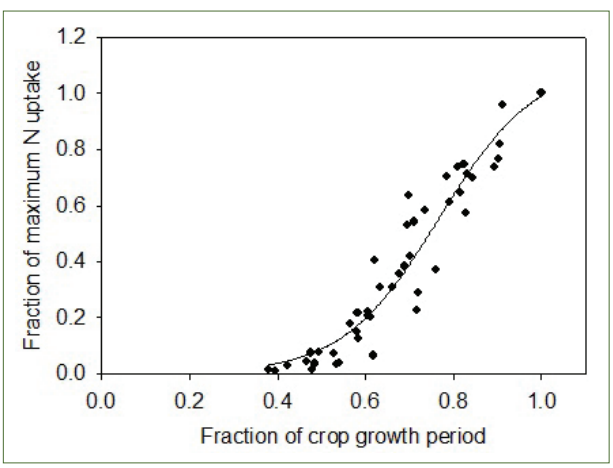


Figure 5. N uptake pattern of iceberg lettuce grown on 40-inch wide beds normalized for maximum N at harvest and number of days in crop cycle

During the third and final year of the project we have continued to improve many features in CropManage:

1. We improved the accuracy of the N uptake, root depth, and mineralization algorithms.
2. We significantly reduced the response time of the software tool. Most calculations are completed in less than 10 seconds.
3. We improved the design of tables and forms in the user interface so that they display quickly and automatically adjust to devices with small screens.
4. An online form can be used to set up new ranches.
5. We linked CropManage to the UC Davis SoilWeb so that users can easily determine the soil type and physical properties of each of their fields within their ranch (**Figure 3**).
6. We added a calculator so that users can accurately estimate the application rate of their sprinkler or drip system (**Figure 4**). The application rate is used to convert irrigation scheduling recommendations from units of volume (inches) to time (hours).

Nitrogen and Water Management Algorithms for Lettuce

In addition to storing and sharing records of soil tests, irrigations, and fertilizations, the software algorithms recommend N fertilizer rates and water applications appropriate for the stage of lettuce growth. The N fertilizer algorithm develops recommendations based on an N uptake curve for lettuce, soil mineral N status (soil nitrate quick test data), as well as estimates of N mineralization contributed from the residue of the previous crop, and soil. The user must enter a fertilization date, a soil N test value, and estimated days until the next fertilization event. Future work will account for nitrogen concentration in the irrigation water in developing the N fertilizer recommendation. The crop N uptake curve follows a sigmoidal shape as shown in **Figure 5**:

$$\text{N uptake (lbs/acre)} = M \times Nmax/(1+\exp[\,(-(day/Maxday)-Yo)/b]\,) \quad \text{eqn. 1}$$

Where *Nmax* is the maximum amount of N (lbs/acre) that the crop takes up by harvest, *b*, *M*, and *Yo* are fitted parameters, *day* is the number of days after planting and *Maxday* is the total days between planting and harvest. Parameters for this model were determined for iceberg and romaine lettuce types grown on 40 and 80-inch wide beds by collecting weekly biomass samples which were analyzed for total N content (**Table 1**).

The irrigation scheduling algorithm uses CIMIS reference ET data, crop coefficient values for lettuce, soil

water holding capacity, and the application rate of the irrigation system to estimate the appropriate irrigation interval and volume of water to apply to maximize lettuce growth and minimize deep percolation. The algorithm is based on the canopy model of Gallardo et al. (1996) for estimating evapotranspiration of lettuce:

$$\text{Canopy cover (\%)} = Gmax/(1 + \exp(A + B \times day/Maxday) \quad \text{eqn. 2.}$$

where *Gmax* is the maximum canopy cover, *A* and *B* are fitted parameters, and *day* and *Maxday* are as described for eqn. 1. Parameters for this model were determined for iceberg and romaine lettuce types grown on 40 and 80-inch wide beds by taking overhead near-infra red canopy photos at 10 to 15 day intervals during the crop cycle (**Table 2**).

Canopy cover is converted to a crop coefficient (Kc) by a modified version of the equation published by Gallardo et al. (1996):

$$Kc = (0.63+1.5\,C - 0.0039C^2)/100 \quad \text{eqn. 3.}$$

where Kc is the crop coefficient, ranging between 0 and 1, and C is percent canopy cover. Evaporation from the soil surface is also estimated by the method described by Gallardo et al. (1996) and used to develop the final Kc value used for estimating crop ET.

To obtain a recommended irrigation volume and interval, the user enters the irrigation date of the next irrigation and the software automatically obtains reference ET data from the nearest CIMIS weather station and uses the algorithms described above to estimate the crop coefficient. Additions to the second version of the software now allow the user to import spatial CIMIS reference ET data or reference data from the nearest CIMIS station. Spatial CIMIS data would presumably increase the accuracy of crop ET estimates for fields located in a different climatic zone than the nearest CIMIS station.

Maximum soil moisture tensions set by the user are used to optimize the recommended irrigation interval. An algorithm relating volumetric soil moisture to soil moisture tension from soil texture data was developed to determine the maximum allowable depletion between irrigations.

Grower Participation, Field Testing, and Outreach

We initially established a core group of growers to use, test, and review the first version of the irrigation and nitrogen management software. Their suggestions were incorporated into a second version that went online beginning in March 2012. After a second year of testing by a wider group of users, the software was updated a third time in March 2013.

Table 1. Parameters for N uptake algorithm (eqn. 1) for various lettuce types and planting configurations.

				Model Coefficients				
Bed width (inches)	Lettuce type	Plant rows per bed	Number of sites	Nmax (lbs N/acre)	M	b	Yo	R^2
40	Iceberg	2	15	130	1.109	0.110	0.767	0.96
80	Iceberg	5 or 6	6	150	1.017	0.075	0.719	0.98
40	Romaine	2	6	120	1.202	0.110	0.828	0.99
80	Romaine	5 or 6	4	145	1.116	0.114	0.763	0.94

Table 2. Parameters for canopy cover algorithm (eqn. 2) for various lettuce types and planting configurations.

				Model Coefficients			
Bed width (inches)	Lettuce type	Plant rows per bed	Number of sites	Gmax (% cover)	A	B	R^2
40	Iceberg	2	7	83	6.78	-11.61	0.77
80	Iceberg	5	2	92	6.83	-12.77	0.93
80	Iceberg	6	2	89	8.23	-14.11	0.97
40	Romaine	2	2	85	3.88	-7.68	0.94
80	Romaine	5	3	86	7.07	-10.73	0.96
80	Romaine	6	7	82	7.06	-10.95	0.94

More than 350 users have registered to use CropManage and more than 100 ranches have been added to the database as of September 1, 2013. We plan to add capacity to generate reports summarizing user activity so that we can determine the percentage of users that are routinely using the decision support tool.

During the 2012 and 2013 seasons we continued testing and demonstrating the CropManage software in 12 commercial lettuce fields on the Central Coast. We installed a flowmeter in each of these fields so that the grower could view the volume of water applied during irrigation events and compare actual and recommended volumes of applied water. We conducted two large-scale, non-replicated trials in commercial fields comparing yield of lettuce grown under standard and CropManage recommended water and nitrogen management in 2012, and we are conducting three additional trials during 2013. Yield measurements were made using commercial harvesters. Approximately 30% less N fertilizer (62 lb N/Acre) was applied under the CropManage regime in one trial and 23% less water was applied during the drip phase of the crop following the water recommendations of CropManage in the other trial. Differences in yields between treatments for both trials were less than 3% (**Tables 3 and 4**). In addition to the non-replicated trials, we conducted two replicated trials at the USDA-ARS Spence research farm in Salinas, CA to further evaluate the accuracy of the water recommendations of CropManage (Johnson et al. 2012, 2013). These trials, funded by a CDFA Specialty Crop Block Grant, demonstrated that similar yields could be attained under the CropManage recommendations compared to the standard grower practice, using 30% to 40% less water.

Extensive efforts have been made to reach out to the agricultural community during the last two years, including more than ten oral presentations at grower/industry meetings, two hands-on workshops on CropManage, and four professional society presentations. Additionally, we are developing a help guide to using the CropManage decision support tool through the CropManage Blog (http://ucanr.edu/blogs/CropManage/index.cfm). Links to specific topics in the blog can be found on the CropManage website under the help menu. We also added the capability to send emails directly to CropManage users to inform them on updates and educational opportunities.

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ACKNOWLEDGEMENTS

We are grateful for the assistance of Bryon Noel, David Krause, and Karl Krist of ANR Communications Services for developing and improving the CropManage software. Barry Farrara, of UCCE Monterey, conducted field measurements used for developing the algorithms in CropManage. Lee Johnson, Forrest Melton, and Chris Lund, of California State University, Monterey Bay, Sharon Benzen and David Lara of the USDA-ARS in Salinas, and Susanne Klose of FreshExpress are also acknowledged for assistance with replicated trials. The CDFA Specialty Crop Block Grant provided funding for the replicated trials, and the California Leafy Green Research Board provided partial support field testing and outreach during the 2013 season.

Table 3. Non-replicated strip trial in a commercial romaine lettuce field comparing applied water use and yield during the drip phase under grower standard and CropManage practices.

Treatment	Applied Water (inches)		Commercial Yield (lbs/acre)
	Sprinkler	Drip[1]	
Grower Standard	4.1	4.9	17935
CropManage	4.1	3.8	18389

[1]Trial compared last 7 irrigations

Table 4. Non-replicated strip trial in a commercial romaine lettuce field comparing applied fertilizer N and yield under grower standard and CropManage practices.

Treatment	Applied N Fertilizer (lbs/acre)	Commercial Yield (lbs/acre)
Grower Standard	211	19114
CropManage	149	18760

Remediation of Tile Drain Water Using Bioreactors

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INTRODUCTION

Vegetable growers on the Central Coast face an unprecedented challenge from environmental water quality regulation. The Central Coast Region Water Quality Control Board has added new monitoring and reporting requirements to the recent renewal of the Conditional Waiver for Irrigated Lands. The waiver renewal focuses on nitrate-nitrogen (NO_3-N) pollution abatement; extensive monitoring in recent years has shown that the NO_3-N concentration in surface runoff and tile drain effluent from fields in this region commonly exceeds the Federal drinking water standard of 10 PPM. While better fertilizer management practices can reduce the NO_3-N load in agricultural wastewater, it appears that some remediation will also be needed to meet environmental targets. Of the techniques that have been considered for the remediation of agricultural wastewater, biological denitrification (BD) appears to be the most promising. BD is a passive process in which bacteria reduce NO_3- to gaseous N compounds (mostly N_2). The requirements for BD to occur are an anaerobic environment, the presence of bacteria capable of this transformation, and labile carbon to power bacterial growth and act as a terminal electron acceptor. This process occurs naturally in wetlands, but limited availability of labile carbon limits the rate at which denitrification occurs, thereby making the use of wetlands to remediate agricultural wastewater problematic.

An alternative approach to harnessing BD is the use of a denitrification bioreactor. A bioreactor consists of a chamber filled with an organic waste material through which agricultural wastewater flows. The organic waste material (most often wood chips) supplies labile carbon while providing a physical matrix on which the denitrifying bacteria can grow. Bioreactors have been evaluated in various agricultural areas around the world, with reasonably consistent success. This project is testing this technique on commercial farms in the Salinas Valley.

OBJECTIVES

1. Evaluate the environmental and economic feasibility of denitrification bioreactors for the removal of nitrate from tile drain effluent and surface runoff.
2. Extend the results of this research to coastal vegetable growers to stimulate action toward compliance with water quality regulation.

DESCRIPTION

Two pilot-scale bioreactors were constructed in 2011 on tile-drained commercial vegetable farms in the Salinas Valley. Pits of approximately 930 ft^3 (site 1) and 450 ft^3 (site 2) were dug, lined with polyethylene sheeting, and filled with chipped wood waste obtained from the Monterey Regional Waste Management District. This material, made by grinding untreated scrap construction wood, is available in sufficient quantity (approximately 7,500 tons per year) to represent a potential source of media for commercial-scale bioreactors in this region. Pumps were installed in the collection sumps of the farms' tile drain systems. Tile drain water was continuously pumped into the bioreactors at a rate to provide approximately 2 days of residence time before the water was released into the surface ditch draining the farm. Beginning in May (site 1) or June (site 2), 2011, inlet and outlet water from the reactors has been sampled 2-3 times per week during the crop production season, and once per week during the winter.

In May, 2012, a pilot-scale bioreactor was constructed on a commercial farm in the Salinas Valley (site 3) to evaluate the remediation of surface runoff from vegetable fields. This reactor is approximately 430 ft^3 in volume, and contains the same wood waste medium used for the 2011 bioreactors, although of a finer grind (most chips < 1", whereas the 2011 bioreactors were filled with 1-2" chips). Water was continuously pumped into the bioreactor from a tailwater collection

pond. Because this water contains a sufficient sediment load to foul the bioreactor, the water was pre-treated with polyacrylamide (PAM) to flocculate soil particles before it was pumped into the bioreactor. Additionally, alum (aluminum sulfate) was periodically injected at approximately 20 PPM. Surface runoff from vegetable fields can have undesirably high PO_4-P, and the use of alum has been successful in removing PO_4-P from municipal wastewater. After pre-treatment, water was routed to a holding tank for approximately an hour before entering the bioreactor; this delay provided time for the precipitation of soil particles and aluminum phosphate. The site 3 bioreactor has been operational since June, 2012, and has been sampled 2-3 times per week during the irrigation seasons of 2012 and 2013.

All samples collected at all bioreactors have been analyzed for NO_3-N concentration. Dissolved organic carbon (DOC, a factor that can affect the rate of denitrification) was analyzed for all samples collected in the first summer of operation at each site and periodically since then. PO_4-P was determined for all samples collected at site 3 and periodically for samples collected from sites 1 and 2.

RESULTS AND DISCUSSION

A high level of DOC was present initially in the outflow from all bioreactors, but declined to <20 PPM after several weeks of operation. High DOC may stimulate the biological oxygen demand of the receiving waters. Additionally, the color of the reactor effluent in the initial weeks of operation was quite dark, suggesting that complex organic compounds were being leached from the wood chips. To minimize any adverse environmental effects arising from the operation of a bioreactor, water released during the initial weeks of operation might best be reapplied on-farm as pre-irrigation water. Tile drain effluent presents a potential problem in this regard, as it can be relatively high in salinity (the electrical conductivity of bioreactor effluent at sites 1 and 2 has ranged between 2-4 dS/m). After a few weeks of operation, bioreactor effluent does not appear to pose any environmental risk not present in the original wastewater.

At all sites, denitrification began within days of the initial filling of the bioreactors; denitrifying bacteria are ubiquitous, and 'seeding' of inoculum was not necessary. High initial denitrification rates over the first month of operation slowed as the reactors matured, undoubtedly related to reduced carbon availability. After the first month of operation, DOC of bioreactor effluent has remained stable at 5-15 PPM, only marginally higher than the incoming water. Once the bioreactors at sites 1 and 2 reached a 'steady state' condition, bioreactor treatment reduced effluent NO_3-N concentration by approximately 9 PPM NO_3-N per day of residence time during the rest of the 2011 summer season (**Figure 1**). Summer denitrification rates in 2012 and so far in 2013 have remained between 8-9 PPM per day of residence time, suggesting long-term stability of performance. During the winters of 2011-12 and 2012-13 denitrification rates averaged approximately 5 PPM NO_3-N per day of residence time at sites 1 and 2. Lower winter rates were undoubtedly due to lower water temperature, which averaged approximately 54° F in winter compared to 61° F in summer.

After the initial month of operation in 2012, denitrification achieved at site 3 averaged 13 PPM NO_3-N reduction per day of residence time through the rest of the summer season. The bioreactor did not operate during the winter (no irrigation runoff), and was put back into service in April, 2013. Summer denitrification rates have averaged approximately 10 PPM per day so far in 2013. The higher rate observed at site 3 compared to the other sites was assumed to be due to higher temperature of the surface runoff, which reached 70° F in mid-summer.

In bioreactor research conducted throughout the world, wood chips have been the most widely used carbon media, due to large-scale availability, relatively low cost, and longevity of performance. However, wood chip bioreactors have been shown to be carbon-limited

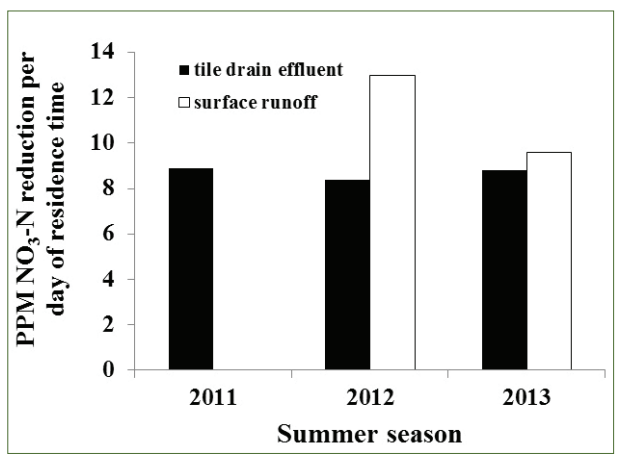

Figure 1. Mean reduction in NO_3-N concentration per day of bioreactor residence time; values for tile drain effluent are averaged across sites 1 and 2.

(the rate of denitrification is limited by the microbial availability of carbon). To test whether our bioreactors were carbon-limited, we injected methanol (a soluble, easily degradable carbon source) into the bioreactors at site 1 and 2 during alternate months in 2013. The injection of approximately 20 PPM methanol increased denitrification by more than 40% at both sites (**Figure 2**).

PO_4-P concentration in surface runoff was relatively high at site 3, typically ranging between 0.4-0.8 PPM. Alum pre-treatment reduced PO_4-P by > 50% (**Figure 3**). With or without alum pre-treatment, PO_4-P was further reduced in the bioreactor, presumably due to denitrifying bacteria assimilating PO_4-P into their biomass. The PO_4-P concentration in tile drain effluent at sites 1 and 2 was much lower than surface runoff, typically ranging between 0.05-0.3 PPM (frequently above an environmentally desirable level of <0.1 PPM). Bioreactor treatment alone (no alum pretreatment) reduced PO_4-P by > 50% on average.

This project has demonstrated that wood chip denitrification bioreactors can substantially reduce NO_3-N loading to groundwater and surface water. Based on the performance of these pilot-scale bioreactors, annual denitrification of approximately 2-3 lb N per cubic yard of bioreactor could be achieved under normal operating conditions along the Central Coast. We are currently performing an economic evaluation of this technology, which would involve significant construction and operational costs. Given the high NO_3-N concentration prevalent in runoff and leachate in this region, it would be impractical to construct bioreactors of sufficient scale to ensure environmental compliance with the 10 PPM NO_3-N drinking water standard. We believe that denitrification bioreactors could be effective as one element of an integrated irrigation and nutrient management system that minimizes both the volume and NO_3-N load of agricultural discharge.

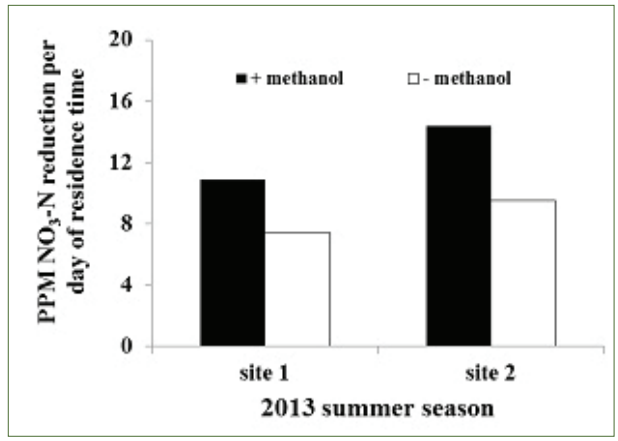

Figure 2. Stimulation of denitrification by the injection of methanol as a soluble carbon source.

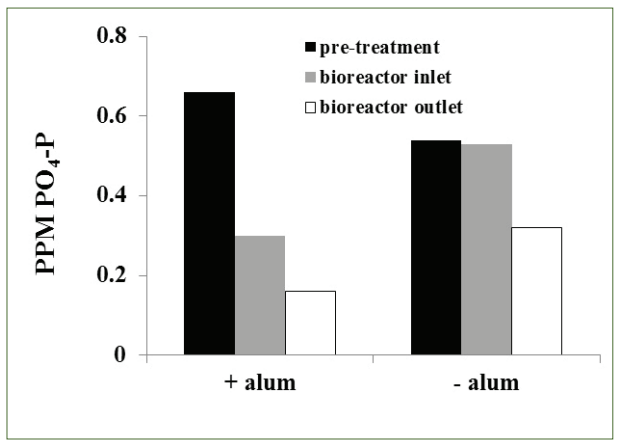

Figure 3. Reduction of PO_4-P concentration by alum injection and bioreactor treatment.

Development of Leaf Sampling and Interpretation Methods for Almond and Pistachio

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INTRODUCTION

At present, growers primarily use leaf tissue analysis to determine tree nutrient status and make fertilizer management decisions. This is often followed by uniform fertilizer application across the entire orchard and across years. An inherent problem with this approach is that some trees may be over fertilized, and others may be under fertilized. Comparing the results of the leaf samples with the established critical values is the standard for nutrient management decisions in California. Results of a survey of almond and pistachio growers, and consultants in California suggested that the existing leaf sampling protocol and comparison of the tissue results with the established standards does not provide sufficient guidance for nutrient management. Two explanations for this observation are possible: a) The current critical values (CVs) are incorrect or not useful for the decision-making process due to lack of sensitivity or inappropriate timing, or b) Leaf tissue analysis alone is not adequate to provide nutrient management recommendations.

Concerns with current 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.

Earlier studies on leaf analysis have also recognized the problem of variability which makes effective leaf sampling extremely difficult. Currently, growers typically collect one tissue sample per management unit or orchard zone, however, no study has been conducted to date to determine how this sample should be collected to adequately represent the spatial variability of the orchard so that a true mean of the nutrients in the orchard can be determined. In general, midsummer is the recommended period of leaf sampling for nutrient analysis in fruit and nut trees including in California, this corresponds to the period from July through early August in the central valleys of California. The midsummer timing has been established because the concentration of most nutrients remains fairly stable during this time. This practice of sampling late in the summer, however, limits the grower's ability to make in season fertilizer adjustments for the current crop load.

The aim of the current projects was to develop new approaches and interpretation tools that better quantify field and temporal variability that are sensitive to yield and provide for in-season monitoring and fertilizer optimization in almond and pistachio across different locations. These projects also offered the unique opportunity to verify the current critical values of major nutrients for almond and pistachio. Parallel to the leaf sampling projects, we have collected fruit nutrient and yield data of all the experimental trees at each of the four pistachio orchards over the growing seasons from 2009-2011 and have developed and validated yield and phenology based nutrient budget curves for pistachio across a range of environmental conditions for major nutrients including nitrogen, phosphorus and potassium. Similar work has been recently completed in almonds (see "Development of a Nutrient Budget Approach to Fertilizer Management in Almond" on **page 26** of this publication). Results from our large and multi-year project indicates that fertilizer use can be optimized and considerable nitrogen losses can be reduced if nitrogen applications are synchronized with the actual tree demand.

OBJECTIVES

The integrated objectives of these research projects were to:

1. Determine the degree to which leaf nutrient status varies across a range of representative orchards and environments.
2. Determine the degree to which nutrient status varies within the canopy and within the year.
3. Validate early season leaf analysis protocols and relationship with yield, validate current CVs and determine if nutrient ratio analysis provides useful information to optimize fertility management.
4. Test utility of use of fruiting spur leaf analysis under variable N and K treatments, validate as an indicator of tree nutrient status, monitor role of fruiting spur leaves in yield, monitor relationship between spur nutrient status and spur survival in almond.
5. Develop and extend an integrated nutrient BMP for almond and pistachio.

RESULTS AND DISCUSSION

Under the current project, we have developed improved leaf sampling protocols and have developed nutrient budget models for pistachio. Also, a nutrient budget approach for almond has been provided in a separate report on **page 26 of this publication**. The nutrient budget model as a management tool helps growers optimize the time and rate of fertilizer application to coincide with the tree demand. Extensive leaf and fruit samples and yield data were collected at multiple times across four growing seasons to determine the degree of variability in tissue nutrient concentrations over time, space, and within tree canopies. Variations in leaf nutrient status of the trees over the growing seasons, between sites and years were used to refine field-sampling methodologies and to develop an early season sampling protocol. This early season sampling protocol offers management advantages to growers by providing information on which to base decisions about in-season fertilizer adjustments. Additionally, the large data set were used to estimate the validity of current critical values. The implementation of the improved sampling strategies combined with the nutrient budget models is expected to help growers to better monitor and manage the nutrient status of their orchards and increase their profitability and environmental stewardship.

In these well managed and visually uniform orchards there is substantial variability in nutrient concentration between orchards and within orchards that needs to be captured to correctly obtain the true mean of the nutrient being sampled and allow correct interpretation of them. This detailed analysis of data from eight well-managed and visibly uniform sites over four years has allowed us to estimate 'typical' field variability in Californian orchards of this type and to use that data to determine best sampling strategies. Thus, data from these field sites has been used to calculate the number of pooled leaf samples that is required to accurately determine the true field nutrient mean. **Table 1a** for the case of almonds and **Table 1b** for the case of pistachio represent the result of this analysis, accepting that growers usually collect one pooled sampled per orchard.

In addition to determining optimum field sampling strategies, the detailed analysis of data from eight well-managed and visibly uniform sites over four years also allows us to extrapolate from a well collected leaf sample to estimate the percentage of the field that will be above a particular established critical value. For example, the

Table 1a. Numbers of trees required to obtain average July N predictions by Model 6 at a desired degree of confidence and interval length.

Sample Size	Confidence	
CI half width (%N)	90%	95%
0.10	29	82
0.15	9	15

Table 1b. Number of trees needed to be sampled to effectively estimate the overall mean of nutrients to within 5% of the true mean with 90% confidence level for July leaf samples at four research sites. The calculation is based on observations from 54 individual trees at each site and year.

Paramount (Kings County)				
Year	N	P	K	Mg
2009	8	9	11	13
2010	5	6	11	15
2011	6	10	13	14
Buttonwillow (Kern County)				
Year	N	P	K	Mg
2009	9	8	15	21
2010	3	5	13	15
2011	7	5	12	19
Kamm Avenue (Fresno County)				
Year	N	P	K	Mg
2009	5	5	15	15
2010	3	3	18	21
2011	5	2	11	17
Madera (Madera County)				
Year	N	P	K	Mg
2009	8	6	21	40
2010	8	8	23	37
2011	7	8	38	40

Table 2a. Relationship between July leaf tissue N concentrations in almond samples collected according to previously described sampling methods (this report) and percentage of trees in the orchard that will exceed the specified critical value of 2.2%.

Relationship between July leaf tissue N concentration and percentage of the trees exceeding the critical value of 2.2%										
July N (%)	2.0	2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9
% of trees above 2.2%	6.6	22.6	50.0	77.4	93.4	98.8	99.9	100.0	100.0	100.0

established critical value is 2.2% N in July for almonds (**Table 2a**), using this knowledge and the sampling strategies we have established, it is possible to better understand the distribution of tree nutrient status in the orchard.

The almond prediction model, which predicts late summer nutrient values, received two types of validation. The first validation consisted of creating the model while holding out one site/year information and then comparing the predicted outputs on that site*year combination (process known as cross validation). The second validation consisted of sampling a new set of Californian orchards in 2012 and applying the models previously developed. Six California almond orchards were sampled and the results of this second validation showed that overall there was a good fit between predicted and observed. The best model is available online at http://ucanr.edu/sites/scri/Crop_Nutrient_Status_and_Demand__Patrick_Brown/ for its general use.

Similarly, the pistachio prediction model was validated extensively with data from several well managed commercial pistachio orchards located in different geographical locations (broader spatial scale) in California (USA). The data used for the validation of the models were completely independent of model development and a wide range of conditions and seasons were tested. The validation outcomes support the apparent validity and reproducibility of our regression models. The web-based model is available online at http://ucanr.edu/sites/scri/Assessment_of_Nutrient_Status_in_Pistachio/PPM/.

In pistachio as well as in almonds, results indicate that fertilizer use can be optimized and considerable nitrogen losses can be reduced if nitrogen applications are synchronized with the actual tree demand. To determine the average nutrient removal in pistachio per 1000 lb of dry CPC yield, we have analyzed data on NPK removal from three seasons and across four locations. On average, pistachio will remove approximately 28 lbs of N, 3 lbs of P and 24 lbs of K in the harvested fruit, producing 1000 lbs of CPC yield in the field. The pattern of yield accumulation in fruit over the year was determined by sequential fruit sampling and analysis. The nutrient removal for the case of almond trees is presented in a separate report (see "Development of a Nutrient Budget Approach to Fertilizer Management in Almond" on **page 26 of this publication**).

Development of a Nutrient Budget Approach to Fertilizer Management in Almond

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INTRODUCTION

Knowledge of growth and development to derive nutrient demand curves that guide the timing and quantity of nutrient applications is widely used in high value agricultural enterprises such as animal production, aquaculture, greenhouse vegetable and flower production, and increasingly in agronomic crops. In these approaches, growth models, estimates of daily nutrient intakes, knowledge of nutrient bioavailability and the interactions between nutrients and other inputs are integrated to ensure that nutrient supply does not limit growth and that profitability is maximized by avoiding excess applications.

Almond production in California is well suited to the adoption of a nutrient budget driven approach to fertilization. Crop values are at an all time high and there is an increasing interest in 'sustainable' production techniques to address customer desires and product image. Management techniques are increasingly amenable to 'on-demand' fertilization through increased adoption of fertigation systems and the use of fluid fertilizer formulations. The mature almond tree is well suited to a budget approach to fertility management as it is relatively determinant in its growth patterns, almonds show limited vegetative re-growth after fruits reach full size, and the majority of whole tree macronutrient demand is partitioned to nuts. Once the spur leaves are fully mature, the N and K requirements for vegetation are largely satisfied. Fruits, on the other hand, continue to accumulate N and K until harvest.

Thus, this project was conducted to develop nutrient demand curves and whole tree budgets for macro and micronutrients in a commercial almond (Prunus dulcis) orchard managed under a variety of N and K fertilization regimes. Experiments and measurements were replicated in drip and fan jet irrigated orchards over a 5 year period, 2008 through 2012. Whole tree nutrient dynamics in annual tissues were derived from multiple in-season samplings of leaves and nuts for nutrients and biomass in all years with the most intensive sampling being conducted in 2009, 2010 and 2011. Trees in this orchard were 9 years old at the commencement of the experiment and 13 years old at completion, with an orchard level light interception of 78% in year 10, increasing to over 88% in year 13. In comparison with industry standards and midday PAR interception, yield in these orchards was very good from 2008 through 2011, while in 2012, for reasons that have not been determined, yields were very low. The majority of the data presented for nutrient dynamics in annual organs was derived from years 2009, 2010 and 2011 in which treatment differences were clearly evident, yields were representative and sampling was most intensive. Data of nutrient dynamics for perennial tissues was solely derived from the 2012 season when tree excavations and tree coring were also performed (task three, objective four).

OBJECTIVES

1. Develop a phenology and yield based nutrient model for almond.
2. Develop fertilizer response curves to relate nutrient demand with fertilizer rate and nutrient use efficiency.
3. Determine nutrient use efficiency of various commercially important N and K fertilizer sources.
4. Determine the role of harvest date on N remobilization, spur survival, tree productivity and NUE.
5. Validate current CVs and determine if nutrient ratio analysis provides useful information to optimize fertility management.
6. Develop and extend an integrated nutrient BMP for almond.

RESULTS AND DISCUSSION

Annual nutrient export in harvested fruit was determined in all years of this experiment. In years 2009 through 2011, nitrogen in fruit at harvest represented >85% of whole tree nutrient fluxes. Total N export from the orchard in harvested crop is proportional to the total size of the crop and the nutrient concentration in that crop which varies in proportion to the ratio of fertilization rate to total annual N demand. In trees provided just adequate N to achieve maximal yield (309 kg.ha in this experiment in years 2009-2011), each 1000 kg of kernel yield at harvest exported from the orchard 59 to 74 kg N (mean 68 kg N) while phosphorus and potassium export by 1000 kg kernel yield at harvest ranged from 7.5 kg to 9 kg and 65 kg to 85 kg respectively (**Table 1**). Mean S, Ca and Mg export by 1000 kg kernel yield was 2.3 kg, 7 kg and 4.5 kg respectively. The accumulation of micronutrients was also determined, but is not presented in this report. Fertilizer N application above or below the 309 kg/ha rate altered N concentration in fruit and hence N export in fruit per 1000 kg kernel yield. In 2012, yield was exceptionally low resulting in a substantial excess N application in all treatments and an increase in fruit nutrient concentration and N export in fruit per 1000 kg kernel of up to 87 kg was observed (**Table 1**).

Sequential analysis of annual and perennial organs demonstrates that the majority of whole tree macro and micronutrient uptake occurs between anthesis and kernel fill with 35-50% of total N uptake occurring before 40 days after full bloom (DAFB) and 80-90% of the total N being accumulated by 112 DAFB coinciding with kernel filling. Over 70% of the total P and 65%-80% of the total K was accumulated in fruits by mid season. Ninety percent of total S, 80-90% of total Ca and

Table 1. Macronutrient export (kgs) in fruit by 1000 kg kernel yield in almond from 2008-2012 under fan jet irrigation. Means not connected by same letter within the same year are significantly different at *<0.05 and **<0.1. ns = not significant, T1= 140 kg N/ha, T2= 224 kg N/ha, T3= 309 kg N/ha and T4= 392 kg N/ha.

	2008				2009				2010				2011				2012			
	T1	T2	T3	T4	T1	T2	T3	T4	T1	T2	T3	T4	T1	T2	T3	T4	T1	T2	T3	T4
N	56 c *	59 bc	61 ab	62 a	53 b *	56 ab	59 a	60 a	55 c *	61 b	73 a	70 a	54 c *	65 b	74 a	75 a	54 b *	86 a	87 a	86 a
P	6.5 ns	6.9	6.7	6.3	7.4 ns	7.4	7.2	6.8	8.6 ns	8.2	8.9	7.8	8.7 ns	8.5	9	8.3	11 b *	14 a	13 ab	11 b
K	53 ns	54	54	52	74 ns	72	73	71	88 a **	81 ab	80 b	82 ab	77 ns	76	78	75	91 ns	100	87	88
S	2.3 ns	2.4	2.4	2.5	2.1 ns	2.2	2.2	2.2	2 b *	2.2 b	2.5 a	2.4 a	2.4 c *	2.7 bc	2.9 ab	3 a	2.4 b *	3.5 a	3.1 a	3.1 a
Ca	8.6 ns	8.2	8.1	8.1	7.5 ns	7.4	6.8	6.9	7.6 ns	7.1	7.1	7.1	6.6 a *	6.2 b	6 bc	5.7 c	6.4 ns	6.2	5.4	4.9
Mg	4.8 ns	4.7	4.7	4.7	4.5 ns	4.5	4.4	4.3	4.6 ns	4.4	4.6	4.4	4.6 ns	4.4	4.5	4.4	5.1 ns	5.5	5.0	4.7

70-85% of total Mg accumulated in fruit by 112 DAFB. Data on whole tree nutrient demand and the in-season accumulation of nutrients in annual and perennial tissues can be used as a basis for managing fertilization in Almond.

Nutrient use efficiencies of nitrogen (N) and potassium (K) under differential fertilization rates and sources was also estimated in this project. Nitrogen use efficiency (NUE) calculated as N exported from the orchard in fruits and N accumulated in perennial tissues for growth over N applied in fertilizer and contributed by soil, ranged from 63% to 104% under sprinkler irrigation and 60% to 114% under drip irrigation for the N rate of 309 kg/ha in different years. In these experiments, an N rate of 309 kg/ha was the lowest N application rate that resulted in maximal productivity. NUE declined as N application rate increased. NUE was not affected by N sources. Potassium use efficiency (KUE) was highest for 112 kg/ha K application rate and declined as K application rate increase. Apparent KUE exceeded 100% in most treatments and most years and increased with tree age for all K rate treatments, suggesting that substantial soil K reserves were being utilized by the tree. K sources only showed significant difference in KUE in 2010 where K application with SOP + KTS was higher than with other K sources. A KUE of over 100% for all K rates suggests that trees are accessing soil mineral reserves.

Nutrient concentrations and biomass of all major organs of mature field grown almond trees was collected by whole tree excavation, sequential tissue sampling and nutrient analysis in trees grown under four nitrogen rate treatments. The amount of nutrient accumulated in perennial organs over one year (2012) was determined as the difference between the total tree nutrient pool in dormant trees prior to, and at the completion of a single season (**Figure 1**). The dynamics of nutrient remobilization in perennial tissues during early season growth, and the accumulation of nutrients in perennial tissues were determined by sequential coring, tissue sampling, biomass estimation and whole tree excavation. Nutrient resorption from leaves was determined from multiple seasonal leaf samples. All measurements were replicated in trees of differing N fertilization regimes. In 2013, more data have been collected and sent to the laboratory for their nutrient content analysis and thus support the results obtained in 2012. Data collected in 2012 were analyzed from January 2013 to July 2013 and will be presented.

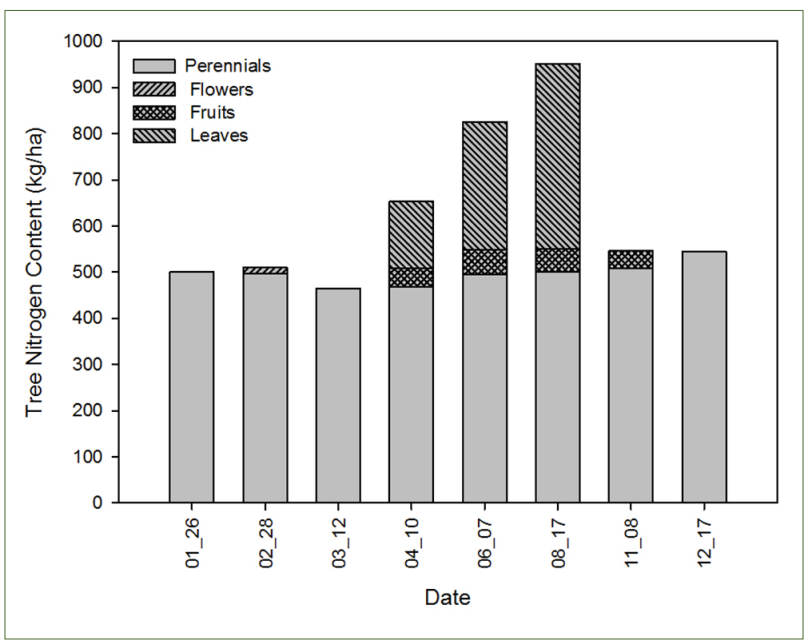

Figure 1. Nitrogen partitioning in perennial and annual organs of mature almond trees. The accumulation in perennial biomass is the total N accumulated in the trees from planting to the age of 13 years.

Towards Development of Foliar Fertilization Strategies for Pistachio to Increase Total Yield and Nut Size and Protect the Environment

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INTRODUCTION

Pistachio (*Pistacia vera* cv. Kerman) is like other tree crops in that flowering (pollination and fertilization), fruit development, shoot elongation, and root growth compete at times for available nutrients. Economic gains in fruit retention, increased fruit or nut size, and marketable yield have been made during these stages with properly timed foliar fertilization of pistachio (Brown et al. 1995) and other tree crops (Lovatt 1999, Boman 2002, Wojcik et al. 2008, Gonzalez et al. 2010). Foliar fertilization is a rapid, efficient way to improve crop nutrient status during periods of high demand or when soil conditions (low or high temperature, low or high soil moisture, salinity, pH) render soil nutrients and soil-applied fertilizers less available to the plant or when nutrients (e.g., phosphate, potassium and trace elements) become fixed in the soil. Under these conditions, foliar fertilization can provide the nutrients required for photosynthesis and other important metabolic functions essential to plant growth and productivity. In addition, because foliar application of fertilizers can reduce nutrient accumulation in soil, run-off water, surface water (streams, lakes, ocean), and groundwater (drinking water supply), where they contribute to salinity, eutrophication or nitrate contamination, with negative consequences to the environment and humans, it is highly desirable to replace soil-applied fertilizers at least in part with foliar-applied fertilizers. For pistachio and other deciduous fruit crops, reproductive growth commences before vegetative shoot growth. Targeting developing floral buds and flowers with fertilizer sprays has resulted in yield increases in pistachio (Brown et al. 1995) and other tree crops (Lovatt 1999, Gonzalez et al. 2010, Righetti n.d.). Mature pistachio leaves, similar to many crop plants, have a thick waxy cuticle shown to compromise uptake of some foliar-applied nutrients.

The goal of our research was to test the capacity of three foliar fertilization strategies to successfully supply key nutrients at phenological stages of high nutrient demand and thereby increase nut size, percent split nuts, fruit set, and floral bud retention. An increase in any one of these yield components would increase grower net profit.

OBJECTIVES

1. To test Strategy 1-The foliar application of boron (B), zinc (Zn) and urea (N) at bud swell to enhance flower nutrient levels (ovary and/or pollen) to increase fruit set. Despite uptake of only small amounts of nutrients, prebloom applications of these elements have been shown to increase yield in other tree crops (Jaganth and Lovatt 1998, Gonzalez at al. 2010, Righetti n.d.). Research testing prebloom foliar applications of Zn to pistachio trees has produced mixed results (Uriu 1986, Brown et al. 1995).
2. To test Strategy 2-The application of foliar fertilizers at 1/2- to 2/3-leaf expansion when leaves have a cuticle thin enough for nutrient uptake and sufficient surface area that the amount of nutrient taken up is large enough to enhance tree performance.
3. To test Strategy 3-The use of urea as a carrier to increase uptake of B, Zn, K and S into buds and/or leaves, especially during kernel filling when all but the most current pistachio leaves have a fully developed wax cuticle. Researchers and growers use urea in foliar treatments to improve the uptake of nutrients with limited evidence of its effect.
4. To calculate a cost: benefit analysis and disseminate it to growers.

DESCRIPTION

The design of the experiment was a randomized complete block with 11 treatments, including an untreated control, and 15 individual tree replications of each treatment in a commercial orchard owned by Paramount Farming in Kings County. The 15-year-old 'Kerman' pistachio trees on Pioneer Gold 1 rootstock were planted in a row/tree spacing of 19 x 17 feet at 135 trees per acre (5.8 x 5.2 m at 333/ha). The experiment was conducted for 2 years to determine treatment effects on yield and its components (nut size, split nuts, kernel weight, stained nuts, insect-damaged nuts, blank nuts) and on retention of floral buds for next year's crop. There were buffer trees between treated trees within a row and buffer rows between treated rows. At the specified stages of tree phenology, foliar fertilizers were applied in 100 gallons of water per acre (934.6 liters/ha) (industry standard). Applications were made using a three-point fan sprayer producing strong canopy movement and fine droplet size. Sets of leaves in the four quadrants of the trees receiving fertilizer sprays were bagged just prior to fertilizer application and uncovered 4 hours later. Buds were sampled just prior foliar fertilizer applications and again 7 to 10 days after application for nutrient analysis. In Year 1, leaves collected 7 to 10 days after fertilizer application failed to show any response to treatment, whereas those collected 21 days after the fertilizer was applied revealed increased leaf nutrient concentrations in response to treatment. Thus, in year 2, leaves were collected 21 days after each treatment was applied. Leaves were also collected at the end of July and mid-August (the standard time for pistachio leaf analysis) and in October to determine if increased leaf nutrient concentrations in response to foliar-applied fertilizers persisted at a level sufficient to "preload" the tree for the following spring bloom. Samples were immediately stored on ice, taken to UCR, washed, oven-dried at 140 °F (60 °C), ground to 40-mesh (0.0165 inches, 0.4 mm), and sent to the UC-DANR Laboratory at UC-Davis for analysis. Tissues were analyzed for the following: N, S, P, K, Mg, Ca, Fe, Mn, B, Zn, and Cu by atomic absorption spectrometry and inductively coupled plasma atomic emission spectrometry. Additionally, one branch (bearing fruit) in each of the four quadrants of each treated tree was tagged and the initial number of floral buds per branch counted just prior to harvest. At harvest, individual tree yields were taken, and a 20-pound (9-kg) sample was submitted to Paramount Farming for quality assessment. Each year, treatment effects were determined by ANOVA ($P = 0.05$). After harvest in year 2, treatment effects on cumulative yield parameters were determined ($P = 0.05$). After harvest in year 2, a factorial analysis by year was used to test for treatment effects on yield, and quality, floral bud retention and leaf nutrient concentrations. The alternate bearing index [ABI = (year 1 yield - year 2 yield) ÷ (year 1 yield + year 2 yield)] was also calculated for each treatment. All data were statistically analyzed using the General Linear Model procedure of SAS. The cost to benefit of each foliar fertilizer strategy for pistachio production was analyzed.

RESULTS AND DISCUSSION

The experiment was well designed. There were no significant differences in the tissue concentrations of any nutrient among the trees in the different treatments before they received foliar-applied fertilizer, with one exception. At the start of the experiment in Year 2, bud N

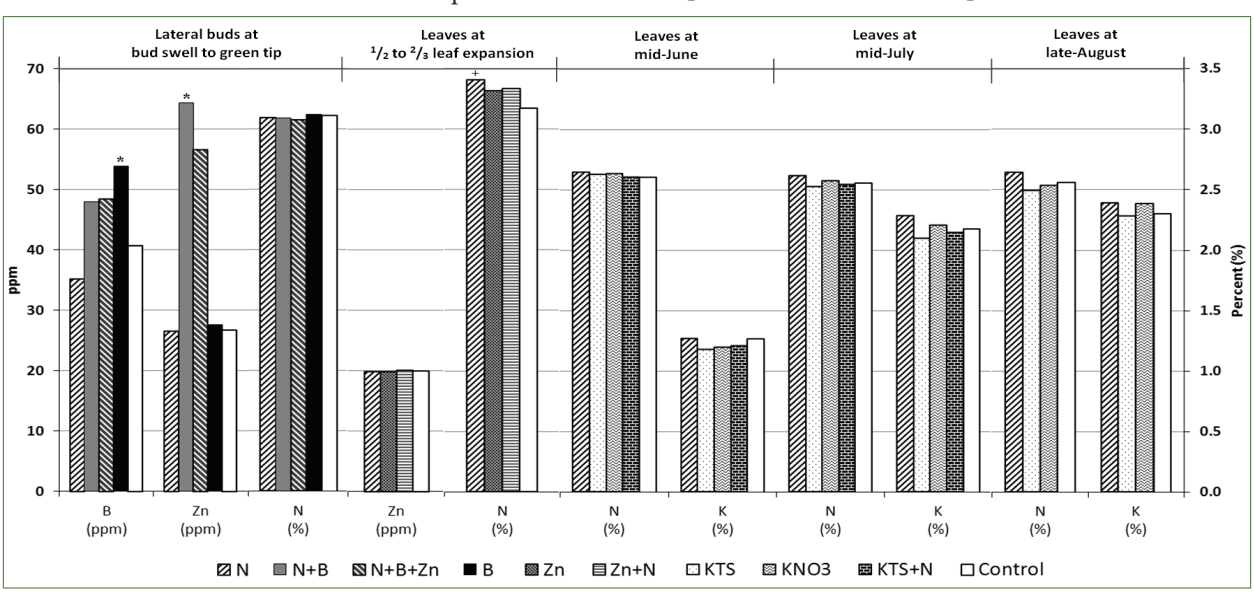

Figure 1A. Year 1 - Effects of foliar fertilizers applied at key stages of 'Kerman' pistachio tree phenology on bud or leaf concentrations of boron (B), zinc (Zn), nitrogen (N) and potassium (K). The fertilizers were: N, low-biuret urea; B, Solubor®; Zn, zinc sulfate; KTS, potassium thiosulfate; and KNO_3, potassium nitrate. Bars (means) with a * or + are significantly different from other means within the group at P < 0.05 or P = 0.0535, respectively, by Fisher's Protected LSD Test.

concentrations were different prior to fertilizer application. Based on the Year 1 October leaf analyses, these differences were not related to the effects of the previous year's N fertilizer treatments. In addition, despite elevated concentrations of B, Zn, N, S and Fe in leaves collected in October of Year 1, elevated levels of these nutrients were not detected in buds collected at the bud swell to green tip stage or in leaves collected at 1/2- to 2/3-leaf expansion in Year 2.

In both Years 1 and 2, boron decreased in floral buds from ~mid-March to the beginning of April in the control trees. Buds from trees receiving fertilizer applications at the bud swell to green tip stage of tree phenology and sampled 8 and 7 days after application showed significant differences in bud Zn concentrations but no differences in bud B concentrations. However, when sampled 19 to 21 days after application, trees treated with B showed a significant increase bud B concentration. After the green tip stage of phenology, boron accumulated throughout the growing season, with all trees having equally excessively high leaf B concentrations significantly above the suggested optimal range of 150 to 250 ppm (Beede 2004) by June and reaching 821 to 1019 ppm and 869 to 1290 ppm in October of Years 1 and 2, respectively.

In both years of the research, Zn (as $ZnSO_4$) (+/- urea) applied at 1/2- to 2/3-leaf expansion resulted in significantly greater leaf Zn concentrations than trees in all other treatments, a result that was not detectable until October. In July, trees that received a June application of urea and the control trees had greater leaf N concentrations than trees receiving foliar fertilizer that did not contain N. Also, trees treated with potassium thiosulfate (KTS) (+/- urea) in June had significantly greater leaf S concentrations in July prior to the second KTS application. By October, trees in these two treatments had significantly greater leaf S concentrations than trees in all other treatments.

The standard time for collecting pistachio leaves for nutrient analysis is late July through mid-August. Analysis of leaves collected on 31 July and 21 August indicated that N, Ca, Zn, Mn and Cu were all within the optimal range, leaf P and Mg were below the critical value, and K and B exceeded the optimal range (Beede 2004). In Years 1 and 2, trees receiving three foliar applications of urea alone in June, July, and August had significantly greater leaf N concentrations by October than trees that received three foliar applications of KNO_3, suggesting that N as NO_3 was not taken up by hardened pistachio leaves. However, in Year 2 the relationship between N fertilization treatment and leaf N concentrations was not as strong as in Year 1. By October there were significant differences in leaf K concentrations that were also related to fertilizer treatment, e.g., three applications of KNO_3 (+/- urea) resulted in greater leaf K concentrations than the control ($P = 0.0577$). In the case of S, significant differences in October leaf S concentrations were clearly due to the fertilizer treatments, with trees receiving three foliar applications of KTS (+/- urea) having the most leaf S.

The relative efficacy of foliar fertilizers applied at specific phenological stages versus multiple applications is presented in **Figure 1**. Note that **Figure 1** does not illustrate the differences in tissue nutrient concentrations before and after fertilizer treatments. The increase in bud Zn concentration in response to foliar-applied urea + B is apparent in both years of the research, consistent with

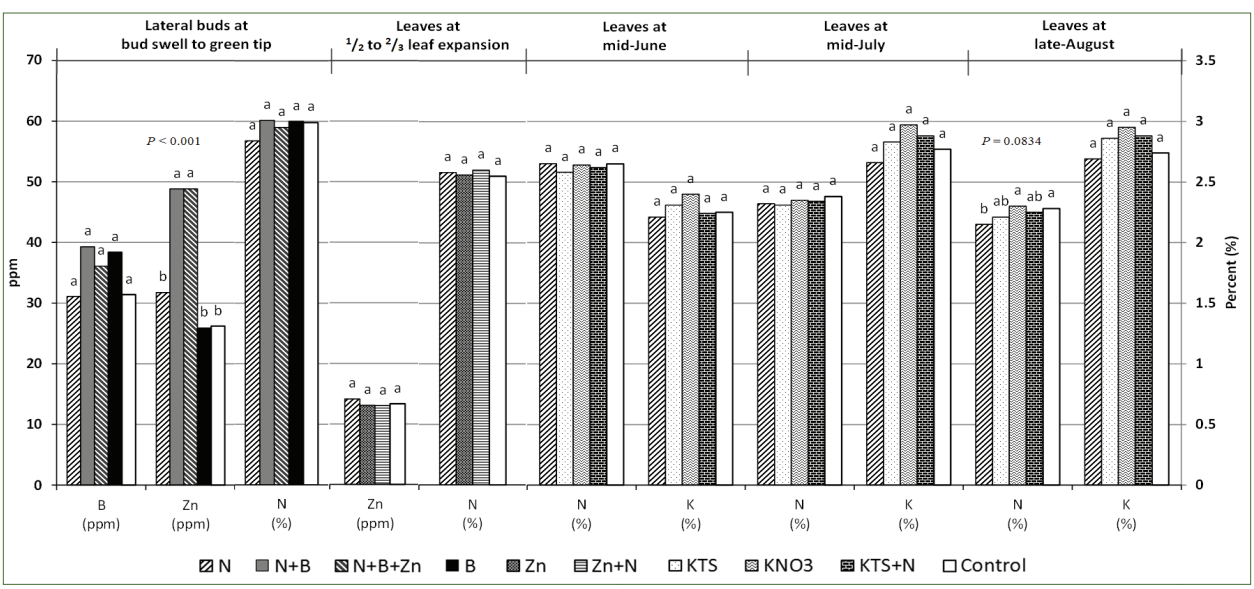

Figure 1B. Year 2 - Effects of foliar fertilizers applied at key stages of 'Kerman' pistachio tree phenology on bud or leaf concentrations of boron (B), zinc (Zn), nitrogen (N) and potassium (K). The fertilizers were: N, urea; B, Solubor®; Zn, zinc sulfate; KTS, potassium thiosulfate; and KNO_3, potassium nitrate. Bars (means) within a group with different letters are significantly different from other means within the group at the specified P-value by Fisher's Protected LSD Test.

increased uptake of soil Zn.

Despite the successful uptake of several nutrients at key stages of tree phenology and significantly greater concentrations of these nutrients through October, yield and nut quality were not increased by any foliar fertilizer treatment in either year of the research. The orchard had an alternate bearing index (ABI) of 0.48 for the two years of the experiment. Year 1 was the on-crop at 5,833 pounds per acre (6,538 kg/ha) followed by an off-crop of 2,560 pounds per acre (2,869 kg/ha). Fertilizer treatments had no effect on ABI, 2-year cumulative yield or 2-year average yield. The results indicate that when pistachio trees are adequately fertilized, additional fertilizer is without effect and not cost-effective. For a complete description of the results of this research, please see the final report at http://www.cdfa.ca.gov/is/pdfs/Pistachio_2009.pdf.

CONCLUSIONS

The results provided clear evidence of the successful uptake of B as Solubor® and Zn as $ZnSO_4$ by buds at the bud swell to green tip stage when buds were sampled 19 to 21 days after foliar fertilization for B and 7 to 10 days after treatment for Zn. The increase in bud Zn concentration in response to the B + urea treatment in both years of the experiment requires additional research for clarification, but contributes to the growing evidence suggesting that foliar fertilizers enhance soil nutrient uptake. Sampling leaves in October at the end of the season proved a highly reliable sampling time for determining which foliar-applied fertilizer treatments successfully supplied a sufficient amount of nutrient to last through harvest into October and provided evidence of the significant uptake of Zn (+/- urea) applied at 1/2- to 2/3-leaf expansion that had not been detected when leaves were collected 7 to 21 days after treatment. Later sampling dates (not included in this research) should be tested to determine whether Zn uptake is detectable before October. Our results provided clear evidence that the optimal time after application for detecting uptake of a foliar-applied nutrient is different for different nutrients. Thus, to fully test the uptake of nutrients applied as foliar-fertilizers, multiple sampling dates must be included in the research.

Adding urea to the fertilizer sprays had a positive effect on the uptake of Zn applied as $ZnSO_4$ at 1/2- to 2/3-leaf expansion (Year 1) and on the uptake of S as KTS (Years 1 and 2) and K as KTS (Year 2) applied to hardened leaves in June, July and August, while also successfully increasing leaf N concentrations above trees in other treatments but not the control. These results suggest that urea might be a useful fertilizer amendment or an alternative wetting agent. Our results demonstrated that foliar fertilizers could be used to supply the above nutrients in the case of deficiency. Interestingly, despite elevated nutrient concentrations in the October leaf analyses, no differences in bud nutrient concentrations related to the October leaf nutrient concentrations were detected the following spring. Thus, if an orchard was diagnosed as low in B or Zn by standard leaf analyses in late-July to mid-August, bud B and Zn concentrations could be increased at the bud swell to green tip stage with an application of Solubor® or $ZnSO_4$, respectively. In addition, Zn can be supplied successfully as $ZnSO_4$ when leaves are 1/2- to 2/3 expanded, with uptake enhanced by the addition of urea. Urea can be used to supply N and to improve the uptake of K and S as KTS when leaves are fully hardened.

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Plant Nutrient Education Materials for Elementary through High School Classrooms

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INTRODUCTION

The California Foundation for Agriculture in the Classroom's (CFAITC) objective for this project was to create and implement educational lessons for elementary through high school students that result in a better understanding of the purpose of fertilizer in food production and new technologies to manage plant nutrients. The project was developed to address public lack of knowledge and in some cases misinformation regarding plant nutrient requirements and how those requirements are met in order to feed a growing population with limited resources.

For the first grant project, two comprehensive units of lessons were developed. Each unit is aligned to the most current educational Content Standards for California including the Common Core and Next Generation Science Standards.

- *Chemistry Fertilizer and the Environment:* A five-lesson unit for grades 8-12
- *What Do Plants Need to Grow?:* A twelve-lesson unit for grades 2-4

Units include background information for teachers and detailed instructions to carry out hands-on activities in the classroom. "Grab 'n' Go" kits are available for teachers to borrow if they lack basic equipment necessary to perform the lesson plans. CFAITC has and will continue to hold teacher workshops at various conferences to train teachers in the use of the lessons with their students.

For the second grant project, one additional unit of lessons and one educational guide for teachers is currently under development and scheduled for completion in December, 2013.

- *How Much is Too Much? How Little is Too Little?:* An eleven-lesson unit for grades 5-8.
- *Educator's Guide to accompany Fun With The Plant Nutrient Team* activity book from the International Plant Nutrition Institute for grades K-3.

OBJECTIVES

1. Create a new comprehensive, multi-lesson unit, *Chemistry, Fertilizer, and the Environment* that will educate students in grades 8-12 about the relationships between fertilizers, food, plant nutrition and the environment.
2. Update the already existing unit *What Do Plants Need to Grow?* for grades 2-4.
3. Update the already existing unit *How Much is Too Much? How Little is Too Little?* for grades 5-8.
4. Develop five "Grab 'n' Go" teacher training kits that will be used to introduce teachers to the new units and encourage them to implement the curriculum into their classrooms.
5. Develop a new *Educator's Guide* to accompany *Fun With The Plant Nutrient Team* activity book from the International Plant Nutrition Institute for grades K-3.
6. Increase student understanding of the essential role of plant nutrients in agriculture production.
7. Enhance student appreciation of the agriculture industry's efforts to improve environmental stewardship.
8. Encourage students to pursue a career in plant sciences.

DESCRIPTION

The project approach for creating the educational materials is as follows:

1. Hold a curriculum development meeting for each unit. Participants include CFAITC. staff, classroom teachers specific to appropriate grade levels, and industry experts.
2. Outline the main components to be taught in each lesson.
3. Draft lessons and graphics.
4. Circulate draft lessons for editing by CFAITC staff and industry experts.
5. Send edited lessons out for piloting in classrooms.
6. Revise lessons based on feedback from pilot classrooms.
7. Send lessons to proof editor.
8. Print lessons and post on CFAITC website.
9. Promote lessons via CFAITC's website, blog, and electronic monthly newsletter sent out to every California school principal.
10. Distribute and present lessons at California Science Teachers Education Conference, California Agriculture Teachers Association Conference, National Agriculture in the Classroom Conference, STEM Conference and other area conferences. Unit lessons are available for download from the CFAITC website and mail order at no charge.

RESULTS AND DISCUSSION

Teachers have responded positively to the release of the two new plant nutrient education units. From June 2013 to August 2013, *Chemistry, Fertilizer, and the Environment* was downloaded 1,950 times and *What Do Plants Need to Grow?* was downloaded 847 times. 650 printed copies of *Chemistry, Fertilizer, and the Environment* were distributed to all high school Agriculture Science teachers attending the annual California Agriculture Teachers Association conference at Cal Poly in June, 2013. An additional 94 printed copies have been mailed to teachers who placed an order from our office. A total of 212 printed copies of *What Do Plants Need to Grow?* have been distributed to teachers at education events or through online and phone orders.

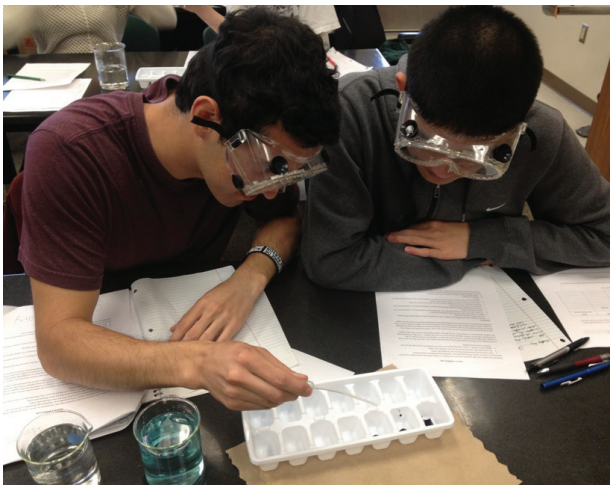
Chemistry, Fertilizer, and the Environment was developed for use in 8th – 12th grade classrooms. This unit is comprised of five lessons. These lessons teach students about: solutes and solvents, serial dilution and parts per million, plant nutrient requirements, best management practices for nutrient management, the nitrogen cycle, basic chemistry concepts, soil pH and nutrient availability, and testing soil samples for available nitrogen.

Twelve lessons from the existing unit, *What Do Plants Need to Grow?* were updated for use in 2nd -4th grade classrooms. The lessons in this unit teach students about: basic plant parts and their functions, requirements for healthy plant growth, soil composition, and the role of decomposers. Students will conduct several investigations to observe plant root growth, phototropism, and the effects of different concentrations of fertilizer solutions on classroom plants.

Lessons are designed to engage students through hands-on activities that allow them to explore the types of activities carried out by farmers and plant scientists to produce our food and fiber while practicing environmental stewardship. After participating in the lessons, students will have a better understanding of what plant nutrients are, why they are important, and how farmers and scientists are continually improving methods to provide crops with the right plant nutrients in the right amounts, at the right time and in the right place.

ACCOMPLISHMENTS

Two educational units were developed for this project. *Chemistry, Fertilizer, and the Environment* is a five lesson unit for 8th - 12th grade students and *What Do Plants Need to Grow?* is a 2nd – 4th grade unit comprised of twelve lessons. Lessons teach students about plant nutrients and the importance of fertilizer and fertilizer management as well as a connection to how students can apply good stewardship practices at home by following package instructions when applying lawn, flower, and vegetable fertilizer.



Students learning about Parts Per Million during dilution lesson.

The newly developed lessons have been presented at teacher workshops and will continue to be promoted. Survey comments from teachers have included:

- *I believe this is going to be a great way to utilize chemistry in my Ag classes.*
- *I loved the stand up activity for the periodic table with the yellow ribbons.*
- *It will fit into common core standards and fits perfectly into my solutions unit. Students will be able to utilize the new school garden to do these activities.*
- *Thank you! It was fun and will be helpful for me as an AP environmental science and biology teacher.*

Since their release at the end of May 2013, both plant nutrient education units have been popular with teachers. In three months, 1,059 copies of *What Do Plants Need to Grow?* have been distributed to 2nd – 4th grade teachers and 2,694 copies of *Chemistry, Fertilizer, and the Environment* unit have been distributed to 8th -12th grade teachers. These teachers reach hundreds of thousands of students per year, providing an effective method for increasing student and parent knowledge of food production, plant nutrient, modern farming technology, and environmental connections.

Teacher contact information is collected on mail orders and at distribution events and will be used to send CFAITC's annual electronic survey to teachers at the end of 2013. This timeframe will provide teachers with a chance to implement the final drafts of the unit lessons in their classrooms prior to answering survey questions about the educational value of the lessons.

Eleven lessons have been drafted for the unit, *How Much is Too Much? How Little is Too Little?* The lessons are currently being reviewed and will then be pilot tested in 5th – 8th grade classrooms prior to printing and distribution at the end of December, 2013. The *Educator's Guide* to *Fun With the Plant Nutrient Team* is also under development and will go through the same review process as described above prior to printing and distribution at the end of this year.

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Haley Clement, Ag Chemistry Teacher at Liberty Ranch High School, Galt, CA

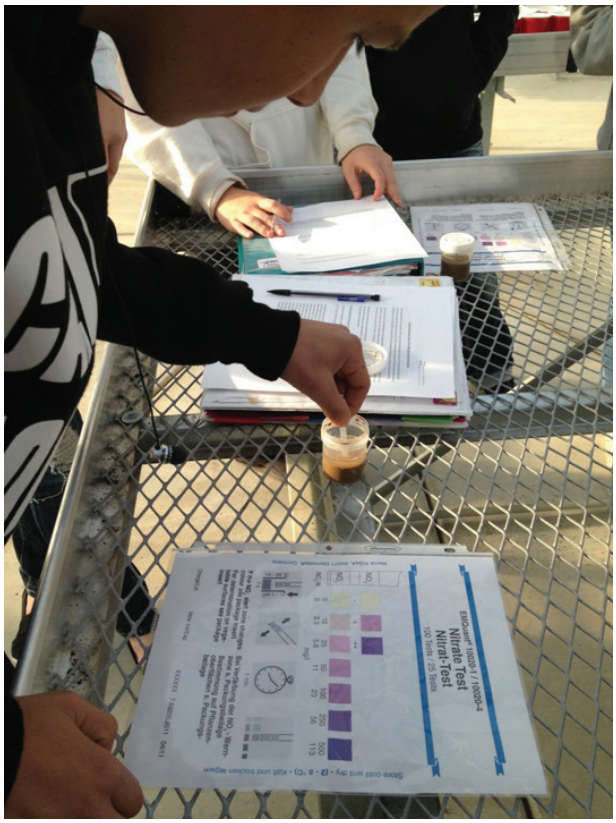
Timothy Doane, Department of Land, Air and Water Resources, UC Davis

Tim Hartz, UC Cooperative Extension, Department of Plant Sciences, UC Davis

Corrie Pelc, former Director of Programs, CA Fertilizer Foundation

Richard Prizznick, Advanced Placement Chemistry and Environmental Science Teacher at University Preparatory Academy, San Jose, CA

Students learning about nutrient availability at different soil pH levels.



Students conduct soil tests for plant-available soil nitrogen.

California Certified Crop Adviser Educational Project

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INTRODUCTION

There is a large human element to the successful management of fertilizers and nutrients in cropping systems, requiring in-depth expertise and ongoing updating of information. Professional nutrient advisors are critical to the hundreds of decisions farmers make each year—decisions that can have large environmental and economic impacts. The ability to provide correct advice to make rapid, intelligent and scientifically-sound management decisions prevents California farmers from over applying fertilizers or manures, from missing the economic opportunities contained in good fertility management, and from knowingly contributing to water quality or air quality contamination from sub-optimum agricultural practices.

The California Certified Crop Advisor (CA CCA) program is the heart of competency certification for this group of professionals in California. The CA CCA educational project has as its goal to provide a needs-based mechanism for the educational credits and certification of qualified individuals. These individuals serve to promote the educational goals of FREP with regard to soil, water, crop and nutrient source management and enhance the viability of crop advisor certification. The CA CCA program tests potential advisors using standardized, scientifically based exams, sets professional requirements, and provides certification for continuing education.

The CCA certification is an accreditation for achievement and knowledge for nutrient management practices and not a regulatory related license.

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

In response to regulatory requirements placed on growers by Regional Water Control Agencies, the CA CCA will be actively consulting growers to manage nitrate contamination in ground water during the grant period.

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

Funding received during the grant period for the CA CCA educational project from CDFA/FREP enabled the all volunteer CA CCA board to achieve work objectives to improve the educational opportunities of California agriculture related to fertilizers, farm management and agricultural sustainability.

OBJECTIVES:

The objectives of this project are to:

1. Provide responsible program administration, leadership and CCA outreach awareness.
2. Strengthen program and certifications through awareness of CCA role.
3. Planning, long term goals and sustainability for the CA CCA program.
4. Efficiently administer the CA CCA program.
5. Implement an evaluation plan to review services and deliverables.

DESCRIPTION AND ACCOMPLISHMENTS:

The FREP-funded program for the California CCA has taken a proactive outreach approach to fulfill its outreach and educational objectives. These include:

- The current number of CCAs in California for 2012 was 650 with CA demonstrating the largest US growth. The program as of August 2013 has 750 CCAs with over 150 credential packages in the approval process.
- CA CCA program approved 367 Continuing Education Classes for CCAs and supported the introduction of online CEU registration.
- The ICCA/CA CCA and Manure Management Exams were held the first Friday in February and August, 2012. Test sites were located in Sacramento, Ventura, Salinas, and Tulare with two proctors located at each exam site. A total of 267 candidates took the ICCA exam, 258 took the CA CCA exam and 2 candidates took the Manure Management exam.
- Pre exam training sessions were offered for both exam periods to individuals prior to each exam testing date (**Figure 1**). Sessions were held in Fresno, Salinas and Sacramento.
- The program maintained a CA CCA Fan Page on Facebook. Updates to the page regularly made with information that is relevant to CCAs. This page allows communication with current and potential CCAs; it also allows communication with other state CCA programs as many representatives of those programs are fans. The page is at http://www.facebook.com/#!/pages/California-Certified-Crop-Advisers/272373776767?ref=ts.
- CA CCA Annual Meeting was held in February in Visalia in conjunction with the California Plant and Soil Conference. ICCA Chair Amy Asmus was the keynote speaker (**Figure 2**).
- Fertilizer articles were published in Western Farm Press and the CAPCA Adviser magazine, providing California growers current and valuable nutrient information.
- The CA CCA candidate program was promoted to agricultural students that qualify for the program, but do not have the necessary experience. Career day outreach and CAPCA's Pathway to PCA program all contributed to career opportunities in the fertilizer industry.
- Representatives of the CA CCA program participated in the Western Plant Health Association (WPHA) Student Dinners at UC Davis, CSU Chico, CSU Fresno, UC Riverside, Cal Poly Pomona and Cal Poly San Luis Obispo.
- The CA CCA program attended and/or exhibited at the following events: California Association of Pest Control Advisers Annual Conference, CA Weed Conference, Central Valley Grape Expo, Central Coast Grape Expo, Pacific Nut Expo, Fresno Raisin Grape Conference, CA Agricultural Teachers Conference, CA Farm Bureau Annual Meeting, CACASA Spring & Winter Conference, Southwest Fertilizer Conference, Yuma Southwest Ag Summit and CA Organic Fertilizer seminars in Modesto, Tulare, San Jose and Salinas.
- Nutrient management presentations were made at CAPCA ED seminars, CAPCA Chapter CE seminars and the WPHA Nutrient Management Series by CA CCAs, encouraging attendees to take the exams and be more aware of fertilizer stewardship responsibilities.
- CA CCA representatives held discussions with representatives of California fertilizer and Ag retail industry on benefits of program and value of the CCA. The CA CCA program is experiencing tremendous support from agricultural retailers as noted by the continuous increase in number of

Figure 1. Richard Rosecrance lectures at CCA Exam Review Session in Sacramento, CA.

Figure 2. Allan Romander incoming ICCA Chair, Harry Cline, Western Farm Press Editor, and Amy Asmus current ICCA Chair.

candidates testing and becoming CCAs.

- The program outreach and regulatory requirements from CA Water Board is having a positive impact on CCA program growth.
- News releases were prepared and distributed on the CA CCA program, nutrient seminars and upcoming exam opportunities.
- The program maintained and updated CA CCA website www.cacca.org on a regular basis.
- CA CCA supported CDFA/FREP/UC leadership to develop stakeholder involvement in nitrate mitigation program training (**Figure 3**). The CCA program leadership actively supported the CDFA/FREP outreach activity to assist growers and agricultural organizations to address nitrate residual concerns in drinking water.
- CA CCA Board continued steps to develop other sources of financing, including increasing exam fees, introducing pre-exam training fees and developing sponsorship opportunities and options for seminars. Notwithstanding, growth of CCA numbers in the program are the most optimum opportunity to work towards less dependence on CDFA/FREP financial support.
- CAPCA as the cooperator coordinated activities with ICCA program, including participating in the ICCA Board Meetings. Current CA CCA member Allan Romander has been elected as Chair-elect of the ICCA Board of Directors and CA CCA Chair Dr. Sebastian Braum is an ICCA Board member.

Figure 3. CA CCA Chair Dr. Sebastian Braum and CDFA Feed, Fertilizer, and Livestock Drug Regulatory Services Branch Chief Dr. Asif Maan field questions regarding nitrate mitigation.

- Electronic newsletters were distributed to CA CCA members. Subjects include program status, upcoming meeting and other relevant information.
- CAPCA as cooperator on this grant provided daily and efficient administration for the CEU approval and member/Board communications.
- CAPCA coordinated with ICCA on all announcements and coordinates the exams.
- CAPCA completed the interim and annual report for the project leader for the CDFA/FREP grant.

SUMMARY

CDFA FREP's support of the CCA program has enabled this program to become a highly successful resource for fertilizer education and awareness, with significant growth over the past 3 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 750 Certified Crop Advisors in California.

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

For more information on the program please contact:

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Optimization of Organic Fertilizer Schedules

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KEY OBJECTIVES

1. Generate two-compartment immobilization-mineralization models of organic fertilizers.
   a. Incubate organic fertilizers at three temperatures.
   b. Data analysis and curve fitting.
   c. Code curve into NBOT.
   d. Code for *lpsolve*.
2. Incorporation of a water management component, derived from NLEAP or a similar model, to represent leaching, denitrification, and root development.
   a. Model components, including proposed changes developed mathematically.
   b. Changes to the Excel 2007 program will be coded as necessary and debugged. The program makes extensive use of macros.
   c. Code for *lpsolve*.
   d. Development of user-friendly interfaces.

INTRODUCTION

Organic fertilizers contain nitrogen (N) derived from animal or vegetable sources in organic forms that are not readily assimilated by plants. Nitrogen becomes plant-available when microbes decompose the organic fertilizer releasing CO_2 and N in the form of inorganic ammonium (NH_4^+-N). This process, called mineralization, is facilitated by soil microbes at rates that vary depending on for chemical and physical conditions of the fertilizer and its environment. Microbes also need and use N to grow and will compete with plants to acquire it. The process by which microbes recover and use inorganic N is called immobilization. Both mineralization and immobilization therefore affect the rates at which N becomes plant available. These processes are affected by many environmental and management factors. Among the most important are fertilizer chemistry, soil temperatures, soil moisture, and time. The significance of immobilization is known to vary according to the C to organic N ($C:N_o$) ratio of the material (Paul, 2007).

Organic N mineralization rates are difficult to predict or measure directly. Mathematical models are used to understand and estimate how quickly organic N becomes plant-available over time. Mineralization is most commonly modeled as a two-compartment first-order process (Benbi and Richter, 2002; Paustian et al., 1997; Valenzuela-Solano and Crohn, 2006) but such models must be parameterized using prolonged laboratory incubations under carefully controlled conditions. Laboratory measurements take time and require repeated destructive sampling. Denitrification losses may also introduce errors leading to underestimates of mineralization as the carbon supplied with organic fertilizers also serves as substrate for denitrifiers. Temperature changes also dramatically affect release rates (Valenzuela-Solano and Crohn, 2006).

The evolution of C during incubations is much easier to measure than the mineralization of N, which requires destructive sampling and can be confounded by denitrification losses. This paper considers whether C measurements can be used instead of N for the purpose of predicting net mineralization rates from organic fertilizers. The model has been previously applied to incubated yard trimmings (Crohn, 2013). Because the approach incorporates immobilization, the temporary tie-up of N by high C:N materials can be considered, a result that conventional first-order process models do not allow. Two classes of materials are included: low $C:N_o$ materials such as processed organic fertilizers, and higher $C:N_o$ materials such as manures or plant residuals.

To assist growers in the planning of fertilizer application rates, results have been incorporated into the NBOT Nitrogen Budget Optimization Tool, a planning model programmed into Microsoft Excel. The model assumes an annual quasi-steady-state condition.

PROCEDURE

Incubation Process

We considered five commercially manufactured organic fertilizers (COF) and six unprocessed residual materials (UR), four unprocessed (UR 1-4) and two anaerobically digested (UR 5,6). To reduce the potential for denitrification, the soil was mixed 1:1 with silica sand to reduce the denitrification losses. To avoid N limitation all samples were amended with KNO_3 at a rate of 100 mg kg^{-1} soil. Carbon decomposition and N mineralization were studied in two separate experiments. The carbon decomposition study was conducted in 100 mL serum bottles, while N mineralization was conducted in 946 mL Mason jars. Fertilizers were applied at rates sufficient to provide a total of 400 kg ha^{-1} total N. An unamended control was also included. Samples were packed to a density of 1300 Mg m^{-3} and moisture was adjusted to 60 percent of field capacity. Nine samples for each material and for the control were then incubated for 60 days, three at 13° C, three at 23 ° C and three at 33° C. Vessels were left open, covered only with moistened cheese cloth, in order to keep them aerobic.

Evolved carbon dioxide (CO_2) was measured from the serum bottles initially filled with 40 g of the sand-soil-fertilizer mixture. The serum bottles were crimped 4 hours prior to gas sampling and 10 mL headspace samples were collected at 24 hour intervals through day 7, at 72 hour intervals through day 30, and weekly thereafter through day 60. A PP Systems EGM-4 infrared gas analyzer was then used to analyze for CO_2. After sampling, the bottles were purged for two minutes with 80 psi fresh air and covered with moist cloth.

Net N mineralization was measured in the Mason jars after filling them with 200 g of the sand-soil-fertilizer mixture. To make measurements, 2 g samples were removed after each of 0, 2, 5, 8, 12, 16, 21, 26, 32, 38, 45, 52, and 60 days. Nitrate and ammonium were assayed through colorimetry after an hour of shaking with 10 mL of 2 M KCl and 10 minutes of centrifuging followed by filtering.

Modeling High C:N_0 Materials

The processes of mineralization and immobilization are represented separately. To obtain an acceptable fit, each contains a labile (A) and a recalcitrant compartment (1-A). At any time, t (days), decomposer microbes are assumed to break down applied organic carbon, C_o (mg/g), in the labile and recalcitrant compartments at fixed rates, k1 and k2 (days-1), respectively.

$$C = AC_o e^{-k_1 t} + (1 - A)C_o e^{-k_2 t} \quad (1)$$

The organic N initially present in the material (N_o) is mineralized at the same rate as the initial organic C (C_o), in proportion to the initial C to organic N (Co:No) ratio of the material, Z_o. A fraction of the mineralized N, ε, is recovered by the microbial community to build its tissue and the rest is released to the soil as NH_4^+-N. This is the substrate conversion efficiency (Gilmour, 1998; Paul, 2007). Recovered N is restored to the soil organic N pool. Because some N is recovered but C is continually lost, the C:N ratio of the fertilizer eventually falls to a final C:N ratio, Z_f. The N kinetics of the labile and recalcitrant carbon compartments can each be represented separately as:

$$N = N_o \left[\frac{Z_o}{Z_f} e^{-kt} + \left(1 - \frac{Z_o}{Z_f}\right) e^{kt/(\varepsilon - 1)} \right] \quad (2)$$

when Z_o, Z_f, Q_{10} and ε are fitted to that compartment (Crohn, 2013). An Arrhenius relationship to fashion a multiplier, h, that modifies k so that heat effects are incorporated:

$$h = Q_{10}^{\left(1 + \frac{T_r}{10}\right)\left(1 - \frac{T_r}{T}\right)} \quad (3)$$

where t is time, T (K) is the soil temperature, T_r (K) is a reference temperature (typically T_r = 298.15 K, or 25°C), and Q_{10} is the relative proportion by which k_r increases after a 10 K temperature increase from the reference temperature ($Q_{10} = k_{T_r+10} / k_{T_r}$).

Together, N contributions are:

$$N = AN_o \left[\frac{Z_{o1}}{Z_{f1}} e^{-k_1 t} + \left(1 - \frac{Z_{o1}}{Z_{f1}}\right) e^{\left(\frac{k_1 h}{\varepsilon_1 - 1}\right)t} \right] + (1 - \mathrm{A})N_o \left[\frac{Z_{o2}}{Z_{f2}} e^{-k_2 t} + \left(1 - \frac{Z_{o2}}{Z_{f2}}\right) e^{\left(\frac{k_2 h}{\varepsilon_2 - 1}\right)t} \right] \quad (4)$$

where subscripts 1 and 2 represent the labile and recalcitrant compartments, respectively.

The initial C:N_O ratios of the labile and recalcitrant compartments are related through conservation of mass as:

$$Z_{o2} = \frac{Z_{o1} Z_o (1 - \mathrm{A})}{Z_{o1} - Z_o \mathrm{A}} \quad (5)$$

Values for N_o and Z_o were measured directly. Other parameters were estimated from incubation data. Then Eq. (1) was fitted to C respiration data. This provided values for A, k_{C1}, and k_{C2}. These values were then used to fit Eq. (3) to incubation soil measurements. The sequence is important because C measurements are more reliable than N measures. Carbon is conserved in the headspace as CO_2, while inorganic N can be lost through denitrification and volatilization. It is therefore important that C decomposition parameters be determined first and N mineralization parameters

second. For this study, the Microsoft Excel 2007 non-linear Solver was used to locate parameters by minimizing the sum of square errors between model predictions and observed data. To avoid overfitting, parameter values were lumped between different treatments whenever reasonable. Determining the degree to which parameter values can be reasonably consolidated has been a major objective for this research.

Modeling C:No Materials

For low C:N_o materials net immobilization is much less important than net mineralization and Eq. (11) was not found to be necessary. In this case a simple two compartment net N mineralization model has been found to serve best:

$$N = BN_o[Be^{-k_{N1}ht} + (1-B)e^{-k_{N1}ht}]. \quad (6)$$

Where k_{N1} and k_{N2} are net mineralization rates for the labile and recalcitrant compartments, respectively (days^{-1}) and B partitions the nitrogen compartments. The form for Eq. (12) is simpler, but potentially more difficult to fit. Parameterization of Eq. (5) requires a N mineralization study. Such studies are subject to drift due to denitrification losses. We have found that denitrification losses are common early in incubation studies. In quality control measures (data not shown) we have observed significant nitrous oxide (N_2O) during the first few days of incubations. Because most denitrified N is in the form of N_2, which we cannot detect, we used fitting techniques to determine a fixed day 1 denitrification loss constant for each studied material. This loss is deducted prior to fitting Eqs. (3) and (5).

To introduce these principals into the NBOT, the program was broadly rewritten. NBOT now works with 64-bit computers using Microsoft Excel and lp_solve, a freely available mixed-integer liner programming solver. Solutions are reliable and rapid.

Table 1. Characteristics of study fertilizer materials

Treatment	Total C (%)	Total N (%)	NH_4^+-N (ppm)	NO_3^--N (ppm)	C: Organic N (%)
BM	28.5	5.5	430	24.0	5.2
FM	49.3	12.7	780	13.4	3.9
GP	46.4	11.8	1799	34.4	4.0
FC	16.4	4.0	5430	12.4	4.8
LGS	42.9	7.8	358	10.6	5.5
A	18.6	1.6	277	95.2	11.9
B	13.2	1.1	157	15.0	12.6
C	43.9	1.5	381	3.9	30.6
D	24.5	2.0	429	25.1	12.5
E	21.4	4.3	2980	16.4	5.3
F	18.6	1.4	825	4.3	14.4

RESULTS AND DISCUSSION

Materials were collected and analyzed (**Table 1**). For COF Q_{10}=1.61 while two were used for UR. For aerobically digested materials Q_{10}=2.67 while for anaerobically digested materials Q_{10}=3.92. COF could be fitted to CO_2 evolution data but these fits did not result in consistent predictions of net N mineralization. This is due to the very low C:N ratios of these materials. Fits using Eq. (6) to directly represent mineralization were effective (**Figure 1**).

Figures 2 and 3 illustrate the result when net N mineralization is estimated for UR based on C

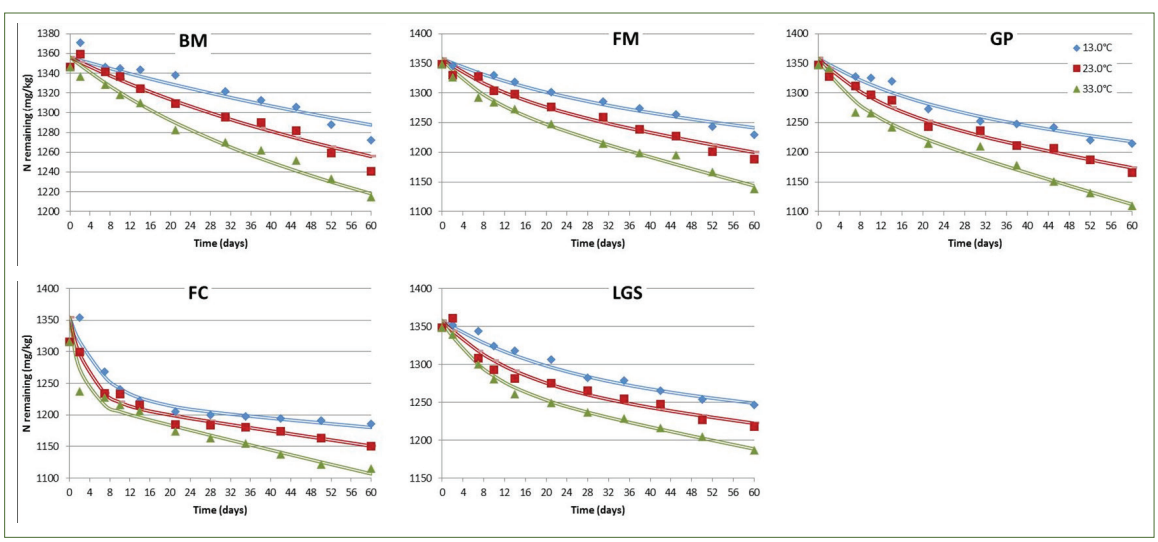

Figure 1. Fitting the N mineralization of COF at three temperatures using Eq. (6).

decomposition rates. All of the curves for all UR materials share common values of $Z_f = 4$ and $\varepsilon = 0.05$. An ε of 0.05 is low compared to reported literature values of 0.4 to 0.6 (Paul, 2007). A value of 0.6 served well for decomposing green waste (Crohn, 2013). It is not clear why decomposers of animal wastes would be so inefficient with N. It may be that efficiency is reduced when N is abundant relative to C in substrates. The poorest fit was associated with UR product E which also had the lowest $C:N_o$. UR E may have more in common with the COFs than with other UR materials. This material also was associated with more sustained N_2O emissions than other fertilizers based on N_2O measurements (data not shown) these losses may have contributed to the fit of the model since we only correct for Day 1 denitrification losses.

To estimate mineralization rates from CO_2 evolution data, it is also necessary to parameterize Z_{o1} the initial C:N ratio of the labile C fraction. Excluding UR product E which had a very low C:N ratio, a strong relationship was found ($r^2 = 0.962$) between the decay rate of the labile carbon fraction, k_1, and Z_{o1} (data not shown). The curves in **Figure 3** were generated using this relationship illustrated rather than with direct estimates of Z_{o1} values. It may be possible to estimate Z_{o1} values from k_1 though other possibilities may also emerge and additional research is needed.

This research demonstrated that immobilization need not be represented with COF. Work on the project

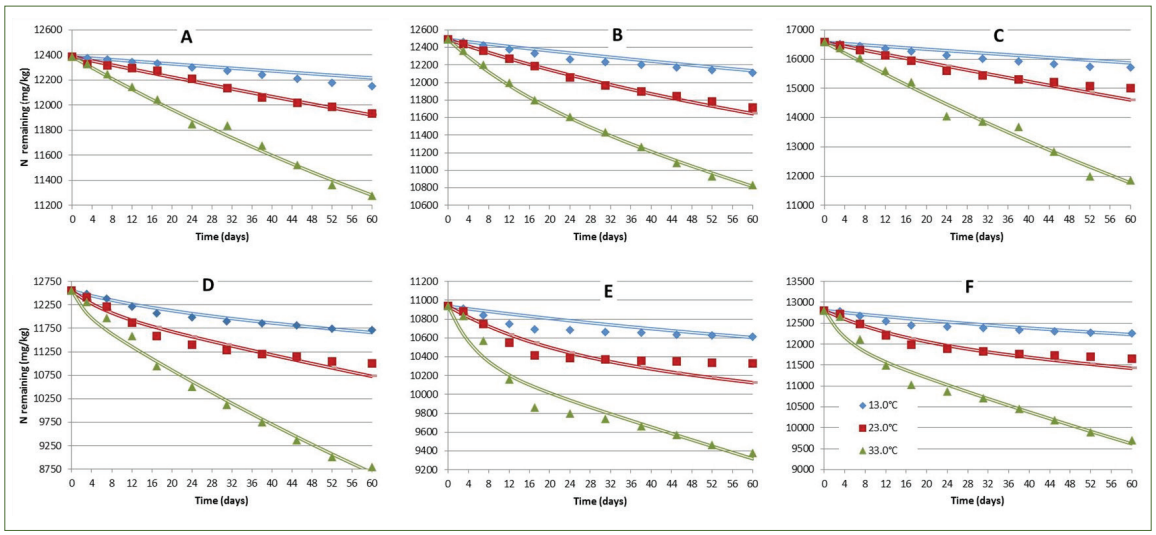

Figure 2. Fitting the C decomposition of UR at three temperatures using Eq. (1).

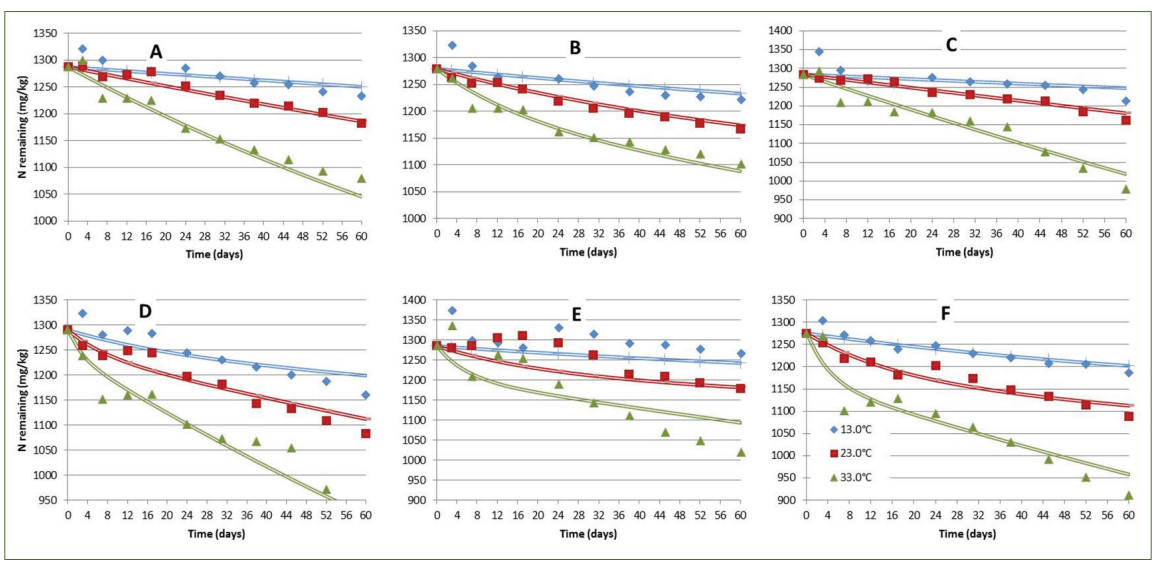

Figure 3. Fitting the net N mineralization of five COF at three temperatures based on C decomposition rates using Eq. (4).

revealed that considerable modifications are needed to incorporate immobilization into NBOT fertilizer plans. A version of the NBOT that includes immobilization has also been produced with convenient data-entry and a user manual to describe its use. Users may enter their plans into a calendar-like interface (**Figure 5**). An alternative data-input approach is under development.

DISCUSSION AND CONCLUSIONS

Net mineralization from low $C:N_o$ fertilizers (<6) was best represented by directly fitting parameters to observed mineralized N. At higher $C:N_o$ levels, inclusion of C provides good results. Fittings depend on which parameters are lumped. The COF were less sensitive to changes in temperature and their Q_{10} could also be lumped. Since COF are processed and marketed by fertilizer companies, their properties should be more consistent from batch to batch than UR. Incubations for describing the mineralization of COFs are quite practical as these fertilizers have consistent properties from batch to batch. The release rates measured here for organic fertilizers are lower than expected. It is possible that some denitrification losses were encountered, though no N_2O losses were detected. The characteristics of UR materials such as composts, cover crops, and manures are much more variable, however, making incubations that include destructive sampling for N less realistic.

Ideally, higher C:N ratio materials should be able to be represented using C measurements or estimates only. The model developed here includes the fundamental relationships associated with N mineralization kinetics that are described in the literature. There are three main reasons to use C to model N mineralization. First, C measurements are more reliable since they are not affected by denitrification. Second, C measurements are easier since they do not require destructive sampling and subsequent extractions. Third, incorporation of C into N net mineralization models permits the influence of microbial immobilization to be included. A two-compartment model is needed to represent C decomposition. Anaerobically and aerobically digested UR appeared to have different Q_{10} values but within these categories Q_{10} parameters could be lumped. Anaerobic UR materials were most strongly affected by temperatures. It may be that the initial C:N ratios of the labile C compartment can be estimated from its decay

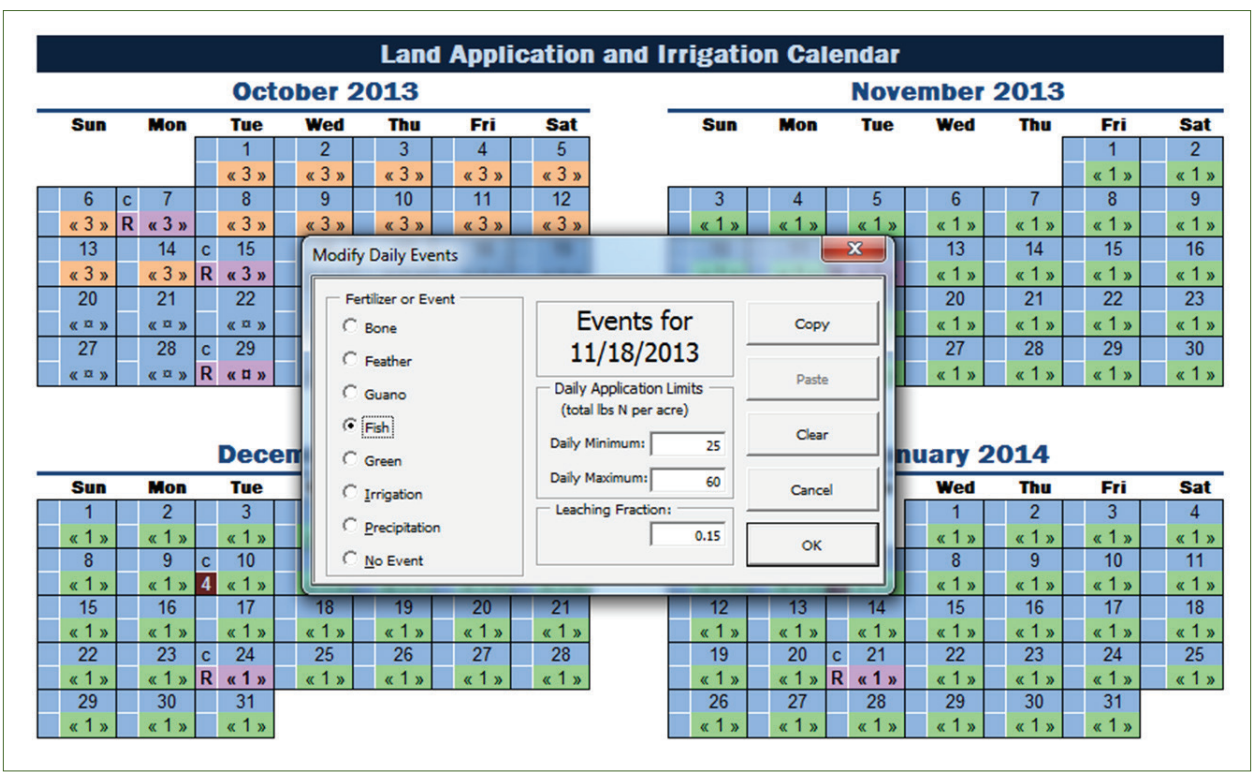

Figure 4. Graphic from the NBOT data entry system.

rate, but more work is needed to verify this. Warm (33°C) incubations may provide more rapid parameter estimates but research is needed to evaluate other approaches.

The NBOT uses the relationships described here to design application rates for organic N fertilizers. The NBOT produced annual plans for managing N by minimizing the amount of N available in the soil at any given moment. Leaching estimates are a function of irrigation management calculations. This component of the model is currently under redesign. Like all programs in development, the program needs further refinement. Nevertheless, the NBOT offers an interesting educational and planning approach for managing organic fertilizers.

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Nitrogen Application Schedule

Date	Material	Method	N (lb/ac)
Mar. 24, 2014	Fish 2	Spray irrigation	125 lb
May. 18, 2014	Fish	Spray irrigation	25 lb
May. 25, 2014	Fish	Spray irrigation	54 lb
Jun. 1, 2014	Fish	Spray irrigation	60 lb
Jun. 8, 2014	Fish	Spray irrigation	60 lb
Jun. 15, 2014	Fish	Spray irrigation	60 lb
Jun. 22, 2014	Fish	Spray irrigation	60 lb
Jun. 29, 2014	Fish	Spray irrigation	60 lb
Jul. 6, 2014	Fish	Spray irrigation	43 lb
Sep. 17, 2014	Feather	Spread no-till	54 lb

Nitrogen Schedule Result Summary

N Application Summary (lb/ac)	
Meal total:	0
Feather total:	54
Guano total:	0
Fish total:	422
Fish 2 total:	125
All applied N:	600

N Fate Summary (lb/ac)	
Total crop N removal:	477
Leaching losses:	92
Denitrification losses:	31
Volatilization losses:	0
Regulatory N supply ratio:	1.26

UC CE University of California Cooperative Extension

Figure 5. NBOT result display.

Improved Methods for Nutrient Tissue Testing in Alfalfa

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INTRODUCTION

Alfalfa is the largest acreage crop in California with typically nearly a million acres. Because of its acreage and nutrient requirements, alfalfa represents an important component of California's fertilizer and agricultural footprint. The most limiting nutrients for alfalfa production in California are phosphorus followed by potassium, sulfur, and occasionally micronutrients boron and molybdenum in the Intermountain area of Northern California. Despite the importance of fertility management, many growers do not know whether their fields are deficient, in excess, or adequate. Fertilizer practices are usually based primarily on past practices with little knowledge of the current nutrient status of fields.

Soil tests are effective to detect nutrient deficiencies such as P and K, and are especially useful before planting. However, plant tissue tests are believed to be more accurate, especially for sulfur and micronutrient analysis. The plant itself is a better indicator of the nutritional status of a field due to soil sampling and laboratory nutrient extraction limitations. Alfalfa roots typically penetrate 5 feet or more into the soil and nutrient concentrations vary with soil depth, yet we typically only sample the top 6 to 8 inches. Additionally, the level of plant-available nutrients in soil using laboratory nutrient extraction techniques may differ from the nutrients actually available to the alfalfa plant. Plant analysis is an indicator of actual nutrient uptake and therefore a better measure of nutrient availability. Unfortunately, most alfalfa growers currently do not utilize tissue testing. There is a need to encourage better management of nutrients in general (excess, deficiencies), but in particular to more widely adapt soil and tissue testing protocols.

OBJECTIVES

1. Evaluate the feasibility of using a whole-plant sample (simulated cored-bale hay sample) to determine the nutrient status of alfalfa fields and to guide fertilization practices.
2. Compare 3 different plant tissue sampling methods for nutrient monitoring (top 6 inches, fractionated plant, and whole-plant sample) as to their ability to reflect the nutritional status of fields.
3. Quantify the phosphorus, potassium and sulfur tissue concentration in alfalfa plant tissue over time as the crop matures from early bud growth stage to 10% bloom.
4. Determine alfalfa yield response from phosphorus, potassium and sulfur fertilization.
5. Evaluate the accuracy of NIRS analysis to determine nitrogen, phosphorus, potassium, sulfur, boron and molybdenum concentrations.

Collecting plant tissue samples from a commercial alfalfa field in the Intermountain area.

DESCRIPTION

The established alfalfa tissue testing protocol in California involves collecting stems at the time of cutting (ideally 10 percent bloom) and fractionating the plant into 3 parts and analyzing each part for a distinct nutrient(s). For alfalfa producers and consultants, this process can be time consuming, tedious and confusing. In addition, there is no way to sample after the crop has already been harvested. This sampling procedure is unique to California and other states have different protocols with no universal nationwide sampling method. Typically, either whole plant or the top 6" (15 cm) of the plant is used, and the samples taken at early or 10% bloom (Kelling, 2000, Koenig et al., 1999, Koenig et al., 2009, Flynn et al., 1999).

Many alfalfa crops in California, especially those destined for the dairy market, are routinely tested for forage quality (e.g. fiber, protein and calculated digestibility values) to determine their nutritional value for feeding purposes by coring the hay bales after harvest. If these same cored samples used for forage quality analysis could also be used for nutrient management purposes, it would greatly simplify the process, promote the practice of tissue sampling to guide fertilizer applications and encourage more careful nutrient management.

Sampling Commercial Alfalfa Fields to Compare Tissue Testing Protocols

Twelve commercial alfalfa fields were sampled over the season in three different alfalfa production regions (5 fields in the Intermountain area, 4 in the Sacramento Valley and 3 in the high desert). Each field was sampled three times over the season—each of the three cuts in the Intermountain area, and cuts 2, 3 and the second to the last cutting (5th or 6th) in the Sacramento Valley and High Desert. Fields were selected to represent a range of nutrient levels. Plant samples were collected at the early-bud, late-bud, and 10 percent bloom growth stages at each of the three cuttings. Plant samples were collected and processed using the following sampling protocol:

1) Fractionated plant sample according to the standard UC protocol. Samples were divided into thirds. The stems from the mid-third portion were analyzed for PO_4-P and K. The leaf portion of the middle third was analyzed for SO_4-S, and the top third portion for boron and molybdenum.

2) The top 6 inches of the alfalfa plant (method used in other alfalfa-producing states) were analyzed for total P, K, total S, boron and molybdenum.

3) Whole plant samples (used in some states and comparable to cored bale samples) were analyzed for the same nutrients as the top 6-inch samples as well as N.

NIRS and Wet Chemistry Validation and Calibration

In addition to the wet chemistry methods mentioned above, all the whole plant samples will also be analyzed using near-infrared spectroscopy (NIRS) by UC Forage Specialist Dan Putnam's laboratory at UC Davis and at a commercial laboratory experienced with NIRS (JL Analytical Services, Inc).

Fertilizer Rate Studies

Fertilizer response trials were conducted in the Sacramento Valley for phosphorus and in the Intermountain area for potassium (phosphorus rate studies have been conducted previously). The purpose was to correlate alfalfa yield with plant tissue nutrient concentration. Each trial had 5 different rates (unfertilized and 4 increasing fertilizer rates) with four replications. The trials were harvested for three cuttings spaced throughout the season in the Sacramento Valley and all three cuttings in the Intermountain area. Plant tissue samples were collected. Yield data was collected to determine the yield response to applied P, K, and S and to correlate those yield levels with plant nutrient concentration. This research will provide information needed to develop critical tissue levels for whole plant analysis, which can be used to interpret results from cored bale samples.

RESULTS AND DISCUSSION

Current plant tissue interpretation guidelines for California (Meyer et al., 2007) and other states throughout the US (Koenig et al., 2009) are based on alfalfa at the one-tenth bloom growth stage. However, to produce highly digestible alfalfa for the dairy industry, growers will frequently harvest alfalfa in the bud stage and many fields never reach one-tenth bloom before harvest.

One of the key impediments to the standardization of sampling methods in alfalfa is the influence of plant maturity on nutrient concentrations. This is important for either standing crop sampling, bale sampling or with plant fractions. The change in nutrient concentration with crop maturity stage has not been adequately accounted for in previous guidelines developed for alfalfa tissue testing. Most guidelines simply state that they are based on alfalfa at the 10 percent bloom stage without indicating how to evaluate less mature alfalfa samples.

In agreement with previous research (Schmierer et al, 2005), we found that nutrient concentrations were significantly affected by alfalfa growth stage. For P analysis, all three methods (whole plant, top 15 cm and stem) provide similar (parallel) results, but with different

average concentrations for each method (**Figure 1**). There was a consistent gradual decline in P concentration with advancing maturity. Potassium concentration also decreased with advancing maturity but the decline was more precipitous (**Figure 2**). In addition, the decline in potassium concentration with advancing alfalfa maturity was not as linear as it appeared for phosphorus. In general, the potassium concentration declined more dramatically when alfalfa matured from the late bud stage to the 10 percent bloom stage than it did from the early to late bud stage. Sulfur concentrations were not as greatly affected by stage of development, but there was still some influence (data not shown).

These results clearly demonstrate that alfalfa maturity must be considered when interpreting alfalfa plant tissue levels for both phosphorus and potassium. Previous guidelines (Meyer et al, 1997) suggested that nutrient concentrations were only 10 percent higher in bud stage than in 10 percent bloom alfalfa; however, our research clearly demonstrates that the difference is far greater, approximately a 30 percent difference between 10 percent bloom and early-bud stage alfalfa. This has likely led to considerable interpretation errors in the past when evaluating plant tissue test results from samples taken prior to the 10 percent bloom stage. For example, a sample collected at early bud stage may appear to have adequate phosphorus but if the same plants were sampled at one-tenth bloom they may be deficient. Critical plant tissue levels are currently being developed to allow for accurate interpretation of bud-stage alfalfa.

Utilizing NIRS for Detection of Deficiencies in Alfalfa

A large percentage of alfalfa hay in California is analyzed with either wet chemistry or near-infrared spectroscopy (NIRS) methods to assess its nutritional value. This technique is used primarily for the evaluation of typical forage quality parameters (Dry Matter, Acid Detergent Fiber, Neutral Detergent Fiber, Crude Protein), but some commercial labs also report values for minerals. NIRS technology, which uses light reflectance and calibration equations to estimate hay quality parameters, has become widely accepted because is faster, highly repeatable and usually less expensive. Although wet chemistry techniques are ordinarily preferred for mineral analysis, some labs have proposed utilizing NIRS (an indirect method) for estimating nutrient concentrations. This may become especially useful with the monitoring of nutrients in crops for the purposes of nutrient management plans. The use of NIRS methodology could greatly simplify alfalfa plant tissue testing if reliable calibration equations exist, or could be developed, for routine prediction of the nutrient status of fields. Note: nitrogen is a very reliable parameter to measure utilizing

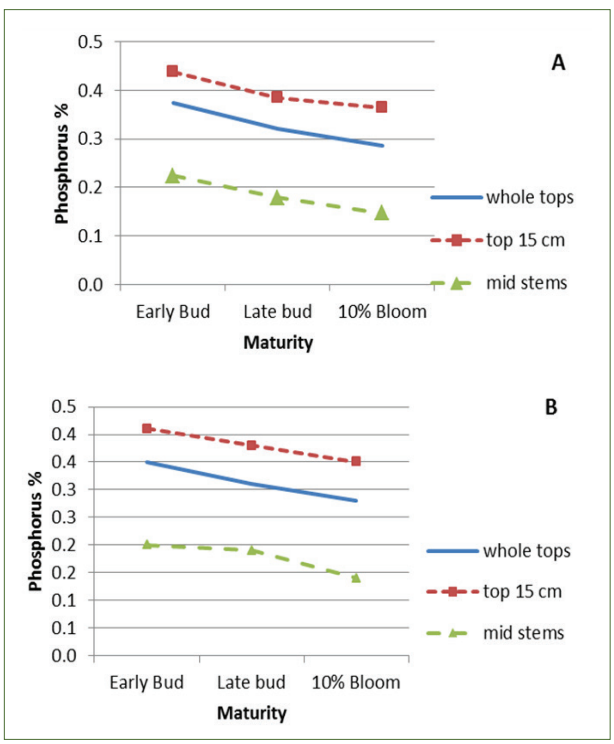

Figure 1. Influence of plant maturity on phosphorus concentrations in alfalfa, average of 10 farms, and all cuttings, (A) 2010 and (B) 2011. Note: Whole tops and top 15 cm are expressed as total P, whereas mid-stem phosphorus is expressed as PO_4-P.

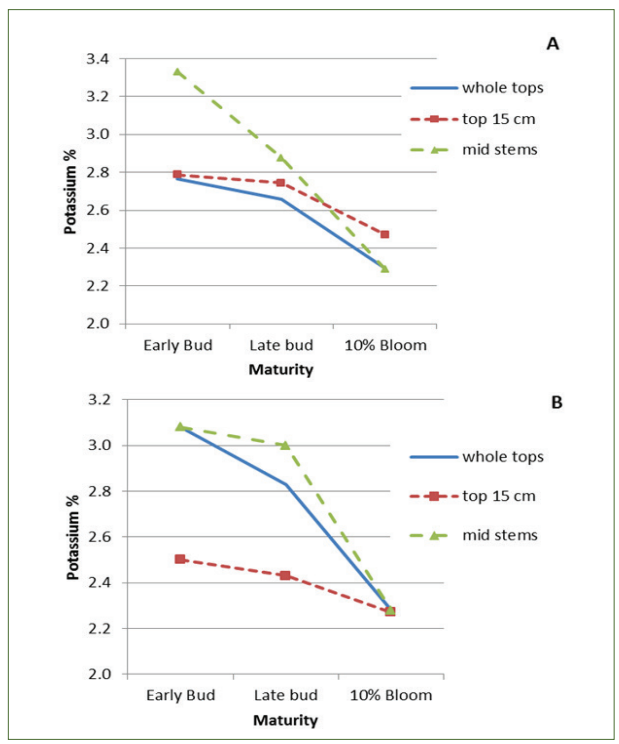

Figure 2. Influence of plant maturity on potassium concentrations in alfalfa, average of 10 farms, and all cuttings, (A) 2010 and (B) 2011.

NIRS – Crude protein values are calculated from %N in plant tissue utilizing robust NIRS equations. However, P, K and S analyses have not been as widely accepted.

NIRS scans were performed on samples from 2010 and 2011, in both the UC Davis lab and a cooperating commercial lab (JL Analytical Services). We used a large set of samples to compare NIRS methodology for prediction of minerals with wet chemistry (standard) procedures. Correlations with NIRS-predicted values compared with wet chemistry values for a range of samples from our studies found relatively high R^2 values. Correlations were 81% (Putnam lab equation, **Figure 3**) for phosphorus. Additionally, R^2 values of 76% to 78% for K were observed using a commercial lab equation and the NIRS Consortium equation. Sulfur correlations (NIRS vs. chemistry) were lower so it is questionable at this point whether NIRS can be used to estimate the sulfur status of an alfalfa field. We tentatively conclude that NIRS can be used for early routine detections of phosphorus and potassium nutrient deficiencies (and perhaps for uptake analysis), but caution should be exercised on this issue, since the mechanism for response of NIRS to different nutrient concentrations is not fully understood.

PRELIMINARY FINDINGS

Analysis of whole plant or cored bale samples for detection of P and K deficiencies appears to be a practical method to monitor deficiencies of these nutrients in commercial alfalfa fields. Plant stage of development has a large influence on nutrient concentrations, especially for phosphorus and potassium. Therefore, different threshold values will be required to account for plant growth stage at the time of sampling. It is likely that NIRS methods can be useful for early detection of nutrient deficiencies, especially phosphorus and potassium. Since many growers routinely analyze their alfalfa hay for nutritional quality using NIRS, this may be a simple method to evaluate the need for supplemental fertilizer. However, an initial NIRS analysis should likely be followed up with more vigorous field testing to confirm the nutritional status of the field. It was apparent that alfalfa tissue testing protocols using whole tops or cored bale samples are simple to use and sufficiently accurate so that nutrient analysis can become a routine component of forage quality testing. Additional evaluation is underway to establish critical plant tissue values for whole tops or cored bale samples at different sampling maturities.

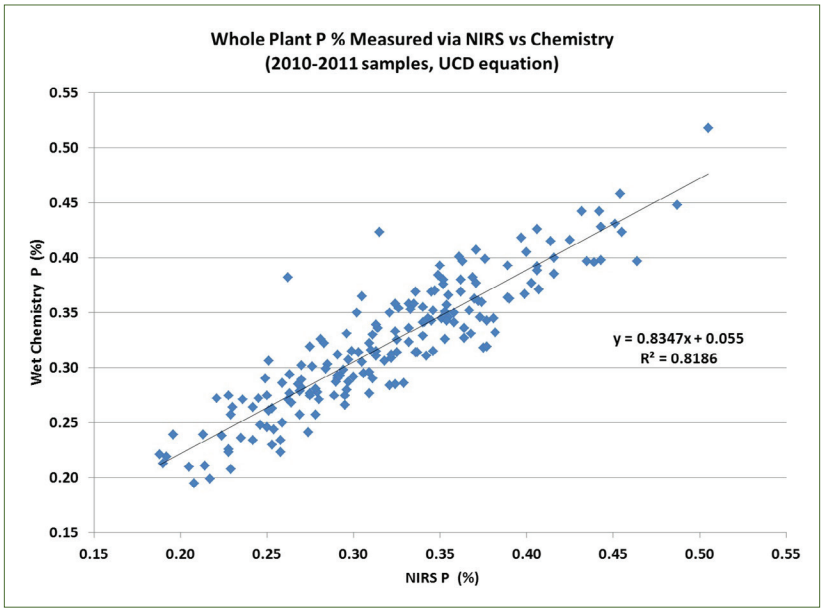

Figure 3. Relationship between whole plant sample P concentration utilizing NIRS vs. chemistry methods.

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European Pear Growth and Cropping: Optimizing Fertilizer Practices Based on Seasonal Demand and Supply with Emphasis on Nitrogen Management

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INTRODUCTION

Best Management Practices (BMP) for European pear in California were re-evaluated, using UC recommendations as a starting reference. Recommendations currently are 2 lb actual N per ton of crop per acre per year (#N_{act}/t/A/yr). Tissue N critical value is 2.2%, adequate N range is 2.3-2.6%, using non-bearing spur leaves for analyses in mid-summer. The 2007 recommendation established BMP based on two physiological premises for N management: (1) efficiency of N use in cropping -- a 30 ton/A orchard should receive 60 #N_{act}/A/yr; (2) vegetative vigor control– no N should be applied if average shoot growth exceeds 12 inches.

OBJECTIVES

1. Determine the relationship between seasonal tissue N partitioning and concentration and tree productivity and growth.
2. Compare typical and reduced N to validate recommended N management and the possibility of customizing BMP based on tissue levels, fruit quality and crop load.
3. Quantify effects on crop load and fruit quality (harvest and postharvest).
4. Refine current management guidelines for fertilizer usage.
5. Cooperate with growers to follow recommended irrigation frequency.

DESCRIPTION

We used three 'Bartlett' orchards with existing conditions that allowed manipulation of nutrients. These orchards represented the majority of Delta 'Bartlett' orchards with a range of yields of (20-32 t/A/yr), tree age, rootstock, soil and growing conditions.

Elliot I ('High N' vs 'Low N' = 60 or 120 #N_{act}/A/yr vs 0 N)

Effects of N level on reproductive and vegetative vigor, yield, fruit quality, with 'High N' typical for this grower's practices and 'Low N' representing the UC recommended guidelines.

McCormack ('High N' vs 'Low N' Customized Annual Program to Equalize Differences Within the Orchard)

Orchard rows had a N-S orientation with a 'drop' towards the south half, with higher water table resulting in increased vigor, earlier harvest, heavier crop load and larger fruit than in the north half. Recent management changes (flood changed to solid set sprinkler irrigation, increased N and better pruning) had increased yields from 20-23 ton/A/yr to 30-32 ton/A/yr. Both halves of the orchard received a total of 152#N_{act}/A/yr until 2010. Prior to harvest, starting 2010, a revised fertilization program was begun to equalize fruit development rate, cropping and vegetative vigor between the N and S halves of the orchard. The annual amounts of N were adjusted by the grower, depending on his evaluation of current cropping conditions, maintaining a high differential between the two halves of the orchard.

	High N, Low Vigor	Low N, High Vigor
2010	282 #N_{act}/A	129 #N_{act}/A
2011	313.5	150.5
2012	255	107.5

Elliot II ('Budgeted' Low N and Nutrient Balance Effects on Fruit Quality and Cropping)

This was our test orchard for N:K:Ca effects on fruit quality and cropping, as well as 'budgeted' low N. We compared the grower's 'traditional' K application (300# K_2O=90 #K_{act}/A/yr applied to soil in fall) to K fertigation ($K_2S_2O_3$, three equal applications during fruit development=84 #K_{act}/A/yr). Responses to treatment were evaluated at harvest and postharvest. There was a soil type change just outside of the area of the trial.

RESULTS AND DISCUSSION

Elliot I ('High N' vs 'Low N' = 60 or 120 #N_{act}/A/yr vs 0 N)

- The most consistent pattern of N was significantly higher N in fully-expanded shoot and bearing spur leaves in spring, prior to spring N applications (where trees had received a fall application of N), and in summer prior to harvest. However, even where statistically significant differences between treatments were found, the range of tissue levels was very small. Non-bearing spur leaves (currently recommended for tissue N sampling) tended not to show significant treatment differences and were within adequate to high levels, even when 0N had been applied for three years.
- Lack of response in vegetative growth to differential N treatments was consistent with numerous other studies in European pear showing a general insensitivity to N level.
- Yields were not improved by increased N; 'High N' treatment resulted in numerically lower yields per tree and acre (in 2010 and 2012, but not in 2011).
- 'High N' treatment tended to improve fruit size and the percentage of the crop that was #1 fruit, but this was most likely due to lower yield. Fruit size was good overall.
- 0N for three years did not reduce yields or fruit quality overall, indicating that soil and tissue N levels were adequate without added N during the study period.
- Yield efficiency (yield on a per tree basis, 320 trees/A), High N yield efficiency averaged 0.077 at 120 #N_{act}/A/year and 0.079 for 0N treatment. 0N yielded as well and saved money.

Recommendation for nitrogen application. Efficiency of N use in cropping is a more powerful tool to manage N demand than either tissue analyses or vegetative growth responses. Yield efficiency and cost savings were maximized at 0N. While this may change in future and application of N will be needed, this should be managed on a 'as needed only' basis (reduction in fruit set and/or tissue inadequacy). The bearing capacity of this orchard varies from ~20-30 tons/A and variation is due to environmental conditions (bloom weather, preharvest crop loss) and tree variability.

McCormack ('High N' Vs 'Low N' Customized Annually)

- Baseline differences between leaf types were greater than that between orchard halves. After differential N treatments were started, the greatest differences in tissue N throughout the trial period were due to sampling time through the growth period (spring, mid-summer, fall) and between leaf types. Replicate differences within each orchard half were as statistically significant as between orchard halves (treatment differences) and between leaf types.
- 2011 (heaviest cropping year): Tissue N for non-bearing spur leaves prior to harvest was adequate for the 'High N, low vigor' trees (2.38% N) and slightly under the adequate range, but above critical value for the 'Low N, high vigor' trees (2.28% N). Bearing spur leaves, those that one would expect to be the strongest nutrient sources for growing fruit, showed a significant difference in tissue N in fall (2.07% N 'High N, low vigor' vs 2.13% N 'Low N, high vigor'). These two results might indicate further need for comparing both types of spur leaves before and after cropping in heavy crop years, from trees with differential bearing habit, as in this orchard. The bearing spur leaves in the heavier cropped half of the orchard may reflect the greater demand by the crop and should be sampled.
- Cropping 2010: The percentage of the crop that were #1 fruit in the second harvest and total yield were not statistically different.
- Cropping 2011: %Yield removed in the first harvest was not different by treatment group, furthering one of the grower's goals—that an improved percentage of the crop be picked in the first harvest on the low vigor trees (i.e. maturity would be advanced).
- Comparing yields of the two halves is almost like comparing yields of two different orchards (averages were 23 vs 30 tons/A over the three year period); a more meaningful measure would be yield increase or decrease in response to nutrient management of each half independently, particularly as their N applications were so different. When comparing

annual yields as a percentage of each half's average, these were: 'High N, low vigor' = 86, 124, 89% vs 'Low N, high vigor' = 87, 113, 100%.

Recommendation for nitrogen application. The grower's two primary goals in this orchard were (1) to increase the reproductive (and vegetative) vigor of the low vigor half of the orchard, by increased N application, (2) to advance maturity of the low vigor half of the orchard such that more fruit could be harvested at the 'first pick', in keeping with the ripening behavior of the high vigor half. The patterns seen in 2010 through 2012 were generally consistent and appeared to support the grower's choices. The high percentages of #1 fruits (fairly consistent year-to-year) with good yields indicate a strong nutritional program appropriate for this situation.

Elliot II ('Budgeted' Low N and Nutrient Balance Effects on Fruit Quality and Cropping); Differential K Treatment by Fertigation (Spring) or Soil Broadcast (Fall)

Baseline tissue nutrients April 2010. (No differential treatments applied.)

- N content was adequate after 0N in 2007-2008 and 63-65 #N_{act}/A/yr in 2009.
- Different leaf types showed variations by location in different nutrients.
- In each case where a nutrient level was significantly different by 'location', the higher value was found in the 'Fertigation' plot.
- Fruit had the highest number of nutrient extremes for both locations combined, and several extremes for each location.
- The reason for higher tissue nutrient levels in the 'Fertigation' plot trees may be that those trees were closer to the 'Scribner clay-loam' transition to 'Egbert clay'.
- 'Location' effects (probably the soil type difference with inherent permeability and uptake effects on the rootstock) were important for a particular nutrient or balance of nutrients. Fruit nutrient levels were the most affected by the combination of rootstock x soil/water.
- Some correlations with nutrients and their interactions that may affect fruit quality, particularly postharvest, including maturation rate and ability to store and ripen without disorders, were found in early spring sampling of tissues, especially shoot leaves.

July 2010 tissue analyses. ('Fertigation' plot had Spring fertigation with K in 2009+2010; 'Soil' plot had Spring fertigation with K in 2009 by this harvest.)

- Shoot leaves and bearing spur leaves – higher levels in Fertigation plot for: N, P, S, Cu, and all the nutrient ratios but N/K.
- Shoot leaves and bearing spur leaves – higher levels in 'Soil' plot for: Ca, Mg, Mn, Zn and Fe (bearing spur leaves).
- Either shoot or bearing spur leaves would have been equally valuable in detecting these K treatment differences. <u>The consistency in these results is very important as it allows greater confidence in interpretation of nutrient status.</u>
- Comparing July and April values: bearing spur – higher in Fertigation for K, (K+Mg)/Ca, K/Ca and N/Ca and higher in Soil for Mg both April and July
- <u>Thus, the consistency across these tissue types in July and across sample timings for nutrients in bearing spur leaves that are important nutrient ratios in fruit quality are important findings.</u>

Harvest and postharvest 2010.

- There were no treatment differences in fruit quality at harvest timing.
- In almost every measure of storage quality in which significant differences between K treatments were found, the 2010 Spring Fertigation treatment resulted in reduced quality (firmness, all evaluation timings; %soluble solids (harvest + 3 months storage; internal browning and senescent scald). Ground color and hue angle (the first is a visual measure, the second a chromameter measure of green vs yellow color, indicating ripening) was different in some evaluation timings but results by K treatment were not consistent.
- Multivariate analysis found that postharvest firmness due to K treatments ('Fertigation' plot vs 'Soil' plot) explained treatment differences at 0.1% level with April bearing spur leaf levels of Mn and Fe (1%), (K+Mg)/Ca and K/Ca (0.1%) and Mg/Ca (5%). No other regressions explain treatment differences as well.
- The 'Fertigation' plot had higher levels for (K+Mg)/Ca, K/Ca and Fe in bearing spur leaves in April and these were among those nutrient ratios associated with firmness problems in fruit from this plot. The significantly higher K level in bearing shoot leaves, especially, would have contributed to this imbalance.
- An important predictor of these potential fruit quality problems is the N/Ca balance in the fruit. The N/Ca ratio found in fruit tissues sampled in April, 2010, was 12.52-13.56, indicative of exceedingly high N to low Ca balance.

- Bearing spur leaf levels of these nutrients were predictive of firmness problems postharvest, as were shoot leaves and small fruit.
- The July tissue analyses supported these findings. In all nutrient ratios with Ca, in both shoot and bearing spur leaves, the Fertigation plot had significantly higher ratios (i.e. lower Ca in relation to K, Mg and N) than the Soil plot.
- These results suggest that potential for storage disorders was not necessarily increased by the Spring 2010 Fertigation treatment (this treatment had not occurred by the April sample timing), but by the tree uptake of nutrients and their resulting balance in the tree. This was likely due to the proximity of these trees to the localized soil textural differences at the transition between soil types and the water permeability of that soil.
- In this case, increasing either N or K, in response to sub-optimal levels measured in leaves in April, would exacerbate the potential for fruit disorders. Indeed, applying calcium nitrate to the soil in spring did not improve the Ca tissue levels but provided increased N, which would be contraindicated.

Recommendations for nitrogen, potassium and calcium management based on 2010 results.

- Leaf (especially bearing spur and shoot) and fruit levels of single nutrients should be obtained in spring before any fertilizer applications, examined as nutrient ratios, rather than single nutrients, and the recommended optimal leaf levels be used with caution in judging whether N, K or Mg should be applied.
- If ratios are high (Ca low in relation to N, K and/or Mg), and no other deficiency symptoms for N, K or Mg are apparent, any further application of N, K or Mg may be contraindicated.
- Uptake of Ca is often difficult and its mobility in the tree limited. There is no assurance that soil applications of Ca will be effective. Ca is needed most by the fruit in the earliest stages of fruit development. Tissue analyses as early as possible, once fully-expanded leaves and small fruit drop has occurred, shoot and bearing spur leaves, and small fruit, should be sampled for nutrients. Leaf Ca level is **not** indicative of fruit Ca level.
- Early N absorption (May to August) is negatively correlated to fruit quality. N builds up in developing fruit tissues faster than Ca does, enhancing the N/Ca imbalance that promotes fruit disorders. Consider eliminating annual N application unless visual deficiency symptoms are apparent; alternatively, apply N in fall.
- Replacing soil Ca application with foliar Ca treatments should be considered, with high frequency and rate of application.
- When an imbalance of K/Ca or (K+Mg)/Ca is found in any leaf or fruit tissues sampled in spring, consider no K application, or consider fall soil application of K in place of K fertigation in spring so that the ratio imbalance will be less likely to affect fruit.
- The conclusions here should not be dismissed for fruit that are not going to be stored long-term. Ripening problems started showing up with the first phase of postharvest ripening (6 days after harvest).

April 2011 tissue analyses.

- Differences among plant parts within a given K treatment were more numerous than between K treatments for a given plant part. Shoot leaves were the best tissue to sample at this timing for K uptake differences (between K treatments). No pattern was seen for non-bearing spurs.
- When comparing tissue types for sampling, within a given K treatment plot, the greatest differences in nutrient level extremes were found between fruit (generally high levels of nutrients where there were significant differences) and shoot leaves (generally low levels of nutrients). Spur leaves from bearing and non-bearing spurs tended to show generally moderate levels of nutrients.
- If a single tissue type were collected, and conclusions drawn from that tissue analysis for nutrient status in the tree, misleading information would result.
- Comparing 2010 and 2011--Virtually no similarities regarding differences by location (2010) or K treatment (fertigation vs soil K) by plant part nutrient level, except in nutrient ratios by 'location' (K treatment plot) **in bearing spur leaves**. These similarities were: Higher N/K in Soil than Fertigation, Lower Soil than Fertigation for (K+Mg)/Ca, K/Ca and N/Ca.
- Together with the April 2011 finding that bearing spur leaves in the Soil treatment showed the lowest ratios of nutrients where Ca was part of the ratio (N/Ca, (K+Mg)/Ca and K/Ca), these data suggest that where fruit quality problems that implicate these balances are found, postponing K application to postharvest may be of benefit. This result was consistent both before and after differential treatment.

July 2011 tissue analyses.

- Shoot leaves, both treatments were low in K, Ca, Mn and Cu; non-bearing spur leaves low in K, Mg and S.
- Soil K in fall may have helped to overcome mid-summer low levels of N and P found in 2010 (Soil plot).
- No deficiency symptoms were seen and trees had good vigor. Where differences existed by K treatment, the Fertigation treatment was higher than Soil for all but B; no nutrient balances were different by K treatment.
- Treatment differences across plant parts were numerous and highly significant in all nutrients we tested. Shoot leaves had highest levels in almost all cases. It was not possible to conclude that one leaf type was better to sample than another based on this data alone.

Harvest 2011.

- Fruit were slightly larger in general with Fertigation, although differences were very small
- A slightly higher number of #1 fruit were found in the Soil treatment as a percentage of the overall harvest, but the difference was small; yield of #1 fruit was higher in the Fertigation treatment in actual numbers.

September 2011 tissue analyses.

- Within a given plant part, K treatment was not different except for Mn. Any leaf type sampled would have given similar results for treatment differences.
- However, bearing spur leaves and shoot leaves showed significant differences in how much of given nutrients they accumulated; these differences occurred often in both treatments.
- In most cases where nutrient level differed by leaf type, bearing spur leaves had higher levels than shoot leaves.
- Because bearing spur leaves accumulated higher levels of Ca than did shoot leaves, ratios with Ca were lower for spur leaves than shoot leaves, across both K treatments.
- July values were not good predictors of September values; this was also the case in 2010.

April 2012 tissue analyses.

- Nutrient values for April 2012 were not different by treatment, for a given plant part, but varied most among sample tissues. No treatment differences may have been due to light cropping in the 2012 year, with lower than usual nutrient demand at this time shortly after small fruit drop. It was not possible to conclude that one leaf type was better to sample than another based on this data alone. Fruit levels--Ca, Fe and Mn were extremely low and Mg much lower in fruit than in April, 2011.

July 2012 tissue analyses and comparison to April values.

- Nutrient values different by treatment were found for shoot leaves (Fe) and bearing spur leaves (Mn) only. All nutrients were different among plant parts and highly significant, except for Cu.
- Shoot leaves highest in N, P, S and N/K in both April and July.
- Bearing spur leaves highest in K, B, Zn, Mn, Fe and (K+Mg)/Ca. Both April and July high values, therefore, were in K, Zn, Mn and Fe. Perhaps more importantly, bearing spur leaves were lowest in N, P, Mg and N/K. Maturing fruit may have been preferentially pulling these nutrients from adjacent bearing spur leaves.
- Non-bearing spur leaves were highest in Ca, Mg, S. Both April and July high values, therefore, were in Ca and Mg. The fact that growing fruit (April) were lowest in Ca, Mg and S and that the non-bearing spur leaves are highest in these same nutrients at the 'standard' sampling time for deficiencies may indicate that non-bearing spur leaves are not the best indicators for nutrient status in fruit quality considerations.
- Inadequacy based on published values (van den Ende and Leece, 1975) for mid-summer non-bearing spur leaves were found in K (non-bearing spur and shoot leaves), N (bearing spur leaves) and Ca (bearing spur and shoot leaves). Of these the lowest was Ca in shoot leaves, which may be a matter of concern when young fruit are also low.
- Both shoot and non-bearing spur leaves were in the range of K/Ca that indicates moderate to high chlorosis (Lindner and Harley, 1944), due to low K status in these leaves.
- Leaf nutrient values were not expressed in harvest fruit quality however low K and Ca in leaves in July and low Ca in fruit in April may have been indicators of potential postharvest disorders. This would be a good research area to pursue.

Harvest 2012 and combined yields 2010-2012.

- No differences in yield or fruit quality were found in 2012.
- When comparing yields from 2010 + 2011, 2010 + 2011 + 2012, the percent change in yield over time

from the same limbs and trees showed no significant difference between treatments from 2010 to 2011. Although there was no significant difference from 2010-2012 in cumulative percent increase in yield, there was a numerical difference with the Soil treatment greater than the Fertigation treatment.

Overall conclusions for Elliot II trial, including nutrient management recommendations.

- This orchard was adequately fertilized, despite apparent deficiencies indicated in leaf samples.
- The potential for nutrient imbalances that can affect fruit quality, especially with storage, was amplified in the area where the soil change was nearby.
- Sampling in early spring and mid-season, especially of small fruit in spring, provided good prediction of potential for fruit disorders.
- Tissue analyses should be interpreted with caution with respect to applying nutrients, (especially N and K), that can exacerbate potential for disorders. Nutrient balances should be calculated and used to assess need for fertilizers before application.
- In order to avoid potential for fruit quality disorders fall application of K is advised and applications of Ca in Spring should be considered as a foliar application, without added N. Any N application should be considered for fall, to reduce the likelihood of nutrient imbalances for fruit quality when those are indicated by early season tissue analyses.
- No adverse effects on yields or fruit size were caused by either K treatment, therefore, the main consideration in this orchard would be reduced exposure of the fruit to N and K preharvest, and consideration of foliar Ca preharvest in numerous applications using forms that are reduced risk for fruit finish.

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We chose orchards for these trials with a range of soils, rootstocks and nutritional management practices so that we might take advantage of both fixed constraints and flexibility to address nutrient management with potential opportunities for effects on cropping and fruit quality. Some horticultural or disease problems that are nutrient-related arise sporadically, both in time and location. Often these kinds of problems, since they are localized, don't receive sufficient attention or research funding to develop solutions. Unanticipated benefits of many research projects can include partial answers to under-researched problems. While many of our results appeared 'non-significant' with respect to treatment differences in nutrient amount, form and timing of application, there were no 'empty' outcomes as our goals, in part, were to question the existing UC recommendations' relevancy to the varied conditions under which California's pear growers make their 'real world' decisions.

Maturing pistachios | Madera, CA

Improving Pomegranate Fertigation and Nitrogen Use Efficiency with Drip Irrigation Systems

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INTRODUCTION

Pomegranate acreage in California is now approximately 30,000 ac with the demand for juices with healthy bioactive compounds, mineral nutrients and high antioxidant contents partially contributing to this growth. Despite this being an "ancient" crop, there are few studies quantifying the water and nitrogen requirements of pomegranate orchard and none using either high frequency surface drip or subsurface drip irrigation. Research has shown that well managed surface drip (DI) and subsurface drip irrigation (SDI) systems can eliminate runoff, deep drainage, minimize surface soil and plant evaporation, reduce transpiration of drought tolerant crops, and significantly reduce fertilizer losses, thus protecting groundwater quality (Ayars, et al. 1999). Avoiding N deficiency or excess is critical to maintaining nitrogen use efficiency (NUE) and knowledge of the operation of DI and SDI, especially for deep SDI, is critical for effective management of N-fertigation . This project will determine the nitrogen fertilizer and water requirements and efficiency for a developing pomegranate orchard.

OBJECTIVES

The overall objective of this project is to determine nitrogen and water requirements of drip irrigated maturing pomegranate to minimize nitrogen losses.

Specific objectives are:

1. Determine the real time seasonal nitrogen requirements (N) of DI- and SDI-irrigated maturing pomegranate that improve fertilizer use efficiency (FUE) without yield reduction.
2. Determine the effectiveness of three nitrogen injection rates with DI and SDI on maintaining adequate N levels in maturing pomegranates.
3. Determine the effect of real time seasonal nitrogen injections (N) with DI- and SDI irrigated maturing pomegranate on N leaching losses.
4. Develop fertigation management tools that will allow the growers to achieve objective 1 and present these results to interested parties at yearly held field days and seminars.
5. Determine if concentrations of macronutrients (P, K, Ca, Mg) and micronutrients (Zn, Cu, Mn, Fe, B, Se) and eventually healthy bioactive compounds in soil, peel and fruit are influenced by precise irrigation/ fertigation management with DI and SDI.

DESCRIPTION

This project is located on the Kearney Agricultural Center (KARE) and uses a 3.54-ac pomegranate orchard (*Punica granatum, L* var. Wonderful) that includes a large weighing lysimeter. This lysimeter is used to determine the water use for the fully irrigated (100%) subsurface drip irrigation (SDI) with adequate nitrogen (N_2) treatment and to automatically manage the hourly irrigation scheduling on the site. Water applied to the DI treatments is increased by 10% to account for evaporation from the soil surface and water used by weeds. The lysimeter tree is irrigated using a SDI system with the same number of emitters per tree as the rest of the orchard. Trees were planted with rows spaced 16 ft apart and trees in the rows spaced 12 ft along the row. The orchard is laid out in a complete randomized block with sub-treatments and 5 replicates. The main irrigation treatments are DI and SDI (installed at 20-22-in depth) systems with dual drip irrigation laterals, each 3.5 ft from the tree row. The fertility sub treatments are 3 N treatments (50% of adequate N, adequate N, based on biweekly tissue analysis and 150% of adequate N, all applied by variable injection of N-pHURIC (10% N as urea, 18% S), AN-20 (10% NH_4-N and 10% NO_3-N). Potassium thiosulfate (K_2T, 25% K from K_2O and 17% S) and phosphorus (from H_3PO_4, PO_4-P) are supplied by variable injection of P=15-20 ppm and K=50 ppm to maintain adequate uptake levels. The pH of the irrigation water is automatically maintained at 6.5+/-0.5. Tree and fruit responses are determined by canopy measurements, bimonthly plant tissue analyses and fruit yield and quality. Analysis of variance (ANOVA) for the Randomized Complete Block Design (RBCD) with sub-samples will be used to determine the treatment significance.

RESULTS AND DISCUSSION

Pomegranate Water Balance

Table 1 shows the components of the water balance from 2010 until July 30, 2013. Reference evapotranspiration (ET_0) was taken from CIMIS weather station located on KARE. The crop water use (ET_c) came from the lysimeter and was adjusted for tree spacing. Precipitation came from the CIMIS station while drainage was measured in the lysimeter and there was no runoff. We matched the crop water requirement with the high frequency irrigation. Even with 10 inches of rain in 2011 we did not record any drainage in the lysimeter, which means that most of the rain was stored in the profile.

A photo comparing weed growth in surface drip irrigation (left) versus subsurface drip irrigation (right). Note the large weed population on top of the drip lines in the surface drip irrigated trees versus the lack of weeds on the subsurface drip irrigated trees. The subsurface drip irrigation method eliminated the need for several herbicide applications during the season.

Yields, Water Use Efficiency (WUE) and Nitrogen Use Efficiency (NUE) from 2012 Pomegranate Harvest

Pomegranate prime fruits were harvested by a local packer on 10/30/12 and for juice on 11/8/12. Sub-samples were harvested from the 5 center trees of each of the 5 yield rows and measured for total weight and quality. Results from harvests are shown in **Table 2** and indicate a significant yield increase due to the SDI system but none from the nitrogen treatments. Much of the yield increase was due to the larger size fruit in the SDI treatment.

Table 1. Components of the pomegranate water balance.

Year	ET_o in.	Precipitation in.	Irrigation in.	Et_c** in.	Drainage in.	Runoff in.
2010	49.73	17.34	1.00	2.10	???	0
2011*	50.9	10.42	8.49	9.8	0	0
2012	54.6	8.97	17.7	19.7	0	0
2013***	34.8	2.36	17.7	17.5	0	0

* 2011 ET_c values from 5/1 to 12/8 only
** Lysimeter ET_c adjusted for orchard spacing
*** 2013 Values until 7/30

Effects of irrigation and nitrogen treatments on WUE and NUE of pomegranate are shown in **Table 3**. The SDI treatment increased the WUE for the "Prime" pomegranate but not for the "Juice" fruits. Even though there was no statistical difference the NUE was improved for the SDI compared to DI. Also, the NUE was reduced as the applied N increased from N1 to N3. There was a large decrease in NUE from N1 to N2. The difference in applied nitrogen was a reduction of 102 lbs/ac which only resulted in a loss of 300 lbs of fruit per acre.

Soil Matric Potential (SMP) Measurements and Hydraulic Gradient Calculations in the SDI Irrigated Lysimeter

With the concern for transport of nitrate to the groundwater it is essential to quantify the movement of NO_3 through and below the crop root zone. To do this we used heat dissipation soil water matric potential (SMP) sensors installed in two columns of 4 SMP sensors each at depths of 24, 36, 48 and 60 in from the soil surface. These SMPs provide the SMP status in the lysimeter and are used to calculate the hydraulic gradient to infer the leaching potential under high frequency SDI (Phene et al, 1989). **Figure 1** shows the calculated daily averaged hydraulic gradient (HG) from 3/26/13 to 8/10/13 (HG>0 indicates upward flux and HG<0 indicate downward flux). HG-1 is the gradient from 24 to 36 inches. HG-2 is the gradient from 36 to 46 inches and HG-3 is the gradient for 48 to 60 inches. Results in **Figure 1** indicate that HG-1 and HG-3 are positive with upward flow while the zone from 35 to 48 inches has

Table 2. Effects of irrigation and nitrogen treatments on pomegranate yields.

Total Marketable Yield 10/30 - 11/08/12	Harvest #1 Prime Fruit 10/30/12		Harvest #2 Juice Fruit 11/08/12		Harvest #3 Non-Marketable 11/08/12	
Main Effects Irrigation Method: (lb/ac)	**Yield (lb/ac)**	**Fruit Wt. (lb)**	**Yield (lb/ac)**	**Fruit Wt. (lb)**	**Cracked (lb/ac)**	**Undersized (lb/ac)**
Surface Drip (DI) 18,738 b	9967	1.18 b	8771	0.80 b	698	299
Subsurface Drip (SDI) 20,631 a	11561	1.29 a	9070	0.86 a	598	399
Prob > "F" value 0.0548	0.067[y]	0.0002	NS	0.032	NS	NS
Nitrogen Level						
N1 - 46 (lb/ac) 19,136	10,365	1.19	8671	0.79	897	199
N2 - 148 (lb/ac) 19,435	10,963	1.27	8,372	0.82	698	299
N3 - 249 (lb/ac) 20,432	10,864	1.25	9,568	0.83	399	399
Prop > "F" value NS	NS[z]	NS	NS	NS	NS	NS
Contrast						
1 vs 2 and 3	NS	0.006	NS	0.045	NS	0.025
Polynomial Fit	-	L*[SD]	-	L[0.09SD]	-	L*[D]

[z]NS, *,** = not significant, significant at P=0.01, respectively, L = linear, Q =quadratic
[Y] Probability of greater 'F' value. Mean separation at P ≤ 0.05

Table 3. Effects of irrigation and nitrogen treatments on WUE and NUE of pomegranate.

Treatments	WUE-Prime lb/ac/in	WUE-Juice lb/ac/in	NUE-N1 lb fruit/lb N/ac	NUE-N2 lb fruit/lb N/ac	NUE-N3 lb fruit/lb N/ac
DI	554a	487a	217	67	40
SDI	680b	534a	251	78	46
%SDI Increase	23	9	15.7	16.4	15.0

water moving to deep depths. However, the gradient from 48 to 60 inches is upward thus preventing drainage and nitrate leaching. This would be expected to occur in the DI and SDI systems as well in the orchard.

The rise in hydraulic gradient starting on 7/4/13 resulted from a relay failure causing the irrigation pump to stay on for several hours (Murphy's Law) longer than required and resulted in excess irrigation. Despite the excess irrigation there was still no drainage.

Soil Nitrate Profiles Measured in 2012

Using SDI places nitrate below the soil surface and within the crop root zone. It also changes the availability and the potential for nitrous oxide emissions. We monitored the effect of irrigation system on nitrate using soil sampling. Soil nitrate (NO3) was measured every 6-in. from the soil surface down to 48-in depth on 4/12, 8/12 and 12/12. **Figure 2** shows nitrate values the DI and SDI measurements averaged for all the N treatments. In nearly every case, the NO_3 in the SDI treatment were lower than those measured in the DI treatments. We measured N_2O emissions and found that use of SDI nearly eliminated all N_2O emissions for all N levels compared to the DI (data not shown).

Effect of DI and SDI Methods and Seasonal N-levels on Tree Canopy Size

Tree development was characterized for each of the treatments. Tree circumference (at 5 feet height) and tree height were measured in early June 2013.

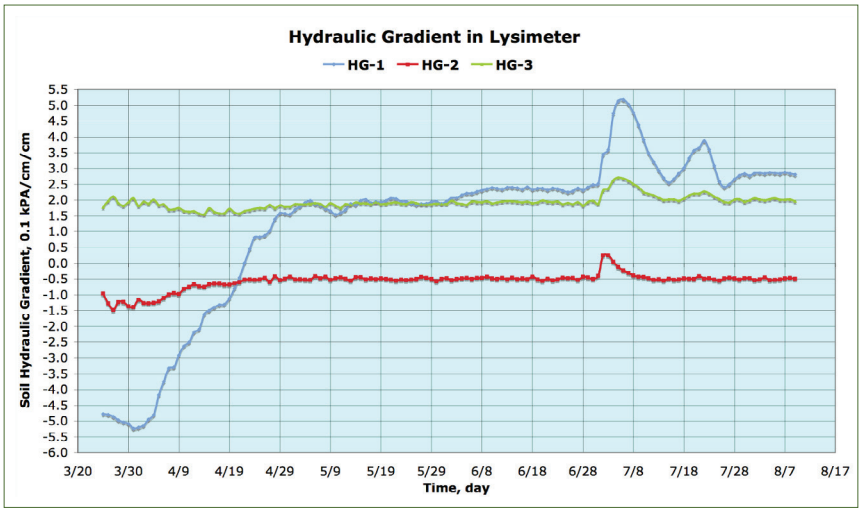

Figure 1. Average hourly hydraulic gradients calculated using soil water matric potential sensors in the lysimeter.

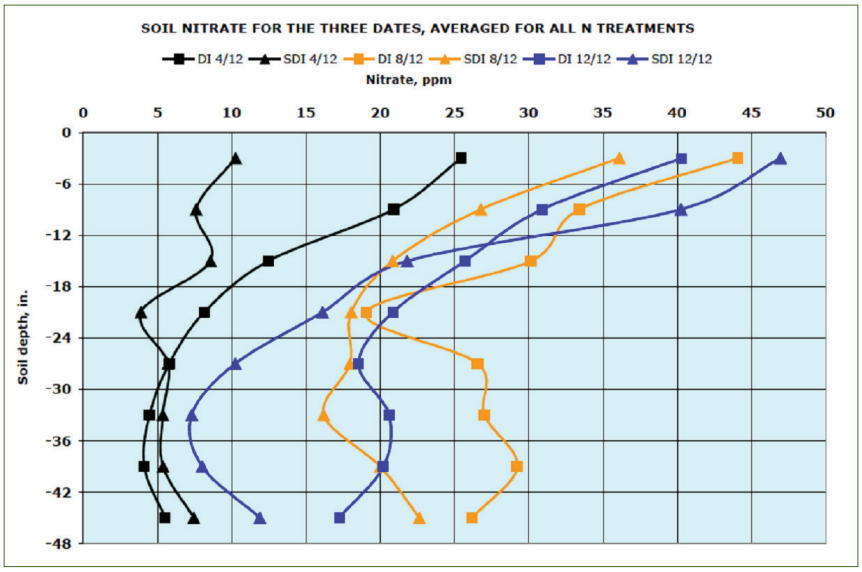

Figure 2. Soil nitrate (NO3) measured every 6-in. from the soil surface down to 48-in depth on 4/12, 8/12 and 12/12. In this graph, these measurements were averaged for all N treatments.

Circumferences were converted to diameters. Results are shown in **Table 4** and indicate significant size increases for the SDI over the DI irrigated trees.

The data show a positive response in both the circumference of the canopy and the height of the trees. This suggests that SDI will develop bigger trees earlier than DI and will shorten the time to reach profitability.

Table 4. Effect of irrigation method and seasonal N-level on tree circumference (measured at 5 feet) and tree height in early June 2013. Circumferences were converted to diameters.

Treatment Effects	Tree Diameter (feet)	Tree Height (feet)
Irrigation method: (IM)		
Surface drip	6.08 b	8.41 b
Sub-surface drip	6.74 a	9.00 a
Prob. > 'F' value:	0.001	0.004
Nitrogen level: (N)		
46 lbs/Ac	6.54 a	8.65 a
148 lbs/Ac	6.33 a	8.55 a
249 lbs/Ac	6.35 a	8.91 a
Prob. > 'F' value:	0.80	0.63

Photo of harvested prime pomegranate, October 2012.

PRELIMINARY FINDINGS

Preliminary results have demonstrated that the high frequency SDI compared to high frequency DI has the potential to provide: significantly higher prime fruit yield of pomegranate; greater WUE and NUE; larger trees; lower potential for NO_3-N leaching; lower N_2O emissions; and improved orchard access for maintenance equipment and weed control (data not shown).

Preliminary findings were presented at the UCCE Pomegranate Field Day on 8/21 to approximately 70 growers, UCCE advisors and irrigation industry representatives.

Preliminary findings were presented at the FREP Conference, October 2012. A field day is planned for October 7, 2013 at the KARE research site.

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ACKNOWLEDGEMENTS

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SDI+ - Consulting Time & equipment

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

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INTRODUCTION

Optimal fertilization practice can only be developed if knowledge of the 4 R's (right source, right rate, right place, and right time) are explicitly developed for the almond production context. To optimize nutrient use efficiency in fertigated almond it is essential that fertilizers injected into irrigation systems are provided at the optimal concentration and time to ensure that deposition patterns coincide with maximal root nutrient uptake. This project has been designed to provide critical information about root physiology and phenology and the interaction with soil nutrients and fertigation practices. Results from the different treatments indicate that root physiology is dependent on current soil nutrient status as well as current plant nutrient status. In addition, different fertigation practices showed that applying the same amount of fertilizers and reducing its concentration may be a viable fertigation management strategy to increase efficiency and reduce groundwater contamination.

OBJECTIVES

1. Determine almond root growth and phenology and characterize root distribution and nutrient uptake activity as influenced by tree nitrogen status, irrigation source, yield and plant characteristics.
2. Determine the patterns and biological dynamics (Km, Vmax, Cmin/max) of tree nitrogen uptake and the relationship to tree demand and phenology.
3. Integrate root phenology and uptake data into the HYDRUS 2D and DNDC model to help interpret and extend findings to a wider range of soils, irrigation and demand scenarios.
4. Publication and extension of results.

DESCRIPTION

In order to achieve the objectives proposed in this project, two experimental trials have been used contrasting different rates of nitrogen (N), fertigation methods and irrigation methods.

1. Nitrogen Rate Experiment

The trees used in this proposed experiment have been selected from among those currently under investigation in related Board and FREP Projects (Brown/Smart/Sanden/Hopmans). The orchard is a high producing 13 year old Nonpareil/Monterey planting located south of Lost Hills in Kern County. The existing experiments provides preliminary individual tree data on yield, soil and plant water (neutron probe and plant based), plant nutrient status (5 in-season leaf samples), tree nutrient demand (sequential crop estimation and determination), leaf area index and photosynthesis and Et_0. The ongoing project of Brown has already established very clear differences in crop yield and nitrogen demand and represents an ideal field site for this work.

The treatments are described in **Table 1**.

Twenty minirhizotron access tubes were installed in the ongoing experiment to follow root phenology (root flushes, root lifespan, growth, etc.) over multiple seasons under four fertilization regimes. Root images have been taken during the 2012 season on a 2 week basis

Table 1. Treatments utilized in the current project. Selected trees within RCBD with 6 x 15 tree replicates per treatment.

Treatment	N source	N amount (lbs/ac)
A	UAN32	125
B	UAN32	200
C	UAN32	275
D	UAN32	350

and images will be analyzed recording number of roots, color, diameter and length. Analysis of these images will be performed at the end of each season.

In addition, a total of 160 root bags filled with media were installed in the different treatments and N uptake was measured in excised roots. The relationship between the parameters of root N uptake and tree demand will be determined once yield and N content are obtained by leaf and nut sampling at harvest.

2. Fertigation Method Experiment

The effect of fertigation technique (pulsed, continuous, drip, microjet) will be examined in a subset of trees in the same orchard as above (**Table 2**) established in 2011.

In this experiment an additional 20 minirhizotron access tubes were installed in order to determine root phenology (root flushes, root lifespan, growth, etc.). Root images have been taken during the 2012 season on a 2 week basis and images will be analyzed recording number of roots, color, diameter and length. Analysis of these images will be done at the end of each season.

In addition, 80 soil solution access tubes (SSAT, a.k.a. "lysimeters") have been installed in each treatment at 2 depths (150 and 250 cm) in order to measure nitrate (NO3) leaching and transport through the soil profile throughout the season.

Individual trees have been analyzed for leaf nutrient analysis, yield, nut size and crackout percentage and contrasted among treatments (see results section).

RESULTS AND DISCUSSION

1. Nitrate Uptake by Roots

Results from 2013 samples are still in progress, since the amount of sampling was doubled, and the concentration range was increased to more realistic conditions (i.e. actual NO_3 soil solution concentration). Preliminary results from below belong to 2012 data, and some of the other findings will be explained based on these parameters. Fine roots from each treatment in experiment 1, were isolated, excised and then incubated in solutions of different NO_3 concentration for 30 minutes. The external concentration (i.e. soil solution concentration) ranged from 0.42 to 14.01 ppm of NO_3. According to literature, root uptake of fine roots will depend mostly on the concentration of the external solution as well as the demand of NO_3 by the plant (i.e. plant N status). Preliminary results from this experiment are shown in **Figure 1**. When roots where incubated in solutions from a low range concentration (0.42 to 3.50 ppm of NO_3), all of the treatments showed an increase in uptake followed by a saturation at the end of this range; however, low N treatments exhibited a higher uptake capacity than the high N treatments. This result suggests that N starved trees can up-regulate N uptake and can access N from lower NO_3 concentrations than trees with sufficient N content. Trees with high N application showed a low capacity to absorb NO_3 and at the lowest NO_3 concentration (0.42 ppm) they lost NO_3 from the roots system to the solution. At high NO_3 concentration ranges (7.01 to 14.01 ppm of NO_3) however, low N trees exhibited lower uptake capacity than high N status trees.

2. Fertigation Method

The objective of this experiment is to determine the best fertigation practice for almonds orchards, and will contrast standard grower practice (4 fertigation events) with fertigation applied in each irrigation event. The most important goal is to reduce the contamination of groundwater with pollutants (NO_3) without reducing crop performance.

Preliminary results from soil solution extraction at different soil depths are shown in **Figures 2 and 3**. In 2013, the methodology was changed in order to get more reliable data. Deeper tubes (150 and 250 cm) were installed in order to monitor the potential leaching of each treatment. Graphs represent the maximal N-NO_3 concentration measured over the season. Nitrate concentration at 250 cm, are higher than shallower depths, probably because root activity at depths greater than 150 cm the root activity is low and the only fate of the nitrate is to leach through the soil profile, producing a cumulative effect on deep soil profile. Regarding treatments effects on NO_3 leaching, even though no significant differences are observed (mostly due to high variability within the treatments), it seem that standard fertilization practices yielded less NO_3 concentration than the continuous treatments (**Figure 3**) at deeper soil profile, presumably because the lower NO_3 concentration that continuous treatments receive in each fertigation event, that may have influence on the root uptake (see **Figure 1**). In addition, NO_3 uptake may be also influenced by the demand of

Table 2. Fertigation treatments in the ongoing project. Selected trees within RCBD with 4 x 7 tree replicates per treatment.

Treatment	N source	K source	Irrigation method	Fertilization method
E	100% UAN32	100% SOP	Fanjet	4 fertigation events / year
F	100% UAN32	60% SOP/ 40% KTS	Fanjet	Continuous (fertilization in each irrigation)
G	100% UAN32	100% SOP	Drip	4 fertigation events / year
H	100% UAN32	100% SOP	Drip	4 fertigation events / year

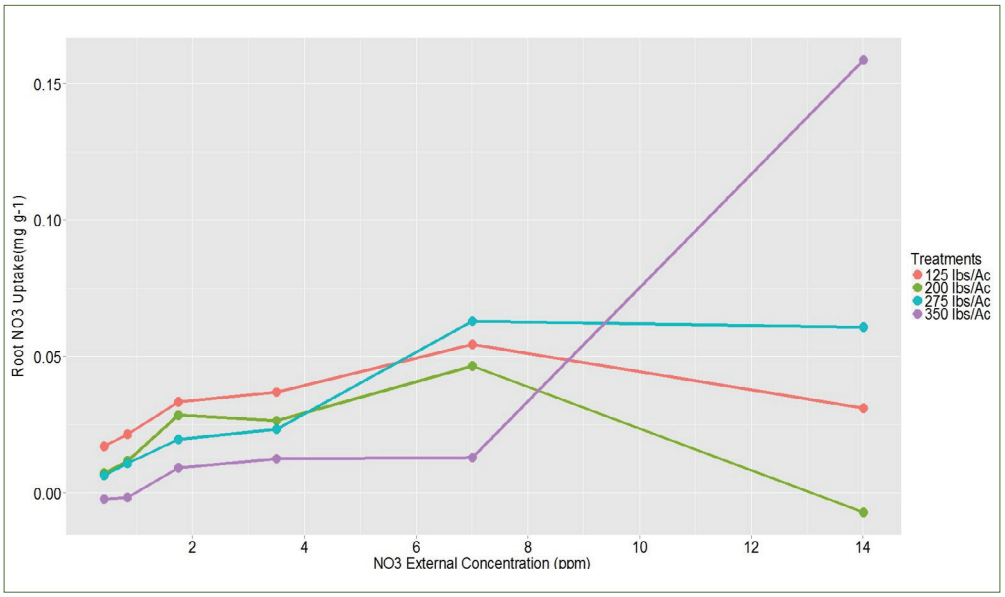

Figure 1. N-NO_3 uptake of almond roots at different N-NO_3 external concentrations.

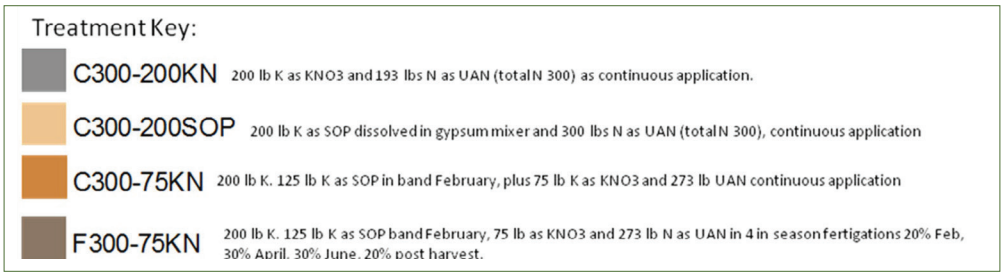

Figure 2. Treatment key for fertigation experiment

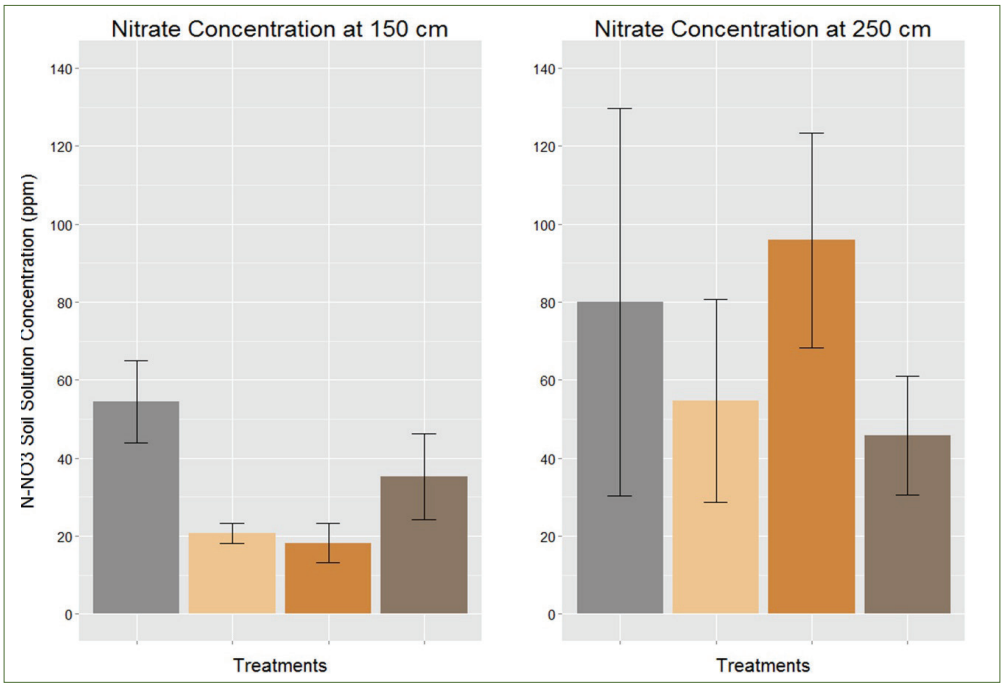

Figure 3. Soil solution N-NO_3 concentration (ppm) at 150 and 250 cm respectively from soil surface.

the tree, therefore, the constant supply of NO_3 to the roots in continuous treatments, alter N dynamics in the soil. However there is a critical interaction of soil water content that must be further resolved before the results can be properly interpreted. In order to compensate for the soil water content, tensiometers have been installed at 220 and 250 cm to calculate soil water flux and to estimate the potential leaching of each treatment. In addition, soil water content will be measured in order to estimate the NO_3 content (rather than concentration).

Preliminary results from the minirhizotron installed in this experiment are shown in **Figure 4**, showing the root growth distribution by soil depth. Most of the roots observed were in the upper 40 cm soil profile, with almost 75% and 60% for the continuous and the standard practice respectively. More quantitative analysis has yet to be performed, including root lifespan, root seasonal dynamics (root emergence and persistence) in order to determine the right timing for nutrient application and plant response to fertigation events.

In terms of productive parameters (yield and nut size), results from last season (second year of the experiment) did not show significant effect of the treatments (**Table 3**). It has to be noted that yields in the entire orchard were significantly lower than previous years, and contrary to previous year yields, continuous treatments yielded higher than standard practices. It is not possible to determine if this change in yield was produced because of treatment's effects or alternate bearing.

Similarly, leaf nutrient status in mid-summer did not show any treatment effect (**Figure 5**), with the exception of leaf K concentration that was significantly lower in the standard nutrient application practice. Potassium concentration in the zero K treatment is even lower than the critical values recommended for almond trees.

ACKNOWLEDGEMENTS

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Paramount Farming Company

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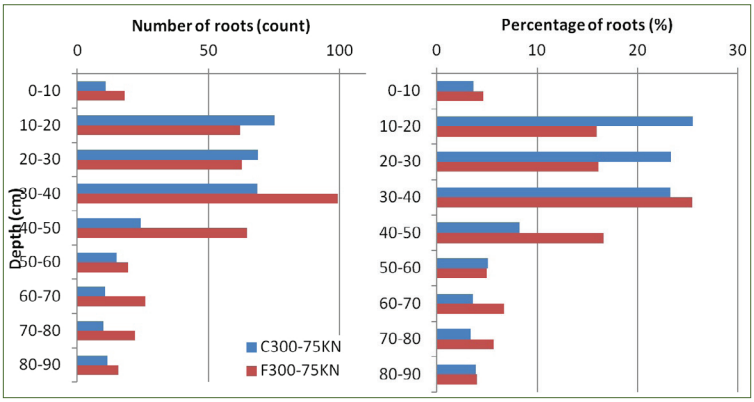

Figure 4. Vertical distributions of roots in soil depth intervals.

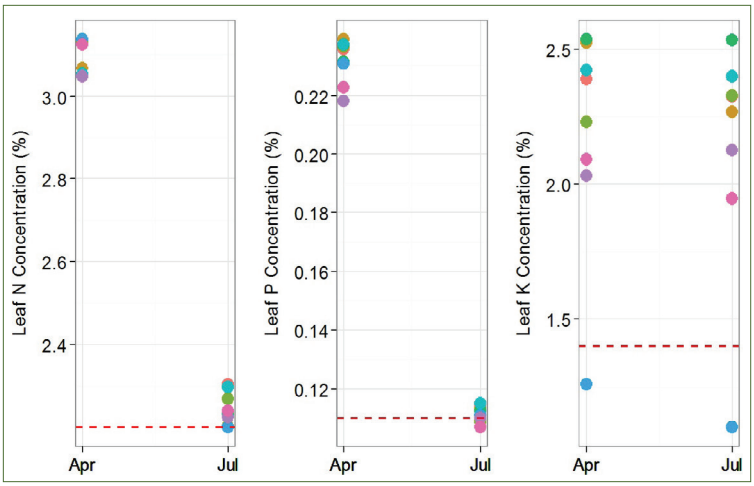

Figure 5. Effect of fertigation practices on mid-summer leaf nutrients. Dashed line shows the recommended critical value for almond trees.

Table 3. Effect of fertigation practices on almond yield and nut size.

Treatments	Yield (lbs/Ac)	Weight/100 Almonds (g)
F300-75KN *	1072.9 a	142.2 a
F300-75KTS	1060.1 a	145.1 a
F300-0K	973.1 a	142.3 a
C300-200SOP *	1192.8 a	144.1 a
C300-75KN *	1275.4 a	140.0 a
C300-150KCL150KN	1194.3 a	142.0 a
C300-200KN *	1224.0 a	141.2 a
C300-300KN	1317.9 a	139.3 a

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

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INTRODUCTION

Nitrous oxide (N_2O) contributes about one third of the total greenhouse gas (GHG) emissions from California's agriculture sector (California Air Resources Board, 2011). With the passage of the Global Warming Solutions Act (Assembly Bill 32), quantifying N_2O emission from different cropping systems is a prerequisite to address the mandated reduction in GHG emissions by 2020 and develop effective mitigation practices and strategies. To date, N_2O emissions in California cropping systems have been assessed in multi-year studies in tomato, wheat, lettuce, alfalfa, almond, and vineyards. Among California's field crops, corn has the largest acreage (610,000 acres). However, missing is a systematic, controlled investigation on the effect of N fertilizer levels on N_2O emissions in irrigated corn production in California.

Nitrous oxide (N_2O) is produced in soil by microorganisms that use inorganic, or mineral, forms of nitrogen (N). Nitrous oxide is generated mainly under oxygen limitation as by-product of nitrification [conversion of ammonium (NH_4^+) to nitrate (NO_3^-)] and denitrification [conversion of NO_3^- to atmospheric nitrogen (N_2)](Zhu et al. 2013). The production of N_2O, therefore, depends on the availability N in mineral form in the soil, as well as on available carbon, moisture, and oxygen concentration. Soil water content and porosity are the main factors controlling the transport in the soil and release of N_2O to the atmosphere. Meta-analyses based on over 1000 studies found that fertilizer nitrogen (N) application rates have significant effects on N_2O emissions (Bouwman et al. 2002; Eichner 1990; Stehfest and Bouwman 2006). Moreover, studies in other regions found that N_2O emissions increase sharply in response to N additions that exceed crop N needs (Edis et al. 2008; McSwiney and Robertson 2005; Van Groenigen et al. 2010). Presently, there are few N fertilization guidelines for corn production in California (Daniel Geisseler, personal communication). Thus, data on both N fertilizer use by the crop and N_2O emissions are needed. The present study takes a systems approach evaluating N_2O emissions, crop performance, N use efficiency, and potential environmental impacts with various levels of N fertilizer applications. The over-arching goal is to develop best management practices that minimize N_2O emissions without sacrificing corn yield potential.

OBJECTIVES

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

DESCRIPTION

A N rate trial will be conducted for two seasons in a grower field in San Joaquin County. The start of the project was in spring 2013. In early May, the corn crop was fertilized with 3, 134, 221, 265, or 337 kg N ha^{-1} as urea ammonium-nitrate (UAN32). The N_2O flux measurements are made by placing chambers in the field and collecting air samples from the chambers at timed intervals.

The air samples are analyzed by gas chromatography. The N_2O fluxes are calculated, using ideal gas relations, from the change in N_2O concentrations over time, chamber air temperature, chamber volume and area covered by the chamber.

Figure 1. Gas flux measurement chamber.

We will calculate annual N_2O emissions by assuming that the measured fluxes represent mean daily fluxes, and that mean daily fluxes change linearly between measurements. Differences between treatments will be assessed using analysis of variance and standard mean separation procedures.

Once the yields and the total N in grain have been measured, the yield-scaled N_2O emissions (N_2O-N divided by grain-N per unit area) will be calculated. The emission factors will be calculated as the amount of N_2O-N divided the amount of fertilizer N applied (per unit area). Apparent N use efficiency will be calculated as grain N content divided by applied fertilizer N (per unit area), taking pre-plant and post-harvest inorganic N levels into account. The economic N yield will be defined as the least amount of fertilizer N necessary to obtain the highest economic return at this site.

Ancillary measurements of soil moisture and temperature, as well as inorganic N levels will be used to characterize the environmental factors that control N_2O emissions.

Figure 2. Smaller gas flux chambers are used in the furrows.

PRELIMINARY FINDINGS

The daily N_2O fluxes were measured on the beds, the shoulders of the beds, and the furrows (**Figures 3-5**). In general, the fluxes were higher on the beds and shoulders than the furrows. The N fertilizer bands were in the bed and shoulder locations. The highest N_2O fluxes were observed within the first three weeks after the N fertilizer application.

Analysis of the data is still in progress. The experiment will be repeated next year at the same location.

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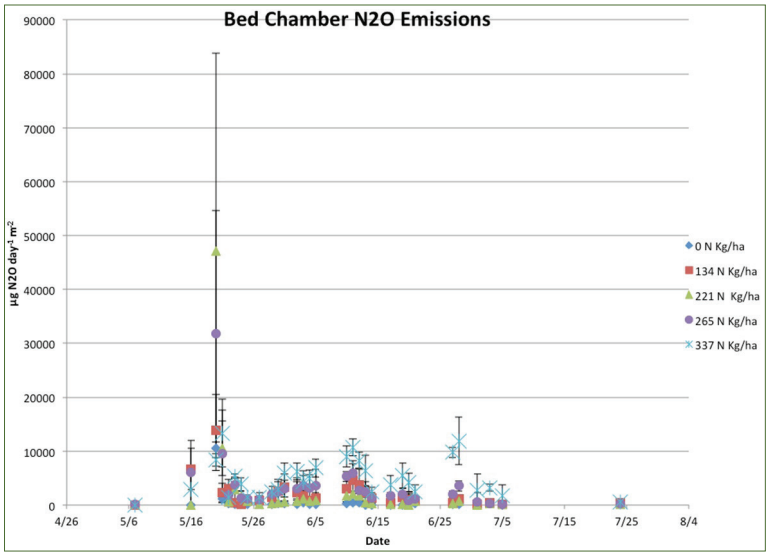

Figure 3. Mean daily N_2O fluxes in the bed position of the corn field. Standard errors shown as line bars. n=3

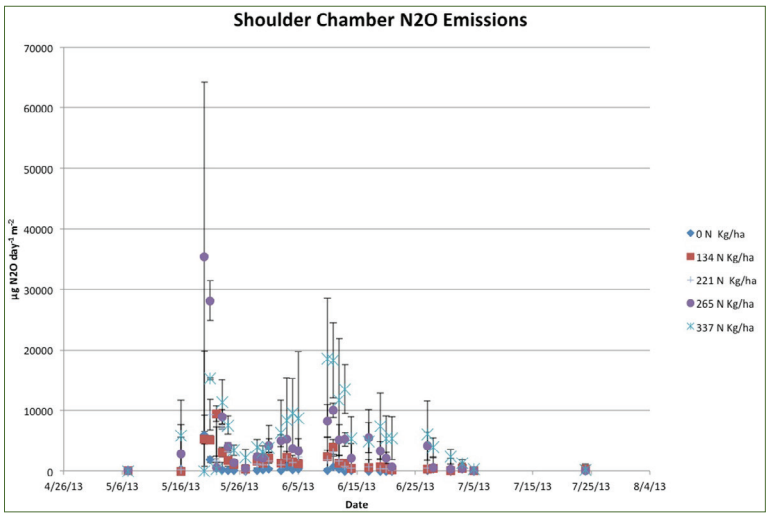

Figure 4. Mean daily N_2O fluxes in the shoulder position of the corn field. Standard errors shown as line bars. n=3.

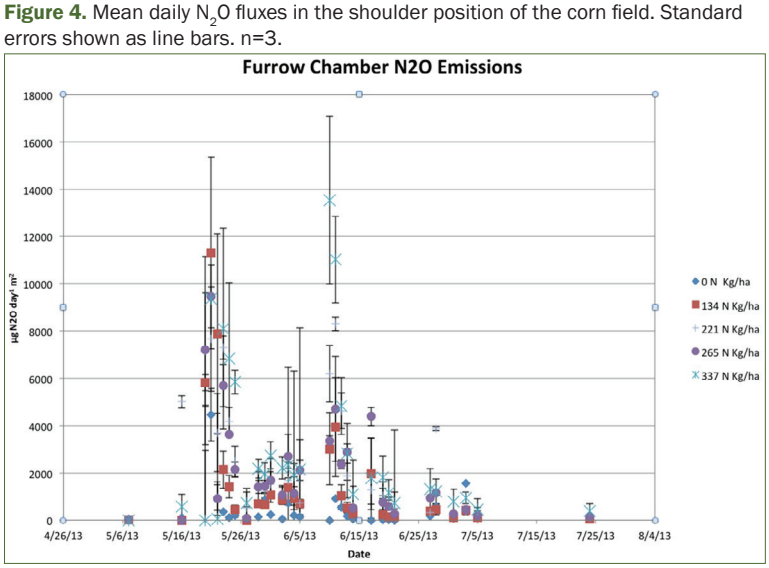

Figure 5. Mean daily N_2O fluxes in the shoulder position of the corn field. Standard errors shown as line bars. n=3.

Determining the Fertilizer Value of Ambient Nitrogen in Irrigation Water

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INTRODUCTION

Irrigation water from many wells on the central coast contain 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. 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. This project will develop information and guidelines for utilizing ambient N in irrigation water for lettuce and broccoli, the primary crops in this region. A total of 5 replicated field trials will be conducted in the Salinas Valley from 2013-15. Three trials will focus on determining the efficiency of lettuce and broccoli to recover N from irrigation water, as affected by concentration and irrigation efficiency. The remaining trials will examine the practical contribution of irrigation water N to crop fertility under a range of typical irrigation and N fertigation regimes. This project will have a strong outreach component, including newsletter and trade journal articles, oral presentations, and online resources. We will add an algorithm for calculating the fertilizer value of NO_3/NH_4 in irrigation water to the online irrigation and N management tool, CropManage, as well as a downloadable spreadsheet tool for making similar calculations.

OBJECTIVES

1. Document broccoli and lettuce N uptake and N recovery efficiency (NRE) of irrigation water N over the range of 2 - 42 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

Field trials (a spring and a summer crop) were conducted on the USDA Spence Road research facility near Salinas in 2013 to address objective 1 for lettuce during the first year of the project. The irrigation water available at this facility contains approximately 2 PPM NO_3-N. Before planting, fields were sprinkler irrigated to leach residual NO_3-N so that each trial was conducted with low background soil N. The experimental design for each trial was a randomized complete block, with four replications. Crisphead lettuce was direct seeded in 2 rows on 40-inch wide beds and germinated and established using overhead sprinklers. After thinning plants to a final stand, the field was subsequently irrigated with surface placed drip tape. Lettuce growth and N uptake were compared across a range of treatments simulating different levels of ambient N in irrigation water during the drip phase of the crop. Nitrogen treatments ranged from 2 to 42 ppm NO_3-N and were compared to an unfertilized control and a fertilized standard treatment (seasonal total of 150 lb N applied in weekly fertigations). In addition, we included a treatment to evaluate crop N recovery from water

dominated by NH_4-N. To observe the interaction of irrigation efficiency and crop nitrogen recovery, each N treatment was evaluated at two levels of drip irrigation [110% and 170% of crop evapotranspiration (ET)]. Water-powered proportional injectors were used to enrich all drip applied water to the target concentrations of treatments (**Figure 1**). Injected NO_3-N was a blend of $Ca(NO_3)_2$ and $NaNO_3$ to maintain the cation balance in the water. Injected NH_4-N was in the form of NH_4SO_4. An emitter inserted into the drip lines collected a composite water sample from each N treatment to confirm that target N concentrations were attained. The fertilized control received N in the form of AN-20.

Data Collection

Canopy cover of the treatments were estimated using a near-infra-red digital camera at weekly intervals. Flow meters were used to determine the volume of water applied to the 110% and 170% ET treatments. In both trials soil samples were collected at 0-1 ft, 1-2ft and 2-3 ft depth prior to the initiation of N treatments, and at harvest; field-moist samples were extracted in 2 N KCl and analyzed for NH_4-N and NO_3-N to document the pattern of mineral N movement. All plots were harvested when the fertilized control treatment reached commercial maturity. Plant above-ground fresh and dry weight, and biomass N content, were determined.

Data Analysis

N recovery from irrigation water N will be calculated by subtracting the crop biomass N of the unfertilized control from the biomass N of each treatment receiving N in irrigation water. Nitrogen recovery efficiency (NRE) of each irrigation N × irrigation volume combination will be calculated by comparing the uptake of irrigation water N to the total amount of N applied to the crop through the irrigation water:

$$NRE\ (\%) = [(BiomassN_i - BiomassN_0)/waterN_i]\times 100$$

where $BiomassN_i$ is the N (lb/acre) in the crop biomass of treatment *i*, $BiomassN_0$ is the N in the biomass of the background water treatment (0 N added), and $waterN_i$ is the total N applied to the crop through the irrigation water treatment *i*.

PRELIMINARY FINDINGS

Results of the first 2 field trials for lettuce are still being analyzed, but will be reported at the annual Irrigation and Nutrient Meeting held in Salinas in February 2014. Preliminary results from the first trial showed a strong relationship between N concentration of the irrigation water and biomass yield, suggesting that a significant portion of the background levels of N in the irrigation water taken up by the crop. Analysis of the water collected after each irrigation demonstrated that we could simulate waters with consistent concentrations of NO_3 and NH_4.

ACKNOWLEDGEMENTS

We thank Laura Murphy, Thomas Lockhart, and Barry Farrara of UCCE Monterey, and Sharon Benzen and David Lara of the USDA-ARS for conducting the field trials described in this project.

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

Adjustable-Rate Fertigation for Site-Specific Management to Improve Fertilizer Use Efficiency

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INTRODUCTION

Uniform application of dissolved fertilizer within large irrigation zones of commercial nurseries may over-fertilize some plants since the fertilizer requirement is based on those with the greatest need. Similar problems exist with many other specialty crops. By decreasing the size of the irrigation/fertigation zones and separating plants based on water and nutrient needs, site-specific fertigation can limit fertilizer waste and loss to the environment, but cannot be easily implemented when there are many small hydrozones each demanding a unique rate of fertilizer application. It is possible to deliver different fertilizer rates to simultaneously-operating zones, but it is complicated (Coates et al., 2012). Zones can be fertigated with different amounts of fertilizer by using different durations of fixed-rate fertilizer injection for each zone, but more effective control of fertilizer application could be achieved by automatic adjustment of the injection rate for each zone. The ability to automatically vary the rate of injection will provide greater flexibility to deliver fertilizer to multiple zones. With a simple and inexpensive injection system, a separate injector could be installed at each zone to provide a unique fertilizer delivery rate. Integration with a wireless control network would allow automated adjustment of the fertilizer delivery rate for each hydrozone.

In this project, we developed simple technology to allow adjustable-rate fertilizer injection, which was integrated with a wireless control network. Our overall goal was to improve fertilizer use efficiency through site-specific fertigation.

OBJECTIVES

1. Develop a simple fertilizer injection system to give adjustable-rate fertigation.
2. Integrate the injector with the wireless irrigation control system to give automated, adjustable-rate fertigation for nurseries.

DESCRIPTION

A variable-rate injector was developed using a simple venturi injector, solenoid valve, electrical conductivity (EC) sensor, and small computer board (controller). Fertilizer injection rate was controlled by pulsing a solenoid valve connected to the suction line of the venturi injector. The rate was adjusted by changing the valve duty cycle (percentage of time that the valve was open). Increasing the duty cycle allowed more fertilizer stock solution into the injector. Decreasing the duty cycle allowed less fertilizer into the injector. For a 2000 ppm nitrogen (N) stock solution, it was shown that the duty cycle could be adjusted from 0 to 100% to deliver an applied fertilizer concentration of 0 to 200 ppm N. A mobile injector station was assembled and integrated with a new wireless sensor and control network in order to test adjustable-rate fertigation in container nurseries. The fertilizer concentrations matched that specified by the user, indicating that the system did a good job of adjusting the duty cycle to meet the target rate, and the irrigation and fertilizer injection durations were correct. Furthermore, the wireless network performed well and exhibited good range. In coordination with another project, a wireless sensor and control network was installed at two container nurseries to control irrigation to

individual beds of plants based on real-time soil moisture measurements. Overall, wireless sensor and control networks coupled with adjustable-rate injection systems provide valuable tools for growers to implement site-specific techniques that optimize water and fertilizer use.

RESULTS AND DISCUSSION

Injection System Design

Our system consisted of a 384 gal/hour venturi injector. It was plumbed in parallel with a main-line flow control valve that could be adjusted to achieve an adequate pressure differential across the venturi. A two-way, normally closed solenoid valve with an orifice diameter of 3/32" was on the suction line of the venturi. The EC sensor was connected to the outlet of the main-line and injector lines and a had working range of 0 to 10 mS/cm. We tapped into the circuitry of the EC sensor to gain access to an analog signal, which was measured by the controller. The EC sensor was calibrated with standards mixed from 20-20-20 fertilizer in distilled water and tap water, from 0 to about 2000 ppm N. Tap water at UC Davis has a background EC of about 0.53 mS/cm, which shifted the calibration curve up by an equivalent amount. EC measurements were converted to nitrogen concentration using a calibration equation that accounted for the background EC measured before each injection sequence.

Tests were completed using the first prototype with a 2000 ppm N stock solution to examine the potential of the system to control the downstream fertilizer concentration. The first tests were done by pulsing the suction line valve at 1 Hz with duty cycles of 0, 13, 27, 39, 50, 61, 72, 86, and 100%. (A duty cycle of 0% means the valve is always off, and 100% means the valve is always on.) Average EC was measured during injection using the inline sensor and was compared with the EC of a water sample collected from the downstream emitters, measured using a bench-top EC meter. The injector ratio was calculated to be about 1:10. Therefore, with a 2000 ppm N stock solution, the fertilizer solution was expected to be 200 ppm N at 100% duty cycle and a fraction of this at lower duty cycles (e.g., 100 ppm at 50% duty cycle).

Average nitrogen concentration measured with the inline sensor, expected nitrogen concentration based on the duty cycle, and nitrogen concentration of the sample collected at the emitter for duty cycles from 0% to 100% were compared. Both the inline EC and sample EC measurements resulted in higher than expected nitrogen concentrations, although the trend showed that fertilizer concentration was proportional to the duty cycle of the suction valve. We expected that automatic control of the duty cycle based on real-time EC measurements would improve the accuracy of injection.

Controlled Injection

Automatic adjustment of the suction valve duty cycle was implemented with an embedded controller. The controller was a small computer board that was programmed to measure the EC sensor signal and output a pulse signal with variable duty cycle. The LCD screen prompted the user to enter the target fertilizer rate as parts-per-million nitrogen. The user then pressed a button to begin the injection sequence. The controller first monitored the background EC of water through the main-line. The user then partially or fully closed the main-line and opened the valves to the injector lines. The controller estimated the starting duty cycle and started to pulse the suction line valve open and closed. During operation, the EC was continually monitored and a running average of the EC signal was calculated. EC was converted to nitrogen concentration and compared with the target concentration. The valve duty cycle was automatically decreased if the measured concentration was too high and increased if the measured concentration was too low.

The final design (**Figure 1**) included solenoid valves to control the flow of water through the main-line and venturi injector. A wireless node passed irrigation and fertigation control parameters to the controller. A manual gate valve provided the ability to adjust the pressure drop across the venturi.

If injected fertilizer concentration changed due to pressure changes across the venturi injector, poor stock mixing, or other conditions, the controller automatically adjusted the duty cycle to compensate. **Figure 2** shows the target nitrogen concentration and the nitrogen concentration of the sample collected at the emitter for target concentrations between 0 and 200 ppm N. The controller did well at applying fertilizer at the target rate.

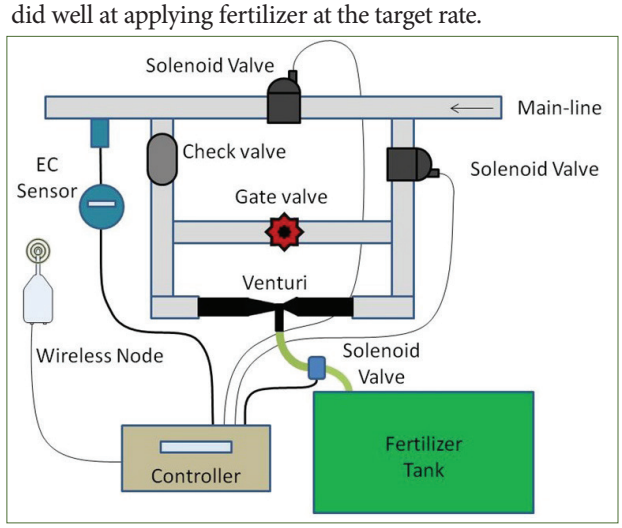

Figure 1. Diagram of the variable-rate injector using venturi, solenoid valves, electrical conductivity sensor, injection controller, and wireless node.

Wireless Control and Field Testing

In our previous FREP project we developed an experimental wireless network for site-specific irrigation and fertigation (Coates and Delwiche, 2009). Wireless nodes eliminate the need for wired valves, thus allowing simpler installation and management of small hydrozones. In coordination with another project, a wireless sensor and control network was installed at two container nurseries to control irrigation to individual beds of plants based on real-time soil moisture measurements (Delwiche, 2012). Water use was reduced by 35% with automated irrigation in one nursery, but increased in a second nursery. A modified control methodology, such as mid-season threshold adjustments by the grower, could have reduced water use in the second nursery. Measurements of leachate showed that automated control reduced runoff containing fertilizer by 23% or more compared to grower controlled beds in nursery 1 and 60% or more in nursery 2.

We also developed strategies that can be implemented for site-specific fertigation in a variety of applications (Delwiche et al., 2009; Coates et al., 2012). Separate, fixed-location injectors located at each hydrozone would allow a different rate of fertilizer injection to each zone, even while operating simultaneously (**Figure 3**). Alternatively, a single injector that serves multiple hydrozones, each with a control valve, could automatically adjust the injection rate for each zone.

Fertigation was tested with a mobile injector, moved between different locations, simulating the strategy of separate, fixed-location injectors. The injector was programmed to complete a single injection sequence based on the parameters in **Table 1**. Some values (i.e., T_PWM, Intgr_EC) were technical in nature and could be left at default values. Once parameters were received by the controller, a fertilizer injection sequence was begun. First, water was applied for 20 seconds and measurement

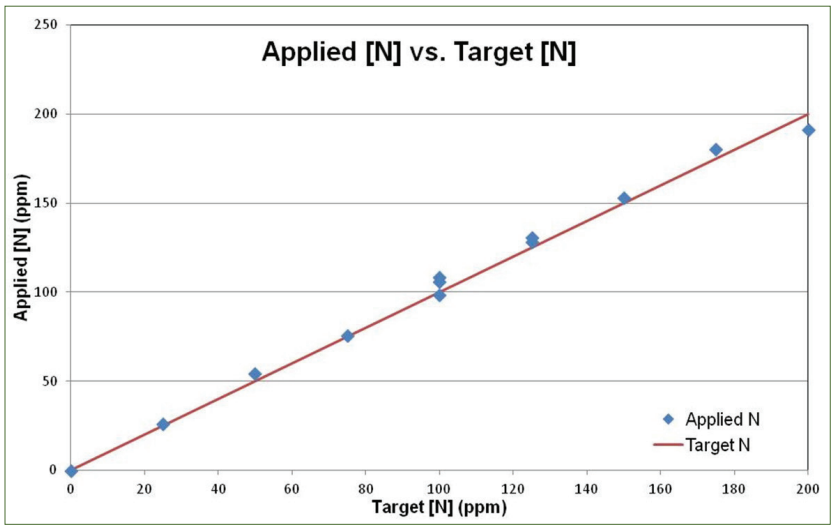

Figure 2. Target and measured nitrogen concentrations of fertilizer solutions delivered by automatic control of duty cycle to venturi suction valve.

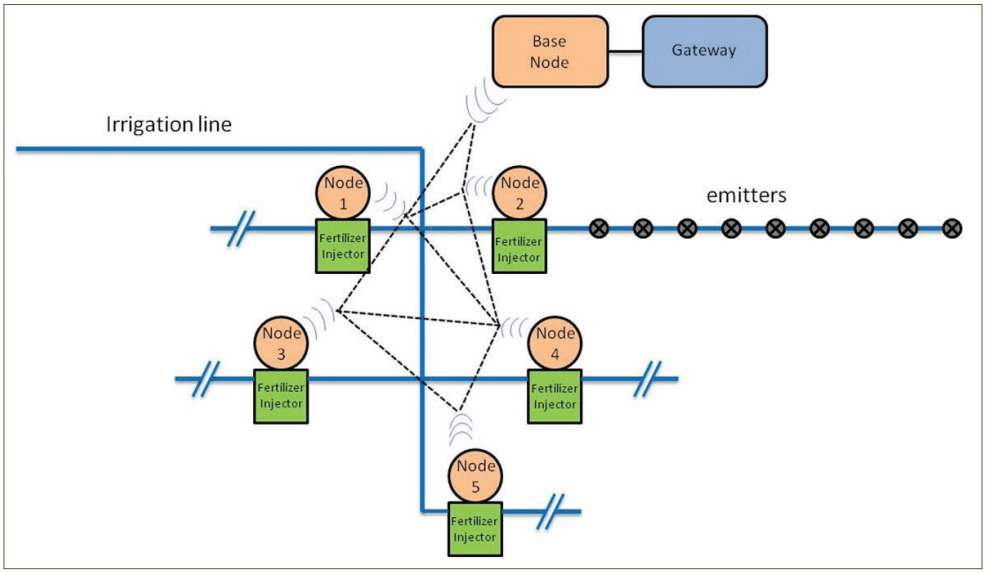

Figure 3. Wireless network for controlled fertigation.

Table 1. Parameters entered by user or sent by wireless radio to fertigation controller.

Parameter	Description	Units	Default value
T_PWM	Suction valve pulse period	millisecond	1000
Intgr_EC	T_PWM periods to integrate EC	(none)	5
Stock_N	Stock solution fertilizer concentration	ppm nitrogen	2000
Target_N	Target fertilizer concentration	ppm nitrogen	100
Prewater	Irrigation duration before injection	minute	1
Fertigation	Fertilizer injection duration	minute	2
Postwater	Irrigation duration after injection	minute	1

of the background EC was made. Then, water was applied for the 'Prewater' duration. Fertilizer injection began with a suction valve duty cycle that was estimated based on the target fertilizer rate. The duty cycle was then automatically adjusted by the controller in response to feedback from the EC meter. The target fertilizer rate was typically reached in about 30 seconds and then held stable for the duration of injection. Further improvements in the control algorithm could decrease the time to stabilization. Last, water was applied to flush the lines for the 'Postwater' duration.

The mobile fertilizer injection station was used to inject fertilizer in a commercial nursery (**Figure 4**). Quick connect fittings were used on the grower lines to allow the injector to be connected or disconnected easily from each point of injection. The injector was connected to a bed of plants in the nursery. A mobile phone was used to access a fertigation control web page on the gateway and start injection of 20-20-20 fertilizer for 2 minutes with a target nitrogen rate of 100 ppm. Irrigation and fertigation timing were monitored to ensure correct operation and a water sample was collected from the microsprayers during fertilizer injection to verify the fertilizer concentration (calculated based on EC measurement with a separate meter). The mobile injector was moved to several different beds of plants and injection was started using different fertilizer injection rates. The fertilizer concentrations matched that specified by the user, indicating that the system did a good job of adjusting the duty cycle to meet the target rate, and the irrigation and fertilizer injection durations were correct. Furthermore, the wireless network performed well and exhibited good range.

ACCOMPLISHMENTS

By providing a means to automatically control the amount of fertilizer delivered to different fertigation zones, this technology reduces waste and promotes the environmentally safe and agronomically sound use of fertilizing materials.

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Figure 4. Fertilizer injector connected to a bed of nursery plants.

Fertigation Education for the San Joaquin Valley

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IN COLLABORATION WITH

USDA – National Resource Conservation Service (NRCS)
Reason for support: NRCS has special incentive programs and interest in helping small and large scale farmers implement proper technologies and applications of chemicals and fertilizers. Many small farmers in the San Joaquin valley lack access to proper technologies and education. NRCS works with them to identify and help them become more efficient and improve their proper practices. This program would further support NRCS goals and programs.

INTRODUCTION

A major issue facing the San Joaquin Valley and other areas of California is nitrate and fertilizer contamination of groundwater and water sources that supply agricultural irrigation. This educational grant, "Fertigation Education for the San Joaquin Valley" specifically highlights the proper application methods and equipment for the injection of fertilizers through the irrigation system. A combination of power point presentation, written materials, and a live dynamic fertigation equipment demonstration are utilized to deliver the message of safe and effective fertigation practices.

Some key aspects highlighted in the educational message are:

1. A discussion of the issues regarding nitrate contamination in groundwater in California.
2. The importance of good irrigation system performance to achieve high Distribution Uniformity of the irrigation and fertigation event.
3. How nutrients move in the soil and how to design a Nutrient Management Plan (NMP) for your farm.
4. A discussion and demonstration of pumps, drip irrigation system components, and fertigation injection equipment that will assure a safe and effective application of fertilizers.
5. Handouts and workshops translated to Spanish, Hmong, and Punjabi to reach a broader audience demographic of farmers employing fertigation practices.

OBJECTIVES

The primary objective of this program was to:

1. Reduce fertigation pollution of drinking water by farmers. To do so we need to change the cultural practices of the growers.
2. A secondary objective is to educate the under-served Hmong, Punjabi and Latino speaking farmers/growers about state rules, regulations, proper management and design so as not to contribute to the problem of farmers contaminating drinking water sources.
3. The CIT goal is that 75% or more of the attendees learn or gain some knowledge about proper fertigation practices and irrigation scheduling to minimize leaching and at least 25% of them will implement changes on their farms as a result of attending the workshops.

DESCRIPTION

The main objective of this program was to change the fertigation practices of small and under-served farms in the San Joaquin Valley. A result of this is the alleviation of fertilizer pollution of drinking water and water sources. To do so, CIT planned to reach 300 attendees on the proper fertigation application, best management practices and regulations. The workshops were geared towards small farms such as the ones owned by the Hmong, Punjabi and Hispanic farmers which are typically under-served.

CIT hosted eight events over one year. The center worked with supporters and collaborators such as NRCS and CAPCA to schedule events. At least three of the events were geared specifically for under-served farmers. CIT provided informational packages for attendees in their specific languages. The events had live demonstrations and on-farm activities along with presentations.

The center worked with local NRCS to reach out to their audience and present at events. CIT worked with NRCS to identify key audiences and locations throughout the San Joaquin Valley. NRCS assisted CIT in curriculum development based on the audience.

To assure a successful program, CIT sent out a post survey six months after the event. These surveys were utilized to see if the attendee has made changes after attending the events. The center benchmarked that at least 25% of surveyed attendees will have made some changes or plan on changing their practices after attending an event. After each event, pre and post surveys were used to evaluate learning at each of the events and comments from evaluations were used to adapt and change the curriculum to assure the best learning experience.

RESULTS AND DISCUSSION

The events were geared towards farmers and industry professionals. Before and after each event, participants were surveyed to see if they gained any knowledge during the events. The surveys for the first event were as follows. At the first event, roughly 58% of the attendees answered our surveys. 81% of attendees did not know that agriculture was a major contributor to ground water contamination, especially nitrate contamination. 90% of surveyed attendees did not know that if nitrate were to be used today, it would take over 30 years to see any alleviation of the problem. 63% of participants did not know what equipment they needed for fertigation through a pressurized system.

Due to the fact that this project is still ongoing, many results will not be finalized until the end of the 2013 year. This project has also been expanded due to the related issues that the California Central Coast is experiencing.

ACCOMPLISHMENTS

The Center has currently hosted two events for hard to reach growers, such as the Hmong and South Asian growers. The other events hosted on campus have been well received and there are plans to host events across southern San Joaquin Valley and Northern San Joaquin Valley.

RECOMMENDATIONS

CIT has been recommended to extend the program to Central Coast as well as into the Sacramento Valley. CIT is working with the state water board and NRCS to extend the program into the central coast and Sacramento Valley.

PRELIMINARY FINDINGS

The primary goal of this program was to reach 1000 growers in the San Joaquin Valley within three years. This year's goal is to reach 300 growers. After three events, CIT has reached over 100 growers already. CIT plans to reach the 300 growers by December 2013. The objective of the workshops is to get growers to change their practices. A follow up survey to attendees will be sent out in September to garner feedback from growers whom attended the workshops. These data will be used to determine if farmers where affected by what they learned at the workshops.

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Nitrogen Fertilizer Loading to Groundwater in the Central Valley

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INTRODUCTION

Nitrate is the most common pollutant found in aquifers of the Central Valley, California. This project will provide the first long-term assessment of past and current nitrate loading to groundwater on irrigated lands across the entire Central Valley of California; assess the long-term implications for groundwater quality in the Central Valley (Sacramento Valley, San Joaquin Valley, and Tulare Lake Basin); and provide a planning tool to better understand local and regional groundwater quality response to specific best management practices and policy/regulatory actions. This assessment will contribute significantly to the scientific framework surrounding the implementation of the salt and nutrient basin plan amendment and of the "irrigated lands regulatory program". The core of this project is an extensive field-scale assessment of the historic and current (1940-2010) crop- and irrigation- method specific nitrogen leaching from irrigated lands in the Central Valley. The primary tool for this assessment is a field-scale nitrogen mass balance. Groundwater loading of nitrogen will be determined, in principle, as the closure term to the mass balance, that is, groundwater loading will be assumed to be the difference between field nitrogen applications (from atmospheric, fertilizer, animal, and human sources) and field nitrogen removal (harvest removal, atmospheric losses).

OBJECTIVES

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

DESCRIPTION

For the first year of this project, the goals included development of a GIS framework and a compilation of spatial land use data, collecting and digitizing data for performance of the nitrogen mass balance (historic and current), and work on the groundwater loading model. Data collection was extensive, including land N applications (from atmospheric, fertilizer, animal, and human sources) and field nitrogen removal (harvest removal, atmospheric losses, surface runoff).

The first 6 months of the second year have focused primarily on the analysis of the cropping data, that is, the annual fluxes into and out of the rootzone of individual fields. This is arguably the largest component of the overall nitrogen flux, as Harter et al. (2012) found that nearly 95% of groundwater nitrate in the Tulare Lake Basin and Salinas Valley was directly attributable to croplands, with approximately one half of this nitrogen coming from synthetic fertilizer and another third attributable to land-applied manure used as a fertilizer source or soil amendment. Crop area and production data have been used to determine the median period harvest removal rates of nitrogen by county, by sub-basin, and for the entire Central Valley, as well as by crop. Published N fertilization rates (Viers et al. 2012, Rosenstock et al. 2013) for each period were then used to estimate total synthetic N applications based on reported crop area.

We have begun surveying extension specialists throughout the Valley regarding their opinion of the published application rates for the 2005 period, for 20 of the most prominent crop species. We are additionally asking for estimated application rate ranges and reasons for their estimates, including varietal and regional differences. Should these experts agree that current fertilization rates for any one crop differ from published data, the application totals for the 2005 period will be adjusted.

Fertilizer sales data were also examined and a preliminary analysis was performed for the 1990 and 2005 periods. Comparison of recorded synthetic sales data with the preliminary application estimates, along with discussions with California fertilizer sales industry representatives, has provided insight into some of the apparent errors in the sales data.

The second half of the project (through 12/2014) will be devoted to the remaining mass balance component analysis and calculation of the nitrogen flux within the Central Valley to determine the leachable fraction. Kourakos et al. (2012) developed a groundwater nitrate transport modeling tool that allows computation of long-term transport of nitrate to individual domestic/municipal/irrigation wells, based on the spatially distributed, field-by-field, annual nitrogen loading to groundwater. Using this software, we are currently developing flow and transport models for the Central Valley. We will apply the nitrogen loading rates obtained from the mass balance assessment and from the literature review with this nitrate transport modeling tool to the Central Valley. The model results will provide long-term (1940 – 2100) statistical predictions of groundwater nitrate in domestic wells, irrigation wells, and municipal wells in several large project areas in the Central Valley. This will allow us to track nitrate travel paths and travel times from recharge zones to the groundwater capture in domestic wells, irrigation wells, and municipal wells. In the final project step, data developed will be published in a web-accessible GIS database.

RESULTS AND DISCUSSION OF PRELIMINARY FINDINGS

The following discussion is focused on croplands, the largest component of the nitrogen mass balance in the Central Valley. Total harvested nitrogen, total synthetic N applications, and total reported fertilizer N sales are compared. Note that alfalfa and pasture have been excluded from these preliminary analyses, as both typically receive no to very little synthetic N and exceptional quantities of nitrogen are harvested with alfalfa, while pasture "harvest" is often not reported.

Harvested Nitrogen

A unified crop classification scheme was developed to rectify crop and crop group naming and categorization differences between the crop data sources, including the Department of Water Resources, the USDA Crop Nutrient Tool, the USDA National Agricultural Statistics Service, and the Agricultural Commissioner Reports. The crop area and yield data were digitized from County Agricultural Commissioner Reports (ACRs) and the yields translated into total nitrogen removal using individual crop nitrogen and moisture percentages as estimated by the USDA Crop Nutrient Tool (http://plants.usda.gov/npk/main).

Harvest rates were then determined separately for each county, each sub-basin (Sacramento, North San Joaquin, Tulare Lake Basin), and the Central Valley as a whole, for each of 5 periods (1945, 1960, 1975, 1990, 2005). To smooth year-to-year fluctuations, median values of the 5 years surrounding each period was used (i.e. the value reported for the 2005 period is the median for the years 2003-2007). Individual crop N removals were also analyzed. Among the sub-basins, overall crop yield is highest in the Tulare Lake Basin counties, followed by the North San Joaquin and the Sacramento Valley. From

the 1990 to 2005 period, the amount of N in harvested crops in the Central Valley increased by 20% (**Figure 1**, red bars). While the total cropped area in the CV has remained relatively stable since 1975, changes in the distribution of individual crop areas (e.g. a general decline in field crops and increase in nuts and other permanent crops) has been responsible for the increases in the total nitrogen harvested and applied.

Estimated Synthetic N Application

Published synthetic N application rates for the 1990 and 2005 period (Viers et al. 2012, Rosenstock et al. 2013) are based on averages of UC crop cost and return studies and USDA grower surveys. The published rates were applied to the median period area of each individual crop to estimate the total synthetic N application in each period. Similar to the estimated harvested N quantities, estimated application of synthetic fertilizer also rose 20% between 1990 and 2005 (**Figure 1**, blue bars). Again, our final report may include minor adjustments to some of the current N application rates, as we are currently in the process of vetting published rates for key crops by surveying experts familiar with fertilization practices and harvest rates in the Central Valley. Note that the

Table 1. Total synthetic N applied and N harvested within the Central Valley in the 2005 period for crop groups that do not receive manure. The partial nutrient balance calculation indicates the nitrogen use efficiency across the entire crop group. 1 gigagram = 1,000 metric tons = 1,103 short tons.

Crop Group	Synthetic N Applied Gg N	N Harvest Gg N	NUE (harvest/applied)
Subtropical Tree Fruit	10	5	53%
Deciduous Tree Fruit	14	3	21%
Nuts	70	46	65%
Rice	32	24	75%
Vegetables and Berries	53	28	52%
Grapes	9	4	47%

Table 2. Central Valley county N sales; averages for the decade prior to and after the 2002 jump in statewide sales. Differences > 10,000 tons highlighted in bold. Outliers were removed from the analysis on 3 occasions as noted, and are assumed reporting errors. (Note: N sales occurring in county "unknown" average 35K per year, ranging 1k-100k).

County	Avg. 1991-2001	Avg. 2002-2012	(tons N)
Butte	18,362*	18,207	*removed 1995 outlier of 43,000 tons
Colusa	**22,932**	**38,549***	*large increase in aqua ammonia
Contra Costa	2,262	2,443	
Fresno	64,784	67,342	
Glenn	13,545	15,019	
Kern	44,304	50,509	
Kings	28,091	33,168*	*spike in 2006
Madera	10,148	9,413	
Merced	17,130	23,217	
Placer	850	1,363	
Sacramento	13,525	18,529	
San Joaquin	**44,265**	**208,549***	*large increase in anhydrous ammonia
Shasta	1,566	4,254*	*removed 2002 outlier of 15,000 tons
Solano	9,142	9,633	
Stanislaus	**18,867***	**28,687**	*removed 1995 outlier of 66,000 tons
Sutter	17,482	14,397	
Tehama	1,345	2,113	
Tulare	24,589	26,808	
Yolo	16,472	14,729	
Yuba	3,262	2,781	
CV Co. Total	**369,333**	**587,802**	*Above outliers excluded*
California Total	**572,042**	**815,416**	*Outliers and county 'unknown' included*

total nitrogen harvest removal is not directly comparable to the synthetic N application estimates, as many forage crops receive substantial amounts of N from manure applications. In crops that typically receive little or no manure, the nitrogen use efficiency (NUE, defined as total N harvested divided by N applied, expressed as a percentage) ranges from 21% in deciduous tree fruit to 75% in rice for the 2005 period (**Table 1**). Grapes have a relatively low NUE, but their typical application rate is low relative to other crops in the Central Valley. Hence, the absolute (as opposed to relative) amount of N loss in vineyards tends to be relatively lower.

Reported Fertilizer Sales

We used California Department of Food and Agriculture reports of fertilizer nitrogen sales for the years 1988-2011, which include figures for individual counties. A significant increase in reported sales occurred in 2002. Reported sales remained relatively high beyond the apparent jump, and this is not mirrored by a jump in harvested nitrogen statewide (**Figure 2**). The increase in reported sales is concentrated in San Joaquin County (**Table 2**). Interestingly, while 2002 marks the beginning of the increase in the average tonnage sold statewide, the percentage of statewide sales being recorded in San

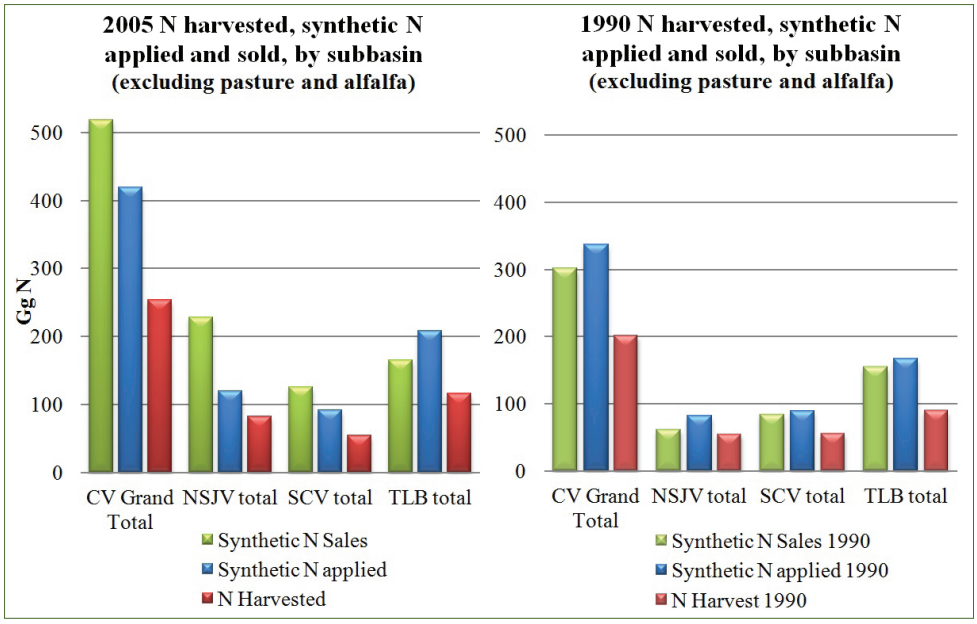

Figure 1. 2005 and 1990 period median reported synthetic N sales, estimated synthetic N applications and estimated N harvest totals for each sub-basin and for the entire Central Valley. The reported sales in the 2005 period are known to be inaccurate due especially to double reporting of ammonia products in San Joaquin and Colusa counties, affecting the NSJV and SCV sales totals. Both harvested N and applied synthetic N increased by 20% from the 1990 to 2005 period.

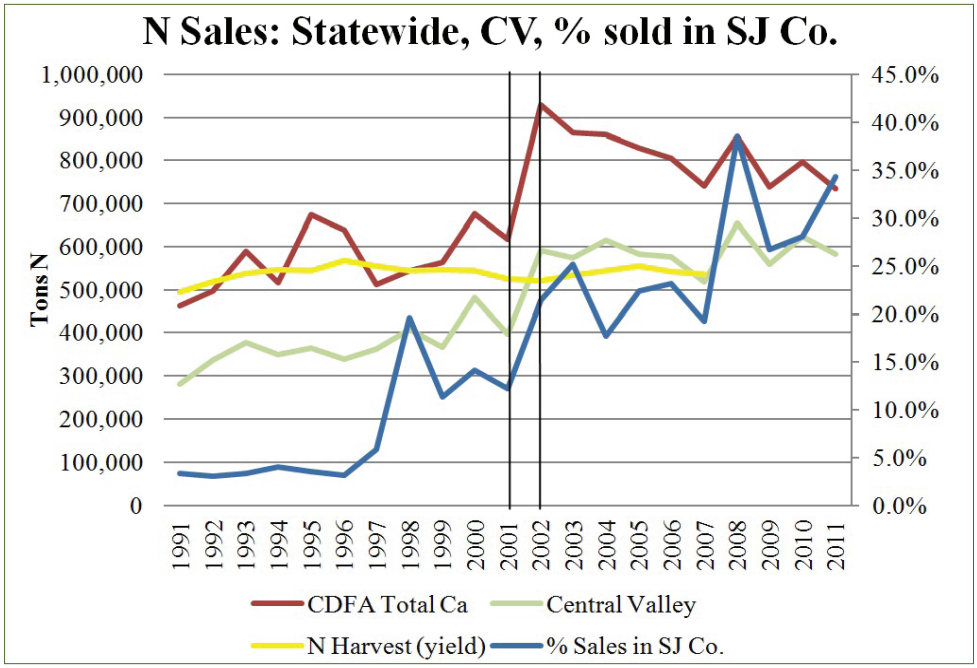

Figure 2. Statewide and Central Valley N sales as reported in CDFA tonnage reports. Statewide production (N Harvest) does not show a similar increase, highlighting a sales reporting anomaly. The CV accounts for ~65-75% of statewide sales while the sales in San Joaquin County have been increasingly and disproportionately high, accounting for up to 38% of statewide sales.

Joaquin county began its steep ascent beginning in 1998 (**Figure 2**).

The bulk of the 2002 sales increases are attributable specifically to sales of anhydrous ammonia in San Joaquin County, and to a lesser degree, aqua ammonia sales in Colusa County. In 2002, 97% of the statewide anhydrous ammonia sales were recorded as taking place in two counties. San Joaquin county accounts for 56% of that year's reported sales, with the remainder reported in San Luis Obispo County, which in all other years reports zero sales of anhydrous ammonia. In 2008, 90% of the statewide anhydrous ammonia sales are reported as taking place in San Joaquin County, accounting for over 35% of statewide total N sales (**Figure 2**).

While fertilizer sales are required to be reported by the dealer who sells to the end-user only, products may change hands several times before being purchased by the end-user. A possible explanation for over-reporting could occur if a company mistakenly reports sales to "middlemen," who then also report sales to the end-user. Such double reporting by one prominent company was verified by a California fertilizer industry expert whom we interviewed. According to this source, this error has affected reliability of reported values for anhydrous ammonia in San Joaquin County and aqua ammonia in Colusa County "for at least 10 years". These are the counties and N materials that show the largest anomalies in the sales reports. Nationally, it is rare for the relationship between an individual state's N fertilizer sales data and crop acreage figures to differ so dramatically from year to year. While transcription errors and even unit conversion errors may contribute to reported sales anomalies, we conclude that double reporting is the main factor in the inaccurate sales data discussed here.

Sales and synthetic N application are thus not comparable for the 2005 period. The 1990 period shows lower harvests, and accordingly, lower application estimates and sales records (**Figure 1**). Estimating more realistic sales figures for the 2005 period based on the relationship between application and harvest estimates in the 1990 period, is not possible with any reasonable certainty. While both the estimated application and N harvest increased by 20% from 1990 to 2005, reported sales are 10% less than estimated N application rates in the 1990 period. To attempt to adjust 2005 sales figures on this relationship (i.e. lower sales than estimated application rates) would not be reasonable.

Attempting to distinguish between importing and exporting counties, which may have improved adjustments to 2005 sales data, is also difficult to perform with any certainty. When looking at the county by county difference between sales and estimated synthetic application rates for both periods, the interpretation becomes more complicated. While in both periods Madera, Merced, Kern and Tulare counties reported less N sales than what we estimated for total synthetic N application, the majority of the remaining counties do not share a relationship between the two periods. Cross-county N sales accounting is further complicated by the fact that there are many different individual nitrogen products and formulations sold, each of which may be more or less regionally important and/or with more or less local dealer representation. While one county may import more of one N product, they may export more of another with a different percentage of total N in the formulation. Thus, while we were able to provide a relatively thorough explanation for reported nitrogen sales anomalies, no attempt was made to adjust sales figures.

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Developing Testing Protocols to Assure the Quality of Fertilizer Materials for Organic Agriculture

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INTRODUCTION

In the last decade, the organic industry has boomed, evidenced by an almost five-fold increase in sales ($6.1 billion to $29 billion in sales) (OTA, 2011). California is the national leader in this sector with the highest number of farms, land under production and sales accounting for 19% of all organic farms and 36% of all organic farm-gate sales in the nation (Klonsky, 2010, Klonsky, 2012). With increased health awareness and marketing, consumer demand is projected to continue to increase in the short to medium term future. This demand has increased pressure on organic growers to maintain and increase productivity; however, growth has been partially constrained by availability and consistency of fertilizer sources. The rapid growth has also far outpaced the regulation of the industry resulting in some unscrupulous organic fertilizer manufacturers entering the market (Downing, 2008). This research was undertaken to help bring transparency and authentication to the array of organic fertilizer products on the market. To date, there is no methodology to validate manufacturer claims of fertilizers labeled "authenticated for organic production". Basic laboratory tests are often unable to identify potential problem samples. For example, analysis of total nitrogen content may confirm a product label, but not shed light on the source of nitrogen (organic or inorganic) allowing for potential adulteration.

OBJECTIVES

This project will contribute to better organize the characterization of materials that can be used in the manufacturing and testing of organic fertilizers and amendments. The major product generated by this project is a protocol of detecting, with high probability, adulteration of organic fertilizers and other amendments by synthetic fertilizer and other chemical nutrient sources. The following objectives guide this research project.

1. Construct a database of materials used in organic and synthetic fertilizers and their quantifiable properties through thorough search of the literature and additional chemical and physical analyses of such materials.
2. Establish natural ranges for the chosen properties of these materials that can be used to distinguish between pure or unadulterated and adulterated materials.
3. Compile a spectral library of organic fertilizers using (Fourier Transform Infrared spectroscopy) FTIR and FT Raman spectroscopic techniques.
4. Develop a stepwise protocol test that labs and regulatory agencies can follow to identify organic fertilizers that have likely been adulterated by synthetic fertilizers.
5. Develop a method utilizing Near Infrared Reflectance spectroscopy (NIRS) for analysis of organic fertilizers.
6. Disseminate the results and products of the project to potential users, such as organic fertilizer test labs and regulatory agencies.

DESCRIPTION

Our work initially involved a comprehensive literature review on organic materials used in organic fertilizer formulations. Next, several wet chemistry techniques were utilized to determine key properties of the organic fertilizers useful for investigating potential adulteration. The analyzed properties were total carbon (C) and nitrogen (N), relative abundance of δ15N (isotopic ratio), and ammonium-N. Literature and analytical data provided a basis for statistical determination of expected ranges of the properties. Spectroscopic techniques, namely attenuated total reflectance (ATR) FTIR spectroscopy and FT-Raman spectroscopy were

performed to investigate the potential use of these techniques in quickly determining potential adulteration. Both techniques require minimal sample preparation and have a high sample throughput making their use amenable to test labs and organic fertilizer regulators. Though somewhat comprehensive, (approximately 200 samples analyzed to date) compilation of the database is continuing through analysis of more commercially available organic fertilizers.

Present work has been focused on use of another near infrared spectroscopy (NIRS) technique. This spectroscopic technique is already widely used in the agricultural sector for testing the quality of forage and feed, making its potential use for organic fertilizer quality determination highly beneficial (Bellon, Vigneau, et al., 1994, Reeves Iii, 1997, Stuth, Jama, et al., 2003, Volkers, Wachendorf, et al., 2003). NIRS is dependent on calibrations derived from correlations of spectral properties to chemical information of the test materials and thus to develop powerful and robust calibrations, analysis of multiple samples is required. Three categories of fertilizers (bat guano, liquid fish and seabird guano) have been utilized to determine the feasibility of this technique.

RESULTS AND DISCUSSION

For comparison and analysis, the organic fertilizer samples were classified into categories based on feedstock components used by Organic Materials Review Institute (OMRI). Some of these categories are liquid fish products, unprocessed fish products, blood meal, compost and manure, bat guano, humates, seabird guano, feather meal, seaweed products, and Chilean nitrate. Blends of varied composition that contained more than two components e.g. kelp/seaweed extract, humic acid, molasses, vinegar, compost and alfalfa tea were combined into one category called "Other blends". The compiled databases of "natural" or expected values for the different properties were created from laboratory organic fertilizer analyses and organic fertilizer literature (**Figure 1 and 2**). All data are shown together, including possibly adulterated products, resulting in a large spread of data in some categories. The data show clear differences in the values of some properties for certain categories, for example C/N ratio of compost compared to seabird guano (**Figure 1**) and δ15N values of bat guano compared to Chilean nitrate (**Figure 2**).

Integrating all of the literature and laboratory information, a proposed protocol is presented for identifying products which may have been adulterated. The suggested evaluation process was selected based on an order of increasing effort and expense. As an initial step, identifying the category to which a sample belongs is necessary in order to interpret the results of analysis, since some property values are suspect for one kind of sample but may not be suspect for another kind.

The protocol (**Figure 3**) is a six-step systematic flow-chart to follow. This protocol minimizes the potential of incorrectly flagging a fertilizer as potentially adulterated and it should be noted that no single property alone is a sufficient determinant to classify a sample as adulterated or unadulterated.

Step 1. Careful analysis of the label on the product is required. Of significant importance is the nitrogen content. As stipulated by the USDA, organic fertilizers labeled as containing > 3% N must be evaluated through a material evaluation program (USDA, 2009). Analytical data of such products should be provided by the supplier. Also knowledge of the constituents is pertinent in directing subsequent analytical tests. Samples such as bat or seabird guano would have higher ammonia compared to seaweed and humates.

Step 2. Determination of the ammonium content is the first analytical step as it can readily discriminate adulterated non fish or guano based fertilizers products. Fertilizers in this category with more than 1% nitrogen as ammonium (10000 mg L-1) should be retained for further analysis. Setting a similar threshold for samples that naturally have ammonium such as fish and guano products is more challenging and other tests of the protocol can be utilized to determine potential adulteration.

Step 3. The next property for consideration is the ratio of carbon to nitrogen (C/N; w/w) which is a good indication of how "organic" a material is. Nitrogen in organic materials is derived primarily from protein, for which the C/N does not fall below 1. The same is true of guano, although guano may contain much of its nitrogen in the form of uric acid rather than protein. For the C/N threshold the upper limit of the 99% confidence interval (CI) for the average of the 5 lowest materials (i.e., seabird guano; fish guano; fish/seaweed; amino acids and other blends; **Figure 2**) is 1.28. For guano alone the upper CI endpoint at the same significance level is 1.09. Any fertilizers that do not contain these materials and yet show C/N ratios below these CI values probably (99%) contain inorganic N. However, if values are higher than these thresholds it is impossible to say whether a given material has organic nitrogen only. However, while theoretically possible, these are conservative values, since it is rare that any protein would have a C/N of less than about 2, hence a threshold value of 2 has been selected for this protocol. For guano fertilizers, a reasonable threshold, based on literature values and the current database, would be a C/N of 1. An obvious exception

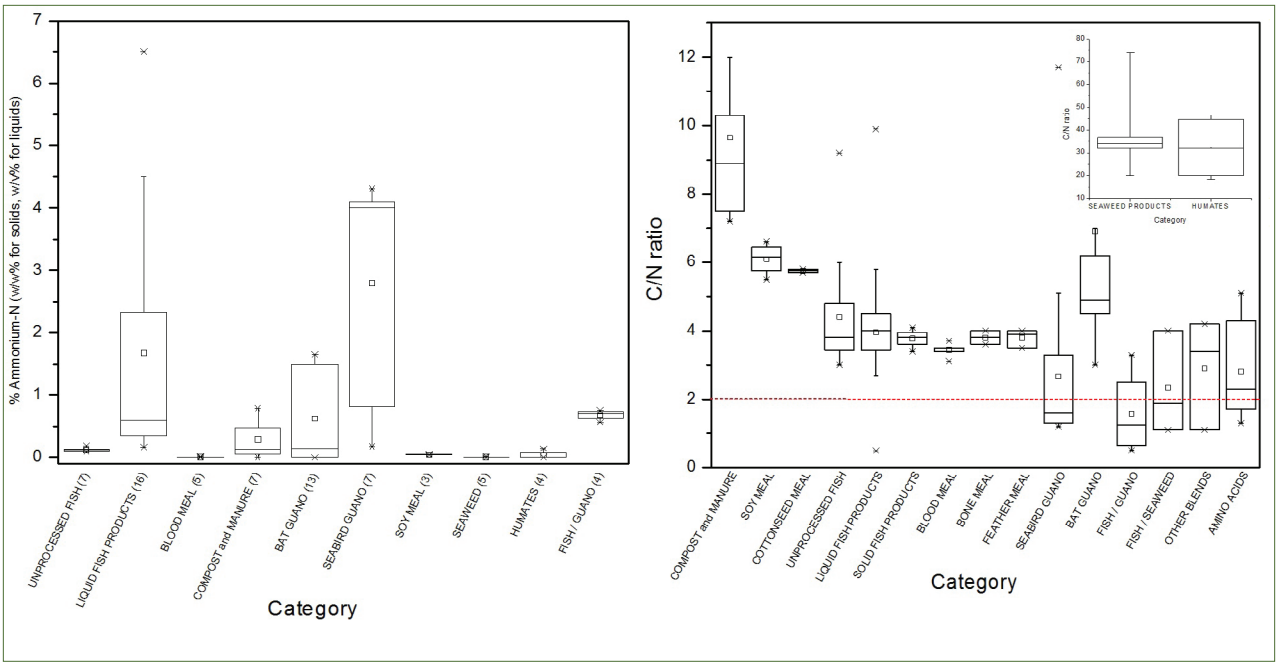

Figure 1. a) Ammonium-N content of the different categories of organic fertilizers b) C/N ratios of the different categories of organic fertilizers. The dashed line denotes the threshold value, based on typical protein C/N ratios, to be used to warrant further investigation for potential adulteration of the organic fertilizer. Based on 99% confidence intervals, guano and guano blend fertilizers are a possible exception . Other blends are blends of varied composition that contain more than two components.

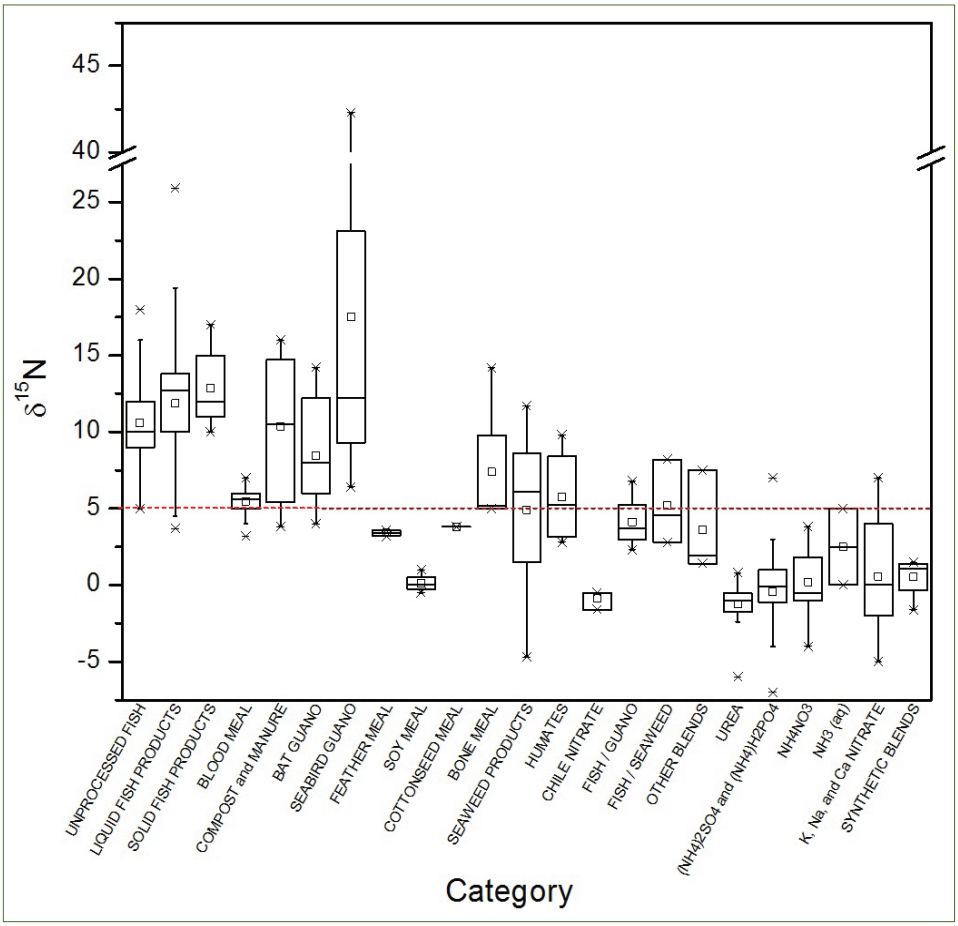

Figure 2. Nitrogen isotope ratios of the different categories of organic fertilizers. The line denotes the threshold value, based on the natural isotopic abundance of different materials, to be used to warrant further investigation for potential adulteration of the organic fertilizer. Based on 99% confidence intervals, seaweed, algae, Chilean nitrate and soybean fertilizers and their blends are possible exceptions. Other blends are blends of varied composition that contain more than two components.

is Chilean nitrate, an approved product with a naturally high level of nitrogen relative to carbon. Due to the potentially low C/N ratios of blends containing guano and Chilean nitrate, questionable samples should be further analyzed.

Samples meeting both criteria of Step 2 and 3 may be considered likely not adulterated however, failure to meet either of the criteria from these steps would warrant further investigation.

Step 4. The ratio of nitrogen-15 to nitrogen-14 (expressed as $\delta^{15}N$) is another parameter which rarely falls below a certain threshold value in natural material, with few exceptions. Fish tissue and guano, for example, do not have a $\delta^{15}N$ value of less than 5, and values are typically greater. A threshold value of 2.3 was calculated based on the 99% CI for the average of all non-organic sources and accounting for variations in sample size (number of values used in the calculation of each product's CI). As in the C/N analysis explained above, $\delta^{15}N$ CI represents a range of values where the probability of obtaining a sample mean similar to that of the non-organic sources is low ($P<0.01$). Any products that go beyond (i.e. show higher $\delta^{15}N$ values) this threshold are almost certainly not adulterated. It is important to note, however, that leguminous plants that rely on symbiotic N uptake can have $\delta^{15}N$ values as depleted, or close to atmospheric values, as non-organic N sources

Step 5. The two spectroscopic techniques provide additional tools for investigating the authenticity of the organic fertilizers. Detection of adulterants by FTIR can be performed by 1) comparing sample spectra with spectra of samples from a similar feedstock; 2) comparing the sample spectra with that of urea or ammonia sulfate and looking for characteristic peaks for ammonia or urea and 3) intentionally doping the sample with urea or ammonium sulfate and analyzing for increased magnitude in peaks characteristic to the adulterants. Peaks at approximately 3450 cm^{-1} (N-H vibrational bond stretch); 1450 cm^{-1} (urea N-C-N vibrational bond stretch); and 1600 cm^{-1} (urea C=O vibrational bond stretch) show the presence of urea and for ammonium sulfate, the peaks are at approximately 1400 cm^{-1} (ammonium sulfate N-H bond deformation) and 600 cm^{-1} (ammonium sulfate SO_4^{2-} bending mode).

For FT Raman, similar methods of analysis can be used. The spectral interpretation of FT Raman is much simpler with clear peaks associated with potential adulterants being evident. In the Raman spectra, the presence of ammonium sulfate and urea can be observed by significant peaks at approximately 980 cm^{-1} (ammonium sulfate SO_4^{2-} stretching mode) and 1012 cm^{-1} (urea N-C-N bond stretch) respectively.

Both techniques require no sample preparation and very little sample set-up resulting in high throughput of samples. The cost of the instrumentation may be prohibitive hence the use of these techniques is suggested after all other less expensive options of verification are exhausted.

Step 6. When a sample clearly fails all or some of the tests, adulteration is likely and warrants further investigation of the manufacturer and the production process.

Method development of Near Infrared Reflectance spectroscopy (NIRS) is ongoing and results are showing the feasibility of utilizing this technique for rapidly and readily predicting some key properties. Trends in the spectra from several categories are evident and initial calibration curves are showing good correlation for some properties (C:N ratio, total N and NH_4-N) of bat guano, liquid fish and seabird guano. As with the overall protocol, the robustness of the calibration curves is dependent on the number of samples per category and efforts to achieve this are ongoing.

ACCOMPLISHMENTS

This work resulted in a protocol with steps for testing potential adulteration of organic fertilizers. The proposed protocol has been peer reviewed and accepted for publication. The protocol is a work in progress but serves as a concrete starting point for test labs and regulators to effectively investigate adulterated organic fertilizers. Increasing the number of samples and also the number of samples per category is necessary to improve the robustness of the protocol. Additional spectroscopic testing is being evaluated in "Phase II" of the ongoing effort to develop a robust organic fertilizer testing protocol.

ACKNOWLEDGEMENTS

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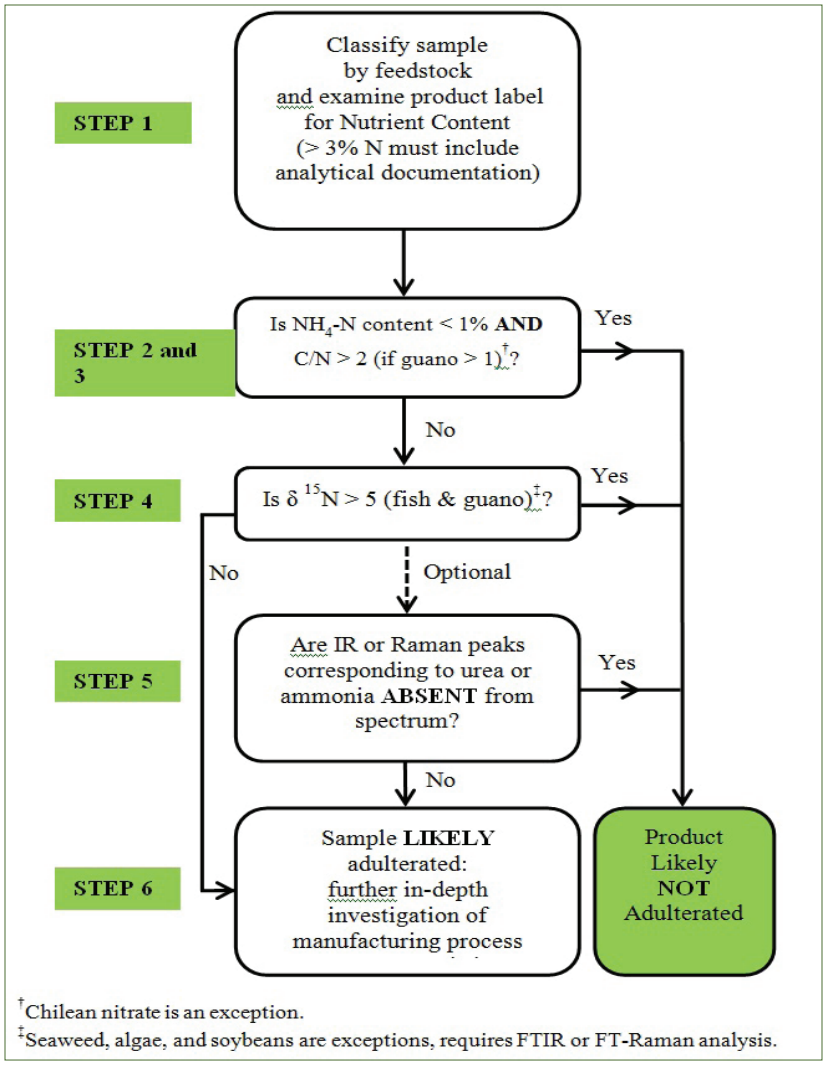

Figure 3. Systematic protocol proposed for use in investigating possible adulteration of organic fertilizers.

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Evaluation of a 24 Hour Soil CO_2 Test for Estimating Potential N-Mineralization to Reassess Fertilizer N Recommendations

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INTRODUCTION

The estimation of growing season N-availability for the purposes of reassessing fertilizer N requirements has proved problematic. Fertilizer recommendations are made without the knowledge of the soil's capacity to supply N for crop uptake. Consequently, fertilizer N recommendations are often made based solely on inorganic N levels (pre-plant nitrate test), total soil N, or fertilizer recommendations from previous years. These tests do not account for the potential mineralization of soil organic N sources, which have been shown to account for more than 50% of crop N uptake (Kramer et al., 2002; Doane et al., 2009). Numerous soil tests have been explored to determine the mineralization capacity of soil organic N. Biologically based tests, i.e. incubations, are based on the activity of the microbial community and have been met with limited success. However, of all test examined to date, biological based tests are generally better predictors of in season soil N mineralization compared to those based on extractions or the total amount of soil organic matter. From a soil-testing perspective, biological based incubations are impractical due to space and time constraints. A short-term, ideally less than 24 hours, biologically-based soil test would allow for rapid estimation of growing season potential N mineralization. The short-term flush of CO_2 following the drying and rewetting of a soil has been shown to correlate strongly with N mineralization (Franzluebbers et al., 2000; Fierer & Schimel, 2002; Mikha, 2005; Franzluebbers, 1999). This flush of CO_2 has not been evaluated within the California's agricultural context, with its generally lower soil organic matter contents, higher fertilizer N requirements, and intensive agronomic practices.

OBJECTIVES

The overall objective of this research is to provide a quick, effective tool to make more accurate fertilizer N recommendations in California agriculture by estimating growing season N mineralization. The specific objectives of this project include:

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

DESCRIPTION OF ACCOMPLISHMENTS

A wide variety of California soils were gathered from several of California's major crops- corn, tomatoes, cotton, and strawberries. These soils were gathered across climatic, soil C content, and soil texture gradients, as well as differing management practices. These soils were then sieved to 4mm and air-dried for laboratory testing. Standard soil physical and chemical tests were performed to assess qualities such as total C/N, soil texture, water-holding capacity (WHC), inorganic N (NO_3-/NH_4+), and dissolved organic carbon (DOC).

In the first stage of this project, we are seeking to evaluate previous studies correlating short-term CO_2 evolution and growing season N mineralization. This relationship is being tested in the laboratory by long-term aerobic incubations in which soil respiration and N mineralization are measured over the course of a growing season (~100 days).

In the second stage of the project, we will perform rate trials to field validate short-term CO_2 data from incubations. These rate trials will be performed over a variety of cropping systems, soil types, and management techniques. The yield, biomass, and soil N measurements will then be cross-referenced with incubation data to provide a model for fertilizer recommendations for California growers. A conceptual, non-quantitative diagram for this model is provided in (**Figure 1**). This information will then be used to provide a more applied graph, such as (**Figure 2**), which would allow for more accurate fertilizer N application.

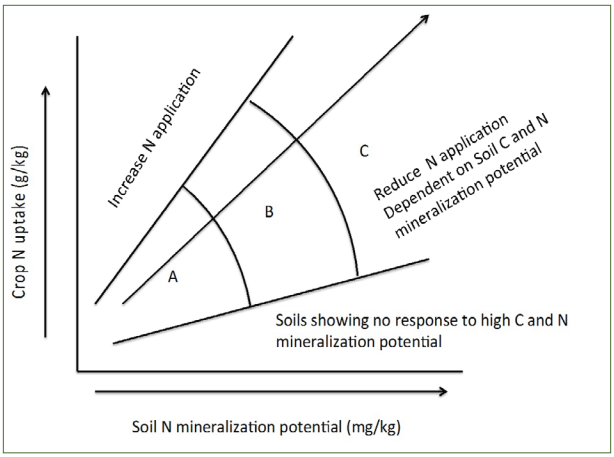

Figure 1. A diagram depicting the relationship between soil N mineralization and crop N demand. As soil N mineralization increases the amount of fertilizer N application can be decreased. The extent of decrease depends on the amount of soil N mineralized and the certainty of the N mineralization results of specific soils and crops. For example, the ranges depicted by A, B and C represent decreasing need for fertilizer N inputs.

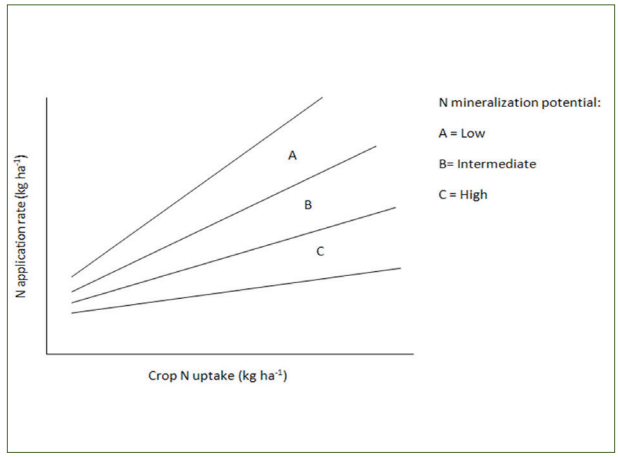

Figure 2. A simplified version of Figure 1.

Table 1. A summary of predicative N mineralization tests.

	Description	Parameters Measured	Limitations	Citations(s)
Aerobic Incubation	A short-term aerobic incubation is used to calculate rate coefficient, which is utilized in $N_t=N_0*(1-e^{-kt})$	NO_3^-, NH_4^+	N0 values are difficult to reproduce; variable *k* values; some soils fit second-order kinetics better	Stanford and Smith, 1972
Anaerobic Incubation	Soils are incubated under waterlogged (anaerobic) conditions for 7 days at 40°C	NH_4^+	Poor correlations found between incubations and field studies	Waring and Bremner, 1964; Fox and Piekielek, 1984
Phosphate-borate Buffer	Soils are distilled for 8 minutes at pH 11.2	Ammonia-N (NH_3-N) evolution	Poor correlation between lab and field measurements	Gianello and Bremner, 1988
Hot KCl	Soils are placed in stoppered tube of 2M KCl solution for 4 hours in a 100°C water bath	NH_4^+	Limited digestion of organic N compounds (amino acids, amino sugars, etc.)	Gianello and Bremner, 1986
Short-term CO2 Flush	Dried soils are aerobically incubated and C mineralization is measured for 3 days after rewetting	C Mineralization	Results are highly dependent on pre-incubation treatment	Franzluebbers et al., 2000
Labile Carbon	Air-dried soils are mixed with 0.2M $KMnO_4$ for 2 minutes and measured spectroscopy	Permanganate-oxidizable carbon (POXC)	Provides non-quantitative estimate of N mineralization potential	Culman et al., 2013

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ACKNOWLEDGEMENTS

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Relationship of Soil K Fixation and Other Soil Properties to Fertilizer K Rate Requirement

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INTRODUCTION

Soils of the Central Valley and bordering uplands display a wide range in the properties that determine K fertilizer requirements. Soil K fixation, which is associated with persistent crop K deficiencies, is found in some soils on the east side of the Central Valley that are derived from granitic parent material and contain the silicate layer mineral vermiculite. During the past 40 years, UC researchers have demonstrated the significance of K fixation for cotton and processing tomato production in the Central Valley (Miller et al., 1997; Hartz et al., 2008). In a UC field experiment (Cassman et al., 1989), 86% of the 1540 lb K_2O/acre applied in a 3-yr period was fixed beyond extraction by NH_4+, and cotton plants remained marginally deficient.

We expanded on previous UC research by investigating the relationship between soil mineralogy and K-fixation behavior in San Joaquin Valley soils used primarily for cotton production. Important findings were the dominant role of silt and fine sand fractions in K-fixation in soils in our study that were derived from Sierran granites (Murashkina et al. 2007b) and the observation that some soils that contain little vermiculite fix K, probably due to the presence of tetrahedrally substituted smectite (Murashkina et al. 2008). More recently, we have identified soils with high K fixation potential in winegrape vineyards in the Lodi district. Research supported by the Lodi Winegrape Commission is in progress to determine whether higher rates of K fertilizer are needed on K-fixing vineyard soils in that district than on non K-fixing soils.

Although several UC researchers have examined K fertilizer responsiveness in K-fixing and non K-fixing soils (Cassman et al., 1990; Cassman et al., 1992; Gulick et al., 1989), additional work is needed to develop practical laboratory methods for determining the K fertilizer requirements of such soils. We have developed a 1-hr incubation method for measuring soil K fixation potential (Murashkina et al., 2007a). Other researchers have shown that a modified version of an older test - sodium tetraphenyl boron, $NaBPh_4$ - is useful for estimating the portion of fixed K that is plant-available (Cox et al., 1999). To be useful to growers in California, these tests must be correlated with K fertilizer response. In research funded by the California Department of Food & Agriculture's Fertilizer Research & Education Program, we are using soils previously collected from the Lodi winegrape district and San Joaquin Valley cotton fields to determine whether our regional model categories (O'Geen et al. 2008) are informative with respect to K fertilizer requirement and whether the two analytical procedures described above predict the rate of K required to achieve sufficiency levels.

OBJECTIVES

1. Determine the rate of K fertilizer required to achieve sufficiency levels (yield not K limited) in both K-fixing and non K-fixing soils.
2. Relate K fertilizer responsiveness of soil profiles for regional model categories (O'Geen et al., 2008). The model groups soils by K fixation potential, landscape location, and geology.
3. For the 1-hour K-fixation potential soil method, determine the effect of sample wetting and drying and sequential K-additions.
4. Provide research summaries and K fertilization recommendations for K-fixing soils to crop management professionals, analytical laboratories, and growers.

In this summary, experiments directed to Objective 3 are described.

DESCRIPTION

Soils and Treatments

For experiments described here, we used 24 soil samples collected earlier from two cotton fields and four wine grape vineyards in the San Joaquin Valley of California. Samples had been screened to 2 mm and stored air-dried. Fields with a history of large K fertilizer applications were excluded from the study. Selected soil properties are shown in **Table 1**.

100 g of each soil sample was mixed with KCl in 25 mL water at a rate of K equal to 2 times the previously measured K fixation capacity shown in **Table 1**. Samples were incubated moist at ~21 °C for 24 hours, after which they were air dried. 22.0 g subsamples were removed and analyzed in triplicate for NH_4OAc-K, TPB-K, and Kfix. The remaining soil was again mixed with KCl in water at a rate equal to 2 times the initial Kfix value, for a total rate of K equal to 4 times Kfix. Incubation, air drying, and analysis steps were repeated, and followed by two additional cycles of K additions and measurements, resulting in analyses performed at rates of 2x, 4x, 6x, and 8x initial Kfix values, with wetting and air drying steps after each addition.

An additional 25 g of soil for each sample were mixed with KCl in 6.25 mL water at a rate equal to the previously measured cation exchange capacity of the soil, or a symmetry of K. These samples were incubated moist for 16 days, and then air dried and analyzed in triplicate as above.

Soil Analytical Procedures

K fixation potential (Murashkina et al., 2007a) (Kfix). Soil K fixation potential procedure: Three g soil samples were shaken in 30 mL of 2 mM KCl for 1 h followed by extraction for 30 minutes with 10 mL 4M NH_4Cl. Following centrifuging, K in solution was measured by flame emission using an atomic absorption spectrophotometer. K fixation potential was calculated as the difference between a without-soil blank and the measured K solution concentrations in triplicate subsamples. Results are expressed as mg K fixed per kg soil, but can also be expressed as percent of initial solution K removed from the solution by fixation.

Table 1. Selected properties of soils used in this study.

Code/soil/classification	Depth cm	CEC cmol (+)kg^{-1}	NH_4OAc-K initial MG kg^{-1}	K fix initial mg kg^{-1}
Archerdale clay loam	9-28	28.8	113	19
Pachic Haploxeroll	28-46	28.4	123	42
	110-135	26.1	119	289
Bruella sandy loam	0-12	11.8	65	235
Ultic Palexeralf	12-30	11.0	45	377
	30-44	9.2	32	259
	60-79	21.2	67	208
	79-100	23.2	53	231
Columbia sandy loam	7-41	16.5	67	243
Aquic Xerofluvent	41-61	18.7	49	348
	61-96	10.8	45	248
	96-135	13.0	36	318
Guard clay loam	20-40	14.5	63	422
Duric Haplaquoll	40-60	16.2	79	500
	80-100	16.4	52	404
	100-120	21.5	50	503
	120-140	16.3	34	450
Armona loam	0-10	22.2	59	384
Fluventic Endoaquoll	10-50	19.7	78	564
	50-100	13.9	48	740
	100-120	29.9	92	475
Gepford clay	0-12	30.8	169	63
Typic Natraquert	12-56	30.4	102	267
	56-95	28.1	104	111

Ammonium acetate-extractable K (Soil Survey Staff, 2004) (NH_4OAc-K). 2.5-3 g soil were saturated and extracted overnight with 1 M NH_4OAc (pH 7) using a mechanicalvacuum extractor, and K was determined by flame emission spectrometry.

Sodium tetraphenylboron-extractable K (Cox et al. 1996, 1999) (TPB-K). 1 g soil was extracted without shaking for 5 minutes with 3 mL of extracting solution (0.2 M NaTPB + 1.7 M NaCl + 0.01 M EDTA). 25 mL of quenching solution (0.5 M NH_4Cl + 0.11 M $CuCl_2$) was then added, and samples were heated, then boiled for 30-45 minutes to dissolve the resulting precipitate. Samples were shaken by hand and then filtered. Solutions were analyzed for K by flame emission using an atomic absorption spectrophotometer.

RESULTS AND DISCUSSION

Figure 1 shows estimated values of K fixation potential for selected depths of each soil. For most samples, estimated K fixation potential began to plateau at high values of added K, approaching a maximum K fixation value. However, it is not clear if a maximum value was reached, even with the addition of a symmetry of K (amount equal to the soil CEC) in every case.

Methods to estimate K fixation potential by difference were less sensitive at higher concentrations of added K, leading to much more scattered data (**Figure 2**). Adjusting to a percentage of added K fixed (**Figure 3**) helps adjust for the reduced sensitivity, and makes trends at the high end of added K more apparent. Estimated K fixation potential as a percentage of K added decreased

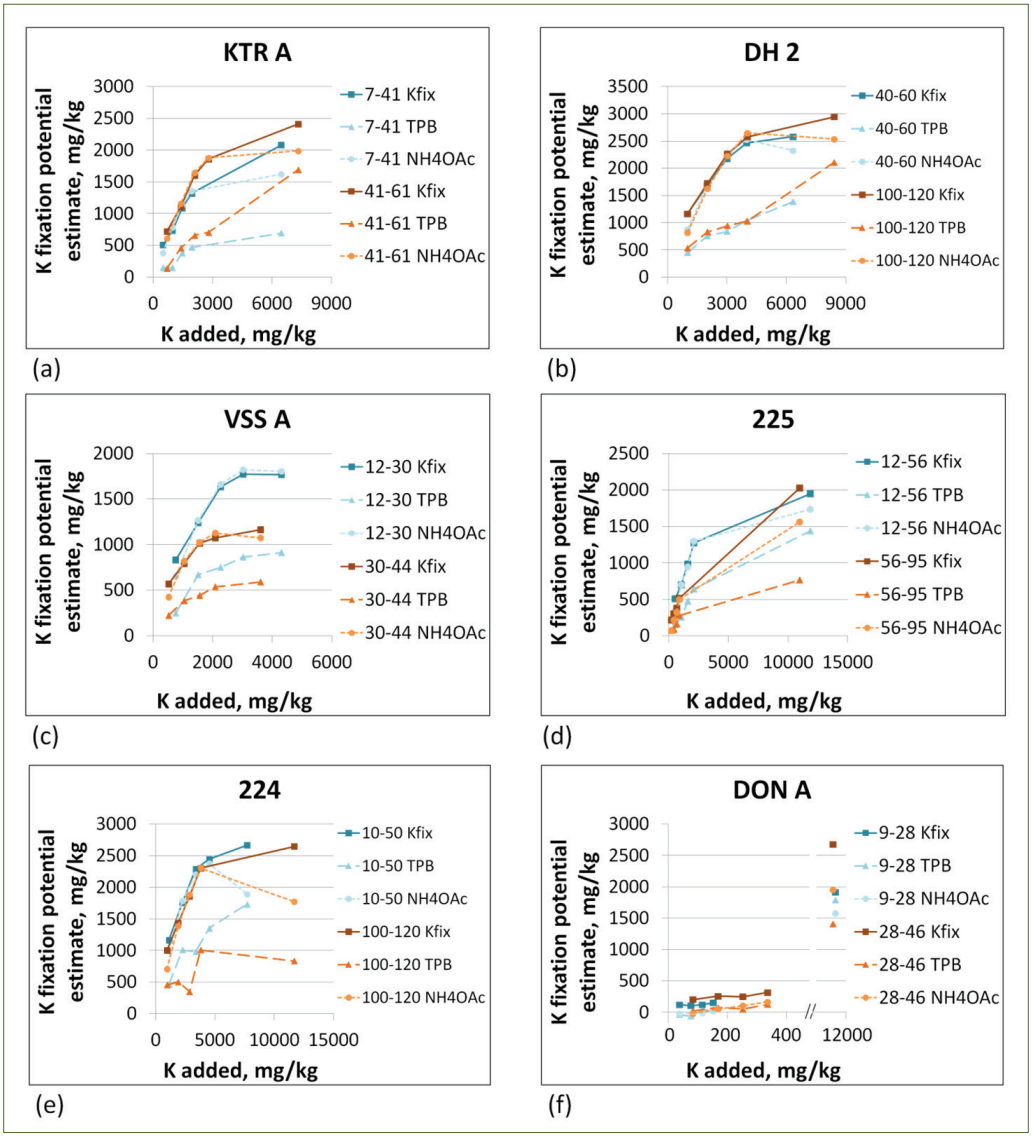

Figure 1. Estimated K fixation potential at increasing rates of applied K for selected depths for each soil. Note the broken x-axis in 1(f).

regularly with all three methods once added K exceeded about 500 mg/kg. TPB-K estimates began at a lower percentage of added K, but decreased more slowly, roughly converging with the other methods at high levels of added K.

For soils with high CEC and low initial Kfix values (DON A - Fig 1(f)), significant K fixation potential was measured at very high application rates. This result was not expected, as the mineralogy of this soil is dominated by smectite, which is typically understood to not fix potassium to the same extent as vermiculite. It is possible that very high K concentrations resulted in the induction of K fixation potential, though additional work is required to test this hypothesis.

In comparing the different methods for estimating K fixation potential (Kfix) and NH_4OAc-K gave fairly similar results. This was an expected result, as both methods use NH_4+ to displace K in the extraction step. Overall, the TPB-K method gave lower estimates of K fixation potential than the Kfix or NH_4OAc-K methods. This indicates that some, but not all, of the added potassium was "weakly fixed" but potentially still plant available.

These results indicate that a soil's potential to fix potassium varies as a function of the amount of K added, though the relationship is not linear, especially at very high levels of added K. Soil mineralogy plays an important role in determining the shape of the Kfix curve. These results will be taken into account as we create fertilizer recommendations for K-fixing soils.

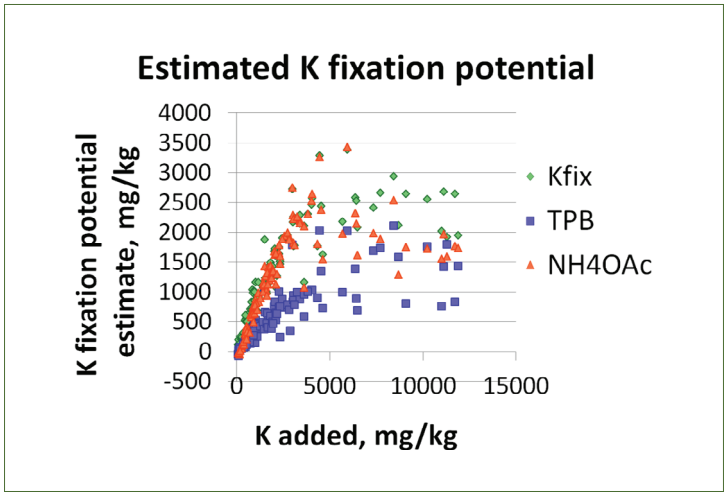

Figure 2. Estimated K fixation potential as a function of K added for all samples.

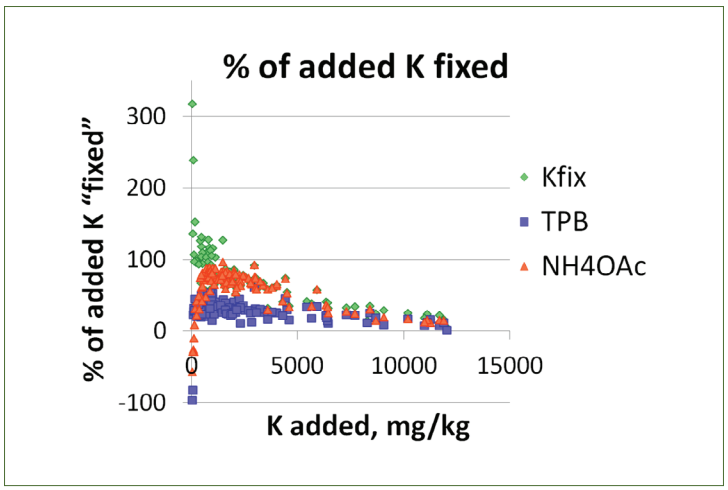

Figure 3. Estimate of added K fixed as a percentage as a function of K added.

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K fixation potential and cation exchange capacity values in **Table 1** were provided by Hideomi Minoshima, graduate student in Soils & Biogeochemistry, UC Davis. That work was supported by a grant to UC Davis from the Lodi Winegrape Commission.

Nitrogen Research and Groundwater

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PROBLEM

The Central Valley Regional Water Board (CVRWB) is promulgating regulations for the management of nutrient impacts on groundwater. Of particular interest is the role of nitrogen fertilizer in groundwater. Growers and members of the plant nutrient industry continue to be under pressure to demonstrate sound decision making in their nutrient application decisions. Seminars and conferences have proven to be effective in delivering new Best Management Practices research. However; despite the need to develop consensus on this issue, the fertilizer industry and growers had not come together to effectively identify what is taking place in the field; or to coalesce on what additional steps can or should be taken in an environmentally safe and agronomically sound program for commercial agriculture, in order to satisfy concerns of the regulatory community with interests in water quality protection.

PROJECT OBJECTIVES

The objectives in outreach is to provide this information to as wide an impacted audience as possible, and to assure BMP projects identified through the FREP do not present unidentified costs or impacts to growers. It is also to facilitate discussion with the CVRWB, industry, and grower groups via scientifically sound programs that meet the needs of grower groups and the regional water board. The project will as a result lessen pressure and frustration of all sides by providing a solution to an identified problem at a minimal cost to all involved. The ultimate objective through this effort and outreach is this process will establish a basis from which water boards and their staffs feel their regulatory requirements are recognized and maintained, and future approvals of nutrient BMPs can be deferred to CDFA for approval.

All aspects of this project will take place on an ongoing basis. Interim task projects related to identification of steps to allow the use of "Farm Management Plans" will be part of ongoing discussions with CVRWB staff. Additional interim task projects will be the reporting of nitrogen research and BMPs identified, and work with outside organizations and water board staff. Project managers will provide interim reports on the status of the project at the end of six months and the end of each year.

PROJECT UPDATE

The first step in facilitating the use of "Farm Management Plans" was receiving approval from the CVRWB. In order to facilitate discussions with CVRWB on the adoption of the use of BMPs as part of a regulatory program to address nitrates in groundwater, WPHA joined the Central Valley Salts Coalition (CVSC). The CVRWB has tasked the CVSC with identifying a strategy for managing nitrates in groundwater, and specific components of an acceptable nitrate management program. Participation in this program has allowed WPHA to meet at least monthly with CVRWB staff. It also allows WPHA to meet on an almost bi-weekly basis with agricultural grower coalitions. WPHA meets regularly with other agricultural associations to apprise them of the status of the program, and to receive their input on issues under discussion by the Coalition. The WPHA serves on the Executive Board of the CVSC, which is made up of CVRWB members and executive officers, staff and other state and federal agency staff members who have a regulatory interest in nitrates and salts in groundwater. As well as serving on the Executive Committee, WPHA serves on the BMP Committee, and Technical Issues Committee.

WPHA staff attends the CVSC board meeting, which meets every month. In addition, WPHA participates in conference calls for the Executive Committee, BMP Committee and Technical Issues Committees. When the CVSC began meeting in 2011, CVRWB staff was recommending the use of numeric limits for the regulation of nitrates in groundwater. Through extensive discussions and submission of technical information explaining the complexities of managing nitrates in

groundwater the BMP committee recommended to the CVSC board that use of BMPs was the more practical direction for a regulatory program related to nitrates in groundwater. From this recommendation the full CVSC recommended the use of BMPs as a regulatory program. Over the past year, and after the acceptance by CVSC to utilize BMPs, the CVRWB has also approved the use of BMPs as part of a compliance program to implement the Agricultural Irrigated Lands Program.

Currently being addressed by CVRWB is identification of appropriate BMPs. Initially, the CVSC & CVRWB were considering that they approve all BMPs. Through the education efforts of CDFA and WPHA, neither group is currently proposing having the Water Board approve BMPs. Instead, the Water Board has deferred approval to BMPs identified through university research, and CDFA. Through discussions with water board members and management via CVSC, it is understood that an acceptable BMP must address environmental benefits of a BMP and not just agronomic benefits. To do this, WPHA continues to meet and explain to growers that acceptable BMPs must be developed or reviewed and approved in association with a university researcher. The BMP must identify the environmental benefit of the BMP, and will also identify the agronomic benefit for growers.

As part of this process, WPHA is meeting with national associations to discuss California needs, and to develop or refine how national nutrient programs could be useable for California regulatory needs. As part of this, WPHA is partnering with the International Plant Nutrient Institute to identify through our Soil Improvement Committee, BMPs for growers and utilization of TFI's 4R program for BMP development.

As part of the acceptance of the use of BMPs by the CVRWB, it was determined that growers must identify what level of BMP reporting is necessary. WPHA has been working with our Soil Improvement Committee and grower coalitions in developing this tool. Over the past year, an assessment tool, a "Nitrate Budget" has been developed. This tool will act as a screen documenting how growers are making their nitrogen management and application decisions, eliminating growers who are in areas that do not require a greater level of reporting from having to develop more comprehensive plans, and demonstrate to waterboard staff the decision making process that a grower utilizes in planning their nitrogen use decisions. The "Nitrate Budget" was finalized by the WPHA Soil Improvement Committee and reviewed by grower groups earlier this spring. This was approved by the CVRWB for inclusion in the Irrigated Lands Program regulatory program. However, because of issues with other agricultural lands programs and activities of the State Water Board, final approval for use of the "nitrate budget" has been postponed for implementation until next year when these other efforts have completed their work. Again, the development of this report has been an ongoing collaborative process between WPHA, industry, and the grower community.

The acceptance of these efforts with agricultural groups is necessary for widespread acceptance by the grower community. CDFA is developing a web-based library of BMPs. WPHA supports this effort and as part of our interaction with grower coalitions and agricultural associations explains the importance of this effort and why production groups should support this effort. As part of WPHA's effort to encourage growers to utilize CDFA's web-based library, we are in the planning stages of beginning production on a series of videos that will be posted to our website, YouTube, and other sites, explaining BMPs included in the library and encouraging growers to utilize the library and BMPs more fully.

WPHA holds ongoing meetings with agricultural groups and the fertilizer industry. Over the past year, WPHA President Renee Pinel has spent on average, 1 day per week directly meeting with either agricultural groups or industry groups discussing the identification of BMPs and BMP reporting. WPHA meets on a monthly basis with a variety of commodity groups in the Central Valley, as well as conference calls on a bi-weekly basis with the leaders of these groups. Pinel also attends grower coalition meetings on a monthly basis for Central Valley California grower coalitions and County Farm Bureaus. Through these discussions, while there is still great reluctance and resistance to growers having to do more reporting, that of the programs that WPHA has participated in, these are the preferred programs of grower groups.

SUMMARY

Because of the complexity of the development of nutrient reporting regulations, we have found that it is not practical to try to complete the various goals of this program in a linear or step by step process. Instead, we have adopted a comprehensive process addressing various components of the FREP project as appropriate and adding additional elements like the development of FREP research videos at WPHA's cost. WPHA is very pleased that as a result of this strategy, that key components for the use of BMPs has been successfully achieved, i.e., the CVRWB approving the use of BMPs as part of a regulatory program, how to utilize a BMP in "Farm Management Plans' in a regulatory program, and to begin to identify appropriate BMPs for use in a regulatory program.

Developing Fertilizer Best Management Guides from FREP Research

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INTRODUCTION

The FREP program has funded over 150 research and education projects since its inception over 20 years ago. The majority of these projects have resulted in completion reports that fulfill the contract requirements, but have not always included an effective outreach component to disseminate the major conclusions. There is a need to deliver the results of the FREP-supported programs to the end users where improvements in nutrient management can be undertaken.

OBJECTIVES

Completed FREP research is the basis for developing a series of high priority guides: "Nutrient Management Research Reviews. Under the direction of the WPHA Soil Improvement Committee, a set of FREP projects will be selected for guide development based on their likelihood for adoption and impact.

A literature search will be additionally conducted of the scientific information from global research that supports the FREP projects. This allows the guide information to be put into proper context for decision making. These supplemental literature references will be valuable to the reader who is interested in more detailed information on a specific research topic.

Surveys consistently report that agricultural retailers and CCA's are the most influential groups for aiding farmers make management decisions. These guides will provide up-to-date information that can be easily understood and adopted.

These guides will be initially delivered to users through the internet at the WPHA website (Healthyplants.org).

DESCRIPTION

This work meets several priority areas identified by FREP.

1. Education and training of fertilizer management in areas with impaired water bodies.
2. Programs to educate growers, fertilizer dealers, students, teachers, and the general public about the relationships between fertilizers and the environment.
3. Preparation of publications and other outreach activities.

ACCOMPLISHMENTS

In this first partial year of activity, the WPHA Soil Improvement Committee selected an initial set of completed FREP research projects. The selection of projects for development into guides was based on their likelihood for adoption and impact.

These selected FREP projects are now being transformed into brief and practical field guides for farmers and CCA's. A literature review of relevant national and international research is underway to include additional supporting information. The draft guides are under review by the WPHA Soil Improvement Committee, the original researchers, and additional relevant specialists (such as crop commodity groups).

A total of 24 guides will be developed during the three-year project period

Figure 1. Example of the Nutrient Management guides that will be developed based on FREP research.

Improving Nitrogen Fertilizer Management in California

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INTRODUCTION

Groundwater is a vital resource for agriculture, urban, habitat, and industrial purposes. Recent reports have demonstrated that nitrate from agricultural activities is contributing to degradation of groundwater quality. Nitrogen fertilizer is essential to productive and sustainable agriculture. One recent report estimated that nitrogen fertilizer is responsible for the production of at least half of the global food supply (Erisman et al, 2008†).

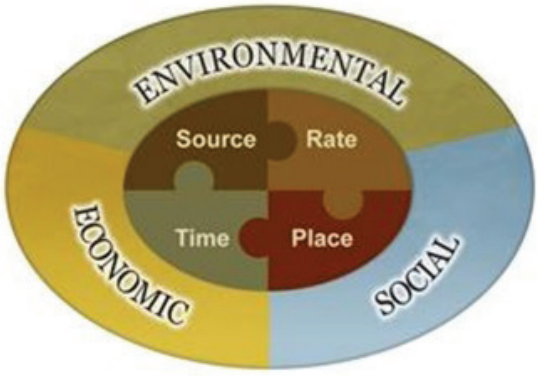

Figure 1. Proper use of nitrogen in the Right Source, the right Rate, the Right Time, and the Right Place will greatly contribute to improved nutrient stewardship and efficiency. Much of this goal will be met with greater communication and education of fertilizer users.

It is clear that advances in the use of nitrogen fertilizer can be made through improvements in the complex management decisions that are unique to every farm and cropping situation. However, the complicated dynamics of the nitrogen cycle require extensive education to integrate these factors at the field level. The 4R nutrient stewardship framework (Right Source, Right Rate, Right Time, and Right Place) provides a solid scientific foundation to make progress in improving nitrogen efficiency.

OBJECTIVES

1. Develop fact sheets on the major processes and components used in making a nitrogen budget.
2. Produce crop-specific nitrogen management guides for the top nine crops that receive the highest nitrogen application rates.
3. Prepare 4R nitrogen management guides for each these nine crops.
4. Program a web-based tool for guiding farmers and Certified Crop Advisers (CCAs) in the development of a nitrogen budget (and transfer to smartphone app).
5. Integrate the NRCS Soil Web database with the University of California Nitrate Hazard Index for web and smartphone use.
6. Adapt educational material for on-line delivery of CEUs for CCAs.

DESCRIPTION

This work meets several priority areas identified by FREP.

1. Education and Outreach: Developing and implementing educational activities that result in more efficient fertilizer use.
2. Crop Nutrients: Determining and updating crop nutrient requirements and uptake rates.
3. Improving Efficiency: Developing efficient fertilizing practices to ensure the right rate, right time, right source and product and the right place of application.

ACCOMPLISHMENTS

In this first partial year of activity, a series of "Nitrogen Essentials" fact sheets on various aspects of the nitrogen cycle have been developed to allow users to better understand the behavior of applied fertilizer. These are accessible through healthyplants.org (WPHA) or ipni.net.

The second-year focus will turn to developing crop-specific nitrogen fertilization guidelines. They will also be posted on-line as they are developed in partnership with industry and academic experts.

Development of on-line nitrogen budgeting educational tools will begin when the Regional Water Quality Control Boards have finalized their expectations for fertilizer management.

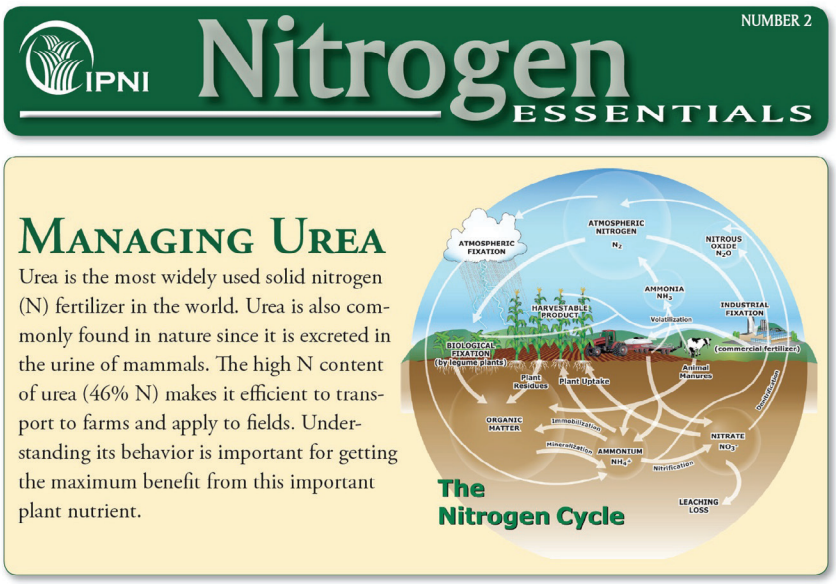

Figure 2. Example of the Nitrogen Essential fact sheets that are available online.

Characterizing N Fertilizer Requirements of Crops Following Alfalfa

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INTRODUCTION

Farmers of row and field crops (corn, small grains, tomato, cotton) in California have been under scrutiny from several quarters to more accurately match the needs of the crop with fertilizer applications. It is well known that perennial legumes such as alfalfa confer benefits to the subsequent non legume crop, especially from residual soil N from N_2 fixation. This N can be effectively absorbed by the following crop, reducing the N fertilizer need of the non-legume in rotation. However, data for quantification of this fertilizer benefit has been generally lacking in California.

Alfalfa produces between 250 and nearly 1,000 lbs. of N per acre per year (above ground), often greater than 90% originating from the atmosphere through N_2 fixation (**Table 1**). A portion of this N is available to a subsequent crop. Estimates of the residual N benefit (from roots, remaining plant parts, and soil microorganisms) from other regions have ranged between 30 and 200 lbs. per year, and in some cases may satisfy the entire N needs of a subsequent crop. There are greater than 200,000 acres of alfalfa which are rotated with other crops each year in California, yet there are no research-based data from this region to guide the quantification of this benefit. Calculation of the N benefit of crop rotations would impact overall N management, with benefits to the environment from reduced risk of leaching from excess N applications, and benefit farmers from reduced costs and optimization of N fertilizer use.

Table 1. Crop removal of Nitrogen at different alfalfa yield and protein levels. Shaded area indicates most likely range for California Central Valley locations.

	Crude Protein of Alfalfa Forage					
	16	18	20	22	24	26
	% Nitrogen in Forage					
	2.56%	2.88%	3.20%	3.52%	3.84%	4.16%
Tonnage	Crop Removal of N					
(t/a)	lbs N/acre					
5	256	288	320	352	384	416
6	307	346	384	422	461	499
7	358	403	448	493	538	582
8	410	461	512	563	614	666
9	461	518	576	634	691	49
10	512	576	640	704	768	832
11	563	634	704	774	845	915
12	614	691	768	845	922	998

Shaded area represents most likely outcome

OBJECTIVES

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

1. Quantify the quantity of N available to a subsequent wheat crop provided by rotation with alfalfa
2. Develop an N-credit recommendation for crops following alfalfa
3. To differentiate 'other' rotational benefits or disadvantages which may accrue to crop rotation following alfalfa, as distinct from N benefits

Figure 1. Crop rotation comparisons have been established at three locations in California: Tulelake, Davis, and Parlier, similar to this one at Kearney Agricultural Center in Parlier in Fresno County. Data collection will begin in late 2013.

DESCRIPTION

Crop rotation comparisons were established in 2012, utilizing existing alfalfa crops of long duration. Wheat was chosen as a test crop, since wheat is grown throughout California and is an excellent indicator crop for Nitrogen response. Sudangrass-wheat in continuous rotation were used as a non-legume rotation. Existing vigorous alfalfa fields were chosen at three different locations, and crop rotations established on portions in an experimental design in strips for two years before the test plots would be applied to allow alfalfa-wheat and non-legume-wheat rotation comparisons to have significant soil effects.

Experiments were successfully established (**Figure 1**) at Tulelake, Davis, and Parlier, CA to provide spatial replication, and two phases (2013-14, 2014-15) were implemented to enable over-year replication. The design will allow internal replications as well as 6 location-years, in two phases, incorporating the differences between Intermountain, Central valley, and Imperial Valley conditions (**Table 2**). Soil samples will characterize N profile prior to the test wheat crop. Crop uptake data in wheat will be measured with whole plant and grain samples, and yield and quality response to N will be measured following either a non-legume (wheat/sudangrass) or alfalfa. The difference method (**Figure 2**) will be used to estimate N credits ascribed to the legume—this includes non-N rotation benefits (such as soil tilth) which may be present. These data will be used to extrapolate and estimate N credits for other crops in addition to wheat following alfalfa.

Table 2. Crop Sequence for the alfalfa-wheat rotation studies.

	Year 1 (unfunded)	Year 1 (2013)	Year 2 (2014)	Year 3 (2015)
Tulelake Phase 1	Establish sudan strips	Continue Rotation Strips - Fall Wheat Establishment	Measure N response in wheat	
Tulelake Phase 2	Continuous alfalfa	Establish non-legume rotation	Continue Rotation Strips - Fall Wheat Establishment	Measure N Response in wheat
Davis Phase 1	Establish sudan strips	Continue Rotation Strips - Fall Wheat Establishment	Measure N response in wheat	
Davis Phase 2	Continuous alfalfa	Establish non-legume rotation	Continue Rotation Strips - Fall Wheat Establishment	Measure N Response in wheat
Kearney Phase 1	Establish sudan strips	Continue Rotation Strips - Fall Wheat Establishment	Measure N response in wheat	
Kearney Phase 2	Continuous alfalfa	Establish non-legume rotation	Continue Rotation Strips - Fall Wheat Establishment	Measure N Response

Locations

These are chosen for the major wheat and alfalfa growing areas of California. Wheat is chosen since it's a great test crop for N and grown throughout the state.

- **Tulelake.** This is an intermountain high elevation climate, with a high-organic matter soil, that has nevertheless been responsive to N applications in other trials. This is a 3-cut alfalfa region, where wheat is the major rotation crop.
- **Davis.** This is often considered typical or representative of the Sacramento Valley region, where wheat and alfalfa is a common rotation. These are clay loam soils with high water-holding capacity. This is a 6-7 cut alfalfa region.
- **Kearney.** This is considered to be typical of the east side of the San Joaquin valley, a Mediterranean climate, with light soils that are sandier than at Davis, with lower water-holding ability. This is a 7-8 cut region, and alfalfa-wheat rotations are very typical.

Estimating the N Rotational Benefit and N Credits

Approaches to estimating the N benefit have included a comparison of the optimum yield under non-legume rotations compared with the optimum yield with legume rotations (see **Figure 2**). This is known as the 'difference method', which compares the economic N rate of the conventionally fertilized non-legume in a grain-grain rotation, and of the non-legume grown in rotation with alfalfa. Analysis to differentiate between 'rotation effects' which may not include N supply, vs. N effects are possible using this method. These 'other' rotation effects may be due to soil structure improvement, microbiology effects, pests, or other effects separate from nitrogen supply.

CURRENT PROGRESS

Since this is a long-term study, crops were established in 2012 and 2013 to provide proper crop rotation comparisons, and sampling and data collection started in fall, 2013 through 2014 for the first phase, and will occur 2014-15 for the second phase. Thus, the first results will only be available in 2014. Successful establishment of control grain-grain rotations were accomplished at Tulelake, Davis, and Kearney (**Figure 1**). Data will be collected in the fall of 2013 to estimate these N effects. This study was featured at field days at the Tulelake Research and Extension Center, at UC Davis, and and UC Kearney Ag Research and Extension Center in May, 2013, July, 2013, and September, 2013. This enabled valuable feedback from farmers, fertilizer experts, and scientists. The results of this study should enable the agricultural sector to promote more sustainable techniques which will reduce the risk to groundwater from excess and unnecessary N applications and better utilize the benefits of crop rotation.

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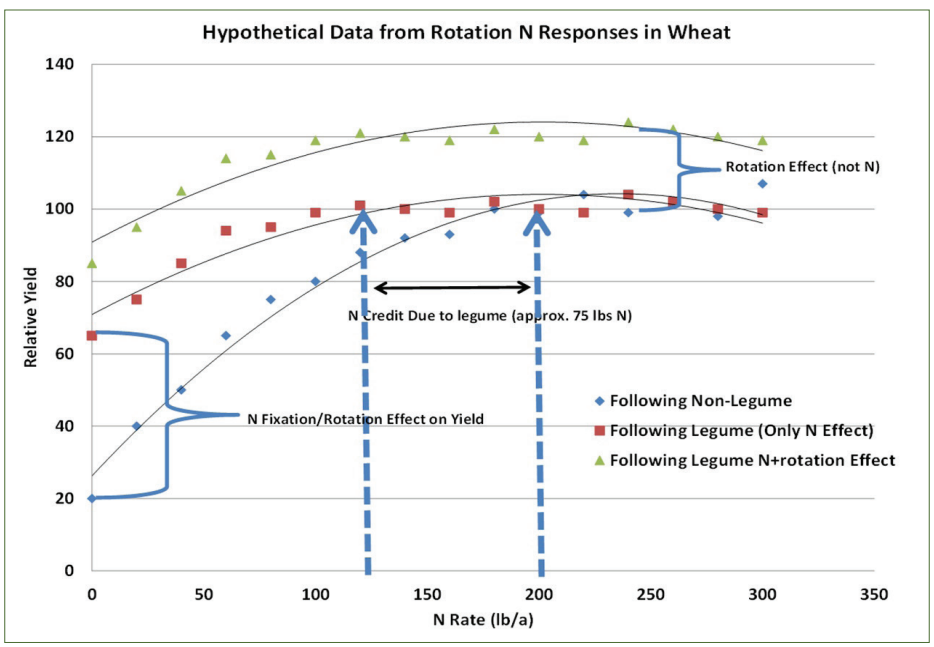

Figure 2. Hypothetical data indicating the 'difference method' for quantification of the N benefits of a crop following alfalfa. This may be distinct from non-N effects such as soil structure or disease effects in a crop in rotation.

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

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INTRODUCTION

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

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

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

OBJECTIVES

The objective of this project is to:

1. Develop economically viable and effective sampling protocols to generate prescription maps for the variable rate application of P,
2. Compare variable rate P application to current methods and evaluate alternative economic outcomes.

In the first phase of the project we will test alternative sampling schemes. Sampling schemes evaluated will include grid sampling at various resolutions, samples schemes which seek to define zones directed by other indices of in-field variability. In the second phase we will evaluate the efficacy and economic returns to variable rate P application. Project success will be the development of economically viable protocols for the implementation of variable rate P application technologies.

DESCRIPTION

Task 1

Although the project was started in 2013, most planting, and certainly all fertilization was already complete. Therefore, field work could not begin until fall 2013. During the spring and summer of 2013 equipment was built, cooperators, were secured. Field surveys and sampling began in September 2013.

Task 2, 3, 4 and 5.

There were no activities related to these task at this reporting period.

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 with integrated GPS receiver and variable-rate function unlocked, Field IQ, 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 P fertilizer.

In September we performed soil EC surveys at three locations for zone sampling (Figure 1). Sites were located in Imperial County, CA (Bard), Riverside County CA (Coachella Valley) and Yuma AZ. Processed EC measurements in USDA-ESAP was used to locate soil samples for zone sample method based on natural variability of the soil. Immediately after these surveys we collected soil samples for both grid and zone based fertilizer application comparisons.

Figure 1. Veris and EM38 survey in the Coachella Valley, Riverside County, CA.

Exploring the Potential for Using Transgenic Crops for Improved Fertilizer Use Efficiency

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INTRODUCTION

Crops produced in the desert receive large annual applications of nitrogen (N) and phosphorus (P) 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. Nitrate might also be lost as N2 and N2O gasses via denitrification 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. Nitrogen fertilizer production depends on natural gas availability and prices.

Amounts of P applied to crop production systems often approach and exceed 200 kg P/ha and crop recoveries of P fertilizers are generally less than 20%. While much of the added P is converted to insoluble forms in the calcareous soils of the region, some of it is potentially carried off 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 compromise world food production.

Over the past two decades, researchers with the Universities of Arizona and California have developed strategies for efficient nutrient management. For N, these practices include fertilizer timing or controlled release fertilizers, pre-sidedress plant and soil testing, and improved irrigation management. For P, these practices include soil test based fertilizer recommendations and exploitation of innovative placement technologies. However, the possibility of genetic modifications to commercial crops for improved fertilizer use efficiency has received little attention. A high fertilizer use crop such as lettuce shows very little variation in response to fertilizer, among commercial cultivars currently used.

More recently, it has been shown that over-expression of type I H+ -pyrophosphatase AVP1 (AVP, Arabidopsis vacuolar pyrophosphatase) contribute positively to many energetic plant processes including general growth, nutrient acquisition, and stress response. This genetic modification enhances nutrient uptake by affecting the abundance and activity of the plasma membrane H+-ATPase in a manner that correlates with apoplastic pH alterations and rhizosphere acidification. Rhizosphere acidification is a central mechanism for plant mineral nutrition since it contributes to nutrient solubility and the plasma membrane proton motive force. Preliminary data we have collected show the potential for yields of AVP1 romaine lettuce to be maximized with less P fertilizer than that required for conventional cultivars.

OBJECTIVES

The objectives of this project are to evaluate the potential for using AVP1 modified plants for improved nutrient use efficiency under desert cropping systems. Studies will include potato, lettuce, and cotton. Field studies will include N and P rate studies and comparisons of AVP1 modified cultivars and conventional cultivar counterparts. Additionally, we seek to genetically modify iceberg lettuce for AVP1 expression and perform preliminary evaluations of these modifications.

DESCRIPTION

Task 1

During 2012 we completed subtask 1a by transforming two cultivars of iceberg lettuce for AVP1-OX. We have grown out T1 seed from at least five transgenic events from each of these modified cultivars in the greenhouse. We are now screening (subtask 1b) this germplasim using our selectable marker (Kanamycin) and growing out T2 seed (subtask 1c).

Task 2

We initiated some small field studies and seed increases with AVP1 modified potato in spring 2012 (subtask 2a). Unfortunately, for potato, it seems this transformation produces an excess number of potatoes, none of which makes acceptable size. However, at the prospect that potato will not work, we have initiated studies with AVP1-OX tomato.

Our initial experiment with tomato was conducted in the greenhouse. Three gallon pots were filled with a 50:50 blend of Grande (fine-loamy, mixed, hyperthermic,Typic Natriargid (reclaimed)) and silica sand to facilitate automatic irrigation without soil cracking. The pre-plant Olsen P test was < 5 mg/kg. All pots received 1.5 g of N as a controlled release N fertilizer (ESN distributed by Agrium Advanced Technologies) so that N would not be limiting. The experimental P rates were 0, 0.125, 0.25, 0.5, and 1.0 g P/pot applied as triple superphoshate. Tomato transplants grown in greenhouse trays were transplanted one plant per pot.

In 2012 we grew out a cotton seed increase (subtask 2b) in the greenhouse due to isolation challenges.

Task 3

Several field and greenhouse studies with N and P were conducted with AVP1-OX romaine lettuce. In most cases we conducted backup greenhouse studies for more intensive sampling since all plant and soil material are regulated articles and the logistics of transporting large numbers of samples from the field to the laboratory and subsequent disposal is onerous (double leak proof containment), laborious, and often cost prohibitive. The experimental design for all greenhouse experiments was randomized complete block with four replications. The treatment design for the field experiments was split plot where fertilizer rate was the main plot and cultivar the subplots. Statistical analyses were performed using SAS where responses to N or P were evaluated by trend analysis and differences among cultivars by least significant difference.

N Studies. Surface soil mapped as Casa Grande (fine-loamy, mixed, hyperthermic,Typic Natriargid (reclaimed)) was collected at the Maricopa Agricultural Center, sieved, and 1.6 kg were weighed into 15 cm diameter pots. The pre-plant nitrate-N test for this soil was 50 mg kg-1. All pots received 0.34 g P as mono-calcium phosphate so that P would not be limiting. The treatments included 'Conquistador' (also referred to as conventional or WT), AVP1D2, and AVP1D6 romaine lettuce and N rates. The AVP-OX lines are transformed 'Conquistador'. The total seasonal rates of N were 0, 0.1, 0.2, 0.4, and 0.8 g N per pot. The N was applied as a potassium nitrate solution in eight split applications to achieve these seasonal total rates. The potassium nitrate solution was labeled with 10 atom percent 15N.

Lettuce seedlings (one-leaf stage) were transplanted into the pre-watered pots. The first N fertilization occurred 5 days after transplanting and continued twice weekly through harvest. These plants were grown to the eight-leaf stage and harvested by cutting the above ground plant at the soil surface. Total leaf area was measured using a LiChor area meter (LI 3100 C), and fresh and dry weights were determined as described above. Total N and 15N percent were determined by combustion mass spectroscopy.

A field study was planted in the same field where we collected soil for the greenhouse experiment. The entire plot area received 125 kg P ha-1 as mono-ammonium phosphate which is the common practice for low P testing soils. Thus, the entire plot area also received 54 kg N ha-1 with the pre-plant phosphate fertilizer.The N rate treatments of 0, 50, 100, 150 and 200 kg N ha-1 (not including that applied with the pre-plant phosphate fertilizer) were applied pre-plant as a polymer coated urea controlled release N product (ESN distributed by Agrium Advanced Technologies). All N and P fertilizers were roto-mulched into the beds. Individual main plots were 25 m^2 and the experimental design was randomized complete block with four replications.

Lettuce cultivars were seeded in elevated double row beds on 1 m centers with a hand planter (Jang JP1 Clean Seeder) and thinned by hoe at the four-leaf stage to approximately 71,000 plants per hectare. The

stands were established by sprinkler irrigation. After establishment, all required irrigations were applied by level (no slope) furrows. Lettuce was harvested at maturity by cutting and weighing all plants from 3 m of double row beds. Marketable yield was determined after grading using standard practices.

P Studies. We conducted four separate greenhouse studies to evaluate the response of conventional and AVP1-OX romaine lettuce to P. For the first experiment we used a Superstition sand (sandy, mixed, hyperthermic Typic calciorthid), for the second and third experiments we used Casa Grande (fine-loamy, mixed, hyperthermic,Typic Natriargid (reclaimed)). These three experiments were watered as needed by hand. For the fourth experiment we used a 50:50 mix of Casa Grande and silica sand because we used an automatic irrigation system and we did not want soil cracking to compromise irrigations. In all experiments 1.6 kg of soil were weighed into 15 cm diameter pots. The pre-plant Olsen soil test levels were < 7 mg/kg in all these greenhouse studies.

All pots received 0.8 g N so that it was not limiting. In experiments 1 through 3 we used split applications of potassium nitrate. In experiment 4, we used a controlled release fertilizer (ESN). The P rates were 0, 0.04, 0.08, 0.17, and 0.34 g P/pot applied as triple superphosphate. All P fertilizers were applied pre-plant. Lettuce seedlings (one-leaf stage) were transplanted into the pre-watered pots and whole above-ground plants were harvested at the eight-leaf stage.

Three field studies were conducted in 2012 on a field mapped as Casa Grande (fine-loamy, mixed, hyperthermic,Typic Natriargid (reclaimed)). However, for purposes of discussion we included another field study conducted in 2011 on an Indio silty clay loam (mixed hyperthermic Typic Torrifluvent) before we had FREP funding. The study conducted in 2011 before FREP funding had a pre-plant Olsen P test of 25 mg/kg. The P source in the study was mono-ammonium phosphate because this is what growers primarily use in the desert for vegetables. This study was direct seeded using an air-planter.

The first study conducted in 2012 with FREP funding was with transplants. The P source in this study was triple superphoshate. The transplants were produced in a greenhouse and set in the field with a mechanical transplanter. The study had a pre-plant Olsen P test of <5 mg/kg. The second study in 2012 had the same P source but was direct seeded using a hand planter (Jang JP1 Clean Seeder). This study had a pre-plant Olsen P test of <5 mg/kg. For the third study in 2012, we again used mono-ammonium phosphate as the P source. The study also had a pre-plant Olsen P test of <5 mg/kg. The P rates in all four field experiments were 0, 25, 50, 75, and 100 kg P/ha. All P fertilizer was applied pre-plant onto the beds and power-mulched into the soil. N was applied to the entire plot area so that it would not limit production. A total N application of 200 kg/ha was applied as a combination of sidedress and water run applications. The lettuce was thinned by hoe at the four-leaf stage to approximately 71,000 plants per hectare. The stands were established by sprinkler irrigation. After establishment, all required irrigations were applied by level (no slope) furrows. Lettuce was harvested at maturity by cutting and weighing all plants from 3 m of double row beds. Marketable yield was determined after grading using standard practices.

Task 4

In the spring of 2013 we initiated field evaluations with AVP-OX potato, tomato, and cotton. The fields used for tomato and cotton were mapped as Casa Grande loam (fine-loamy, mixed, hyperthermic,Typic Natriargid (reclaimed)). The P rates for both studies were 0, 50, and 100 kg P/ha. The experimental design was split-plot with fertilizer as the main plot and cultivar as the sub-plot.

The cotton experiment was conducted on a soil mapped as Superstition sand (sandy, mixed, hyperthermic Typic calciorthid). We had to conduct the cotton experiment in a citrus area to obtain the APHIS mandated isolation. For the N study, the rates of fertilizer were 0, 75, 150, and 225 kg N/ha. For the P study, the rates were 0, 25, 50, and 75 kg P/ha. The treatment design was split plot with fertilizer main plots and cultivar (conventional and AVP-OX) sub-plots.

Task 5

Two studies evaluating the response of AVP-OX romaine lettuce to N and water. We seeded romaine studies on irrigation and N fertilization on November 5, and December 22. The first and second lettuce romaine studies were harvested on April 4 and April 26, respectively.

RESULTS

Task 1

Screening and seed increase of our newly transformed AVP-OX iceberg lettuce continues. We should have sufficient seed to take our AVP-OX iceberg lettuce to the field in the fall 2013.

Task 2

In 2012 potato from all AVP-OX plots were numerous but small. No yield difference among cultivars was observed. However, at the prospect that potato will not work, we have initiated studies with AVP1-OX tomato.

Figure 1. Image demonstrating tomato growth to increasing P rate (left to right) and conventional (front) and AVP-OX (back) tomato.

Overall, the AVP1-OX tomato showed more rapid growth and development compared to the conventional type across all P rates (**Figure 1**). The yield data are interesting where early production was higher for AVP1-OX tomato compared to the conventional at all P rates (**Figure 2**). However, as harvests continued, cumulative yields at higher P rates were greater for the conventional compared to the AVP1-OX tomato. For example, maximum yields of AVP1-OX tomato were approximately 1200 g fresh fruit per pot at 0.125 g P/pot and were significantly greater than the conventional at this P rate. However, AVP1-OX tomato showed no further increase to higher P rates while conventional did, ultimately out-yielding the AVP1-OX tomato at P rates greater than 0.125 g P/pot.

Task 3

N Studies. Lettuce above ground dry matter and significantly (P<0.01) increased by N rate (**Figure 3**). Furthermore, cultivar effects were also statistically significant where AVP1D6 outperformed AVP1D2 which in turn outperformed the conventional conquistador.

Romaine lettuce showed a significant (P<0.05) quadratic response in the field where marketable yields were essentially maximized to the first N rate (50 kg N ha-1) and N rates beyond 100 kg N ha-1 reduced yields (**Figure 4**). Cultivar response was highly significant (P<0.01) where both AVP1D2 and AVP1D6 produced more marketable yield across all N rates compared to unmodified Conquistador.

P Studies. In all greenhouse experiments, lettuce dry matter yields increased to P rate (**Table 1**). Further, the AVP-OX lettuce consistently outperformed the conventional "Conquistador". In all field experiments there was response to P and there were significant differences among cultivars (**Table 2**). In experiment 1 (2011), response to P was small as pre-plant soil test were 25 mg/kg. Lettuce typically does show some response

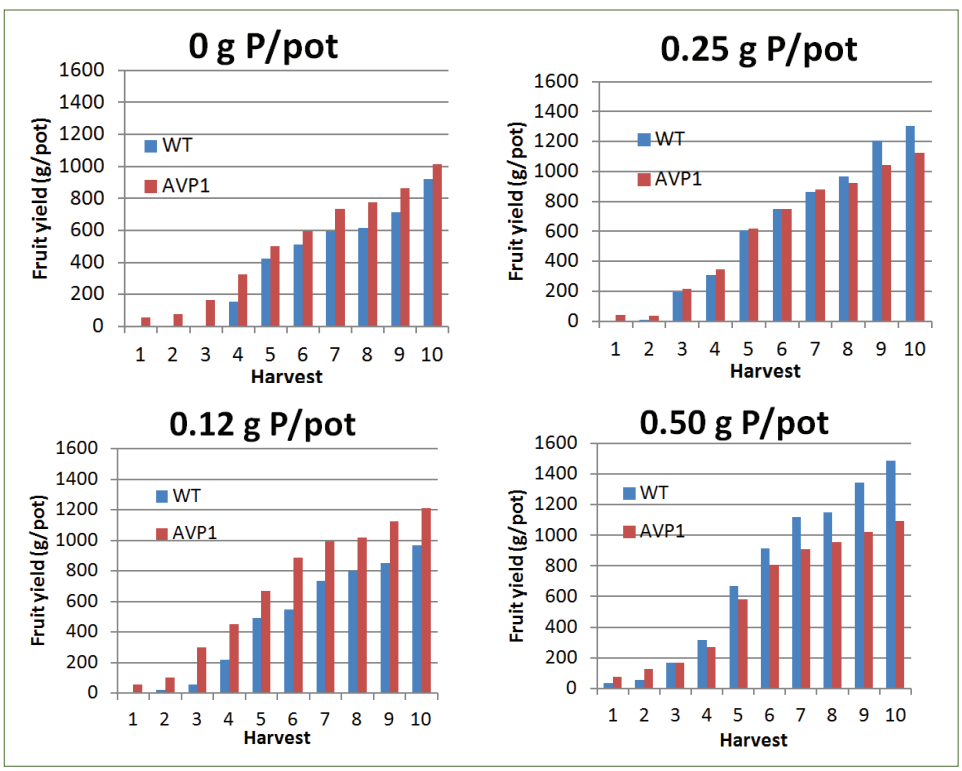

Figure 2. Cumulative fruit yield of greenhouse tomato by P rate and cultivar.

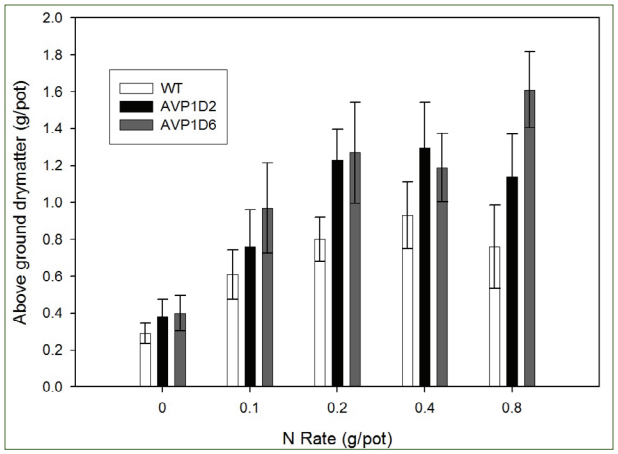

Figure 3. Dry weight of conventional and two selections (AVP1D2 and AVP1D6) of modified romaine lettuce to N.

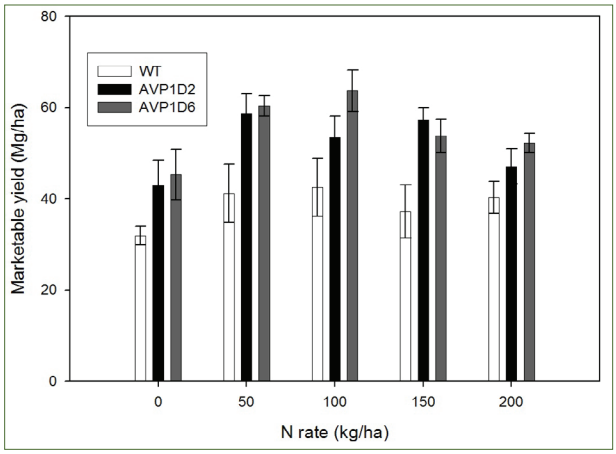

Figure 4. Marketable yield of conventional and two selections (AVP1D2 and AVP1D6) of modified romaine lettuce in a field N study.

Table 1. Main effect dry matter means in greenhouse P experiments to P rate and cultivar.

Treatments	Experiment			
P rate (g/pot)	1	2	3	4
Above-ground dry matter (g/pot)				
0	1.33	0.65	0.15	0.17
0.04	2.88	1.1	0.52	1.42
0.08	2.91	1.6	0.80	1.95
0.17	3.25	1.65	0.87	2.86
0.34	3.24	2.17	0.94	3.71
	L*Q**	L**	L**Q**	L**Q*
Cultivar				
Conventional	1.74a	1.06a	0.56a	1.52a
AVP1D2	3.19b	1.77b	0.71b	2.48b
AVP1D6	3.23b	1.47ab	0.69ab	2.06ab

*,**Significant linear (L) and quadratic (Q) responses to P rate at P<0.05 and P<0.01, respectively. Cultivar effect followed by same letter were not significant at P=0.05.

Table 2. Main effect marketable yield means in field P experiments to P rate and cultivar.

Treatments	Experiment			
P rate (kg/ha)	1	2	3	4
Marketable yield MT/ha				
0	28.0	47.3	33.0	37.0
25	36.7	49.9	38.5	55.6
50	34.3	52.0	41.9	63.6
75	34.8	59.2	39.8	75.2
100	38.7	57.4	42.2	72.6
	L**	L**	L*	L**Q*
Cultivar				
Conventional	31.5a	47.5a	35.5a	51.9
AVP1D2	36.7b	52.2a	40.3ab	63.8
AVP1D6	35.2b	59.2b	41.4b	66.7

*,**Significant linear (L) and quadratic (Q) responses to P rate at P<0.05 and P<0.01, respectively. Cultivar effect followed by same letter were not significant at P=0.05.

to P fertilizer up to Olsen soil test P of 35 mg/kg and there was a modest response to P for the conventional cultivar (**Figure 5**). However, yields of the AVP1-OX romaine lettuce were near maximum and significantly higher than the conventional cultivar when no P was added suggesting these plants can take up P that the unmodified cultivar could not.

In the experiments conducted on a low P testing soil (experiments 2 through 4), marketable yields were generally higher for AVP1-OX lettuce across most P rates (**Table 2 and Figure 6**). Interestingly, marketable yields for AVP1D6 lettuce were generally a little higher compared to AVP1D2 lettuce, although usually not statistically significant. This is in contrast to the greenhouse experiments where dry matter was generally higher for AVP1D2 compared to AVP1D6, although not statistically significant. We have other data showing greater root growth for AVP1D6 compared to AVP1D2 and perhaps in the greenhouse the pots restricted root growth.

Task 4 and 5

Analysis of data collected in 2013 for these tasks is not yet complete.

DISCUSION AND CONCLUSIONS

Overall, the large number of greenhouse and field experiments conducted with lettuce show that AVP1-OX shows great promise as a tool for improving nutrient use efficiency in the desert. AVP1-OX lettuce consistently outperformed conventional lettuce at most N and P rates in greenhouse and field experiments. The inconsistent results with tomato were surprising. While AVP1-OX lettuce outperformed conventional lettuce at all P fertilizer levels, AVP1-OX tomato only outperformed conventional tomato at suboptimal P levels. Perhaps the differences observed between lettuce and tomatoes are associated with a crop harvested in a vegetative state such as lettuce, and a crop harvested at a reproductive state, such as tomato. Perhaps the differences are associated with root limitation in pots where we only have greenhouse data to report for tomato at this time. Pot restriction on root growth may also explain the different relative responses of AVP1D2 and AVP1D6 in greenhouse compared to field experiments. The AVP1D2 was slightly better than AVP1D6 in greenhouse experiments but the reverse was true in the field. Field studies conducted with tomato in 2013 may shed light on this inconsistency.

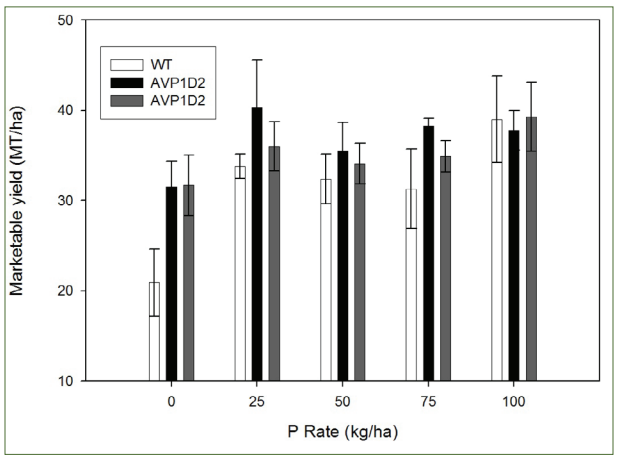

Figure 5. Marketable yield of conventional and two selections (AVP1D2 and AVP1D6) of modified romaine lettuce to P fertilizer in field experiment 1.

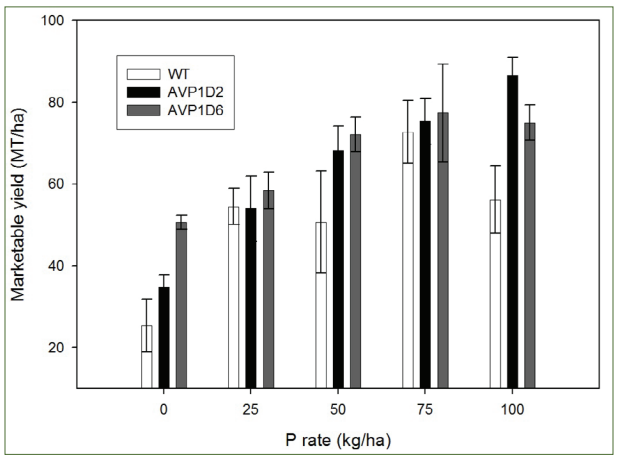

Figure 6. Marketable yield of conventional and two selections (AVP1D2 and AVP1D6) of modified romaine lettuce to P fertilizer in field experiment 4.

Optimizing the Use of Groundwater Nitrogen for Nut Crops

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INTRODUCTION

The overarching objective of this project is to test the efficacy of the pump and fertilize approach to nitrogen (N) management in nut crops. The problem of N loss to water (and air) is currently one of the most important challenges to environmental sustainability for California agriculture. Nitrate (NO_3^-) is the primary contaminant of well waters and NO_3^- contamination of water is believed to be "overwhelmingly the result of crop and animal agricultural activities" (Harter et al. 2012), particularly the application of synthetic fertilizers to irrigated crops. In addition, nitrogen fertilizer applications result in emissions from soils of nitrous oxide (N_2O), a greenhouse gas 300 times more potent than CO_2 and that can offset greenhouse gas mitigation by photosynthetic CO_2 assimilation by perennial crops. In order to assist growers and agencies in understanding this problem and its mitigation will require multi-disciplinary approaches. Information is needed to inform and satisfy impending regulatory demands and to provide growers with improved management tools. Nitrate present in groundwater (GWN) is a potential source of N for crop use, and can potentially reduce fertilizer costs to growers, reduce N concentrations in irrigation water and hence reduce N loading to the environment. The overall goal of this project is to examine, and provide demonstration sites to optimize understanding of the utility of the 'pump and fertilize' (P&F) approach for integrated N management in Almonds and Pistachio. It basically tests the hypothesis, in a vertically integrated, multidisciplinary project if a unit of N in ground water is functionally equivalent to a unit of synthetic N fertilizer applied to these systems.

OBJECTIVES

1. Establish research and demonstration orchards for pump and fertilize (P&F) approach to N management in Almond and Pistachio within 'hydrogeologically vulnerable areas' (HVAs) and contrast with advanced grower practices.
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 develop metrics for those practices with P&F N management treatments.
3. Characterize key biological and physical parameters relevant to the P&F concept (seasonal plant-soil N balance, soil NO_3^- and water movement).
4. Establish proof of concept for use of stable isotopes of $^{15}NO_3^-$ in N tracing under P&F practices.
5. Develop and ground verify decision support models (including HYDRUS) to assist growers with optimal management of groundwater nitrogen.
6. Demonstrate and proactively extend developed results, technologies and BMPs to growers.

DESCRIPTION

To achieve the stated objectives, this project aims to integrate among the multidisciplinary expertise of orchard N management (PH Brown), nitrogen biogeochemistry and root biology (DR Smart) and both vadose zone hydrology (J Hopmans) and ground water hydrology (TH Harter). The proposed experiments are currently in the planning stages and are moving forward with continuous dialogue with the primary stakeholder

groups supporting the project and with intensive scrutiny of proposed areas and sites (orchards).

RESULTS AND DISCUSSION

Site Selection

We anticipate a total of two to three sites. One site is located in an HVA (USGS, 2000) on the East side of the Southern San Joaquin Valley. The area is located between the city of Madera on the North, the San Joaquin River on the South and West and was scrutinized during the first half of 2013. We intensively characterized candidate orchards in the area for depth to ground water (GW), inter-annual variation in GW levels, NO_3^--N levels in irrigation water wells and characterization of soil horizons in open pit profiles (**Figure 1**). Numerous pit and soil samples were analyzed for particle size distribution, saturated conductivity (K_{sat}), bulk density (compaction) and are currently undergoing comprehensive soil chemical analyses. These data layers were combined with soil NRCS databases and mapped using GIS tools to reveal extreme heterogeneity (as expected) within and between targeted orchards (**Figure 2**). The above careful compilation of data for this area allowed for selection of initial orchards to be used in this CDFA-FREP funded experiment. For the almond and pistachio orchards identified, trials are being established for replicated experiments that test nitrogen balance and nitrogen use efficiency (NUE) for P&F N management. While those experiments are being established for the 2014 season, one to two other sites are being evaluated in a similar manner with the goal of establishing experiments for 2014.

Figure 1. In the left hand panel, MSc student Nicole Niehues gathers samples from specific horizons for soil chemical and physical analysis. In the right hand panel indicates exposure of roots for assessment of rooting depth and therefore a metric for the depth to which instrumentation to monitor water and NO_3^- movement will be installed.

Figure 2. NRCS soil contours for the area under investigation shows extreme intra- and inter-orchard variation indicating it's a good initial site for examining the influence of soil on P&F.

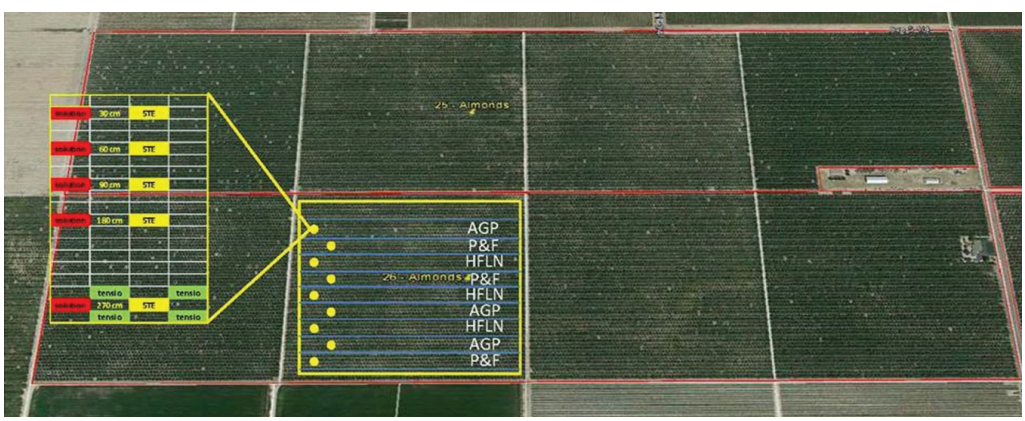


Figure 3. Randomized complete blocks experimental design being plumbed into a 90 acre orchard to test efficacy of pump and fertilize (P&F), advanced grower practice (AGP) which consists of split N applications targeted to peak root growth and tree N demand and high frequency low nitrogen (HFLN) applications ('spoon feed') . Yellow circles indicate trees intensively instrumented to monitor water and NO_3^- movement to below the root zone. Each row represents an increment in soil depth while red, green and yellow cells represent positioning of tensiometers, soil moisture and suction lysimeter positions.

Nitrogen Management Experiment

The P&F approach rests upon the assumption that a pound of nitrate in groundwater is equivalent to a pound of properly managed nitrogen from fertilizer. On a purely chemical basis, this assumption is correct, in the context of orchard nutrient supply however, this assumption may not be biologically or functionally valid since GWN will often be applied at lower concentrations and at different phenological stages than well managed N fertilizers would be. Further, while the timing of N application during the year and during a fertigation event can be controlled by the grower, GWN will be delivered according to irrigation schedules and will generally be uniform through all irrigation events and thus may be differentially susceptible to leaching loss. Soil properties, irrigation management, crop nutrient status, and crop demand can all interact to alter these dynamics.

The pump and fertilize approach for N management will be contrasted with widely adopted grower practices of split applications targeted to periods of heightened root growth and/or phenological stages of high N demand such as nut fill. The almond orchard in the SJV HVA are high producing 12 year old Nonpareil/Monterey planting located approximately 1 mile from the westward meander of the San Joaquin River south of Madera. The funded experiments consist of three N management scenarios proposed and approved by the CDFA FREP program panel. The most critical experiment consists of pump and fertilize (supplementing GW NO_3^- with synthetic fertilizer applications. This primary management scenario will be contrasted with targeted, split applications targeted to root flushes and stages of high N demand (nut fill) and high frequency, low N applications (spoon feed).

For the N management experiment we'll conduct at least one experiment on almond and one on pistachio in the described HVA. The future two to three sites will consist of almond, pistachio or walnut depending on site characteristics and plantings in the optimal identified locations. The primary and routine data collected from each treatment in each orchard will be used to develop a nitrogen balance including harvestable fruit, leaf, wood and root absorbed N contrasted among N applied as GW (P&F), synthetic applied N (AGP and HFLN) will be used to characterize nitrogen use efficiency (NUE, here defined as N applied versus N assimilated), status (5 in-season leaf samples), tree nutrient demand (sequential crop estimation and determination). The ongoing project of Brown and colleagues has already established very clear differences in crop yield and nitrogen demand and represents an ideal background framework for this work.

Five suction lysimeters, five soil moisture sensors and four soil tensiometers will be installed at appropriate depths for monitoring root zone water and NO_3^- movement and concentration. These data will help elucidate whether or not P&F versus the other potential BMPs being evaluated in this investigation will realistically minimize accumulation of potentially leachable NO_3^- below the rooting zone.

Ground Water Monitoring Component

One issue that has emerged from our preliminary characterization of the first site is extreme variation of NO_3^- in well waters within an approximate 10 square mile area (**Figure 4**). The well waters selected for this experiment consist of roughly 10 ppm NO_3^--N and therefore would result in the application of about 100 units of N per season if a irrigation amount of approximately 4 acre feet is assumed.

Results from 2013 samples are still in progress, since the amount of field sampling has so far exceeded the capacity of laboratories to process the samples. Included are natural abundance levels of the stable isotope of ^{15}N on well water NO_3^-, fertilizer sources, soil solution NO_3^-, soil and water quality (chemical) analyses. The following data provides profile horizon textural data derived from the hygrometer method.

NO3-N (mg/L)	Lbs. N /acre @ 4 ac/ft/yr	Well #
2.79	30.27	30
8.62	93.51	31
9.65	104.68	33
4.15	45.02	34
4.06	44.04	35
3.00	32.54	36
0.19	2.06	39
0.79	8.57	43
4.73	51.31	45
4.87	52.83	46

Figure 4. Graphic showing extreme variation of NO_3^- in well waters within an approximate 10 square mile area of the first site.

The following images and tables indicate particle size distribution with depth for 10 candidate orchards (outlined in red) whose characteristics of proximity to high NO_3^- irrigation well water, depth to ground water, perceived grower cooperation and location within the identified HVA rendered them optimal for use in the proposed experiments. Three of the orchards are pistachio orchards and seven are almond orchards.

RECOMMENDATIONS

Because of the variability we encountered on a square mile basis of NO_3^--N in irrigation water it is apparent that a P&F program will be highly site specific. Thus, it will be critical to have site specific and temporal measurements of well water NO_3^--N.

ACKNOWLEDGEMENTS

The California Department of Agriculture Fertilizer Research and Education Program (CDFA FREP), the Almond Board of California and the California Pistachio Research Board have provided support for this effort.

LITERATURE CITED

Harter, T., & Lund, J. R.et al. (2012). Project and Technical Report Outline Technical Report 1 Addressing Nitrate in California' s Drinking Water, (March).

State Water Boards (2000) Hydrogeological Vulnerable Areas Map (http://www.waterboards.ca.gov/gama/docs/hva_map_table.pdf)

Pi-19A-1	
0-8"	Sandy Loam
8-16"	Sandy Loam
16-22"	Sandy Loam
22-32"	Loam
32-40"	Silt Loam
40-48"	Loam
48-56"	Sandy Loam
56-64"	Loam

Pi-19B-1	
0-8"	Loamy Sand
8-16"	Sandy Loam
16-24"	Sandy Loam
24-32"	Loamy Sand
32-40"	Loamy Sand
40-48"	Loamy Sand
48-56"	Loamy Sand
56-64"	Loamy Sand

Pi-19A-2	
0-8"	Sandy Loam
8-16"	Sandy Loam
16-22"	Sandy Loam
22-32"	Sandy Loam
32-40"	Sandy Loam
40-48"	Sandy Loam
48-56"	Loam
56-64"	Silt Loam

Pi-19B-2	
0-8"	Sandy Loam
8-16"	Sandy Loam
16-24"	Loam
24-32"	Sandy Loam
32-40"	Sandy Loam
40-48"	Loam
48-56"	Loam
56-64"	Sandy Loam

Al-21-1	
0-8"	Loamy Sand
8-16"	Loamy Sand
16-24"	Loamy Sand
24-28"	Loamy Sand
28-32"	Loamy Sand
32-	Impermeable

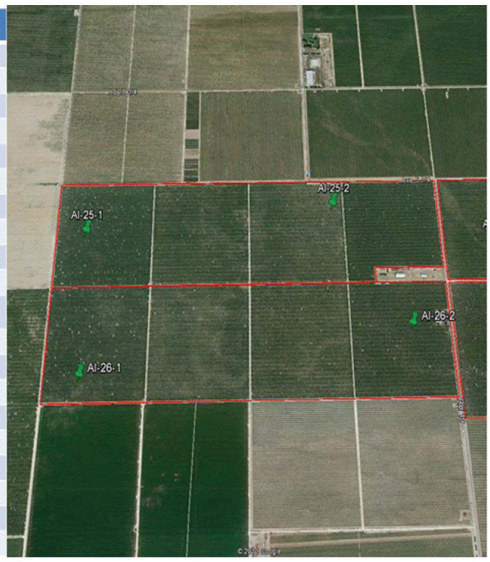
Al-22-1	
0-8"	Loamy Sand
8-16"	Loamy Sand
16-24"	Loamy Sand
24-32"	Loamy Sand
32-40"	Loamy Sand
40-48"	Loamy Sand
48-56"	Sand
56-64"	Sand

Al-17-1	
0-8"	Sandy Loam
8-16"	Sandy Loam
16-24"	Sandy Loam
24-32"	Sandy Loam
32-40"	Sandy Loam
40-48"	Sandy Loam
48-56"	Sandy Loam
56-64"	Sandy Loam

Al-17-2	
0-8"	Loam
8-16"	Loam
16-24"	Loam
24-28"	Sandy Loam
28-32"	Sandy Loam
32-40"	Loamy Sand
40-48"	Loamy Sand
48-56"	Loamy Sand
56-62"	Sandy Loam
62-64"	Loamy Sand

Al-25-1		Al-25-2	
0-8"	Sandy Loam	0-8"	Loamy Sand
8-16"	Loamy Sand	8-16"	Loamy Sand
16-24"	Sandy Loam	16-24"	Sandy Loam
24-32"	Loamy Sand	24-32"	Loamy Sand
32-40"	Loamy Sand	32-40"	Loamy Sand
40-48"	Loamy Sand	40-48"	Sand
48-56"	Loamy Sand	48-56"	Loamy Sand
56-64"	Sand	56-61"	Sand
		61-64"	Loamy Sand

Al-26-1		Al-26-2	
0-8"	Loam	0-8"	Sandy Loam
8-16"	Sandy Loam	8-16"	Loamy Sand
16-24"	Sandy Loam	16-24"	Loamy Sand
24-29"	Sandy Loam	24-32"	Loamy Sand
29-40"	Sandy Loam	32-40"	Loamy Sand
40-48"	Sandy Loam	40-48"	Sandy Loam
48-56"	Loam	48-56"	Loamy Sand
56-64"	Silt Loam	56-64"	Loamy Sand
61-64"	Loamy Sand		



Al-54-1		Pi-52-1	
0-8"	Sandy Loam	0-8"	Sandy Loam
8-16"	Sandy Loam	8-16"	Sandy Loam
16-24"	Sandy Loam	16-24"	Sandy Loam
24-32"	Sandy Loam	24-32"	Sandy Loam
32-40"	Sandy Loam	32-40"	Loam
40-48"	Sandy Loam	40-48"	Loam
48-56"	Loam	48-56"	Sandy Loam
56-64"	Silt Loam	56-64"	Sandy Loam

Al-54-2		Pi-52-2	
0-8"	Sandy Loam	0-8"	Sandy Loam
8-16"	Sandy Loam	8-16"	Loamy Sand
16-24"	Loamy Sand	16-24"	Sandy Loam
24-32"	Loamy Sand	24-32"	Loamy Sand
32-40"	Sandy Loam	32-40"	Sandy Loam
40-48"	Loamy Sand	40-44"	Sandy Loam
48-56"	Loamy Sand	44-51"	Loamy Sand
56-64"	Loamy Sand	52-55"	Sandy Loam
		55-	Impermeable

Pi-70-1		Pi-70-3	
0-8"	Sandy Loam	0-8"	Sandy Loam
8-16"	Sandy Loam	8-16"	Loam
16-24"	Sandy Loam	16-24"	Sandy Clay Loam
24-32"	Sandy Loam	24-32"	Sandy Clay Loam
32-40"	Sandy Loam	32-40"	Sandy Loam
40-48"	Sandy Loam	40-48"	Sandy Loam
48-56"	Sandy Loam	48-55"	Sandy Loam
56-64"	Sandy Loam	55-64"	Loamy Sand

Pi-70-2		Pi-70-4	
0-8"	Sandy Loam	0-8"	Sandy Loam
8-16"	Sandy Loam	8-16"	Sandy Loam
16-24"	Sandy Loam	16-22"	Sandy Loam
24-32"	Sandy Loam	22-32"	Sandy Loam
32-40"	Sandy Loam	32-40"	Sandy Loam
40-48"	Sandy Loam	40-48"	Sandy Loam
48-51"	Sandy Loam	48-56"	Loamy Sand
51-56"	Silt Loam	56-64"	Loamy Sand
56-64"	Silt Loam		

Survey of Nitrogen Uptake and Applied Irrigation Water in Broccoli, Cauliflower and Cabbage Production in the Salinas Valley

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INTRODUCTION

Vegetable production on the Central Coast is dominated by cool season vegetables. The N uptake pattern of lettuce, which has the most acreage in this region, has been examined in numerous studies over the past 15 years. The information provided by these studies has proven useful for this industry to respond to regulations proposed by the Central Coast Regional Water Quality Control Board (CCRWQCB) to regulate N application. However, other crops that have significant acreage and value on the Central Coast include broccoli, cauliflower and cabbage but have not received the same level of attention because they do not have commodity board support. These crops also play an important role in achieving water quality goals set by the CCWQCB.

The overall goal of this project is to provide detailed measurements of total N uptake and the N uptake pattern of broccoli, cauliflower and cabbage. Total applied N is critical to crop production, but irrigation efficiency is critical to maintaining nitrate in the root zone. This project is evaluating irrigation management of these crops in comparison with their water requirements to identify potential practices that may reduce nitrate leaching losses. Together, this information will provide the basic information necessary for growers to better manage nitrogen inputs to these crops and safeguard water quality.

OBJECTIVES

1. Evaluate N uptake, water application and rooting depth of broccoli, cauliflower and cabbage.
2. Extend the findings of this research to growers on the Central Coast to increase understanding of N uptake and publish results to provide documentation of the findings.

DESCRIPTION

This project is in the second year of the project that is conducting a survey of well-managed, high-yielding broccoli, cauliflower and cabbage fields in Monterey, Santa Cruz, San Benito and Santa Clara Counties. Evaluations include nitrogen uptake during the cropping cycle. Survey fields utilize typical production practices for this region as well new production practices (i.e. five-line 80 inch bed broccoli, three-line 80 inch bed cauliflower and transplanted broccoli); irrigation and fertilization practices of selected fields will also be typical of the region (i.e. sprinkler and drip irrigation). Fields were selected that encompass the range of microclimatic factors close to the coast and inland. Evaluations will be conducted on a total of 36 commercial fields (six of each commodity) in 2012 and 2013. Crop biomass, biomass N and soil nitrate-N were measured three to four times during the growing season to evaluate N uptake pattern and total N uptake. At harvest, total biomass and commercially harvested biomass and biomass N were measured. Also at harvest, total crop biomass were analyzed for phosphorus and potassium. Fertilizer application rates and timing in each field were also documented.

Rooting depth was measured at weekly intervals during plant establishment and then bimonthly intervals until harvest. Flow meters were installed at each monitored field to quantify the volume of water applied from crop establishment to harvest. Data collected from flow meters and soil moisture sensors allowed us to estimate the volume of drainage below the root zone.

RESULTS AND DISCUSSION

Evaluations of all three cole crops were conducted during the summers of 2012 and 2013, and of broccoli and cauliflower during the winter of 2012. The response of

the crops to the season of production were dramtically different and were separated out for the analysis.

Summer Evaluations

Broccoli and cabbage took up about 330 lbs N/A and cauliflower 280 lbs N/A (**Table 1**). Cabbage had the highest N content in the harvested portion of the biomass at 188 lb N/A; 87 and 51 lbs of N are removed in the harvested biomass for broccoli and cauliflower, respectively. Applied fertilizer averaged 181, 260 and 215 lbs N/A for broccoli, cauliflower and cabbage, respectively. Subtracting the quantity of N applied to the crops from the amount taken up indicated that each of these crops scavenged N from the soil. In the fields survey thus far, the mean amount of N scavenged by Broccoli was 148 lbs N/A.

Cabbage produced the highest overall biomass per acre (10,811 lbs/A) followed by broccoli (8,106 lbs N/A) then cauliflower (6,930 lbs N/A) (**Table 2**). Cauliflower was the most succulent tissue and cabbage had the lowest percent N in the biomass at harvest.

Potassium (K) concentrations in the plant tissue was higher than N and total uptake of K was higher than N.

Winter Evaluations

Broccoli and cabbage took up 249 lbs N/A and cauliflower 273 lbs N/A (**Table 3**). 94 and 70 lbs of N were removed in the harvested biomass for broccoli and cauliflower, respectively. Applied fertilizer averaged 273 and 351 lbs N/A for broccoli and cauliflower, respectively. More N was applied to both broccoli and cauliflower than was taken up during the winter production by 23 and 78 lbs N/A, respectively.

Broccoli produced 5,539 lbs/A and cauliflower 6,491 lbs/A (**Table 4**). Broccoli had greater moisture content than Cauliflower and had greater percent N in the tissue

Table 1. Summer 2012. Above ground N/A in crop, yield components, applied fertilizer, N scavenged from soil and N in residue at harvest

Crop[1]	Total Uptake N/A	Heads Harvested N/A	Leaves Unharvested N/A	Stalks Unharvested N/A	Roots N/A	Fertilizer Applied N/A	Scavenged from Soil N/A	Unharvested Residue N/A
Broccoli	329.4	86.7	205.1	37.6	8.9	180.6	148.7	242.7
Cauliflower	280.7	50.6	210.2	19.9	9.3	260.0	20.7	230.1
Cabbage	330.0	188.3	141.7	---[2]	10.5	215.0	115.0	141.7

1 – Broccoli n=6; cauliflower n=5; cabbage n=7; 2 – leaves and stalks are combined for cabbage in leaves column

Table 2. Summer 2012: Biomass, and content of N, P and K in total biomass at harvest of cole crops

Crop	Dry Biomass	% Solids Whole Plants	%N Total Biomass	%P Total Biomass	%K Total Biomass	Total P Uptake lb/A	Total K Uptake lb/A
Broccoli	8,106.5	9.2	4.1	0.51	4.24	41.6	345.0
Cauliflower	6,930.5	7.5	4.1	0.65	4.31	45.0	299.9
Cabbage	10,811.2	8.0	3.0	0.39	3.18	41.0	338.3

Table 3. Winter 2012-13 Evaluations. Above ground N/A in crop, yield components, applied fertilizer, N scavenged from soil and N in residue at harvest

Crop	Total Uptake N/A	Heads Harvested N/A	Leaves Unharvested N/A	Stalks Unharvested N/A	Roots N/A	Fertilizer Applied N/A	Applied - Uptake N/A	Unharvested Residue N/A
Broccoli	249.5	93.9	128.0	28.7	7.7	272.7	23.2	155.6
Cauliflower	273.7	70.2	160.3	14.1	8.6	351.7	78.1	174.5

1 – Broccoli n=4; cauliflower n=4

Table 4. Winter 2012-13 Evaluations. Biomass, and content of N, P and K in total biomass at harvest of cole crops

Crop	Dry Biomass	% Solids Whole Plants	%N Total Biomass	%P Total Biomass	%K Total Biomass	Total P Uptake lb/A	Total K Uptake lb/A
Broccoli	5,539.2	10.0	4.5	0.58	3.35	32.4	194.1
Cauliflower	6,490.5	9.0	4.2	0.56	3.69	36.4	236.0

at harvest. Potassium (K) concentrations in the plant tissue and total uptake was lower than N.

Total applied water and rainfall for production of cole crops monitored ranged from 8 to 35 inches. Estimated crop evapotranspiration (ET) for these fields ranged from 3.5 to more than 33 inches depending on the time of year, location, and method of irrigation. The average cumulative applied water and rainfall measured in commercial broccoli, cabbage, and cauliflower fields was 18.5, 25.2, and 15.3 inches, respectively (**Table 5**).

Canopy growth has been measured at weekly to bi-monthly intervals in 24 commercial fields using an infra-red camera. Broccoli canopy cover increased during the season following a sigmoidal pattern (**Figure 1**), usually reaching maximum cover (98%) within 60 days after planting during the summer. Collected canopy cover data was used for estimating crop coefficients and calculating ET at each commercial site. The data will also be used for developing water use algorithms that will be integrated into the web-based tool, cropmanage (ucanr.edu/cropmanage).

Rooting depth of broccoli, cabbage, and cauliflower increased linearly with time, reaching maximum depths near the time of harvest (**Figures 2 – 4**). The rooting depth of Cole crops was generally less than 10 inches during the first 20% of the cropping period. Broccoli and cauliflower roots reached a maximum depth of 36 inches and cabbage roots reached a maximum depth of 31 inches. At some sites, broccoli and cauliflower roots reached a maximum depth of 48 inches. Root development patterns were generally consistent across different soil types, locations, and seasons. These data are useful for understanding the depth from which these crops extract water and nutrients at different stages of development. The rooting depth data will also be incorporated into algorithms used in CropManage for estimating water needs of Cole crops.

Table 5. Water use of cole crops grown under commercial conditions.

Crop	Establishment Method	Number of Fields	Applied Water and Rainfall (in)
Broccoli	Direct seed	7	16.3
	Transplant	3	23.8
	All methods	10	18.5
Cabbage	Direct seed	1	29.7
	Transplant	5	24.3
	All methods	6	25.2
Cauliflower	Transplant	10	15.3

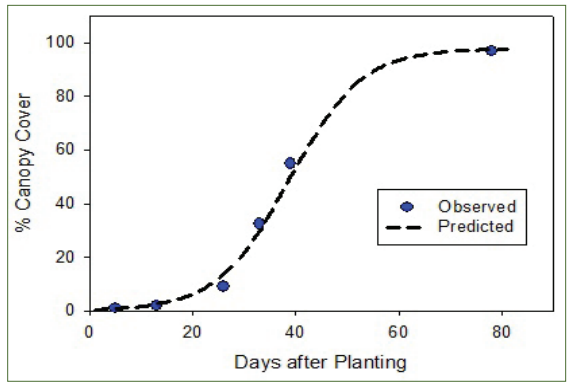

Figure 1. Canopy development of broccoli grown during the summer.

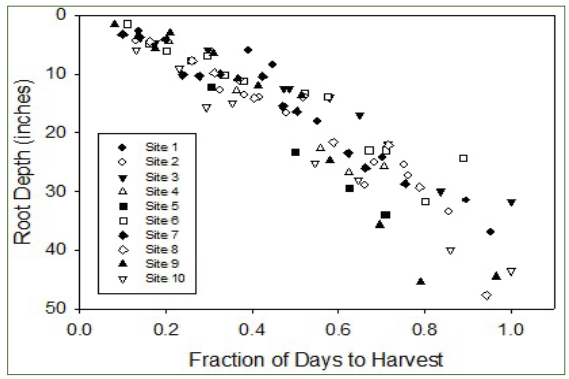

Figure 2. Rooting depth of broccoli measured in commercial fields from plant establishment to harvest.

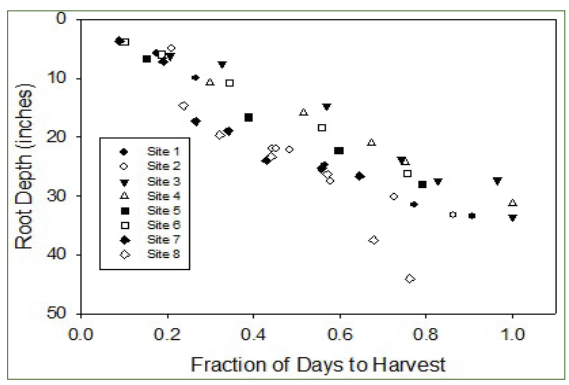

Figure 3. Rooting depth of cabbage measured in commercial fields from plant establishment to harvest.

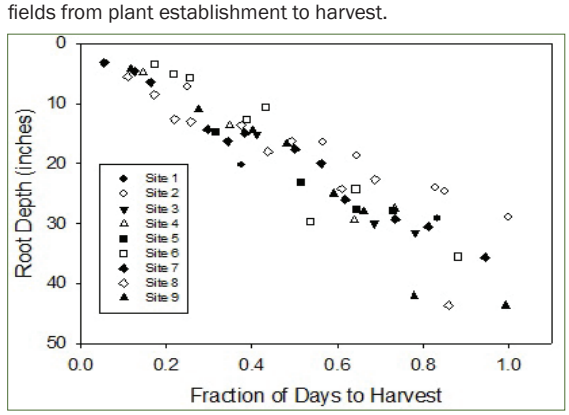

Figure 4. Rooting depth of cauliflower measured in commercial fields from plant establishment to harvest.

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

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INTRODUCTION

Regulations issued by the Central Coast Regional Water Quality Control Board have created the need for N uptake data for a variety of crops as well as practices that can improve nitrogen use efficiency. Crops such as baby lettuce, spinach, cilantro and spring mix are grown on high density 80-inch wide beds and present a particular challenge for managing nitrogen and water. These crops are planted in high-density stands with 24 to 32 seedlines across the 80-inch wide bed top and planting 2 to 4 million seed per acre. The crops are typically fast maturing, shallow rooted and exclusively sprinkler irrigated. These characteristics may create challenges for achieving high N-use efficiency. A further limitation on N use efficiency are the strict quality standards the growers must meet for these leafy vegetables that can at times compel growers to apply greater quantities of nitrogen fertilizer to "green up" a crop that may have already achieved an acceptable level of yield. Given the combined acreage and value of these commodities and their importance in the crop rotational schemes of the coastal production district, there is a need for research to evaluate their N uptake and irrigation water requirements.

The overall goal of this project is to provide detailed measurements of total N uptake and the N uptake pattern of leafy vegetables grown on high-density, 80-inch wide beds: spinach, baby lettuce, salad mix product (mizuna) and cilantro. Total applied N is critical to crop production, but irrigation efficiency is critical to maintaining nitrate in the shallow root zone of these crops, and therefore this project will also evaluate irrigation management of these crops in comparison with their water requirements. These evaluations will identify potential practices that may reduce nitrate leaching losses.

OBJECTIVES

1. Document the quantity and pattern of N uptake pattern over the life cycle of spinach, baby lettuce, salad mix and cilantro.
2. Evaluate quantities of irrigation water applied to these crops over the course of the growth cycle.
3. Evaluate the rooting depth of the crops over the growing season.
4. Evaluate fertilizer additives such as urease and nitrification inhibitors with pre/at-planting fertilizer applications to improve N use efficiency .
5. Utilize the information gained on nitrogen uptake, water needs and rooting depth in the third year to refine the algorithms in the CropManage web based tool and conduct a demonstration evaluation in the third year of the project .

DESCRIPTION

A survey of well-managed fields of spinach, baby lettuce, a representative salad mix (mizuna) and cilantro grown in the Monterey Bay production district was initiated in the summer of 2013. Fields were selected that have typical production practices and that encompass the range of microclimates (coast and inland). These evaluations will be conducted on 20 commercial fields (five of each commodity) in 2013 and 2014 production seasons for a total of 40 total fields. Soil samples for each field were collected and analyzed for pH, EC, Olsen P, exchangeable K and organic matter. Crop biomass and biomass N were measured at 3-4 times during the crop cycle (including harvest) to provide an estimate of the rate of N uptake by these crops. Biomass samples were collected from four replicate areas per field. At harvest, total biomass and

commercially harvested biomass and biomass N were measured. Fertilizer application rates and timing in each field were documented. Biomass samples at harvest will also be analyzed for phosphorus and potassium to provide information on the uptake of these key nutrients.

Rooting density of the crops was measured and these data will be used to quantify the effective rooting zone of these crops during the various stages of development and will provide information that will improve the estimates of nitrogen and water uptake by the CropManage program.

Flow meters will be installed in the two fields of each commodity that are being evaluated each week to monitor the volume of water applied from crop establishment to harvest. Infra-red canopy photos were taken weekly to develop crop coefficients for estimating crop ET. These data will provide an estimate of the volume of irrigation water drainage below the root zone.

Two fertilizer trials were conducted in 2013 on baby spinach to evaluate pre/at planting fertilizer applications with fertilizer additives including urease and nitrification inhibitors (Agrotain Plus) as well as controlled release fertilizer (Agrium D45) in comparison with ammonium fertilizers to determine if these products can improve N use efficiency of early season fertilizer applications.

The above mentioned data on crop water use, N uptake, and rooting depth of high density plantings of leafy greens will be summarized in algorithms that will be incorporated into the CropManage program.

RESULTS AND DISCUSSION

Biomass evaluations are underway, but preliminary results indicate that high density plantings of leafy green vegetables such as baby lettuce, spinach and cilantro grow rapidly in the 3-4th week of the crop cycle. Spinach and cilantro both accumulated about one ton/A of biomass at harvest at 31 and 42 days after the first germination water, respectively (**Table 1**); five different varieties of baby lettuce were evaluated, and on average, accumulated half a ton of dry biomass by 29 days after the first germination water. Laboratory analyses are pending and will give us information on the nitrogen uptake curve of these vegetables as well as total nitrogen uptake at harvest.

Two trials evaluating the following fertilizer technologies for spinach production were conducted during the summer of 2013: nitrification inhibitors, Instinct (nitrapyrin) and Super U (dicyandiamide (DCD)) and controlled release fertilizers Duration 45 and NSure; these treatments were applied preplant and were compared with the grower standard applied as ammonium sulfate which was applied as a split between pre and topdress applications. The goal of these trials was to determine if the fertilizer technology could improve the nitrogen use efficiency of spinach. Given the rapid growth of the high density crops, we are interested to see if these technologies can maintain nitrogen in the shallow root zone of these crops. The two trials were conducted in the cooler part of the Salinas Valley and Duration 45 as well as Super U looked promising under the cool conditions (data not show). Further evaluations of the nitrogen status of the soil and crop tissue are still underway as of this writing.

Table 1. Dry biomass of high density crops over the crop cycle and harvest evaluations.

Crop	Biomass 1 lbs/A	Biomass 2 lbs/A	Biomass 3 lbs/A	Harvest Dry Biomass lbs/a	Harvest Fresh Biomass lbs/A	Harvest % Solids of Whole Plants
Cilantro	240 23[1]	632 29	1264 35	2161 42	15,713	14.3
Spinach	182 17	499 22	1146 26	2055 31	33,160	6.2
Baby Lettuce	204 19	697 26	---	1058 29	17,385	6.3

1 – days after first irrigation water

Photo of pistachio orchard showing drip irrigation lines | Madera, CA

List of Completed FREP Research 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, as well as a tag listing one of six subject areas (**Educational & Miscellaneous**, **Field Crops**, **Fruit, Nut, & Vine Crops**, **Horticulture Crops**, **Irrigation & Fertigation**, or **Vegetable Crops**). We invite you to view the full final reports by visiting the California Department of Food and Agriculture's Fertilizer Research and Education Program website at www.cdfa.ca.gov/is/ffldrs/frep.html; or, you may contact the program at frep@cdfa.ca.gov or (916) 900-5022 to obtain printed copies.

Management Tools for Fertilization of the 'Hass' Avocado
Richard Rosecrance & Carol J. Lovatt, 11-0437
Fruit, Nut, & Vine Crops

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** • **Fruit, Nut, & Vine Crops**

Development of Leaf Sampling and Interpretation Methods for Almond and Pistachio • **Patrick Brown, 10-0015**
Fruit, Nut, & Vine Crops

Chemistry, Fertilizer and the Environment – A Comprehensive Unit • **Judy Culbertson, Shaney Emerson, & Lyn Hyatt, 10-0010** **Educational & Miscellaneous**

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** • **Fruit, Nut, & Vine Crops**

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

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

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

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** • **Vegetable Crops**

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

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

Comparing the Efficiency of Different Foliarly-Applied Zinc Formulations on Peach and Pistachio Trees by Using ^{68}Zn Isotope • **R. Scott Johnson, 07-0669** • **Fruit, Nut, & Vine Crops**

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

Cherry Growth, Yield and Fruit Quality: Demand-Driven Optimization of Nitrogen Availability Relative to Storage Reserves and Fertilization Practices
Kitren Glozer, 07-0666 **Fruit, Nut, & Vine Crops**

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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Crum/Stark, 02-0331 • **Educational & Miscellaneous**

California State Fair Farm Upgrade Project
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Robert Green et al., 01-0508 • **Educational & Miscellaneous**

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