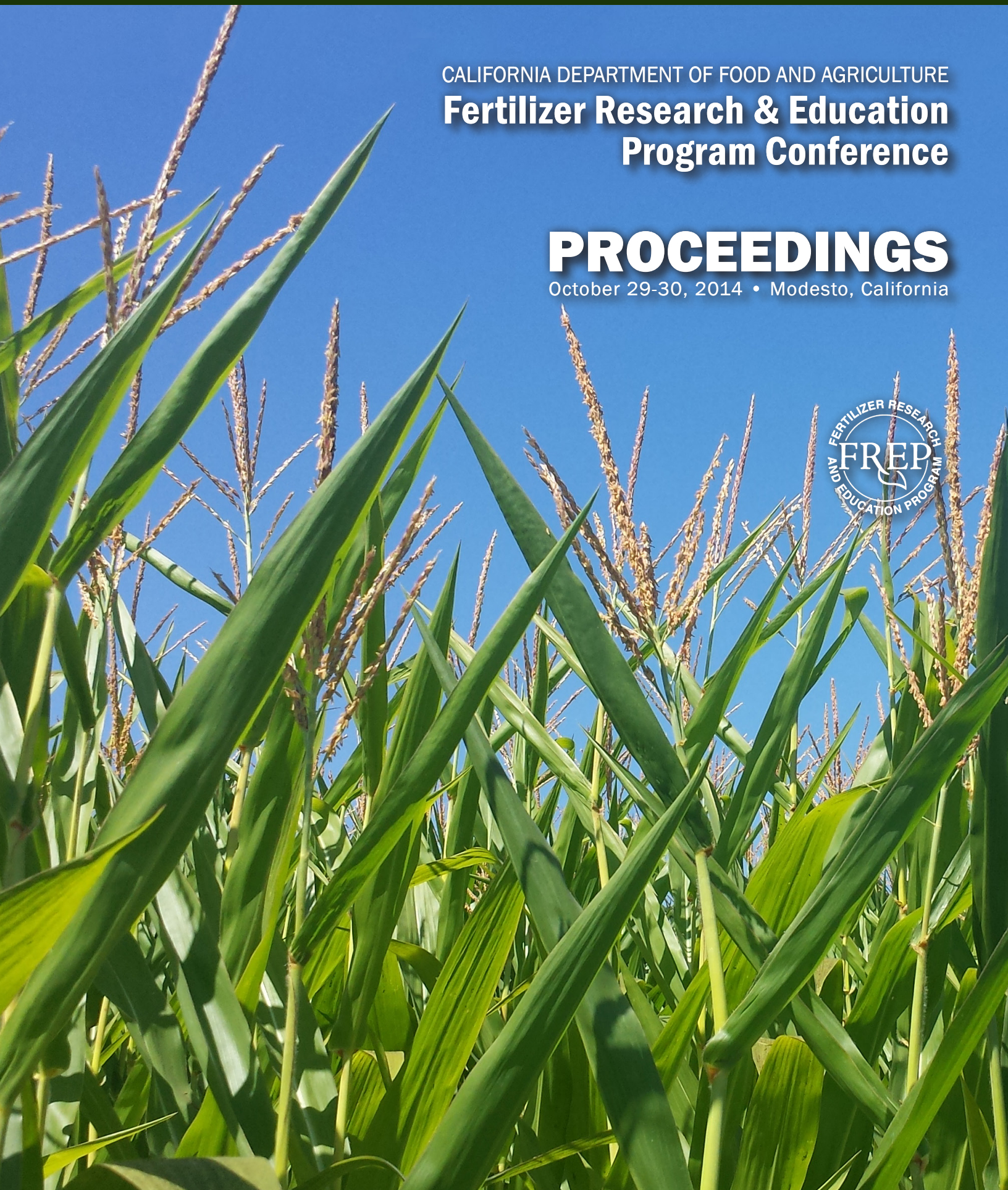
Twenty Second Annual



CALIFORNIA DEPARTMENT OF FOOD AND AGRICULTURE

Fertilizer Research & Education Program Conference

PROCEEDINGS

October 29-30, 2014 • Modesto, California

FERTILIZER RESEARCH AND EDUCATION PROGRAM
FREP

Twenty Second Annual

CALIFORNIA DEPARTMENT OF FOOD AND AGRICULTURE

Fertilizer Research & Education Program Conference

PROCEEDINGS

October 29-30, 2014 • Modesto, California

Editors
Brooke Elliott
L. Douglas West, Ph.D.

FERTILIZER RESEARCH AND EDUCATION PROGRAM
FREP

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Corn field | Stockton, CA

INTRODUCTION

Fertilizer Research and Education Program

FOR 22 YEARS, the Fertilizer Research and Education Program (FREP) of the California Department of Food and Agriculture (CDFA) 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 extend 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 of Nutrient Efficiency for the Future," the 2014 event combines the 22nd 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 and other relevant research presented during the conference, as well as other ongoing and recently completed FREP research projects, are included in these proceedings.

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 advisors (CCAs) and pest control advisors (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, including, but not limited to, nitrates in groundwater and emissions of greenhouse gases resulting from fertilizer use. To fulfill this mission, FREP has undertaken initiatives in the following three key areas: technical education, education and outreach, and research.

Technical Education

One of FREP's technical education efforts is the Nitrogen Management Training Program (NMTP) for CCAs, a voluntary nitrogen management curriculum. The Program is a joint effort between CDFA, University of California Agricultural and Natural Resources (UC ANR), and the California CCA Program. The curriculum addresses the management of nitrates from plant nutrients to reduce unintentional emissions throughout the state. The Program facilitates CCAs' understanding of sound nitrogen management practices and increases their ability to make informed recommendations to growers, thereby improving environmental performance relative to nitrogen management for crop production. In 2014, educational sessions were held in five locations in California. Over 500 Certified Crop Advisors were trained, with an additional 300 expected to complete the 2015 trainings. Read more about this on page 42.

Education and Outreach

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.

The database makes the wealth of information contained in FREP research reports readily available, easily understandable, and convenient for growers and crop advisors to implement. Available at http://www.cdfa.ca.gov/is/frep/Default.aspx, new records will continue to be added as FREP research projects are completed. You can read more about this effort on page X of this publication.

The crop fertilization guidelines are based on a synthesis of peer reviewed journal articles and research reports. Currently, there are guidelines for ten crops. The guidelines are uploaded regularly, and are available at http://apps.cdfa.ca.gov/frep/ docs/Guidelines.html.

Research

FREP continues to fund research to improve nutrient management practices through the 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 2014 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 and extension efforts to implement best management practices.

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

Corn: Very little California information is available for corn.

Pima cotton: Anecdotal evidence indicates that Pima nutrient requirements differ from that of Acala types.

Processing tomatoes: Most research has been done on furrow irrigated tomatoes before the adoption of buried drip.

Walnuts: Determine temporal soil N status (quantity of additions and losses), validate leaf nutrient CV's for the most popular walnut cultivars, improve leaf sampling protocols, develop a monthly nutrient demand model for walnut and develop BMP's to share the findings.

Citrus: Determine temporal soil N status (quantity of additions and losses), validate leaf nutrient CV's for citrus, improve leaf sampling protocols, develop a monthly nutrient demand model for citrus and develop BMP's to share the findings.

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

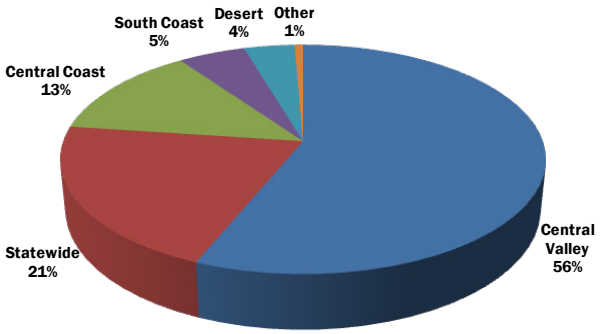

Figure 1. FREP Projects by Location, 1990-2012.

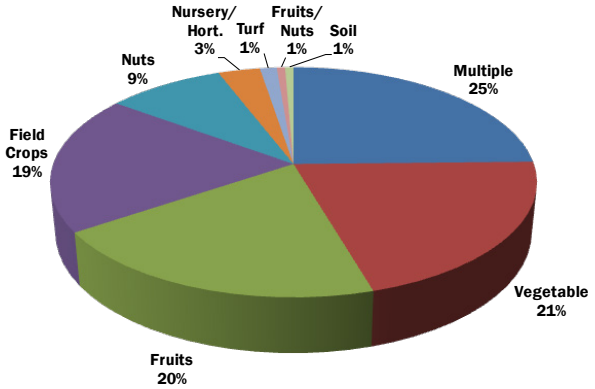

Figure 2. FREP Projects by Commodity, 1990-2012.

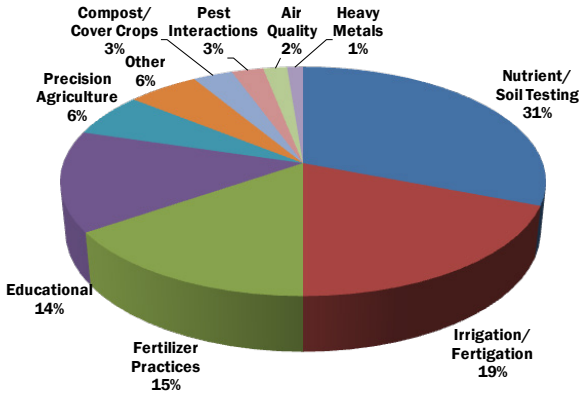

Figure 3. FREP Projects by Discipline, 1990-2012.

new projects that offer farmers alternative methods to address environmental issues and fertilizer use efficiency.

There are more challenges facing the agricultural industry than ever before. FREP has maintained its commitment to outreach and education by continually seeking new ways of making scientific research accessible to a broad audience of agricultural professionals. We are always interested to hear how we can improve FREP services and activities. 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, Dr. Michael Cahn, Dr. Dennis Chessman, Dr. Eric Ellison, Charles Hornung, Dr. Marja Koivunen, Dr. Holly Little, Steve Spangler, 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 of Nutrient Efficiency for 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. Amadou Ba, Environmental Program Manager II; Brooke Elliott, Research Analyst I; Dr. Doug West, Environmental Scientist; Dr. Barzin A. Moradi, Senior Environmental Scientist (Supervisory); and Mark Cady, Senior Environmental Scientist (Specialist). In addition, special thanks to Dr. Daniel Geisseler, Extension Specialist with the UC Davis Department of Land, Air, and Water Resources for his diligent work on creating and managing the FREP research database and crop fertilization guidelines.

Nitrous oxide sampling chambers | Stockton, CA

Wednesday, October 29, 2014

Facilitator: *Mike Buttress, A&L Western Agricultural Laboratories*

9:00-9:10 **Welcome**
Renee Pinel, Executive Director, WPHA
Karen Ross, Secretary, CDFA

9:30-10:00 Sources and Mitigation Potential for Nitrous Oxide From Agricultural Activities
Dr. William R. Horwath, Professor of Soil Biogeochemistry, UC Davis, Department of Land, Air and Water Resources

10:00-10:30 Measuring Water and Nitrate Fluxes Below the Root Zone of Crops: Possibilities and Limitations
Dr. Barzin A. Moradi, Fertilizer Research and Education Program, CDFA

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

10:50-11:20 UC Division of Agriculture and Natural Resources Responds to Drought
Dr. Doug Parker, Director, California Institute for Water Resources, UC Division of Agriculture and Natural Resources

11:20-11:50 Remote Sensing of Crop Development and Evapotranspiration
Dr. Lee Johnson, Senior Research Scientist, NASA

11:50-1:00 **Lunch (provided)**

1:00-1:30 Irrigated Lands Regulatroy Program and Recently Added Nutrient Management Plan Requirements
Glenn Meeks, Senior Engineering Geologist, California Regional Water Quality Control Board

1:30-2:00 2014 Nitrogen Management Training Sessions
Terry W. Stark, CEO/President, California Association of Pest Control Advisers

2:00-2:30 Fertility Management in Drip Irrigated Processing Tomato Production
Dr. Timothy K. Hartz, Extension Specialist/Agronomist, UC Davis, Department of Plant Sciences

2:30-2:50 **Break**

2:50-3:20 Fertilizer Best Management Guides
Dr. Robert Mikkelsen, Director, Western North America, International Plant Nutrition Institute

3:20-3:50 Determining the Fertilizer Value of Ambient Nitrogen in Irrigation Water
Dr. Michael Cahn, Farm Advisor, UCCE Monterey County

Thursday, October 30, 2014

Facilitator: *Mike Buttress, A&L Western Agricultural Laboratories*

8:00-8:30 **Welcome and Recap**

8:30-9:00 Suggestions on How to Optimize N Application Rates While Minimizing the Risk of Yield Loss
Dr. Daniel Geisseler, Cooperative Extension Specialist,
UC Davis, Department of Land, Air and Water Resources

9:00-9:30 Exploring the Potential for Using Transgenic Crops for Improved Fertilizer Use Efficiency
Dr. Charles Sanchez, Professor, University of Arizona

9:30-10:00 Characterizing N Fertilizer Requirements of Crops Following Alfalfa
Dr. Daniel Putnam, Cooperative Extension Specialist, UC Davis, Department of Plant Sciences

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

10:15-10:45 Evaluation of N Uptake and Water Use of Leafy Greens Grown in High-Density 80-Inch Bed Plantings and Demonstration of Best Management Practices
Richard Smith, Farm Advisor, UCCE Monterey County

10:45-11:15 Phosphorus and Boron Fertilizer Impacts on Sweetpotato Production
Scott Stoddard, Farm Advisor, UCCE Merced County

11:15-11:45 Management Tools for Fertilization of the 'Hass' Avocado
Dr. Richard Rosecrance, Professor, CSU Chico, College of Agriculture

Nitrous oxide sampling | Stockton, CA

Management Tools for Fertilization of the 'Hass' Avocado

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INTRODUCTION

This project focuses on developing best management fertilizer practices to improve nutrient use efficiency (yield per unit input of fertilizer) and reduce environmental pollution related to excessive fertilizer applications. For the 'Hass' avocado (*Persea americana* L.) industry of California, fertilization rates and optimal leaf nutrient ranges have been borrowed from citrus for all nutrients except nitrogen (N), zinc (Zn) and iron (Fe). Competition from Mexico, Dominican Republic, Chile, Australia, Peru, and South Africa requires the California avocado industry to increase production per acre to remain profitable. Optimizing fertilization is essential to achieve this goal.

The development of best management fertilizer practices is particularly important for alternate bearing avocado trees, for which most growers use the results of their August-September leaf analyses to replace nutrients used by the current crop. If not managed correctly, trees that are setting fruit in an off year receive more fertilizer than is needed (Lovatt, 2001). Over fertilization with nitrogen can significantly decrease avocado fruit size (Arpaia et al., 1996). Properly timing soil-applied nitrogen can increase yield and fruit size and reduce alternate bearing of the 'Hass' avocado.

Included in the model is links to an irrigation scheduling model. Recent water shortages have highlighted the need to improve plant water use efficiency. Maximizing fertilizer uptake in plants produces a crop with roots that explore more soil volume for water and nutrients in less time. This results in a healthier crop that can more easily withstand seasonal stresses.

We believe that the deliverables of this project will increase yield, fruit size and profitability for California's 6,000 avocado growers, while protecting the groundwater. Information on best management fertilizer practices will be supplied in two formats: 1) graphically – plots will be developed documenting the stage-to-stage (month-to-month) changes in the concentrations of each essential mineral nutrient in vegetative and reproductive organs for both on- and off-crop trees, and 2) Dynamically – A computer-based fertilizer model will be developed. Computer-based fertilizer recommendations have been successfully adopted by growers for other crops (almond, pistachio, walnut, macadamia, etc.) and should be developed for avocado.

OBJECTIVES

Develop user-friendly phenological timelines reporting biomass accumulation and total nutrient uptake for specific reproductive structures and vegetative components.

Develop a computer program that growers can easily use to calculate their own fertilizer recommendations (nutrient, application time and rate) based on tree phenology, crop load, and vegetative growth calculations.

Trouble-shoot, and finalize the computer program and make it available on the web. Our computer-based approach involves mathematical data mining, graphic representation of results for ease of use, and development of the computer program.

DESCRIPTION

The PIs completed the difficult task of quantifying nutrient partitioning during all stages of tree phenology by excavating on- and off-crop avocado

trees every two months over two years at Somis Pacific in Moorpark, California. At excavation, trees were dissected into inflorescences, fruit, leaves, green shoots (<½ inches), small branches (½-2 inches), mid-size branches (2-4 inches), scaffolding branches (4-6 inches), wood (> 6 inches), scion trunk, rootstock trunk, scaffolding roots, small roots and new roots. Total weight of each component was recorded. Sub-samples were washed, dried, ground, weighed and analyzed for nutrient content of 12 essential elements.

A basic phenology and yield-based nutrient model has been developed for avocado using these tree nutrient partitioning data (called Avomodel). Currently, we are expanding the model parameters to produce a more comprehensive model that include factors such as crop load in the current and previous year and nitrogen leaching based on irrigation practices.

RESULTS AND DISCUSSION

Development of avocado nutrient fertilization model

Calculating the appropriate rate of fertilizer to apply is a complex process that involves interpretation of leaf and soil analyses, and a range of orchard and site condition factors.

In a typical well-managed orchard with reasonably fertile soil, nitrogen, potassium and zinc are likely to be the only nutrients that need to be applied regularly. Thus, the fertility model developed for this project will include these nutrients. Factors to consider when developing a nutrient fertilization model include:

- crop load or yield in the current year;
- crop load or yield in the previous year;
- canopy size;
- leaf nitrogen, potassium and zinc levels;
- soil texture.

Nitrogen and potassium fertilizer model for the 'Hass' avocado in California, input and output is shown in Figure 1. The model is simple to use with minimal inputs required.

The relationship between avocado yield and nutrient removal in the crop must be determined in order to develop a fertilizer recommendation model. Crop nutrient removal values of important macro- and micro-nutrients is presented in Table 1.

It is a common practice in avocado orchards to apply N fertilizer at rates that exceed those required for maximum yield and sustainable production. Over-irrigation, due to a poor irrigation plan can increase the risk of nitrate leaching. Therefore, updated nitrogen leaching factors were recently included in the model. The factor was based on irrigation water applied (percent acre-feet of water applied above required amount) soil type, and the amount of N applied (Table 2).

We have an adapted the California almond nitrogen model to avocado. The model can be seen at the website: http://www.csuchico.edu/~rr19 and is being linked to the UC Davis Fruit and Nut Center web page.

New additions to the model

Tree phenology and soil type

Avocado trees are unique because the fruits can remain on the tree for 15 to 18 months after full bloom (two growing seasons). The tree must support the growing fruitlets and the maturing fruit from the previous growing season. Moreover, both developing and maturing fruit are strong sink for nutrients. Recent modifications to the avocado nutrient fertilization model include:

Inclusion of the developing fruitlets and the maturing crop in the avocado nutrient model. Mature avocados can be harvested over an extended period of time. Therefore, the harvest date was also included in the model

Addition of a nitrogen leaching factor into the model based on irrigation water applied (Percent acre-feet of water applied above required amount) and soil type (Table 3).

Climate Regime

We are evaluating an irrigation module in the program. Avocados are grown in three main areas in the state: San Diego, Ventura, and San Luis Obispo. The climate is very different between San Luis Obispo and San Diego. We developed irrigation requirements for these three main growing regions (Table 2). These irrigation requirement values were determined using the CIMMIS weather station data and crop coefficients from the Wateright program <http://www.wateright.org>.

Macro- and Micro-Nutrient Removal in the Crop

The output results for a 10,000 pound per acre avocado crop yield are presented in Figure 1. In the soil potassium section of the Avomodel we have included common potassium fertilizers for growers to select. This model will do all the calculations converting pounds of elemental K to pounds of fertilizer. This feature should facilitate the use of this model.

Macro- and micro-nutrients removed in the avocado crop were included in the output of the model (Table 1.) Thus, growers will be able to determine nutrient removal values and in coordination with tissue and soil analyses assess if fertilization is required. Finally the output of the model was changed to allow for it to be downloaded into Excel and saved. This enables growers to run the program, save it to Excel, and refer back to the results at some later date.

CONCLUSIONS

The main contribution of the presented fertilization model is the application of mathematical functions in the calculation of the amounts of plant-available nutrients in avocado orchards. In the calculation of fertilization rates, the model includes factors such as crop load (current and previous year), canopy size, leaf nutrient levels, soil texture, and irrigation rate. The model is adjustable for different agro-ecological conditions and crop requirements.

LITERATURE CITED

Arpaia, M. L., J. L. Meyer, G. W. Witney, G. S. Bender, D. S. Stottlemyer, P. R. Robinson. 1996. The Cashin Creek nitrogen fertilizer trial - what did we learn? California Avocado Society 1996 Yearbook, 80: 85-98.

Lovatt, C. J. 2001. Properly timed soil-applied nitrogen fertilizer increases yield and fruit size of 'Hass' avocado. Journal of the American Society for Horticultural Science, 126(5): 555-559.

Other Nutrients Removed in the Crop		
Phosphorus	12.08	lbs/acre
P_2O_5	27.67	lbs/acre
Sulfur	21.73	lbs/acre
Boron	14.78	oz/acre
Calcium	6.09	lbs/acre
Magnesium	11.72	lbs/acre
Zinc	7.23	oz/acre
Manganese	4.05	oz/acre
Iron	2.15	oz/acre
Copper	2.65	oz/acre

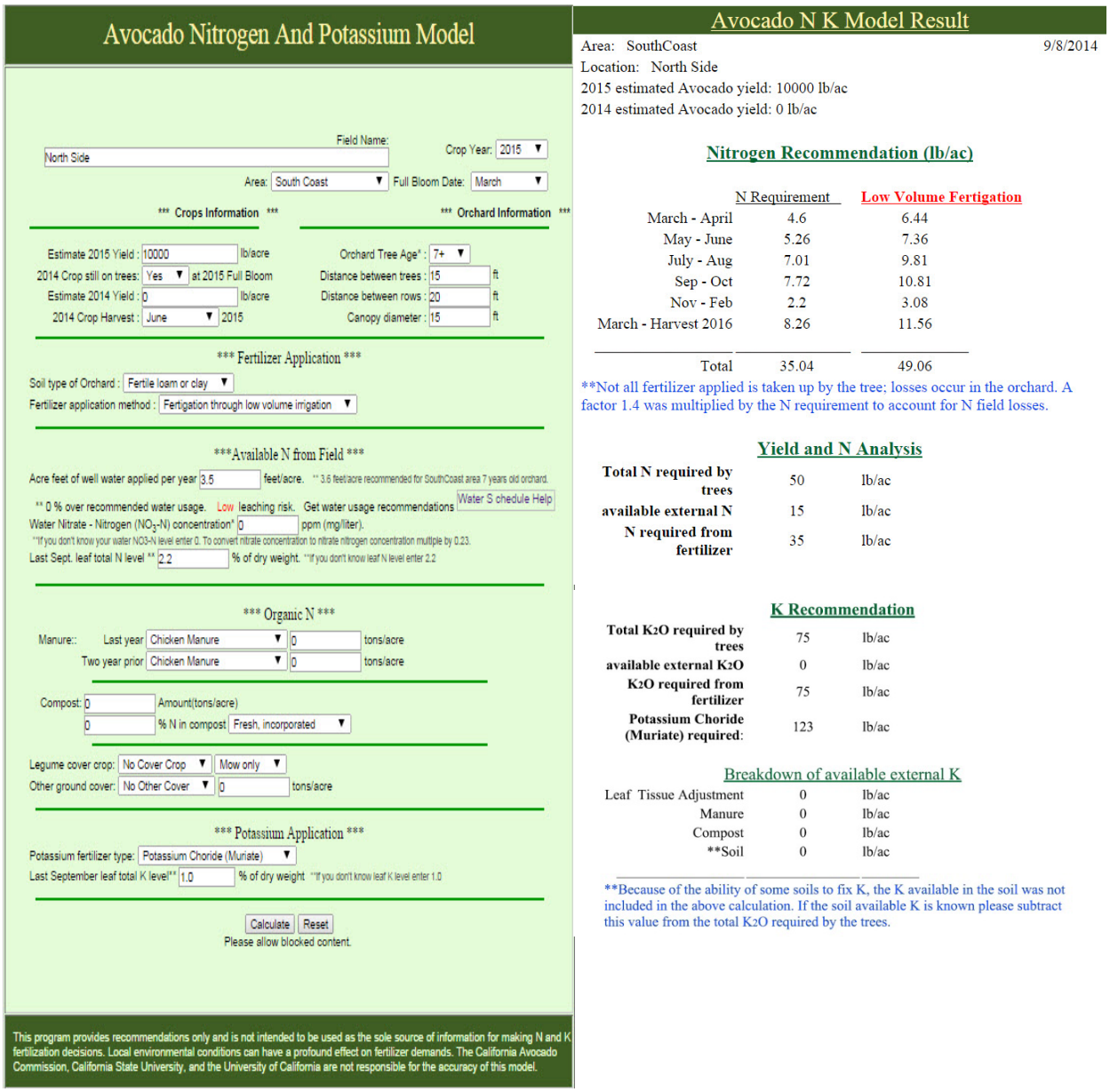
Table 1. Nutrient removal in the avocado crop based on a 10,000 pound per acre yield.

% of acre-feet of irrigation water applied above required amount	% of leaching Fertile Loam	% of leaching Sandy loam	% of leaching Sand
0	0	0	0
15	0	0	45
30	15	30	60
45	30	45	75
60	45	60	100
75	60	75	100
100+	85	90	100

Table 2. Nitrogen leaching factor in three soil types based on excess irrigation water applied (percent acre-feet of water applied above required amount).

Tree Age	Tree Age vs Water Needed (feet per acre)		
	Ventura	San Diego	San Luis Obispo
1	0.4	0.5	0.5
2	0.7	0.9	0.9
3	1	1.5	1.3
4	1.2	2.2	1.8
5	1.4	2.5	2.2
6	1.6	3.2	2.4
7+	1.6	3.6	2.8

Table 3. Avocado water requirement as a function of tree age for the three major avocado growing regions in California.



Avocado Nitrogen And Potassium Model

Field Name: North Side
Crop Year: 2015
Area: South Coast
Full Bloom Date: March

*** Crops Information ***
Estimate 2015 Yield : 10000 lb/acre
2014 Crop still on trees: Yes at 2015 Full Bloom
Estimate 2014 Yield : 0 lb/acre
2014 Crop Harvest : June 2015

*** Orchard Information ***
Orchard Tree Age* : 7+
Distance between trees : 15 ft
Distance between rows : 20 ft
Canopy diameter : 15 ft

*** Fertilizer Application ***
Soil type of Orchard : Fertile loam or clay
Fertilizer application method : Fertigation through low volume irrigation

***Available N from Field ***
Acre feet of well water applied per year 3.5 feet/acre. ** 3.6 feet/acre recommended for SouthCoast area 7 years old orchard.
** 0 % over recommended water usage. Low leaching risk. Get water usage recommendations Water S chedule Help
Water Nitrate - Nitrogen (NO_3-N) concentration* 0 ppm (mg/liter).
*If you don't know your water NO3-N level enter 0. To convert nitrate concentration to nitrate nitrogen concentration multiple by 0.23.
Last Sept. leaf total N level ** 2.2 % of dry weight. **If you don't know leaf N level enter 2.2

*** Organic N ***
Manure:: Last year Chicken Manure 0 tons/acre
Two year prior Chicken Manure 0 tons/acre
Compost: 0 Amount(tons/acre)
0 % N in compost Fresh, incorporated
Legume cover crop: No Cover Crop Mow only
Other ground cover: No Other Cover 0 tons/acre

*** Potassium Application ***
Potassium fertilizer type: Potassium Choride (Muriate)
Last September leaf total K level** 1.0 % of dry weight **If you don't know leaf K level enter 1.0

Calculate Reset
Please allow blocked content.

This program provides recommendations only and is not intended to be used as the sole source of information for making N and K fertilization decisions. Local environmental conditions can have a profound effect on fertilizer demands. The California Avocado Commission, California State University, and the University of California are not responsible for the accuracy of this model.

Avocado N K Model Result

Area: SouthCoast 9/8/2014
Location: North Side
2015 estimated Avocado yield: 10000 lb/ac
2014 estimated Avocado yield: 0 lb/ac

Nitrogen Recommendation (lb/ac)

	N Requirement	Low Volume Fertigation
March - April	4.6	6.44
May - June	5.26	7.36
July - Aug	7.01	9.81
Sep - Oct	7.72	10.81
Nov - Feb	2.2	3.08
March - Harvest 2016	8.26	11.56
Total	35.04	49.06

**Not all fertilizer applied is taken up by the tree; losses occur in the orchard. A factor 1.4 was multiplied by the N requirement to account for N field losses.

Yield and N Analysis

Total N required by trees	50	lb/ac
available external N	15	lb/ac
N required from fertilizer	35	lb/ac

K Recommendation

Total K_2O required by trees	75	lb/ac
available external K_2O	0	lb/ac
K_2O required from fertilizer	75	lb/ac
Potassium Choride (Muriate) required:	123	lb/ac

Breakdown of available external K

Leaf Tissue Adjustment	0	lb/ac
Manure	0	lb/ac
Compost	0	lb/ac
**Soil	0	lb/ac

**Because of the ability of some soils to fix K, the K available in the soil was not included in the above calculation. If the soil available K is known please subtract this value from the total K_2O required by the trees.

Figure 1. Nitrogen and potassium fertilizer model for the 'Hass' avocado in California, input (left) and output (right) based on 10,000 pounds per acre avocado crop yield.

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

Project Leaders

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INTRODUCTION

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

OBJECTIVES

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

DESCRIPTION

The research for this product was conducted on commercial vegetable production fields in Monterey County. Five nitrogen uptake evaluations were completed in 2013 and five will be completed in 2014 for each of the following crops grown on high density 80-inch wide beds: baby lettuce, cilantro, mizuna and spinach. Biomass samples were collected from two to four times during the crop cycle and evaluated for total N uptake. The number of biomass evaluations depended on how quickly the fields matured and our success in working around the irrigation and spray schedules. At harvest, total N, P and K in the biomass was measured, as well as the total N in the commercial harvested portion of the crop and in the residue that remained in the field.

A total of four fertilizer trials that include controlled release fertilizers and nitrification inhibitors were established in commercial spinach fields in 2013 and 2014. Soil mineral N was measured over the crop cycle, as well as total N uptake and yield at harvest.

Flow meters were installed in two fields of each

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

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

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

Table 2. Phosphorus and potassium uptake evaluations

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

RESULTS AND DISCUSSION

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

Four fertilizer trials on spinach have been conducted with the following nitrogen technology materials: nitrapyrin (Instinct®), Super U® (DCD + urease inhibitor impregnated on prills of urea), Novatec (ammonium sulfate treated with DMPP), triazone (NSure®), and polymer coated urea (D45®). These materials were compared with a standard application of ammonium sulfate. Fertilizer technologies were applied at a suboptimal rate with and without the fertilizer technologies and compared with the standard fertilizer rate. Trials were conducted on commercial farms in the north and south end of the Salinas Valley. The goal was to examine the efficacy of these materials for use on spinach, a fast growing crop grown on high-density beds that is sensitive to N deficiency. It is difficult to get a good response to nitrogen on the commercial fields due to high levels of residual soil nitrate in the soil. As a result, results were inconsistent. D45 and Super U applied at 120 lbs N/A gave yields equal to the standard treatment of 160 lbs N/A in only one trial (Table 3). Some materials maintained greater levels of available ammonium and/or nitrate in the soil over the course of the growing season, but this did not result in higher yields in most cases.

At-planting lbs N/A	Total lbs N/A	Tons/A
Ammonium sulfate +Nitrapyrin 0.50 ai/A	80	8.37
Ammonium sulfate +Nitrapyrin 0.50 ai/A	120	10.39
Ammonium sulfate +Nitrapyrin 0.50 ai/A	160	11.23
NSure (50:50)	80	6.96
NSure (50:50)	120	8.29
NSure (50:50)	160	10.58
Super U	80	10.45
Super U	120	12.51
Super U	160	12.38
D45	80	10.57
D45	120	13.40
D45	160	12.82
Ammonium Sulfate	80	9.50
Ammonium Sulfate	120	10.29
Ammonium Sulfate – Standard	160	12.22
Untreated	0	3.36
Pr>F treat		<0.0001
LSD 0.05		2.2

Table 3. Yield of spinach: nitrogen technology trial Castroville

The total volume of water applied to high density leafy green crops was monitored using flow meters and rain gauges. The initial data showed that total water (irrigation water and rainfall) applied to a crop ranged from 2.5 to 10 inches. Although there is insufficient data to make final conclusions, it appears that more water is applied for producing spinach as compared to cilantro (Table 4).

		Applied Water		
Crop	n	Irrigation	Rain	total
		------ inches -------		
spinach	2	8.06	0.02	8.07
mizuna	1	3.48	0.00	3.48
cilantro	5	4.29	0.70	4.99

Table 4. Total water applied to high density leafy green crops.

Crop coefficients for high density leafy greens were developed by monitoring canopy development during the crop cycle of commercial fields using an NDVI multispectral camera. Data were fit to the equation based on the canopy model of Gallardo et. al. (1996) for estimating evapotranspiration of lettuce:

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

Where *Gmax* is the maximum canopy cover, *A* and *B* are fitted parameters, *day* is the number of days after planting, and *Maxday* is the total days between planting and harvest. Table XX summarizes the fitted parameters.

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

$$Kc = (0.63+1.5\,C - 0.0039C^2)/100 \qquad (3)$$

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

Table 5. Parameters of canopy models for high density leafy green crops.

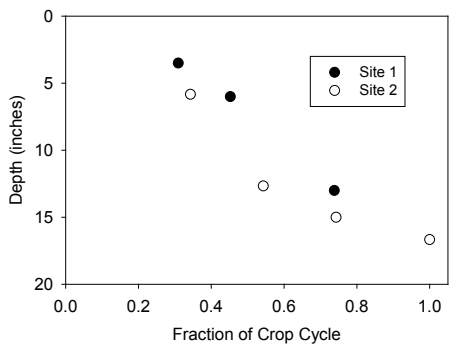

Figure 1. Rooting depth of spinach

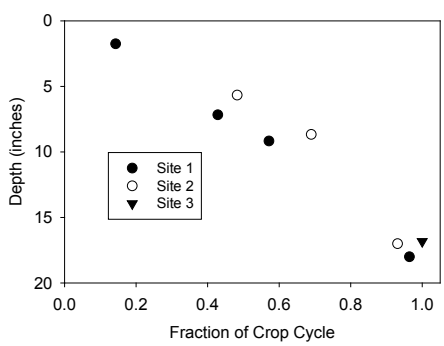

Figure 2. Rooting depth of mizuna

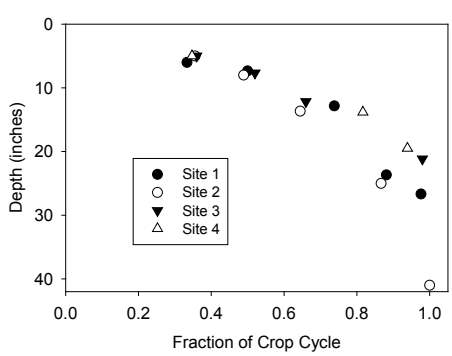

Figure 3. Rooting depth of cilantro

where Kc is the crop coefficient, ranging between 0 and 1.0, and C is percent canopy cover determined in eqn 2. 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.

Rooting depth of high density leafy green crops was monitored in commercial fields at weekly intervals (Figs. 1-3). Rooting depth of baby spinach and mizuna reached 18 inches by harvest (30 days), while roots of cilantro reached deeper than 30 inches by harvest (46 days).

RECOMMENDATIONS

Data from these evaluations indicate that the high-density crops take up moderate amounts of N, but over a short crop cycle. N applied:N uptake ratios were highest for baby lettuce and lowest for spinach. Nitrogen technologies may provide an opportunity to improve nitrogen use efficiency in these crops. Data from these trials will be used to develop algorithms for the CropManage web based program to assist growers in managing nitrogen and irrigation applications to high density crops.

ACKNOWLEDGEMENTS

The California Fertilizer Research and Education Program and the California Leafy Greens Board

Exploring the Potential of 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 percent. 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 N_2 and N_2O 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 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 objective of this project is 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 germplasm using our selectable marker (Kanamycin). This task has took longer than anticipated due to delays in methodology development. We screened and collected T2 seed. We are now collecting T3 seed for these iceberg lettuce cultivars at present (subtask 1c). Due to delays, we do not foresee initiating fertility field trials with AVP1-OX inbred iceberg cultivars until fall 2014 when we have inbreds.

Task 2

We initiated some small field studies with AVP1 modified potato in spring 2012 (Task 2a). Unfortunately, for potato, it seems this transformation produces an excess number of potatoes, none of which makes acceptable size. We planned to try once more in 2013. However, at the prospect that potato would not work, we have initiated studies with AVP1-OX tomato.

We had transformed the cultivar "Money Maker" which is a greenhouse cultivar. Thus, our initial experiment 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.

We increased our cotton seed under greenhouse conditions (subtask 2b). Cotton had initially proved difficult for APHIS permitting as well as to protect our own germplasm from contamination from commercial GMOs. Essentially all of the cotton planted commercially in Arizona and southern California is double-GM modified for BT protection and Glyphosate tolerance, and we do not wish to be caught in a legal dispute if these traits cross into our lines. Thus all our seed increase is being conducted in the greenhouse. We proceeded to the field in 2013 once we had sufficient seed and negotiated an acceptable field protocol with APHIS. The cotton field trials included N and P trials.

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 was 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 ^{15}N.

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 ^{15}N 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

N and water studies with romaine lettuce

Two studies were conducted evaluating the response of AVP-OX romaine lettuce to N and water. The studies were factorial combinations of water (60, 100, and 140% ET) and N (60, 120, and 180 kg N/ha). These studies were conducted under drip irrigation. The system was designed with nine manifolds and nine mains to deliver the various treatment combinations to plots in a randomized complete block design. The irrigation were based on AZMET generated ET measurements.

We seeded romaine studies on irrigation and N fertilization on November 5 and December 22. The crops were established by sprinkler irrigation. After stand establishment, all irrigation and fertilizations were applied through the drip system. The first and second lettuce romaine studies were harvested on April 4 and April 26, respectively.

P studies with potato

A second potato experiment was planted February 26, 2013. The P rates were 0, 50, and 100 kg P/ha. The study included non-transgenic "Desirae" and three transgenic transformations of this cultivar. The experiments was irrigated and fertilized with N (200 kg N/ha) by buried drip irrigation. These potatoes were harvested June 17, 2013.

1st P field study with tomato

Tomato "Money Maker" and "AVP-OX Money Maker" were seeded in the greenhouse. The P rates in this experiment were 0, 25, 50, and 100 kg P/ha. The tomato transplants were set in the field on March 23, 2013. The experiments were irrigated and fertilized with N (200 kg N/ha) by buried drip irrigation. Tomato yields were harvested from July 3, 2013 to July 17, 2013.

2nd P field study with tomato

We did a second study evaluating 7 AVP-OX back-crossed tomato. These were started in the greenhouse as above and transplanted on March 23, 2013. The P rates for this study were 0, 40, and 100 kg P/ha. The experiments were irrigated and fertilized with N (200 kg N/ha) by buried drip irrigation. Tomato yields were harvested from July 3, 2013 to July 17, 2013.

3rd P field study with tomato

Work with tomato was repeated in spring 2014. The transplants were set in the field on April 28, 2014. Harvests began in May and continued through July 2014.

Subtask 4b

In spring 2013 we initiated field fertility trials with cotton. For the N study, the N rates were 0, 75, 150, and 225 kg N/ha. For the P study, the P rates were 0, 25, 50, and 75 kg/ha. These studies included wild-type "Coker" and two transgenic lines of this cultivar. Both experiments were planted by hand on April, 4 2013. The experiment design was randomized complete block with 4 replications. These experiments were harvested by hand on November 21 and 28, 2013.

Cotton N and P trails were initiated again in 2014 as planned. These studies were planted on April 18, 2014 and will be harvested in the late fall.

The Ad Hoc and TASC reviewers suggested we include agronomic crops in our evaluations. Although we included cotton, we also included corn. The corn was transformed at the Plant Transformation facility at Iowa State University. The seed from several transgenic events were planted in the greenhouse and field, and was harvested on December 10. These seed were screened using selectable marker and re-planted in the field on May 19. We hope to have inbreds for field testing in spring 2015.

RESULTS AND DISCUSSION

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 fall 2014.

Task 2

In 2012 and 2013, 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.

The data for greenhouse tomato have been presented

in previous report. Briefly, the AVP1-OX tomato showed more rapid growth and development compared to the conventional type across all P rates. The yield data are interesting, where early production was higher for AVP1-OX tomato compared to the conventional at all P rates. 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

These data have also been presented in detail in previous reports. Lettuce above ground dry matter and significantly ($P<0.01$) increased by N rate. 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 1). 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

These data have also been presented in detail in previous FREP reporting. In all greenhouse experiments, lettuce dry matter yields increased to P rate. 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. In experiment 1 (2011), response to P was small, as pre-plant soil test were 25 mg/kg. Lettuce typically does show some response 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 2). 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 (Figure 3). 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

Water and N Experiment with AVP-OX romaine lettuce

The yield responses of conventional and AVP-OX romaine lettuce to water and N are shown in Table 1 for one experiment. Results for both experiments were similar. Overall, there was a large response to irrigation. Unfortunately, this soil had high residual N levels and there were no positive responses to N fertilization. In the first experiment there was no response to N at all. In the second experiment, N fertilization reduced yields, where the reduction was more pronounced when N was limiting. There were no significant differences in conventional and AVP-OX romaine lettuce. Previous reports had disclosed enhanced drought tolerance to AVP-OX. We did not observe that in this experiment. In experiments conducted in 2011-2012, AVP-OX showed improved N utilization efficiency. In this experiment, it appears N was not limiting, so we could not validate this response in 2012-2013.

P studies with potato

The response of conventional and AVP-OX potato to P is shown in Table 3. There was no response to P. The initial P soil tests were medium, which may have limited the response because potato is not as responsive to P as lettuce. There were no significant differences in yields of conventional and AVP-OX potato. It has been reported that potato largely relies on symplastic transport nutrient pathways that may limit response to AVP-OX. We will not continue work with potato in year 3.

P studies with tomato

The response of conventional and AVP-OX tomato

to P is shown in Table 4. There was no yield response to P. The initial P soil tests were medium, which may have limited the response because tomato, like potato, is not as responsive to P as lettuce. There were no significant differences in yields of conventional and AVP-OX tomato. At harvest day time, day time high temperatures approached 115 F, and heat stress seemed to limit yields of the "Money Maker" cultivar. Interestingly, we also evaluated some back-crossed AVP1-OX, and two of these back crosses performed exceptionally well.

The data to be collected in 2014 will not be as complete as that collected in 2012 and 2013 due to a high incidence of disease. We will repeat tomato study in spring 2015 under a six-month extension.

N and P studies with cotton

Preliminary studies with cotton suggest that AVP-OX cotton may be more efficient at utilizing N and P. As of the writing of this summary, not all ginning and quality analysis of cotton fiber is complete.

Transformation of corn

We are currently screening corn lines by selectable marker and PCR.

ACCOMPLISHMENTS AND PRELIMINARY FINDING

We are near completing most deliverables associated with this project. The exception is Task 5 and 6, which are related to iceberg lettuce. We were delayed in perfecting our screening methods for selecting AVP iceberg lettuce. It is our intention to make progress in Task 5 and 6 in the fall of 2014 and spring of 2015.

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. Preliminary results with cotton looks promising. Outreach activities during 2012 through 2014 included presentations at the SW Ag Summit in Yuma, the Desert Ag Conference, and the Irrigation and Nutrient Management meeting in Salinas CA. Our FREP AVP plots were also visited as a stop on field tours at the Maricopa Ag. Center.

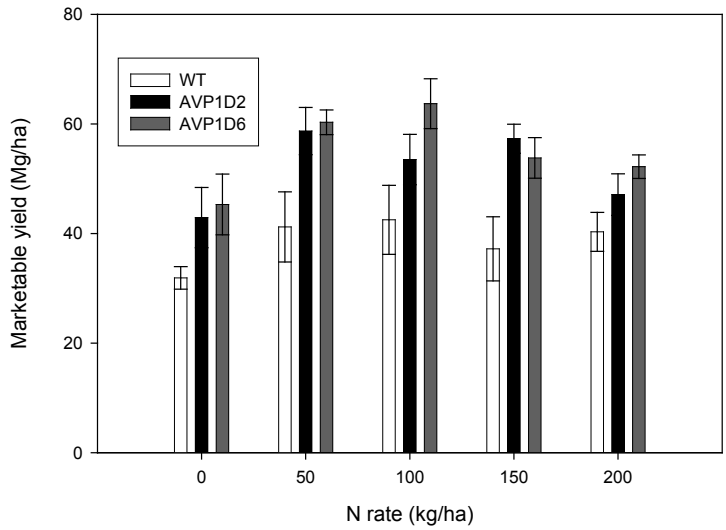

Figure 1. Marketable yield of conventional and two selections (AVP1D2 and AVP1D6) of modified romaine lettuce in a field N study.

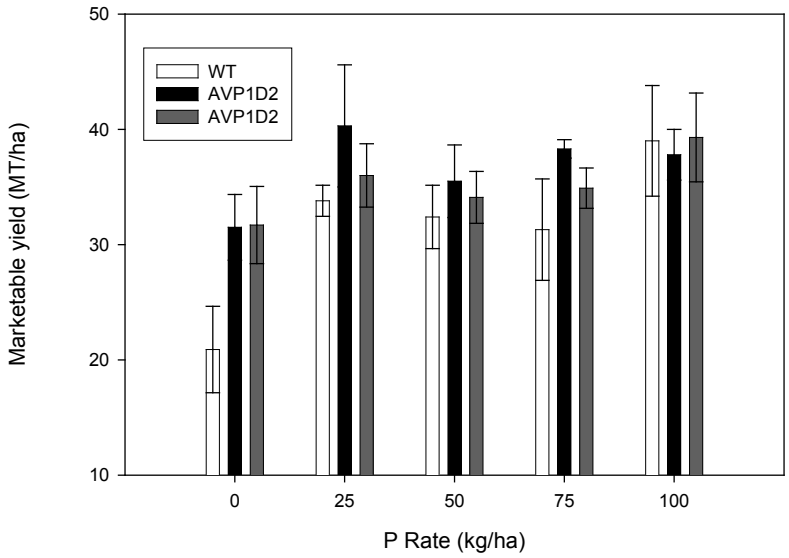

Figure 2. Marketable yield of conventional and two selections (AVP1D2 and AVP1D6) of modified romaine lettuce to P fertilizer in field experiment 1.

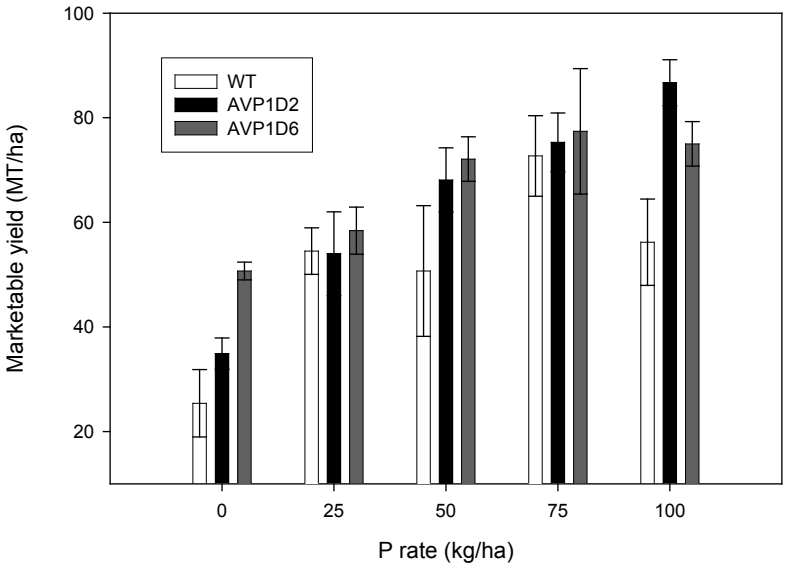

Figure 3. Marketable yield of conventional and two selections (AVP1D2 and AVP1D6) of modified romaine lettuce to P fertilizer in field experiment 4.

Table 1. Yield of conventional and AVP-OX romaine lettuce to irrigation and N fertilization in first experiment.

Treatment	Marketable Yield (MT/ha)
ET (%)	
60	43.3
120	56.5
100	60.6
N (kg/ha)	
60	50.0
120	49.7
180	57.2
Cultivar	
Conquistador	51.3
AVP1-OX	53.0
ET	**
N Rate	NS
Cultivar	NS

**Significant at the 1% level. NS=not significant.

Table 2. Main effect responses of conventional and AVP-OX potato to P in 2013.

Treatment	Marketable Yield (MT/ha)
P Rate (kg/ha)	
0	11.2
50	12.4
100	11.0
Stat.	NS
Cultivar	
Desirae	13.1
Desirae AVP-OX 1	9.7
Desirae AVP-OX 2	12.1
Desirae AVP-OX 3	11.2
Stat.	NS

NS=not significant

Table 3. Main effect responses of conventional and AVP-OX potato to P in 2013.

Treatment	Marketable Yield (MT/ha)
P Rate (kg/ha)	
0	6.0
25	6.4
50	7.1
100	6.6
	NS
Cultivar	
Money Maker	7.4
AVP-OX Money Maker	5.7
	*

*Significant at the 5% level. NS=not significant.

California Certified Crop Advisor Educational Project

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INTRODUCTION

For the 'educational' component of the CDFA-FREP program to succeed, there must be a mechanism and incentive for practitioners to improve their knowledge and skills in the area fertilizer and nutrient management. The California Certified Crop Advisor program is the key mechanism to accomplish this goal. It has been increasing in importance in California, as it has responded to the emerging issues of water and air quality, manure management, and profitability that are so vital to the state's agriculture. The CCAs in California have neared 900 participants, nearly double the number of 10 years ago, and may total 1,000 in the coming months and years.

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. Additionally, scientifically-sound educational opportunities for advisors prevents growers 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.

What is CA-CCA?

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 grass roots professionals serve to promote the educational goals of FREP with regard to soil, water, crop and nutrient source management and enhance the viability of crop advisor certification. The CA CCA program tests potential advisors using standardized, scientifically based exams, sets professional requirements, and provides certification for continuing education.

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

Outreach and Expansion provided by FREP Support

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

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

The CA CCA program is a voluntary, non-profit 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

CA CCA Board of Directors

with the stewardship of the state's natural resources. Its purpose is to credential new applicants under the leadership of the American Society of Agronomy and provide continuing education to maintain current fertilizer knowledge and practices.

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

OBJECTIVES

The objectives of this project are to:

1. Provide responsible program administration, leadership and CCA outreach awareness
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 pro-active outreach approach to fulfill its outreach and educational objectives. These include:

- The number of CCAs in California for 2013 was 800 with CA continuing to demonstrate the largest US growth. The program as of August 2014 has 894 CCAs with over 100 credential packages in the approval process.
- CA CCA program approved 399 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, 2013. Test sites were located in Sacramento, Ventura, Salinas, Indio, Yuma and Tulare with two proctors located at each exam site. The CA CCA program tested 350 new applicants with a pass rate of approximately 60%.
- Pre exam training sessions were offered for both exam periods to individuals prior to each exam testing date. Sessions were held in Fresno, Salinas and Sacramento.
- The program maintained a CA CCA Fan Page on Facebook. Updates to the page regularly

CA CCA Booth

made with information that is relevant to CCAs. This page allows communication with current and potential CCAs; also it allows communication with other state CCA programs as many representatives of those programs are fans. The page is at http://www.facebook.com/#!/pages/California-Certified-Crop-Advisers/272373776767?ref=ts.

- CA CCA Annual Meeting was held in February in Fresno in conjunction with California Plant and Soil Conference.
- Fertilizer articles were published in Western Farm Press and the CAPCA Adviser magazine providing CA growers current and valuable nutrient information.
- The CA CCA candidate program was promoted to agricultural students that qualify for the program, but do not have the necessary experience. Career day outreach and CAPCA's Pathway to PCA program all contributed to career opportunities in the fertilizer industry.
- Representatives of the CA CCA program participated in the Western Plant Health Association (WPHA) Student Dinners at UC Davis, CSU Chico, CSU Fresno, UC Riverside, Cal Poly Pomona and Cal Poly San Luis Obispo.
- The CA CCA program attended and/or exhibited at the following events: California Association of Pest Control Advisers Annual Conference, CA Weed Conference, Central Valley Grape Expo, Sonoma County Grape Expo, Pacific Nut Expo, Fresno Raisin Grape Expo, 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 Tulare, Chico, Fallbrook, San Mateo, and Cloverdale, Western Alfalfa and Forage (Reno), Eco Farm Conference, The Fertilizer Institute, 4R Stewardship/Nutrients for Life Open House, Association of American Plant Food Officials Meeting and Spring National Organic Standards Board.
- Nutrient management presentations were made at 35 CAPCA ED seminars including an additional 5 fertilizer only seminars with a total of 500 CCAs attending, CAPCA Chapter CE seminars and the WPHA Nutrient Management Series by CA CCAs encouraging attendees to take the exams and be more aware of fertilizer stewardship responsibilities.
- CA CCA representatives held discussions with representatives of California fertilizer and Ag retail industry on benefits of program and value of the CCA. The CA CCA program is experiencing tremendous support from agricultural retailers

as noted by the continuous increase in number of candidates testing and becoming a CCA.

- The program outreach and regulatory requirements from 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. 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. 2017 has been identified as the goal for CA CCA program to be self-sustaining.
- CAPCA as the cooperator coordinated activities with ICCA program, including participating in the ICCA Board Meetings. Current CA CCA member Allan Romander is the Chair of the ICCA Board of Directors and CA CCA Chair Dr. Sebastian Braum is an ICCA Board member.
- Electronic newsletters were distributed to CA CCA members. Subjects include program status, upcoming meeting and other relevant information.
- CAPCA as cooperator on this grant provided daily and efficient administration for the CEU approval and member/Board communications. The Cooperator's participation in the support of the CA CCA program is dependent upon grant funding.
- CAPCA coordinated with ICCA on all announcements and coordinates the exams.
- CAPCA completed the interim and annual report for the project leader for the CDFA/FREP grant.

SUMMARY

The CDFA FREP-supported CCA program has enabled this program to become a highly successful resource for fertilizer education and awareness, with significant growth over the past 4 years. The CA CCA Board would 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 800 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

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Fertility Management of Drip-Irrigated Tomatoes

Project Leader

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INTRODUCTION

As the processing tomato industry has transitioned to drip irrigation, there has been considerable research on nutrient management to achieve the higher yields possible with drip. Based on intensive monitoring in many commercial fields, the typical macronutrient uptake pattern has been established (Fig. 1). Nutrient uptake is slow in the initial month after transplanting and then accelerates, reaching maximum uptake during later fruit set and early fruit bulking (roughly 6-11 weeks after transplanting). Nutrient uptake is roughly proportional to fruit yield, with about 60-70% of total crop N/P/K uptake ending up in the fruit. Although fields can vary substantially, a ton of fruit typically contains about 2.5-3.5 lb N, 0.4-0.5 lb P and 4.0-5.0 lb K. Peak uptake rates reach approximately 4-5 lb N, 6-7 lb K and 0.5-0.7 lb P per acre per day.

Soil testing should be the foundation of P and K fertility management. With buried drip, the most concentrated root zone is not the surface soil, but down closer to the drip tape; for accuracy, soil sampling should be done in this most active root zone. Soils with bicarbonate extractable P > 20 PPM will require little P fertilization to reach maximum yield potential; application of no more P than is likely to be removed with harvested fruit should be adequate to maintain soil P availability. Conversely, soils with bicarbonate P < 10 PPM should be highly responsive to P fertilization, and application in excess of total crop P uptake may be warranted. P application technique may affect its efficiency; P availability is typically most limited during early growth, so providing P close enough to the transplant plug to be accessible in those early weeks is ideal.

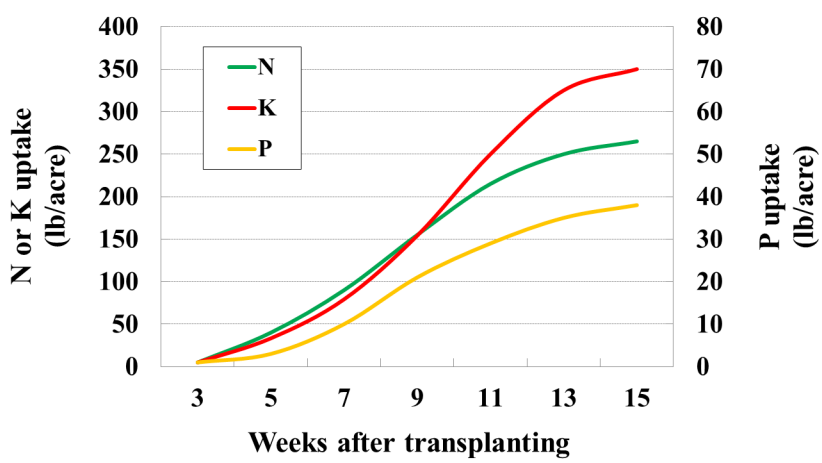

Figure 1. Pattern of typical macronutrient uptake in a 50-60 ton/acre processing tomato field. P and K are on an elemental basis; multiply by 2.3 and 1.2 to convert to P2O5 and K2O equivalents, respectively.

If pre-plant or at-transplanting P fertilization is handled appropriately, in-season P fertigation should seldom be necessary.

Soil K management is more complex. For decades, tomato growers have applied little K, relying mostly on native soil reserves. Over that time, those reserves have been diminished, and many California tomato fields are now at or near K deficiency status for high-yield tomato production. Because soil K availability is affected by other cations in the soil, soil K fixation characteristics, and the extent and density of rooting, no firm rule exists to identify fields that will be responsive to K fertilization. In general, soils with exchangeable K < 200 PPM, representing < 2% of cation charges, are potentially K limited, and candidates for K fertigation. Even fields with greater K availability may be responsive to K, particularly under very high yield conditions. To maximize K efficiency, concentrate fertigation during the late fruit set / early fruit bulking phase.

Efficient nitrogen management requires a reasonable estimate of yield potential (which determines the crop N uptake requirement), and an estimate of the amount of residual soil nitrate present in the field at the beginning of the season. A 2013 survey of 14 commercial tomato fields showed that residual soil NO_3-N in the top 20 inches of soil varied from about 20-220 lb/acre, averaging about 80 lb/acre; clearly, the N fertilization requirement would be quite different for fields at the opposite ends of that range. In-season soil N mineralization also contributes to soil N availability; that same survey estimated that N mineralization averaged 50 lb N/acre, based on laboratory incubation studies. Considering that a 50-60 ton/acre crop would require an N uptake of about 250 lb/acre, it would be unusual for a field to require a seasonal fertilization total of more than 200 lb N/acre to reach that yield level; considerably lower N rates may be adequate where a large amount of residual soil NO_3-N is present. Whatever seasonal N rate is used, fertigating in step with the crop N uptake pattern should be maximally efficient.

Determining the Fertilizer Value of Ambient Nitrogen in Irrigation Water

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INTRODUCTION

Irrigation water from many wells on the central coast contains a significant amount of nitrate-nitrogen (NO_3-N). Recycled water from the Monterey Regional Water Pollution Control Agency, the sole water source for approximately 12,000 acres of prime Monterey County farmland, is high in both NO_3-N and NH_4-N. Growers historically have been reluctant to modify their N fertilization practices on the basis of irrigation water N content because it is unclear how one can reliably calculate the 'fertilizer value' of this N. This issue has taken on added significance with the adoption of the new 'Ag Order' by the Central Coast Region Water Quality Control Board during March 2012. The revised Ag Order requires growers to report the total amount of nitrogen applied to crop land, including N contained in irrigation water. It is also unclear what distinction, if any, the Board will make between fertilizer and water sources of N, but it is clear that the Board expects growers to modify their N management practices based on the N content of irrigation water applied to their crops.

Unfortunately, a limited body of research documents the efficiency of crop uptake of N from irrigation water (Bauder et al., 2011, Hopkins et al., 2007, Vavrina et al., 1998) upon which to base an estimate of 'fertilizer value' under normal irrigation and N management practices. Central coast vegetable growers have several concerns with a simplistic concentration × volume approach to estimating the fertilizer value of ambient N in irrigation water. High N water sources, including both groundwater and recycled water, often also have significant levels of sodium and chloride. It is unclear what portion of the N in the irrigation water applied to leach salts should be credited as N value to the crop since that water would percolate below the root zone. Similarly, variation in irrigation uniformity in a field also affects the portion of N in irrigation water that can be credited as N value to a crop since some areas of a field would have more deep percolation than other areas. Crops such as lettuce and broccoli with characteristically different rooting depths may also have varying abilities to utilize ambient N contained in applied irrigation water. A second concern is that relatively low N concentrations in irrigation water may not significantly contribute to crop N uptake under normal production conditions. In fertilized vegetable root zones, soil water NO_3-N concentration is typically 50-150 PPM. In growers' minds, it is unclear if the addition of water with much lower N concentration represents a significant net benefit to crop N nutrition.

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

OBJECTIVES

1) Document broccoli and lettuce N uptake and N recovery efficiency (NRE) of irrigation water N over the range of 10-40 PPM, and at high and low irrigation efficiencies.

2) Determine the contribution of irrigation water N to broccoli and lettuce N fertility under a range of typical drip irrigation and fertigation practices.

DESCRIPTION

This project will develop information and guidelines for utilizing ambient N in irrigation water for lettuce and broccoli, the primary vegetable crops in this region. A total of six replicated field trials will be conducted in the Salinas Valley from 2013 to 2015. 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.

Year 1 trials:

Replicated field trials (spring and summer crops) were conducted on the USDA Spence research facility near Salinas in 2013 to address Objective 1 for lettuce. The irrigation water available at this facility contains approximately 2 to 3 PPM NO_3-N. 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. 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. To observe the interaction of irrigation efficiency and crop nitrogen recovery, each N treatment was evaluated at two levels of applied water [Trial 1: applied water = 110% and 170% of crop evapotranspiration (ET), Trial 2: applied water = 120% and 210% of crop ET].

Year 2 trials:

Three replicated field trials were conducted on the USDA Spence research facility near Salinas in 2014 to address Objective 2 for lettuce and Objective 1 for broccoli. All trials used methods similar to year 1 trials to simulate irrigation water with varied concentrations of N. Fertigated N treatments for Objective 2 trials ranged from 0 to 150 lbs N/acre and irrigation water NO_3-N concentration varied from 3 to 43 ppm NO_3-N. Data from these trials is currently being analyzed.

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

RESULTS AND DISCUSSION

The average NO_3 and NH_4 concentrations of the irrigation treatments were very close to the target concentrations (Table 1), which confirmed that the methodology used to simulate irrigation water with different nitrate concentrations was accurate and reliable.

Results of the summer and fall trials demonstrated that

Table 1. Measured NO_3-N and NH_4-N concentrations of irrigation water treatments (trial 1, summer harvest)

		Measured N concentration[x]		
#	Irrigation water treatments	NO_3-N	NH_4-N	Mineral N
		---------- ppm ----------		
1	Unfertilized Control	3.1	0.2	3.4
2	Fertilized Standard	3.1	0.2	3.4
3	12 ppm NO_3-N	12.8	0.4	13.1
4	22 ppm NO_3-N	22.3	0.6	22.8
5	42ppm NO_3-N	41.9	1.1	42.9
6	42ppm N (30 ppm NH_4-N)	13.2	27.3	40.5

[x]Average of 17 irrigations

the concentration of nitrogen in the irrigation water significantly affected lettuce plant size, N content of tissue, biomass yield (Figure 2), and confirmed that a significant portion of the N in the irrigation water was taken up by the lettuce crops (Figure 3). Even relatively low concentrations of NO_3-N in the irrigation water were utilized by the crop.

The response of biomass yield, plant weight, and plant N uptake to N concentration of the water treatments was greater during the summer than the fall (data not presented), presumably because the N demand of the crop was greatest during the summer, when growth was most rapid. The average biomass yield (88,697 lbs/acre) of the highest N rate (175 lbs N/acre) of the summer crop was 37% greater than average biomass yield (64,791 lbs/acre) of highest N rate (195 lbs N/acre) for the fall crop. Also, N uptake of the summer crop at the highest N rate was 42 lbs N/acre greater for the summer than the fall crop. In contrast, the N content of the plant tissue at the highest N rate was highest in the fall crop (data not presented), indicating that the fall crop was taking up N, but was growing at a slower rate than the summer crop.

The volume of water applied to the crops did not affect the recovery of N from the water treatments, demonstrating that all of the applied water could be credited as having N value to the crop. All treatments fit similar quadratic relationships for the fall and summer crops as shown in Figures 2 and 3. Although the N rate of the fertigation treatment was higher than the N rates of the water treatments, the data from all treatments fit the same quadratic response curve ($R^2 = 0.99$, $p < 0.0001$), which would suggest that the crop recovery of N from the water and fertilizer would likely be similar at the same N rates.

Average NRE was determined for each trial from the slope of a linear plot of the amount of N applied by water and crop N uptake (Figure 4). Crop recovery of N from the water treatments averaged 86% during the summer and 41% during the fall trials. As mentioned before, the higher recovery during the summer reflects the fact that the crop was growing more vigorously than during the fall. The source of N in the irrigation water (NH_4 vs NO_3) had no significant effect on N recovery by the crop (Figure 5).

Preliminary Findings

The results of the two field trials conducted in 2013 demonstrated that ambient N in irrigation water has fertilizer value for shallow rooted vegetable crops such as lettuce, even when the N concentration in the water was low (< 20 ppm N). The trials also showed that the source of N (NH_4 vs NO_3) did not affect crop recovery. Presumably, NH_4 would quickly transform to NO_3 when added to the soil. Also, the volume of water applied did affect the recovery rate of N, suggesting that all water applied containing N had fertilizer value to the crop. These results were attained under well-managed drip irrigation, with a high application uniformity and irrigations were frequent (2 to 3 times per week) so that irrigation volumes were small, which likely minimized leaching losses, even under high ET applications rates. It is possible that under poor water management or less efficient irrigation methods (eg. furrow), recovery

of N would be less than was reported in these trials. The second year of trials will allow us to evaluate if giving full fertilizer credit to the N in the irrigation water can reliably reduce fertilizer N rates without affecting yield.

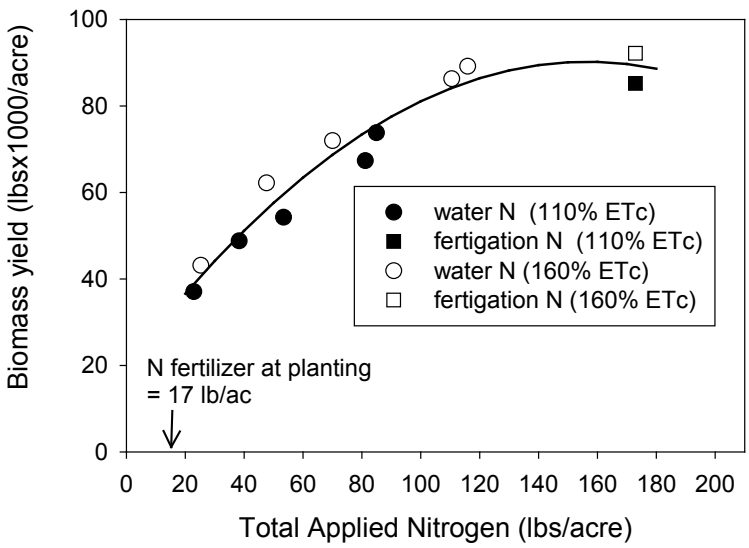

Figure 2. Effect of applied nitrogen (irrigation water and fertilizer) on biomass yield (trial 1, summer harvest).

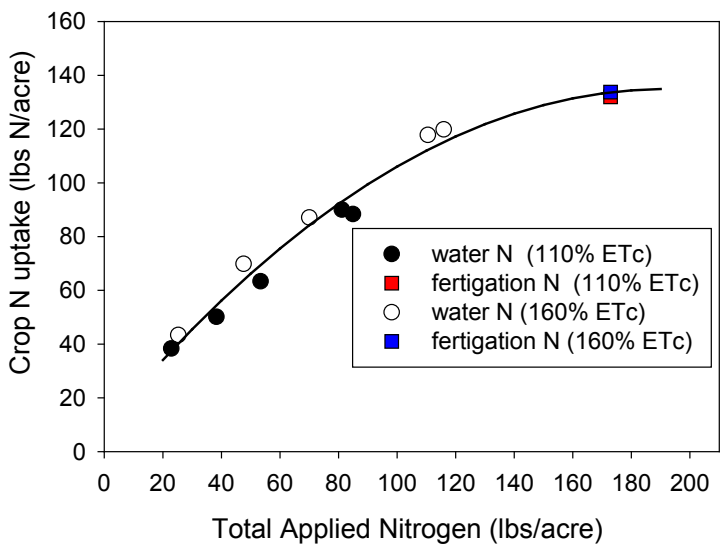

Figure 3. Effect of applied nitrogen (irrigation water and fertilizer) on N uptake of crop (trial 1, summer harvest).

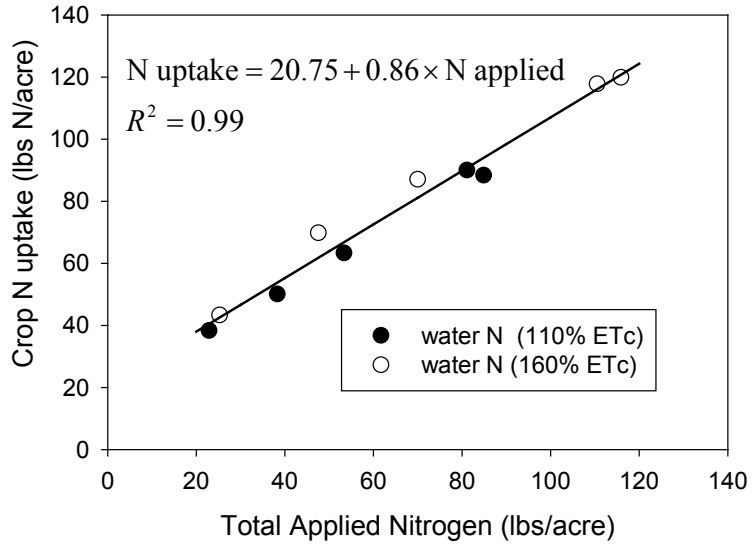

Figure 4. Effect of applied nitrogen in water treatments on crop N uptake (trial 1, summer harvest).

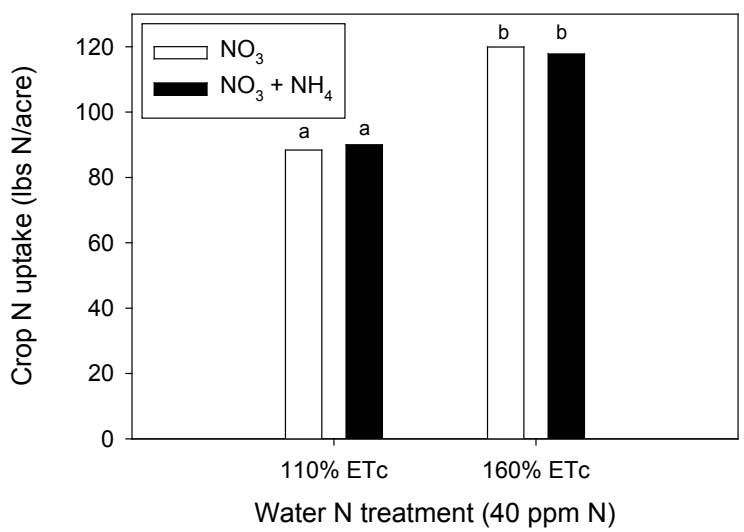

Figure 5. Effect of 40 ppm NO_3-N and NO_3+NH_4-N water treatments on crop N uptake (trial 1, summer harvest).

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Phosphorus and Boron Fertilizer Impacts on Sweetpotato Production and Long-Term Storage

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INTRODUCTION

Sweetpotatoes present a growing industry in the U.S. They have received much positive publicity in the last few years regarding their nutritional benefits. Additionally, the production of sweetpotato fries has been a consumer success that is growing each year. In 2012, California was the second top producing state, harvesting approximately 21 percent of the national production from 18,500 acres (approximately 650 million pounds). The estimated farm value of the sweetpotato crop in 2011 was nearly $130 million. This project addresses two issues currently facing the industry in California: 1) very little information regarding phosphorous requirements for this crop; and 2) a skin discoloration problem in the main cultivar that Extension Specialists in other states have suggested appears to be boron deficiency.

Multi-year fertilizer trials conducted with sweetpotatoes, including one such FREP sponsored trial in 2001-2002, on nitrogen and potassium have provided information regarding rates, timing, source, and impacts on storage quality (the most recent report is in the 2009 Sweetpotato Research Progress Report, available online at http://cemerced.ucdavis.edu). Since that first work ten years ago, the industry has changed substantially, with increased use of compost, new varieties, and much greater emphasis on long-term storage in order to meet customer expectations of having availability to sweetpotatoes year-round. Additional issues within the industry include:

- Phosphorous rate determination and nutrient removal in the stored crop. The last documented fertilizer trial conducted in California for P on sweetpotatoes was in 1974. No yield response was observed and soil P levels were not determined. In the Fertilizer Guide for California Vegetable Crops , the suggested phosphorous rate for sweetpotatoes is 60 – 120 lbs P_2O_5 per acre. Based on root analyses from my own work, phosphorous is removed at the rate of 1.0 lb P_2O_5 per 1000 pounds of harvested roots. Average yields are about 31,000 lbs/A; high yielding fields are 60,000 lbs/A. Thus the current recommendation may be too high.
- Boron impacts on root quality and long-term storage. A new variety, Covington, now the dominant variety used in California, has problems after 6 months of storage with darkening of skin ("tea staining") and dark spot formation that suggests boron deficiency (Figures 1 and 2, below). No Boron recommendations are made for sweetpotatoes in California, but fertilizer guidelines from other states suggest 0.5 – 1.0 lbs B per acre (NC Sweetpotatoes, Borax 2012).

This project addresses two of FREPs priority research areas: Demonstrating agronomically sound uses of fertilizing materials at the field scale, and developing best management practices and education materials.

OBJECTIVES

1. Evaluate different rates of soil-applied phosphorous on sweetpotato crop response in soil, leaves, and roots to determine P rate recommendations for this crop.
2. Evaluate different rates of boron fertilizer on sweetpotato roots to determine impacts on yield and skin color after long-term storage.

Figure 1 (left). Dark spots on the left suggest B deficiencies, though the biotic pathogen Scurf may also be involved.
Figure 2 (right). Though subtle, this root is turning dark and becoming unmarketable in storage.

DESCRIPTION

Project is located within a commercial sweetpotato field on the north side of Linwood Road and the Turlock main canal, near Delhi in Stanislaus County. Initial fertilizer treatments were on May 2, 2014, with the application of pre-plant, banded 8-8-8 fertilizer by Simplot at 60 gpa to certain plots within the project site. The fertilizer was applied as two bands, about 9" deep and 9" off-center in the bed. This application established the baseline P fertilizer levels at 50 lbs P_2O_5 per acre throughout most of the plot area except the untreated control. Additional P fertilizer, as MAP (11-52-0), was applied on May 12, 2014, by shanking in the dry fertilizer as a band on either side of the drip tape in the center of the bed (Figure 3). The amount of MAP applied varied by plot to establish P_2O_5 treatments of 0, 50, 100, and 150 lbs/A. These rates are slightly higher than originally proposed to better match current industry practices. Ammonium sulfate and potassium sulfate were also added to each plot as appropriate, so that N and K were equivalent.

Boron fertilizer, as Granubor 14.3% B, was applied by hand down the center of the bed on May 28 and lightly incorporated, after which the drip tape placed on top (Figure 4). The amount of B varied by plot to establish B treatment rates of 0, 1, 2, and 3 lbs/A. These rates are higher than originally proposed based on discussions with growers and currently used rates that vary from 0.5 to 6 lbs B/A. Additional nitrogen fertilizer was added by the grower through the drip tape throughout the growing season (approximately 100 lbs N/A by mid August).

Treatment design is a randomized block split-plot with four replications. Phosphorous rates are the main plots; Boron rate is the split plot. Split-plot

Figures 3 (left) and 4 (right). Phosphorous treatments were shanked into the soil at 8" depth between the drip line and row of transplants. Boron was added later to each plot by hand to the center of the bed where the water from the drip tape could move it to the roots.

size is 6 rows (20 feet) by 30 feet. There are 64 total plots, and total trial size is 0.88 acre. This trial was planted on May 6 with the cultivar "Covington", which has had more problems with long-term storage and possible B deficiencies than other cultivars.

RESULTS AND DISCUSSION

The field is growing well and should be ready for harvest by mid-September. Early season growth was reduced in the 0 lb/A phosphorous and boron plots as compared to the others plots, though this was no longer apparent in August. Plant canopy measurements were greatest in the plots with the highest rate of P (150 lbs P_2O_5 per acre). In-season soil, plant, and water samples have been taken for B and P analysis, however, results are unavailable until later this fall. Plant canopy, root yields, and root nutrient content will also be measured to determine whole-plant partitioning and nutrient removal. Roots will be stored in a standard shed and weighed and evaluated for 8 months after harvest.

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California Certified Crop Advisor-Nitrogen Management Training

Contributing Partners

University of California Agriculture & Natural Resources

California Institute for Water Resources- UC ANR

California Department of Food & Agriculture

Fertilizer Research & Education Program (FREP) CDFA

California Association of Pest Control Advisers (CAPCA)

INTRODUCTION

The California Certified Crop Advisor (CA CCA) program is comprised of over 850 professional crop consultants who have demonstrated their knowledge of fertilizer and nutrient management by achieving the CCA credential. The CCA certification requires experience, education and on-going training. 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) has provided funding for this educational program, achieving valuable outreach components to increase the number of CA CCAs while increasing awareness of proper fertilizer practices.

In response to both proposed and implemented regulatory requirements during the reporting period of 2014 placed on growers by Regional Water Quality Control Agencies, CA CCAs have embraced their responsibility of consulting growers to manage nitrate contamination in ground water. The University of California and CDFA/FREP established nitrogen mitigation training to assist CCAs in their understanding of the challenge ahead.

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. However, in a cooperative/supporting effort, the CA CCA board of directors welcomed the opportunity to participate in the UC/CDFA FREP nitrogen training.

The California Association of Pest Control Advisers (CAPCA) as the administrator of the CA CCA program assumed the duties of establishing the administrative and operational support requirements to conduct five one-and-a-half-day certification seminars in designated regions of the state to conduct nitrogen management seminars for the CCAs.

California CCAs participating in Irrigation and Nitrogen Management Training

Dr. Tim Hartz, University of California Davis presenting Annual Crops at the Nitrogen Management Training

Registration included a fee and was conducted on-line allowing verification of each attendee status as a CCA. All logistics for the five site nitrogen training was realized by CAPCA allowing UC ANR, CDFA FREP with regional water board participation to provide the nitrogen management instruction. CCAs received eleven hours of CEU credit and a certificate of training.

OBJECTIVES

The objectives of this project were to:

Provide a refresher nitrogen management orientation to include current mitigation alternatives

To enhance economic and environmental benefits through improved management of agricultural use of Nitrogen and irrigation water

Provide awareness of CCA role in nutrient management consulting to support mitigation goals

Identify/quantify knowledgeable consultants to support growers compliance

Develop a data base of CCAs completing the nitrogen management training

Obtain a current evaluation of nitrogen management knowledge

ACCOMPLISHMENTS

- Each training site (Fresno, Modesto, Tulare, Salinas and Woodland) enjoyed maximum attendance, allowing 530 CCAs, 62 percent of all CA CCAs, to receive nitrogen management refresher training.
- UC ANR and CA Institute for Water Resources was able to engage key research professionals to interact with boots on the ground CCAs to address nitrogen management alternatives.
- Core seminar discussions addressed nitrogen cycle in crop production systems, nitrogen sources, irrigation and nitrogen management, nitrogen budgeting, and available tools / resources to assist in nitrogen management planning.
- Key nitrogen management planning exercises were conducted at the seminars, allowing for specific discussions for annual crops and permanent crop scenarios.
- General educational awareness of stewardship responsibilities by CCAs in providing their expertise to assisting CDFA/FREP in articulating importance of managing nitrogen inputs, insuring safe groundwater availability.

- Seminar analysis questionnaires show that the presentations were well-received, positive learning experiences.

FINDINGS

The CDFA FREP-supported CCA program has enabled this program to become a highly successful resource for fertilizer education and awareness, with significant growth. The nitrogen management training program was an important aspect of educational component of the FREP objectives.

The opportunity to have CCAs participate in this educational opportunity demonstrated the value of FREP and the stakeholders that have the daily due diligence of advising growers on their nitrogen applications. The feedback from CCAs and the research input from UC ANR was a win for the fertilizer industry and raised the awareness of the challenges being addressed by the Regional Water Quality Control Boards as they strive to manage safe drinking water involving the agricultural sector.

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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How to Optimize Nitrogen Application Rates While Minimizing the Risk of Yield Loss

Presenter

Daniel Geisseler
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Nitrogen (N) fertilization for crop production is a major contributor to increased nitrate concentrations in groundwater in some agricultural areas of California. For this reason, growers face increasing pressure to improve N use efficiency in crop production. However, growers who have consistently produced high yields with a specific nutrient management program are understandably reluctant to reduce N application rates, even when recommendations suggest that the same yield can be produced with a lower N application rate.

In my presentation I will discuss some approaches that can reduce the risk of yield losses when the N application rate is adjusted to better match crop demand.

Before adjusting the nitrogen application rate

Changes in nutrient management should be based on results from research trials. Many field trials have been carried out in California, focusing on different aspects of nutrient management. In a FREP-funded project we have summarized the available literature from research trials for some major crops grown in California. The product of this effort is now available in the form of online crop fertilization guidelines (http://apps.cdfa.ca.gov/frep/docs/Guidelines.html). The guidelines give growers and crop advisers an overview of optimal nutrient management practices based predominantly on results from California.

The optimal N application rate depends on many field-specific factors. Therefore, fields with different properties need to be managed separately. If practical, large, non-uniform fields should be divided into smaller, uniform blocks. The less variable fields or blocks are, the lower the risk that yields in some parts of the field are reduced because of inadequate N availability while other parts are over-fertilized with a higher risk of N losses.

The optimal N application rate from research trials may not produce an optimal yield when N losses are high. Therefore, before adjusting the application rate, growers need to make sure that the applied N is used efficiently by the crops. Nitrogen needs to be available in the zone of active roots at the time the crops need it. This can be achieved, by adjusting the irrigation management to the temporal water requirements of the crops, and by applying the right fertilizer at the right time and the right place. Optimizing N and irrigation management ensures high N use efficiency and minimizes the risk of yield losses when the application rate is reduced.

Approaches to optimize nitrogen application rates

Where possible, a new nutrient program is best evaluated first in smaller plots within a representative part of the field. Plant development and yield can then be compared to the rest of the field, which serves as a reference. If it is not possible or impractical to establish plots with different nutrient management, e.g. in drip irrigated fields, the new nutrient program can be implemented in a representative field. If research suggests that the application rate can be reduced substantially, the rate may be adjusted in several steps over a period of two to three seasons.

When a new nutrient management program is introduced, it is important to closely monitor the field with regular in-season field observations, such as crop development, deficiency symptoms, and plant tissue and soil nitrate samples. Plant and soil analyses help detect possible N limitations early and allow for in-season adjustments. The results of plant and soil analyses are best compared with a reference plot or field where the grower's traditional program is used. When a new program is adopted, more intense monitoring may be continued for another season or two to ensure that the new program is adequate in years with different weather conditions. Continued monitoring is also important in orchards and other perennial crops where the effects of sub-optimal N supply may not become apparent during the first year or two.

When combined with the growers' experience and knowledge of local conditions, fertilization recommendations and the approaches discussed above for implementing them can help reduce N losses while minimizing the risk of reduced yields.

Characterizing N Fertilizer Requirements of Crops Following Alfalfa

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INTRODUCTION

As early as the time of Christ, agriculturalists recognized the benefits of alfalfa to the soil for subsequent crops ("alfalfa - it dungs the land" – Cullumella, circa 50 A.D). The importance of N_2-fixing bacteria in legumes to this soil benefit was only known in the late 1800s, and the benefits of N_2-fixing bacteria were then promoted throughout the regions where alfalfa was newly-introduced, such as Wisconsin (Graber, 1918). Early California writers recognized that alfalfa provided rotational benefits, benefitting crops such as barley and corn (Bomberger, 1913).

Alfalfa is an important crop in California, with nearly 1 million acres grown each year (USDA NASS), with 20-25% of these fields are rotated into other crops as newer alfalfa stands are established. However, to date, quantification of the N benefits to the rotation crop have been lacking for irrigated alfalfa in California.

Alfalfa is a legume and obtains the majority of its N requirements from N_2 present in air, through symbiosis with the bacterium *Sinorhizobium meliloti* present in nodules in the roots. It also contributes N to the soil through the residual plant material and soil biota. Thus, for non-legume crops grown after alfalfa, less N fertilizer may be required to produce high yields (Hesterman et al., 1986). Ignoring this contribution may lead farmers to over-fertilize, which is costly and has potentially negatively impacts on the environment (Basso and Ritchie, 2005; Toth and Fox, 1998). Reducing fertilizer use to account for alfalfa's N contributions would not only reduce the environmental impact of N fertilization, but could also help increase profits (Legg et al., 1989).

For crops following alfalfa, calculation of "N credits" is frequently recommended for determining N fertilizer requirements following a legume. N credit recommendations have been developed in several rainfed environments, with estimates of N contributions ranging from 35 to 85 kg N ha^{-1} for seeding year alfalfa stands (Kelner et al., 1997; Hesterman et al.; 1986), and up to 196 kg N/ha (Harris and Hesterman, 1980; Hesterman et al., 1987) for older stands. Additionally, two to five-year-old stands of alfalfa have frequently been found to supply all the N needs of subsequent corn crops (Yost et al., 2014). Besides stand age, alfalfa's N contribution also depends upon soil and environmental factors (Yost et al., 2014).

However, calculation of N credits from field data is mostly lacking for semiarid irrigated environments. In an irrigated semiarid system in Spain, alfalfa was estimated to contribute 160 kg N ha^{-1} to a subsequent corn crop (Ballesta and Lloveras, 2010). Another study in Spain found alfalfa's N contribution to be radically different depending on irrigation methods. Corn following alfalfa required 0 to 115 kg N ha-1 under sprinkler irrigation and 118 to 196 kg N ha-1 under flood irrigation (Cela et al., 2011).

California's wide range of environments, soils, and management strategies could affect alfalfa's N contributions. Developing an N credit recommendation for California could help growers

statewide reduce fertilizer input costs. Thus, we have established experiments in three locations, replicated over two years, to help develop N credits for California. Currently, this study is at the halfway point.

OBJECTIVES

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

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

THEORY

This type of trial which aims to estimate the N-credits due to rotation with alfalfa requires that control treatments (grains-wheat) and crop rotation (alfalfa-wheat) be compared, and the subsequent non-legume be grown with various levels of N fertilizer. Possible outcomes are shown in Figure 1. The N credit from fixation can be compared at 0 N treatments, and the N credit can be estimated from the maximum yield compared between the two rotation treatments. The red symbols represent situations where N is the primary factor, and the green symbols if N plus another factor may be important. If non-N rotation effects are present in the experiment (these could be soil structure, water infiltration, micorrhizal, disease, or other non-N effects of rotation) – these can be demonstrated as increases in yield even when the N needs of the non-legume are satisfied (Figure 1).

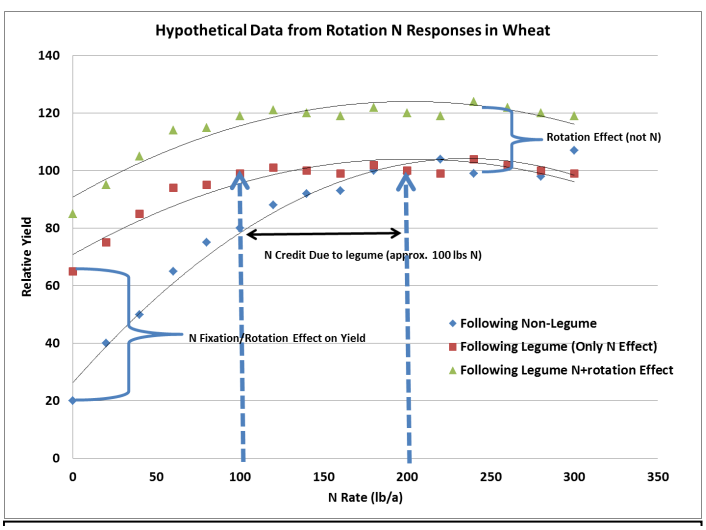

Figure 1. Hypothetical results from a rotation study designed to estimate the N-credits due to rotation with a legume.

DESCRIPTION

This research project consists of two rotation treatments: 1) wheat following grains (the grains are both wheat and sudangrass), and 2) wheat following alfalfa plowed under after at least 2.5 years of production. The design was a randomized complete block design with 4 replications in a split plot arrangement with cropping rotation as the main plot, and subsequent N-fertilizer treatments on the wheat as sub-plots. The experiment was also replicated at three locations in California: Davis (UC Davis campus, Solano County), Parlier (UC Kearney Research and Education Center, Fresno County), and Tulelake (UC Intermountain Research and Education Center, Siskiyou County), and over two complete years (phases) to accomplish 6 location-years with 4 in-field replications. Soils in Davis and Tulelake are clay loams, with Tulelake having a very high organic fraction, and in Parlier, a sandy loam soil. Locations were selected to represent a range of growing conditions under which wheat and alfalfa are commonly grown.

Rotation treatments for the first phase were established in existing stands of alfalfa in 2011-12 when strips of alfalfa were removed and planted to a grain rotation (sudangrass-wheat-sudangrass) (Figure 2). None of the crops in either rotation treatment were fertilized, but plants were otherwise managed and harvested according to recommended practices. .

In the Fall of 2013, the experiment commenced, and soil samples were taken to characterize soil chemical and physical properties and for determining soil total N content. Both the continuous alfalfa treatment and the grain rotation treatment were then planted to wheat for comparing N response under the two rotation treatments. Six N rate treatments were imposed on the wheat, ranging from 0 kg N ha-1 to 280 kg N ha-1, in 56 kg N ha-1 increments. To avoid excessive leaching, 56 kg ha-1 of the N for

Figure 2. In the photo on the left, sudangrass was established as a rotation following wheat, with the continuous alfalfa on the right at Kearney (photo August, 2013). Both crops were then plowed under and wheat planted under either rotation at different N rates. Photo on the right in Davis shows N response in wheat sown after unfertilized wheat-sudangrass rotation (to the right of photo taken June, 2014). Separate plots with alfalfa (not shown) showed nearly zero visual response to applied N.

each treatment except the control, which did not receive any N fertilizer, were applied as a preplant fertilizer. The rest of the fertilizer for each treatment was applied as a topdress when the wheat plants were tillering and were assumed to be assimilating N most rapidly. Phosphorus fertilizer was also applied at the Davis site to safeguard against possible P deficiencies. For all sites, plants were irrigated as necessary to ensure maximum N uptake. Plots were weeded as necessary.

When the wheat reached the soft dough stage, whole plants were harvested from a 5.5 m2 to 18 m2 portion of the plot area to determine forage yields and sub-samples were taken for determining moisture content and N content. Once the grain became ready for harvest, plants were harvested for determining grain yields. Grain sub-samples were taken for determining moisture content and protein content.

Estimating the N Credit

Several methods exist for estimating N credits. In the traditional N credit method, an N response curve is developed for yields of a non-legume grown after several seasons of non-legumes (Figure 1). This N response curve is then compared to the yield of the non-legume when grown after a legume. Estimating the N credit then requires finding the N fertilization rate at which the non-legume produces the same yield as the unfertilized non-legume when grown after a legume (Lory et al., 1995; Shrader et al., 1966). Another method, the difference method, requires developing N response curves for yields of non-legumes grown in sequence both after non-legumes and after legumes. These N response curves are then used to find economically optimum N rates (EONR), and the difference between the EONRs for the two treatments is the N credit (Lory et al., 1995). This project is designed to use the difference method for estimating N credits, and N

credit recommendations developed will be based on the difference method. Additionally, the difference method allows potentially differentiating between yield gains due to N contributions and yield gains due to non-N rotation effects (Figure 1).

RESULTS AND DISCUSSION

Preliminary results for forage yields are presented below. Wheat was generally responsive to N fertilizer in this trial, but N responses varied between sites. Differences in wheat forage yields between rotation treatments were statistically distinguishable at every location. We note that wheat forage yields at Parlier following the grain rotation treatment did not reach maximum yields achieved in the continuous alfalfa treatment (Figure 3, bottom of graph) even at the highest N rate applied. Parlier is a sandy soil location, and N from fertilizer may have been lost through leaching or volatilization.

There were differences among rotation treatments in plant moisture content at harvest at Davis (data not shown). Moisture contents varied widely at Parlier, but appeared to differ between replicates. At Tulelake, moisture contents at harvest were not statistically distinguishable between treatments, but mean moisture contents appeared to follow the same patterns as dry matter yields.

Non-N Rotation Effects?

Results from Tulelake and especially Parlier indicated possible non-N rotation effects due to the differences in maximum yields between rotation treatments at these sites on plots receiving the highest N rates.

Results from Davis indicated that the alfalfa may have satisfied all of the wheat forage's N needs, since yields at zero N were equal to those at the maximum N rate of 112 to 280 kg/ha (Figure 3, middle).

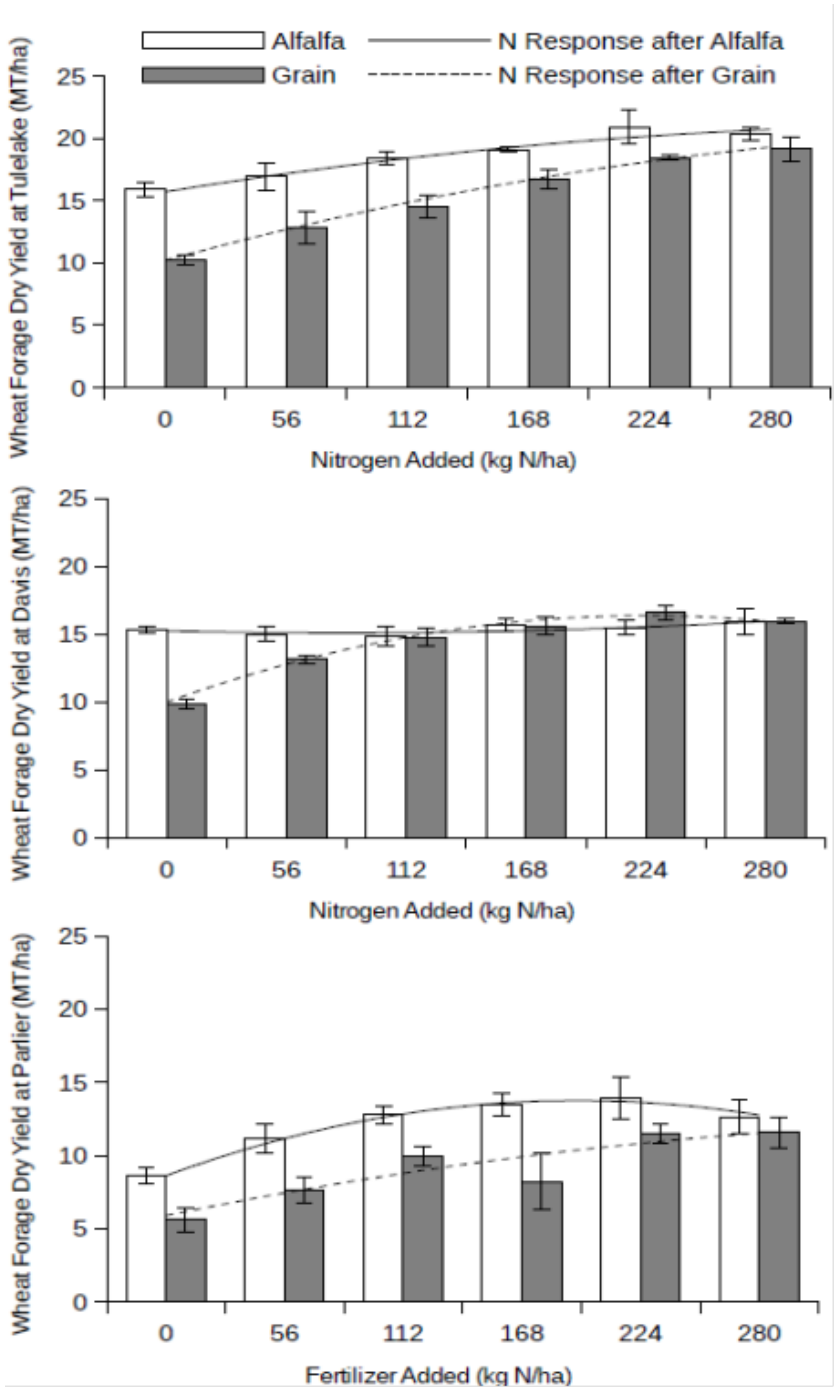

Figure 3. Forage yields of wheat (reported as dry weights) in 2014 after continuous alfalfa and after grain rotation at Tulelake (top), Davis (middle), and Parlier (bottom). Error bars represent standard errors of the mean. Response curves are quadratics.

This result was in line with previous research on corn following continuous alfalfa in humid rainfed systems, which found that crops following alfalfa in finer textured soils would often not respond to N fertilization (Yost et al., 2014).

PRELIMINARY FINDINGS

This study is in mid-stage, and should be completed in 2015-16. Remaining work includes a second year at the same sites for replication of the same treatments, in addition to analysis of the N uptake data, soil N data, and N yields under the different rotation and fertilization regimes. We also measured grain yields which are not presented here. In these first-year results alfalfa's N contribution ranged from about 100 kg N/ha at Parlier and Davis to about 170 kg at Tulelake, but there was evidence for above 170 kg N/ha contribution at Kearney and Tulelake. These results correspond well with those reported by researchers in Spain for irrigated plots in a climate similar to California. (Ballesta and Lloveras, 2010, Cela et al., 2011).

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Nitrous oxide sampling chambers | Stockton, CA

Measuring Water and Nitrate Fluxes Below the Root Zone of Crops: Possibilities and Limitations

Project Leaders

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Agricultural lands in California have been regarded the main source of nitrate loading into the groundwater. This issue requires further optimization of fertigation/irrigation methods and development of best management practices where irrigation water and fertilizers are applied at the rate, place and time that ensure maximum yield and crop quality while leaching of water and subsequently nitrate to groundwater is minimized, and build-up of salts in the root zone of crops is avoided. While yield, crop quality, and salt accumulation in the soil profile can be easily evaluated with some level of certainty, quantification of water and nitrate leaching below the root zone remains challenging. We have tested a combination of field instrumentation and modeling to calculate downward fluxes of water and nitrate at the scale of single tree, plot, and field. By calculating the gradients of soil water head across a soil layer deep below the root zone, with known soil hydraulic properties, the daily fluxes of water and nitrate (measured concentrations) can be calculated using Darcy equation. Further simplification of the necessary instrumentation used in this method would make it a reliable and attractive tool for quantifying leaching of water and nitrate below the root zone of agricultural lands under any management practices. This method is being tested in various crops in California including tomato, citrus, and almond. We will present experimental approaches that provide the necessary data on soil moisture, soil water potential, and nitrate concentration to calculate fluxes of water and nitrate under various fields and various management practices. These results will be used to evaluate and optimize irrigation and fertigation management practices for multiple locations, crop types, and irrigation systems.

$$q_{A-B} = -K(\theta)\frac{H_B - H_A}{\Delta z_{A-B}}$$

$q = leaching(cm/day)$
$K(\theta) = average\ unsaturated\ hydraulic\ conductivity\ between\ A\ and\ B$
$\theta = Volumetric\ soil\ water\ content$
$H_B = total\ head\ at\ B$
$H_A = total\ head\ at\ A$
Δz_{A-B} = distance between A and B

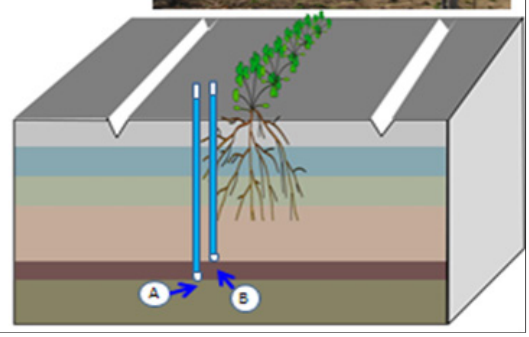

Figure 1. Darcy equation and the schematic of the instrumentations needed for calculating fluxes of water and nitrate below the root zone of crops

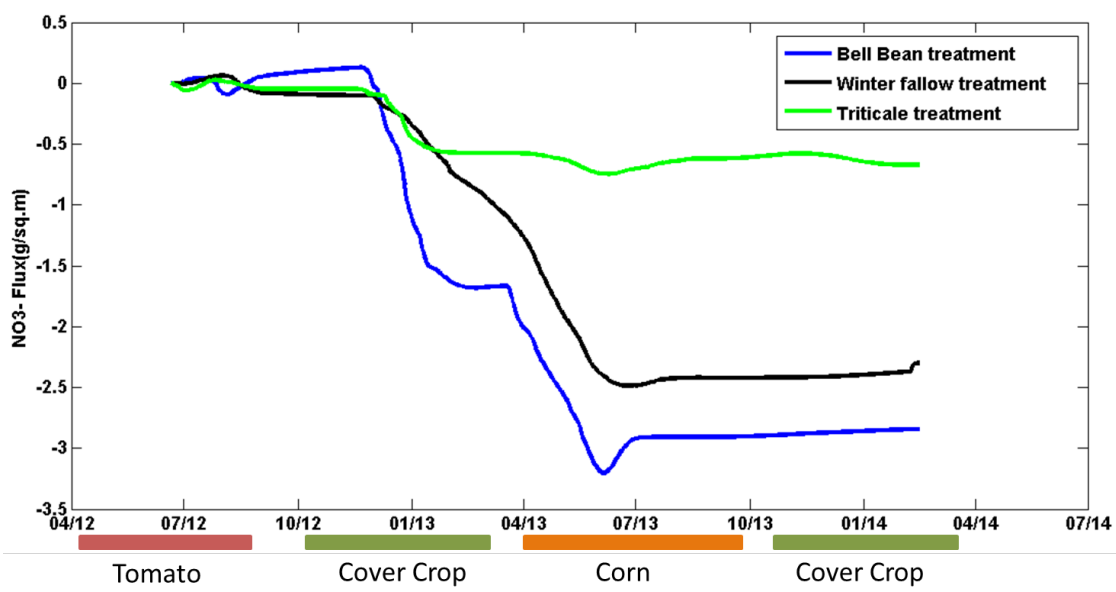

Figure 2. Comparison of different cover crops and fallow treatments on vertical downward leaching of nitrate (negative values) in a crop rotation field in Davis, CA. Triticale showed to be the most efficient in reducing the nitrate leaching below the root zone (150 cm deep). Note the difference in nitrate leaching rate during different seasons in different treatments. While nitrate continuously leached below the root zone of winter fallow in the winter of 2013, it slowed down in the two cover crop treatments.

Sources and Mitigation Potential for Nitrous Oxide from Agricultural Activities

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INTRODUCTION

More than half the total greenhouse gas (GHG) emissions, in terms of global warming potential, in agriculture, are attributed to Nitrous oxide (N_2O) emissions[1]. Nitrous oxide missions from California agriculture come from a variety of sources, but the main source is agricultural soil management (the practice of utilizing fertilizers, soil amendments such as manures, and other N inputs, including cover crops and wastes. The reduction in N_2O emission is key to reducing overall GHG emissions from agriculture.

BACKGROUND

Estimates of N_2O emissions from agricultural soils are often based on emissions inventory guidelines developed by the IPCC[2]. At present, to conform to the Global Climate Change Solution Act, California uses default emission factors (EFs) that are derived from a global dataset of field experiments covering a wide range of crops, environments, water management regimes, and N management practices. The IPCC's default EFs for N_2O is defined as the proportion of applied N (from synthetic fertilizer, organic fertilizer, manure, and N-fixing crops) that is directly and indirectly emitted as N_2O. Direct emissions are those that occur directly from the field where a fertilizer N source is applied. Indirect emissions are those that occur elsewhere in the environment following runoff of N into surface water, leaching of nitrate-N or volatilization and deposition of other gaseous N forms (e.g., NOx or NH_3). Based on this method, the EF for direct N_2O emissions from typical agricultural soils is approximately 1.1% of applied N, with an additional 0.35-0.45% emitted indirectly, following runoff, leaching and volatilization[2].

Many factors control the release of N_2O from soils. In addition to fertilizer N, soil N, moisture and carbon (substrate) availability control N_2O emissions. Denitrification occurs under oxygen (O_2) limitation, typically when diffusion of O_2 from the atmosphere into the soil is limited at high soil water content, for most soils at a water-filled pore space (WFPS) >60%. The highest N_2O fluxes from denitrification occur at WFPS 60-90%. Nitrous oxide is also produced during nitrification although the exact mechanisms are not as well described as those for denitrification[3]. The main driver for the production of N_2O during nitrification is NH_4^+ availability and O_2 content, with low O_2 conditions producing the most N_2O. The fact that both denitrification and nitrification related N_2O production occurs at low O_2 contents creates uncertainty on which pathway is dominant. Knowing which pathway is more significant would assist in developing targeted practices and strategies to reduce N_2O emissions. Irrigation, rainfall, fertilization, tillage etc., can stimulate microbial activity that can increase N_2O production. Studies in a variety of crops in California strongly suggest the nitrification pathway contributes substantially to N_2O emissions[4]. This uncertainty surrounding production pathways has hampered developing and optimizing mitigation practices to reduce N_2O emissions.

CONCLUSION

In California, the paucity of information on N_2O emissions is in part a result of the vast diversity of crops (annual vs. perennial), crop rotations (vegetables vs. grain) and unique management practices (irrigation, intensive tillage, etc.) making for sparse datasets for individual crops. Questions that remain to be answered include impacts of

farmland loss versus urbanization, effects of tillage and emerging microirrigation systems, role of cover crops, the efficacy of fertilizer formulations and stabilizers and the accuracy of biogeochemical models in predicting N_2O emissions. This "to do" list demonstrates that research is important, but also not the entire answer to reduce N_2O emissions from agriculture. More effort to bring together producers, manufacturers and distributers of fertilizers and consumers is necessary to promote the efficient use of fertilizer N and the development and adoption of GHG mitigation strategies.

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Remote Sensing of Crop Development and Evapotranspiration

Presenter

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In California and other irrigated agriculture regions that are vulnerable to water shortage, satellite-derived estimates of key hydrologic variables can support agricultural producers and water managers in maximizing benefits of available water supply. Among these variables, estimation of crop water use, or evapotranspiration (ET), is particularly relevant to both operational water management and longer-term planning. Ground-based ET measurements often prove both difficult to perform and expensive to collect, and thus are generally taken only at sparsely distributed point locations. Advances in satellite-based modeling, meanwhile, have created the possibility of generating spatially continuous ET maps of reasonably high resolution over large areas, either retrospectively or potentially in near real-time. One such capability is NASA's Satellite Irrigation Management Support (SIMS), which uses Normalized Difference Vegetation Index (NDVI) images, mostly from Landsat, to monitor crop development (fractional ground cover) and derive estimates of associated basal crop coefficients. These data can be combined with daily reference ET from the California Irrigation Management Information System (CIMIS) to estimate crop water use under so-called "basal" conditions (crop unstressed, exposed soil surface dry). Fractional cover and crop coefficient maps are updated every 8 days in keeping with the satellite revisit interval, while ET maps are generated on a daily timestep. Maps are produced at ¼-acre resolution and cover approximately 8 million acres of irrigated farmland in the Central and Coastal valleys. Location-specific data products are distributed by dynamic web services that support graphic visualization and data download, to allow users to extract crop cover and basal water use information at field-level or finer. A soil water balance model can be run on a case-by-case basis to refine basal ET for any effect of crop water stress (e.g., due to water availability shortfall or regulated deficit irrigation) or wetting of exposed soil surfaces by rainfall or use of delivery systems other than microirrigation (e.g., sprinkler, gravity). Wireless sensor networks have been deployed on several farms to collect data for evaluation of the satellite-based ET estimates. A beta-version web and mobile interface is undergoing pilot-testing by agricultural cooperators.

UC Division of Agriculture and Natural Resources Responds to the Drought

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Drought is not new to California. This year was the third year of well below normal precipitation and one of the driest years on record. What will 2015 bring? Will the drought continue or will it abate? How will we respond to a continued drought? This presentation will provide an update on the severity of the drought and discuss ways that the University of California is helping the state respond to the current drought and to long-term water scarcity.

The UC Division of Agriculture and Natural Resources (UC ANR) has been helping California agriculture (the state's largest water user) manage water for decades. Our research and outreach programs reach agricultural producers, residential homeowners, landscapers, water supply system managers, and more. UC has been integral to increasing the efficiency of how California manages its water from the source to the end user.

Within UC ANR, the California Institute for Water Resources, CIWR, works with producers, consumers and stakeholders on water resource management. The Institute is enabled by the federal Water Resources Research Act (WRRA), with the mission of supporting research and extension activities that contribute to the efficient management of California's water resources. Headquartered at ANR's offices within the University of California's Office of the President, CIWR is well positioned to coordinate research, education, and extension activities across ANR, the ten campuses of the UC system, as well as academic institutions across the state.

In early 2014, as it was clear the drought would be severe, CIWR developed a series of drought information and education webpages (http://ucanr.edu/drought). We began with a list of drought and water experts from across the state's academic institutions. This experts list became a popular resource that increased our web traffic by more than 1,000% (http://ciwr.ucanr.edu) and our Twitter following by more than 1,000 followers (@ucanrwater). In the first four months of 2014 alone, over 400 articles in a variety of major media outlets including the *New York Times*, *Washington Post*, *Time*, *BusinessWeek*, and *Mother Jones* have included interviews with California's academic water and drought experts.

In addition, drought events ranging from seminars to workshops have been held across the state. Many of the early drought impacts were first felt by the communities that UCANR serves, such as ranchers, farmers, and the horticultural industry. As word of the drought spread beyond the agricultural community, workshops on drought response in the urban sector became in demand. Many of those programs continue to be developed and promoted on our drought webpages. Many that have already happened are captured on video and available on the web.

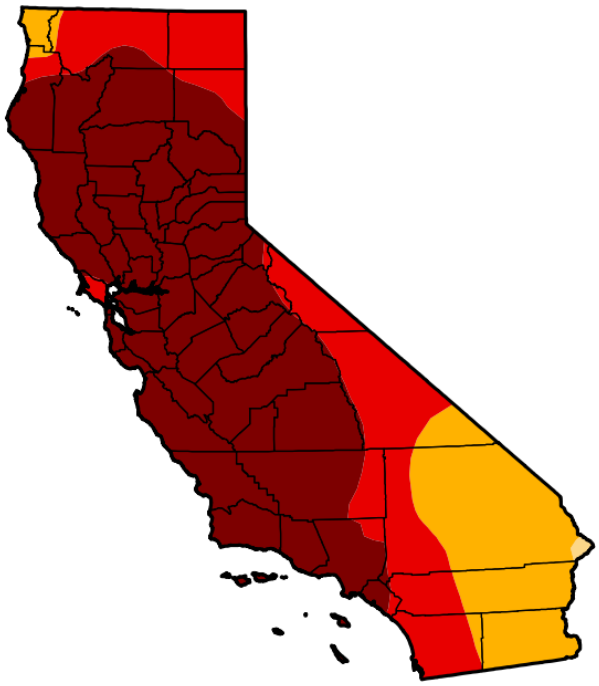
As the drought continues, we are gathering practical resources from across the UC system that have been of immediate use in agriculture, rangelands, and home and commercial landscape management. We have a wide variety of tools, including a virtual tour of California's water system, developed by researchers throughout the UC system, and a series of drought and water related scientific presentations known as "Insights: Water and Drought Online Seminar Series". We are in the process of creating a new drought-tip series that will involve over 30 short publications on how to manage agricultural

operations during a drought. These CIWR drought resources are continually updated to provide California with the latest information and resources to address the California drought.

The University of California has a long history of helping California adapt to drought and other variations in our water supplies. While droughts will always create hardship in this state, our research and outreach has benefited millions and reduced the impacts caused by drought.

U.S. Drought Monitor

California



August 5, 2014

(Released Thursday, Aug. 7, 2014)

Valid 8 a.m. EDT

Drought Conditions (Percent Area)

	None	D0-D4	D1-D4	D2-D4	D3-D4	D4
Current	0.00	100.00	100.00	99.80	81.92	58.41
Last Week *7/29/2014*	0.00	100.00	100.00	100.00	81.89	58.41
3 Months Ago *5/6/2014*	0.00	100.00	100.00	95.93	76.68	24.77
Start of Calendar Year *12/31/2013*	2.61	97.39	94.25	87.53	27.59	0.00
Start of Water Year *10/1/2013*	2.63	97.37	95.95	84.12	11.36	0.00
One Year Ago *8/6/2013*	0.00	100.00	98.23	93.86	0.00	0.00

Intensity:

- D0 Abnormally Dry
- D1 Moderate Drought
- D2 Severe Drought
- D3 Extreme Drought
- D4 Exceptional Drought

The Drought Monitor focuses on broad-scale conditions. Local conditions may vary. See accompanying text summary for forecast statements.

Author:
Brad Rippey
U.S. Department of Agriculture

http://droughtmonitor.unl.edu/

Corn silk during growth stage of corn | Stockton, CA

Remediation of Tile Drain Water Using Denitrification Bioreactors

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INTRODUCTION

Vegetable growers on the Central Coast face an unprecedented challenge from environmental water quality regulation. The regulatory focus continues to be on nitrate-nitrogen (NO_3-N) pollution abatement; extensive monitoring 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 process in which bacteria reduces NO_3^- to gaseous N compounds (mostly N_2, the benign gas that dominates the atmosphere). 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 is channeled. The organic 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 using denitrification bioreactors to remove 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 spring, 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. 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 hydraulic residence time (HRT, calculated based on total porosity in the bioreactors) before the water was released into the surface ditch draining the farm. Inlet and outlet water from the reactors has been sampled, on average, 2-3 times per week during the crop production season and once per week during the winter. Both bioreactors were operated continuously until fall, 2013, when the site 2 reactor was removed.

In May, 2012, a third pilot-scale bioreactor was constructed on a commercial farm (site 3) to evaluate the remediation of surface runoff from vegetable fields. This reactor was approximately 430 ft^3 in volume, and contained 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 contained 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. 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. The site 3 bioreactor was sampled 2-3 times per week during the 2012 and 2013 crop production seasons, and then removed in the fall of 2013.

All inlet and outlet samples were analyzed for NO_3-N concentration. Dissolved organic carbon (DOC) was analyzed for all samples collected in the first summer of operation at each site, and periodically thereafter. Nitrite-N (NO_2-N) was measured in selected samples; NO_2-N is an intermediate compound formed during denitrification, and was of interest because its measurement gave insight into denitrification dynamics.

In bioreactor research conducted throughout the world, wood chip bioreactors have been shown to be carbon-limited (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 sites 1 and 2 during alternate months in 2013. Methanol injection did increase denitrification rate, confirming a carbon limitation. The focus of our 2014 work has been to more fully investigate the effects carbon enrichment on denitrification rate, both at site 1, and in laboratory-scale bioreactors at UC Davis. Two carbon sources were evaluated, methanol and glycerin, both of which have proven useful in municipal wastewater treatment.

RESULTS AND DISCUSSION

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 (due to high C availability of the new chips) slowed as the reactors matured, and carbon availability declined. Denitrification rates achieved during the crop production season were similar across sites, and reasonably constant across years, suggesting that bioreactors can provide long-term service with minimal maintenance; annual addition of approximately 10% of the initial wood chip volume appears to be sufficient to replace the chips as they degrade. Summer denitrification rates averaged approximately 8-10 PPM NO_3-N per day of HRT (Fig. 1); the higher rate observed at site 3 in 2012 included the 'break-in' period. During the winters of 2011-12 and 2012-13 denitrification rates averaged approximately 5 PPM NO_3-N per day of HRT at sites 1 and 2. Lower winter rates were undoubtedly due to lower water temperature, which averaged approximately 54 ^{o}F in winter compared to 61 ^{o}F in summer in the tile drain water.

The tile drain water at sites 1 and 2 averaged >100 PPM NO_3-N, and the surface runoff >30 PPM, meaning that a bioreactor with enough capacity to consistently reduce NO_3-N to a 10 PPM environmental standard would have to be very large; also, since the NO_3-N fluctuates widely over time, a reactor would be by turns under- and over-sized.

Methanol enrichment of laboratory-scale bioreactors at rates of 40-100 PPM C dramatically enhanced denitrification (Fig. 2). Enrichment at or above 80 PPM C gave a stoichiometric ratio (gram of C added : gram of additional NO_3-N denitrified) of approximately 1.3 for methanol; glycerin was less efficient, with a ratio of approximately 2.0. These estimates somewhat overstate the effect of C enrichment, because NO_2-N (an intermediate step in the denitrification reaction) increased with enrichment, indicating incomplete denitrification. Preliminary 2014 data from the site 1 bioreactor confirmed that denitrification was greatly enhanced by 100 PPM C enrichment by either carbon source, but NO_2-N concentration also increased. We are currently investigating management practices that will maximize the completeness of C enrichment-driven denitrification.

Our economic analysis has shown that, depending on design and performance assumptions, it would cost approximately $1.50-2.00 per pound of N denitrified to build and operate a wood chip bioreactor in a passive mode (no C enrichment). Carbon enrichment at the stoichiometric ratios achieved in the laboratory reactors appears to be cost-effective, with the chemical costs in the same range per pound of additional N denitrified. A bioreactor treatment system utilizing C enrichment would have the advantage of being scalable, in the sense that the injection rate could be varied depending on inlet N load. This would allow a reasonably consistent outlet NO_3-N concentration to be achieved with the minimum reactor size.

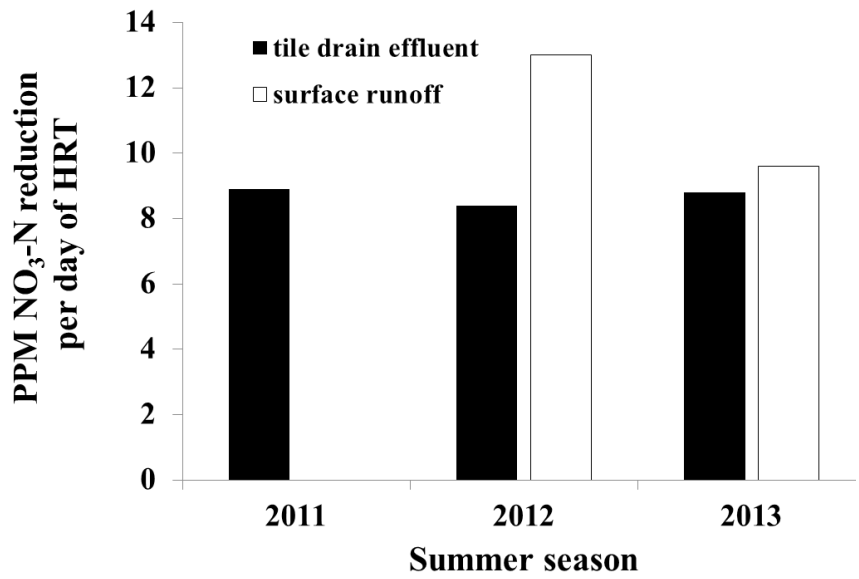

Figure 1. Mean reduction in NO_3-N concentration per day of hydraulic residence time (HRT) in the bioreactor; values for tile drain effluent are averaged across sites 1 and 2.

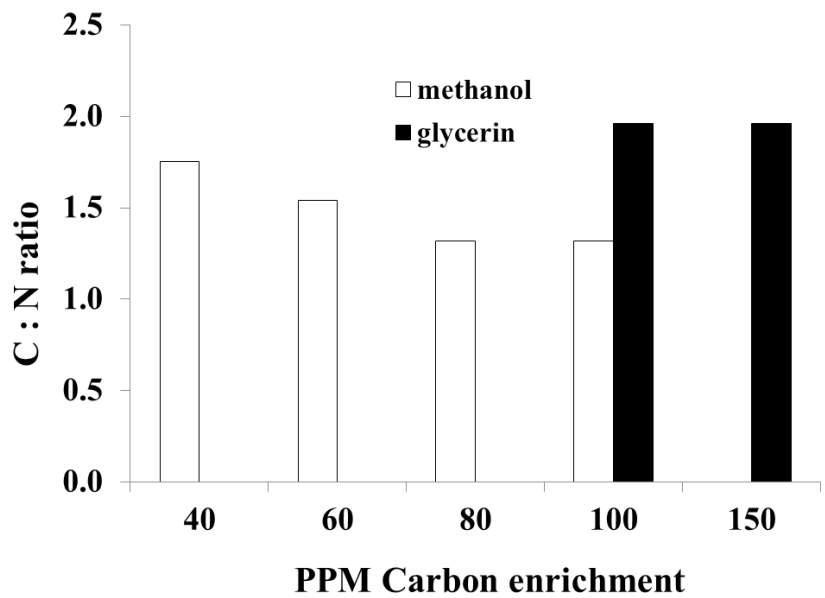

Figure 2. Stimulation of denitrification by carbon enrichment using either methanol or glycerin; C : N ratio refers to the ratio of g C applied to g N denitrified.

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

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INTRODUCTION

Nitrate leaching in vegetable production in the Salinas Valley is a continuing problem that contributes to groundwater contamination and affects the ability of municipalities to access sources of drinking water that meet federal water quality standards. Strategies to improve the efficiency of applied nitrogen (N) fertilizer are needed. A key technique for improving N use efficiency is to be able to retrieve nitrate that has been pushed below the root zone of crops such as lettuce and spinach. Cover crops can retrieve nitrate pushed deep into the soil profile, but the use of cover crops is limited in the Salinas Valley due to the high production and land rent costs. It was observed in a FREP-funded project entitled, "Survey of Nitrogen Uptake and Applied Irrigation Water in Broccoli, Cauliflower and Cabbage Production in the Salinas Valley" that cole crops routinely take up more N than is applied. This may indicate that cole crops serve as a scavenger for soil N during the crop production season. This project investigates the role of broccoli in scavenging nitrate from deep in the soil profile. This project hopes to delineate the ability of broccoli to retrieve nitrate deeper in the soil profile during the crop production cycle and make it available for subsequent crop growth after the crop residue is incorporated into the soil.

OBJECTIVES

1. Determine the effective rooting depth of broccoli for removing residual N from the soil profile though direct evaluation of rooting pattern and replicated field trials.
2. Adapt soil nitrate quick test for broccoli to guide N fertilizer applications by evaluating factors including soil sample depth, threshold of soil nitrate sufficiency, and crop stage.
3. Conduct commercial field trials evaluating the efficiency that broccoli can remove residual nitrate from the soil following a lettuce crop under normal production practices.
4. Examine the mineralization rate and quantity of nitrate mineralized from broccoli residue to assist its utilization by subsequent crops.
5. Conduct an outreach program to growers and consultants on the results of the study and how to utilize the nitrogen scavenging attributes of broccoli to improve nitrogen utilization in the cool season vegetable production system.

DESCRIPTION

A trial has been established at the USDA Spence Research Station, Salinas, in which drip tape has been injected into the soil at three soil depths: 12, 18 and 24 inches deep. We had equipment built to inject the drip tape, and originally proposed to inject the tape to 12, 24 and 36 inches deep; however, it turned out to be impossible because pulling an implement through the soil three feet deep required a more powerful tractor, which would tear listed beds. We plan to overcome this issue by using calcium nitrate as the N source and to apply excess irrigation water to leach the fertilizer applications to deeper soil; this may partially offset having the tape at shallower depths than proposed.

Five surveys have been established in commercial broccoli fields with cooperating growers. Broccoli fields were selected that were following a prior crop of lettuce. Residual soil nitrate levels at one-foot increments down to three feet were evaluated

to establish baseline soil nitrate levels for each field. Soil samples for nitrate-N are being collected as mentioned above, are being collected every 25 to 30 days from the standard grower practice and small subplots that receive no sidedress nitrogen treatments. There are four replications of the grower standard and untreated control strips in each field. Total irrigation water applied to the fields is being monitored with a flow meter and will be evaluated to establish the degree of leaching in each field. Crop biomass and biomass N are being evaluated when we collect soil samples. Soil nitrate levels in the first two feet are being posted on CropManage and being made available to the grower; the results are being discussed with the grower to inform them of the total quantity of nitrate available to the crop in the top two feet of soil.

RESULTS AND DISCUSSION

We are in the early stages of this project and there are no results to report yet.

ACKNOWLEDGEMENTS

California Fertilizer Research and Education Program

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 50 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).

More recently, we have identified soils with high K fixation potential in Lodi district wine grape vineyards (O'Geen et al., 2008). However, in K fertilizer experiments conducted in four commercial vineyards during 2009-2012, only a marginal yield response to K was observed, and there was no indication of the need for extra K fertilizer in K-fixing soils.

More research is needed to develop a practical soil test for determining the K fertilizer requirements of K-fixing soils. We have developed a one hour incubation method for measuring soil K fixation potential (Murashkina et al., 2007). Other researchers have shown that a modified version of an older test -- sodium tetraphenyl boron, NaTPB -- is useful for estimating the portion of fixed K that is plant-available (Cox et al., 1996 and 1999); however, this test is not well suited to production laboratory operation.

We have used both newly collected and archived soils from Lodi district wine grape vineyards and San Joaquin Valley cotton fields to determine whether various measures of soil K can be related to K supply capacity of K-fixing soils.

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, previously published by O'Geen et al. (2008). The model groups soils by K fixation potential, landscape location, and geology.
3. For the one-hour K-fixation potential soil test method (Kfix), determine the effect of sample wetting and drying and sequential K-additions. Also compare the Kfix method with another published method for estimating K-fixation potential of soil.
4. Provide research summaries and K fertilization recommendations for K-fixing soils to crop management professionals, analytical laboratories, and growers.

WORK DESCRIPTION

Soils and analytical procedures

Soil samples from 18 pedons and a total of 52 depth increments were used. Samples came from twelve wine grape vineyard locations, two cotton fields, one alfalfa field, and three almond orchards in the Central Valley of California. A subset of Fields with a history of large K fertilizer applications were excluded from the study.

K fixation potential (Kfix) was measured on 3 g of soil by the procedure of Murashkina et al., 2007. This procedure involves shaking the soil for 1 hr with 2 mM KCl, then measuring the concentration of K in the

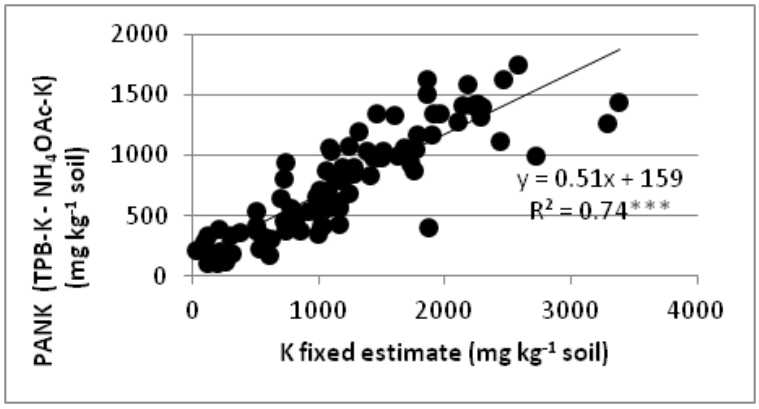

Figure 1. Plant-available nonexchangable K compared to K fixed as estimated by Kfix method for 2x through 8x incremental additions.

	XK % of added K recovered		TPB-K % of added K recovered	
K added	Mean	Range	Mean	Range
2x	21%	11-38%	59%	46-80%
4x	22%	16-35%	66%	55-80%
6x	28%	21-41%	71%	64-88%
8x	37%	29-47%	75%	69-89%
Symm†	74%	58-85%	83%	75-93%

†Amount of K added equivalent to soil cation exchange capacity

Table 1. Percent of added K recovered for soils with significant K fixation capacity (Kfix 200-600 mg kg^{-1}).

solution, which for K-fixing soils is decreased from the initial 2 mM. Results can be expressed as mg K fixed per kg soil or as a percent of initial solution K removed by fixation. An alternative measure of K fixation potential (Kfp) was used per Hartz et al. (2002). This includes a drying step and adds a lower concentration of K to the sample than our Kfix method.

Ammonium acetate-extractable K (XK) (Soil Survey Staff, 2004) was also measured. This is a version of the commonly used agricultural soil test for available K.

Sodium tetraphenylboron-extractable K (TPB-K) was measured by the procedure of Cox et al. (1996, 1999). This involves extracting 1 g soil with a solution of 0.2 M NaTPB + 1.7 M NaCl + 0.01 M EDTA, quenching the reaction with additional reagents, then measuring the K in the resulting precipitate. This typically extracts more K than NH4OAc, and has been shown to correlate better with plant-available K in soils with non-exchangeable (fixed) K.

RESULTS

Incremental K additions

In experiments in our laboratory, roughly 75% of added K was recovered from soils with Kfix values less than 200 mg kg^{-1} by both methods. For soils with Kfix values greater than 200 mg kg^{-1}, the XK method recovered around 20%, and the TPB-K method recovered 60% of added K (Table 1). Of the added K estimated to be fixed, approximately 50% was recovered by the TPB-K method but not by the XK method (Figure 1). This pool of K is termed "plant available non-exchangeable K" (PANK).

Table 2. Forms of K in soils used in greenhouse pot study.

Pedon Code	Soil/Classification	Depth (cm)	XK (mg kg^{-1})	TPB-K (mg kg^{-1})	TotK† (mg kg^{-1})	Kfix (mg kg^{-1})
VSS E	*San Joaquin silt loam*	0-20	79	189	2100	241
	Abruptic Durixeralf	100-120	95	183	3950	632
DH 2	*Guard clay loam*	0-20	194	553	2820	58
	Duric Haplaquoll	40-60	116	234	2810	420
KTR A	*Columbia sandy loam*	0-20	167	770	4500	-26
	Aquic Xerofluvent	40-60	88	300	3940	243
DON A	*Archerdale clay loam*	0-20	269	558	4000	-70
	Pachic Haploxeroll	40-60	159	234	2840	225
RM X	*Redding gravelly loam*	0-20	87	130	830	-45
	Abruptic Durixeralf	40-60	40	66	880	14
DOUG	*Vina fine sandy loam*	0-20	301	395	1430	-186
	Pachic Haploxeroll	40-60	144	155	740	-60

†Total K measured after aqua regia digestion (Rajashekhar Rao, 2011).

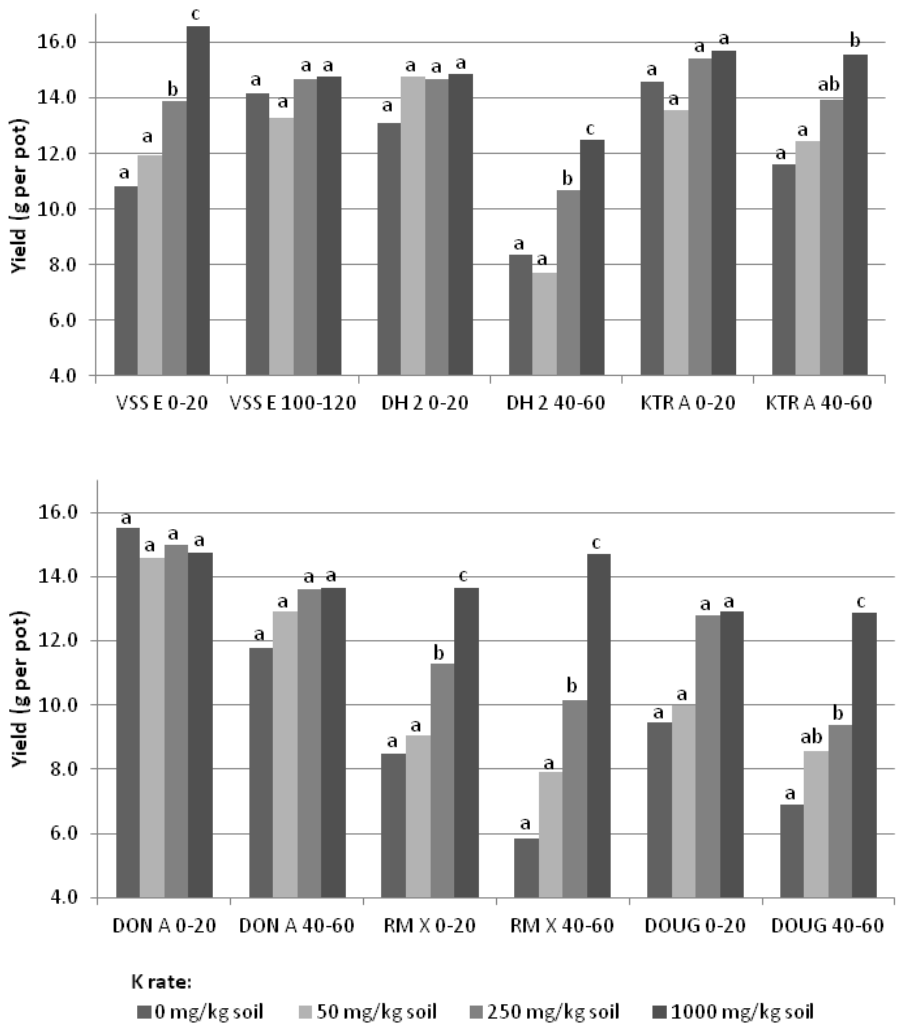

Figure 2. Ryegrass dry matter yield (total of 3 clippings) for 4 K fertilizer rates and 12 soils. Values with same letter within soils not significantly different at $p<0.05$ by the Tukey HSD method.

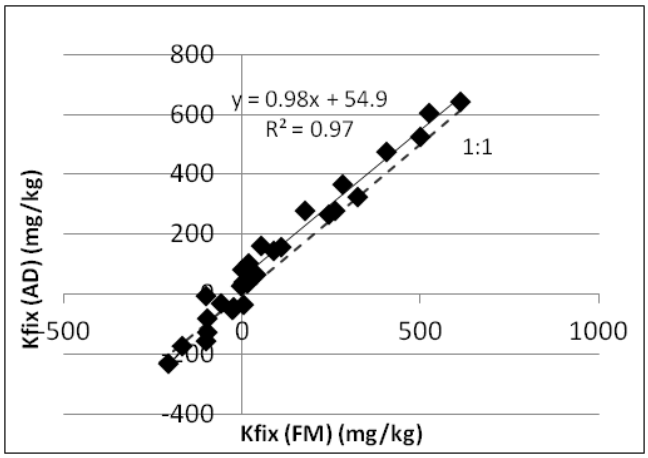

Figure 3. Air-dried (AD) vs field-moist (FM) Kfix values. Regression is for Kfix>0 only.

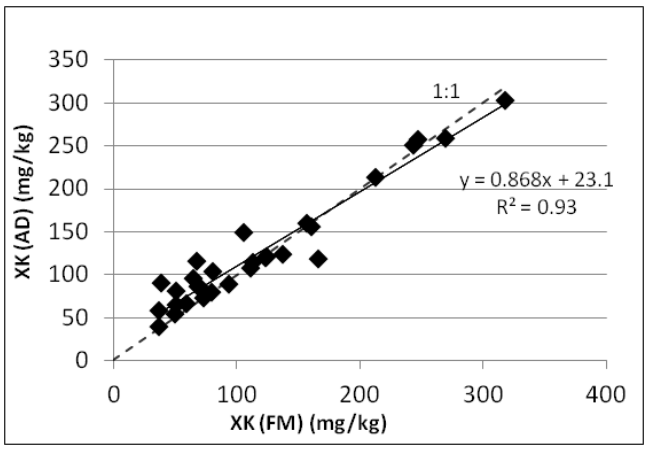

Figure 4. Air-dried (AD) vs field-moist (FM) XK values

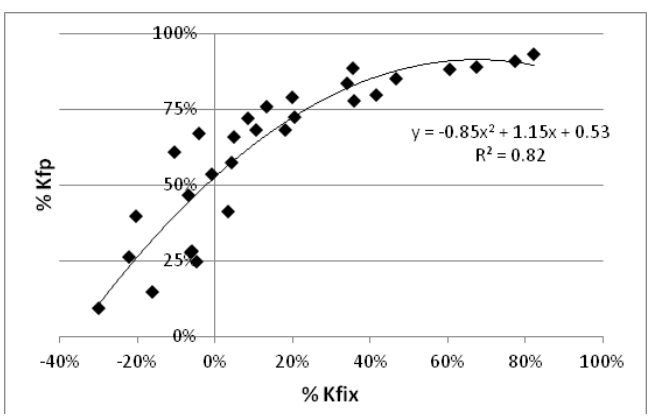

Figure 5. Comparison of the Kfp method to the Kfix method. Kfp approaches 100% more quickly than Kfix, plateauing at approximately 90%.

Greenhouse pot K fertilizer study

Annual ryegrass (*Lolium multiflorum*) was grown in 15-cm diameter pots in a greenhouse in 12 soils (6 soil series, 2 depths) selected from our 52-sample collection. Content of K fractions is shown in Table 2. Soils were fertilized at four rates of K: 0, 50, 250, and 1000 mg kg^{-1}. Oven dry weight of aboveground biomass (yield) was recorded, and tissue K was measured by acetic acid extraction (data not shown). Dry matter yield response to K was observed in 8 of the 12 soils (Fig. 2)

From the plant dry matter results, we estimated critical soil values for K below which a K response would be anticipated. Critical values were: for XK, 167 mg/kg soil; for TPB-K, 419 mg/kg soil; and for TotK, 1663 mg/kg soil.

Calculating mean XK and Kfix values for soil profiles

We have found that plant-available K (measured as XK) tends to decrease with depth, and K fixation capacity (as measured by Kfix and observed in some soils formed from granitic parent material) tends to increase with depth.

We calculated weighted mean soil K levels in 12 soil profiles sampled to maximum depths of 90-170 cm. Nine of the profiles had surface layer XK levels of <125 mg kg^{-1}, and therefore would be considered K-deficient. Profile mean XK values (weighted by thickness of depth increment) were very low (<70 mg kg^{-1}) in 11 of 12 profiles. Samples of six of the 12 sites showed little or no K fixation capacity (Kfix<50 mg/kg) in the surface depth increment; but four of those profiles had much higher Kfix in the subsurface and therefore showed high mean profile values of Kfix. Mean profile Kfix values (in the 9 strongly K-fixing profiles) expressed as a percentage ranged from 19 to 54%., lower than the 60% critical value recommended for cotton by Miller et al. (1997).

Field Moist versus Air Dry soil K measurements

Kfix and XK were measured for selected sam-

ples before and after a single drying event of field moist samples. Field-moist and air-dry values are compared for Kfix in Figure 3 and for XK in Figure 4. The Kfix value increased with drying for all K-fixing soils by an average of about 55 mg kg^{-1} soil. The change in XK due to drying was small (less than 20 mg kg^{-1}) for most samples. Multiple cycles of wetting and drying after an initial application of K equal to the Kfix value did not significantly affect the values of Kfix, NH_4OAc-K, or TPB-K (data not shown).

Comparison of Kfix to Hartz Kfp method

The Kfix method was also compared to the Kfp method of Hartz et al. (2002). Both are simplified versions of the Cassman et al. (1990) method. The Kfp method maintains an air-drying step and adds K at half the rate used in the Kfix method. Results in figure 5 show a correlation between the methods, but the Kfp method approaches 100% of added K fixed more quickly than the Kfix method, resulting in a curvilinear relationship.

DISCUSSION AND CONCLUSIONS

Sufficiency levels for annual ryegrass in our pot study were 167 mg kg^{-1} for XK and 419 mg kg^{-1} for TPB-K. These levels were not perfect in predicting yield responses to K applications, but the TPB-K method was most accurate, and best correlated with measured uptake. Based on the efficiency results from the incremental additions of K, in order to increase soil test levels of XK and TPB-K to these levels, K should be applied at 1.33 times the desired increase for soils with Kfix<200 mg kg^{-1} for both methods. For soils with Kfix>200, K should be added at 1.67 times the desired increase for TPB-K, and 5 times the desired increase for XK. Adjustments are not necessary for non-K-fixing soils. These numbers are estimates based on our set of soils, and some variation in response by soil is to be expected. As a caution, given the limited correlation of Kfix values to observed growth response in the pot study, further validation of these methods and recommendations is necessary.

In K-fixing soils, drying consistently results in an increase in K fixation capacity relative to moist samples, both with and without K additions prior to the drying event. Relative to field moist samples, on dried samples, Kfix increased by an average of 55 mg kg^{-1}. Changes in XK, however, were less consistent.

Additions of K to K-fixing soils results in a new distribution of K across the various pools of soil K. Some of the added K remains exchangeable, some becomes non-exchangeable, but still plant available, and some is fixed in a non-plant-available form. A portion of K added sequentially to soils continues to be fixed, with the fraction fixed decreasing with each addition, meaning that K fixation potential is only partially satiated by K additions, and a single application of K at a high rate in K-fixing soils will not remove the potential for continued fixation of applied K in the future.

K management in K-fixing soils is a complex task, influenced by a variety of soil properties. Our research provides several critical insights into the dynamics of K in these soils and some rules of thumb for adjusting K applications in K-fixing soils. Broadly, this work demonstrates that K fertility cannot be assumed to be simple in any setting, and even soils with similar soil K test levels may behave very dissimilarly in the field.

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Irrigation and Nitrogen Management Web-Based Software for Lettuce Production

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INTRODUCTION

Vegetable growers on the central coast of California are under regulatory pressure to reduce nitrate loading to ground water supplies. Additionally, over pumping of ground water for agricultural production has contributed to seawater intrusion into coastal aquifers, which may be accelerated during the current drought. Two tools available to farmers for improving nitrogen and water use efficiency are the soil nitrate quick test (SNQT) (Hartz et al. 2000) for monitoring soil mineral nitrogen levels and weather-based irrigation scheduling for estimating water needs of crops (Cahn and Smith, 2012, Johnson et al. 2013). Under a previously awarded CDFA FREP grant we developed the web-based software application, CropManage (CM) (ucanr.edu/cropmanage), to facilitate the implementation of both tools for lettuce, and subsequently through additional CDFA-FREP funding, for cole crops and leafy greens (Cahn and Hartz, 2012, Cahn et al. 2013a, 2013b, 2013c, 2014d). Users can access the software through a web browser on their smart phones, tablet and desktop computers. The software allows growers to quickly determine a fertilizer N rate based on the SNQT and N uptake curves for cool season vegetables. In addition, the software estimates the water requirement of the crop using evapotranspiration data from the California Irrigation Management Information System (CIMIS) and models of canopy development. Preliminary field testing of the software in commercial fields indicated that growers can significantly reduce N fertilizer and water use without reducing crop quality and yield. Large-scale field trials comparing the CM fertilizer N recommendation with grower standard practices resulted in similar yields using an average of 32% less N fertilizer. Replicated trials resulted in a 25% to 40% savings in water by following the irrigation schedule of the online tool compared to the grower standard practice, and equal commercial yields between treatments (Johnson et al. 2013).

Since CM was first developed in 2011, the decision support tool has more than 450 registered users and more than 100 registered ranches. Some of these users represent large vegetable and berry farming companies on the central coast that are interested to adapt CM practices for their operations. Despite recognition by these growers that CM can help them efficiently use nitrogen fertilizer and water for their crops, they have been challenged to integrate the CM tool into their daily farming practices. Many growing operations needed to hire and train new personnel to sample fields and to test soil nitrate levels before applying fertilizer, and to record and to monitor irrigation applications, as well as to oversee the input of data into CM. Growers have also invested in tools such as soil moisture sensors and flow meters, to verify that changes made in their management are not risking yield and quality of their crops.

OBJECTIVE

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

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

DESCRIPTION

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

Specifically, we will collaborate with major vegetable shipping operations to identify at least two growers on the central coast and one grower in the Imperial Valley that are currently implementing or desire to implement best management practices (BMPs) for nitrogen and water in their farming operations using CM. We will provide training for personnel who will be participating in the project, including grower operators, farm managers, farm management staff, and associated consultants. Participating growers will identify two to three vegetable fields of the same commodity (either lettuce, broccoli, cabbage, or cauliflower) for monitoring current water and N use practices. Each field will be equipped with a flowmeter (Figure 1) for recording applied water volumes and sensors for monitoring soil moisture (Figure 2). Fields will be evaluated for residual soil nitrogen at planting, before each fertilizer N application, and after harvest. All collected information will be maintained using the online CM decision support tool. Biomass will be sampled near harvest to estimate total N uptake of the crop. Participating growers will provide commercial yield data for the fields. Opportunities to improve management will be identified by comparing the amount of N fertilizer and water applied to the CM

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

recommended amounts. During the second phase of the project, participating growers will identify an additional two to three vegetable fields of the same commodity for evaluating CM recommendations for nitrogen and water applications. The same procedures will be followed as described above, with the exception that the CM recommendations for nitrogen fertilizer and water will be followed as closely as the grower can practically accomplish. Results will be compared with the recommended values to estimate the improved efficiency for nitrogen and water management.

ACCOMPLISHMENTS

Monitoring Current Nitrogen and Water Management Practices in Lettuce

Two growers were identified who were interested to implement CM decision support for their vegetable farming operations in the Salinas Valley during the 2014 season. Each growing operation annually farms more than 2000 acres of vegetables. Growers selected three commercial lettuce fields for monitoring current nitrogen and water management practices. Fields were equipped with a flowmeter for recording applied water volumes and sensors for monitoring soil moisture. Data were automatically updated in CM using cell phone and radio modem communications. Fields were evaluated for residual soil nitrogen at planting, before each fertilizer N application, and after harvest. All collected information was maintained using the online CM decision support tool. Biomass was sampled near harvest to estimate total N uptake of the crop. Opportunities to improve management were identified by comparing the amount of N fertilizer and water applied to the CM recommended amounts. Preliminary results indicated that applied N could be reduced by 40% to 50% and applied water by 20% to 30% without harming marketable yields.

Implementing BMPs for Nitrogen and Water Management in Lettuce

During the second year of the project, each participating grower will select an additional group of lettuce fields where the fertilizer N and irrigation will be adjusted during the season following the guidance of the CM decision support tool. Because of the interest of one of the participating growers, we monitored an additional three lettuce fields during

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

the 2014 season following the guidelines of CM. The combination of improving water management and testing the soil for residual nitrate before fertilizer applications reduced fertilizer N by an average of 40% (100 lbs N/acre) for these 3 fields. Similar demonstrations will continue during the 2015 season.

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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 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

Initially, we developed the GIS framework and compiled spatial land use data, collecting and digitizing data for performance of the nitrogen mass balance (historic and current), and worked 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).

This was followed by extensive analysis of cropping data, that is, the annual fluxes into and out of the rootzone of individual fields (Harter et al., 2013). 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 also completed a survey of extension specialists throughout the Valley, regarding published application rates for the 2005 period, for 20 of the most prominent crop species to confirm or adjust estimated application rate ranges, including varietal and regional differences.

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 (Harter et al., 2013).

An extensive review of dairy nitrogen sources to groundwater was performed. Dairy related landuses are categorized into three groups: dairy corrals, dairy lagoons, and cropland receiving dairy manure. Groundwater monitoring data and literature reports were used to estimate ranges of nitrate loading to groundwater from dairy corrals and lagoons. A mass balance approach is applied for dairy cropland nitrate loading. For the analysis, we obtained estimated and reported data on manure production, manure exports, and manure and fertilizer applications to dairy forage crops.

Non-agricultural sources of nitrogen – some of the land applied to agricultural lands – also include waste effluent and biosolids from wastewater treatment plants and from food processors, leachate from septic systems, urban wastewater systems, and urban lawns and golf courses.

Based on our work in Kourakos et al. (2012), we continued to develop 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 have developed 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 simulation of groundwater contamination from non-point sources has been an active arena of research for several decades. Approaches to evaluate the impact from non-point source pollution fall into three categories: index methods, statistical methods, and physically based methods. For example, the internationally widely applied DRASTIC tool (Aller et al., 1987) or the California nitrogen hazard index (Viers et al., 2012), are index-based tools that aggregate information such as soil type, landuse, topography, irrigation/precipitation, recharge, etc. using expert-assigned indexing levels. Index methods provide a composite vulnerability assessment map. Similarly, statistical methods such as multivariate statistics (Kaown et al., 2007), regression analysis (Nolan et al., 2006), artificial neural networks (Khalil et al., 2005) are employed to extract relationships between control variables (potential contaminant

sources, climate-soil-aquifer conditions) and water quality data (nitrate, pesticides) in wells or springs to provide a tool to assess potential groundwater quality impacts. For example, the California Department of Pesticide Regulations uses a multivariate statistical approach to delineate groundwater protection zones vulnerable to pesticide contamination (Troiano et al., 1994, 1997).

Streamlines consist of a set of positional vectors $X = \{\mathbf{x}_0, \mathbf{x}_1, \dots, \mathbf{x}_{n,}\}$ that hold the coordinates of the streamline and a set of velocity norms $V = \{v_0, v_1, \dots, v_n\}$, which contain the velocities at the points of the positional vectors. Note that we are using backward particle tracking that associates each streamline with a contamination source, thus identifying contributing land uses within the source area of a CDS.

Physically based methods – often referred to as "groundwater computer models" – explicitly capture the flow and transport dynamics that govern the contamination processes. These methods are based on the solution of partial differential equations of groundwater flow and contaminant transport. Physical or process-based approaches provide scientifically more rigorous insights into flow and transport dynamics than indexing or statistical methods. They allow for a wide range of analyses and assessments, including sensitivity, scenario, and stochastic analyses. A major drawback of physically based models is that their implementation is computationally demanding. NPS pollution often takes place in large agricultural basins that extend across thousands to tens of thousands of square miles, while individual sources such as crop fields, dairy lagoons/corrals, septic systems, etc. vary in extent from less than a few acres to few hundreds of acres. Groundwater and pollutant discharge to streams or to the large number of irrigation wells in semiarid and arid basins forces highly localized flow and transport systems. Therefore, the simulation of very large agricultural basins with sufficiently detailed discretization to account for the proper transport dynamics between the large assembly of relatively small but heterogeneous sources and the affected array of spatially distributed groundwater discharge locations (wells, springs, stream sections) would potentially require computer models with tens to hundreds of millions of pixel cells (currently, typical groundwater transport models employ up to one million pixel cells). The large contrast between the extent of groundwater basins and the size and number of contributing sources and affected receptors makes the simulation of NPS pollution a challenging problem, despite current software and hardware developments.

To simulate groundwater pollution from agricultural sources in Central Valley aquifer, we developed the Non-Point Source Assessment Tool (NPSAT Kourakos and Harter 2014a) which is based on our previous theoretical work (Kourakos et al., 2012). NPSAT employs the streamline transport approach on a highly resolved steady-state groundwater flow field to derive an ensemble of unit response functions (URF) for each discharge point of interest (e.g., wells, streams etc.). The URFs are stored in a GIS database and can be used for predictions by convolution with actual spatiotemporally distributed pollutant loading functions to rapidly calculate breakthrough curves

For each streamline we solve the one dimensional transport problem:

$$R\frac{\partial c}{\partial t} = \frac{\partial}{\partial x}\left(D\frac{\partial c}{\partial x} - vc\right) - \lambda Rc$$

subject to:

$$c(x)_{t=0} = 0 \; \forall x \in [0, L]$$

$$c(\mathbf{x}_n)_{t>0} = 1$$

$$\left(\frac{\partial c}{\partial t}\right)_{x=\mathbf{x}_o} = 0$$

where $c(x,t)$ is the solute concentration at point x and time t, v is the pore velocity, D is dispersion coefficient, λ is first order degradation (or decay) constant and R is the retardation factor. Dispersion $D = \tilde{\alpha}_L v$ is a function of the effective macrodispersivity, $\tilde{\alpha}_L$. The latter, $\tilde{\alpha}_L = f(L)$, is typically scaled relative to the length of the streamline L (Gelhar et al., 1992; Green et al., 2010).

In the formulation of the transport problem, we do not require any knowledge of loading. Instead, a continuous unit loading is applied at the source side $\mathbf{x}_n$. Solving the transport problem we calculate the unit response function (URF) at the CDS side $\mathbf{x}_0$ by shifting the solution of the 1D transport problem by the basic time unit defining the temporal discretization of the NPS loading function (e.g., one year for annually varying loading) and subtracting it, for a given time, from the original solution.

The URFs are subsequently archived into a Geodatabase and can be used during the implementation phase. In addition to URFs, archives are also established for the coordinates of point $\mathbf{x}_{n,}$ and the velocity v_0.

(BTCs). The approach has two distinct advantages. First, based on the premise of steady-state flow (see Kourakos et al., 2012 for full justification of the assumptions), the transport problem can be separated from the flow problem and second, using the URF concept, the transport problem becomes independent of the loading history.

The NPSAT consists of two phases, the construction phase and the implementation phase. During the construction phase, the groundwater flow is simulated with sufficiently detailed discretization around wells, streams or other sources or receptors of interest. Due to the highly non-uniform distribution of boundary stresses, we apply the finite element method (FEM), which allows for locally variable size discretization. The groundwater flow field provides the basis for the streamline transport simulation. Note that this method was specifically developed for diffuse pollution problems where all or most recharge sources are associated with an identifiable and relevant level of pollutant concentration, and where a large number of discrete receptors or Compliance Discharge Surfaces (CDS) exist (e.g., wells, springs, stream sections).

To identify the pathways of contaminants that are associated with each particular CDS, a large number of particles are released in the immediate vicinity of the CDS. The particles are tracked backwards until they exit the aquifer at the point of recharge, thus defining streamlines. For each streamline, the computer model solves a one-dimensional transport problem (see textboxes).

In the implementation phase, actual BTCs for each CDS are computed as a response to actual pollutant loading functions. The typical form of a loading function is a time series of spatially variable loading rates, varying, e.g., by field, possibly grouped into land use or crop type categories. Therefore the first step during the implementation phase is to associate the points with the associated field or land use types that have a known loading function. Next, the loading functions are convolved with the URFs to derive the streamline BTCs. The convolution operator is a fast operator that involves only analytical calculations and the execution time is practically negligible. The NPSAT requires a highly detailed resolution around the receptors to avoid the weak sink problem (Starn et al., 2012) during backward particle tracking. In addition, the scale of the discretization at the aquifer surface needs to be on the same order as the scale of the individual contributing recharge and pollution sources. Therefore, the simulation of large agricultural groundwater basins leads to a very large system of linear equations.

To deal with large scale simulations, we modified the approach of Kourakos and Harter (2014a) to allow parallel implementation (Kourakos and Harter 2014b). Generally, the construction phase of NPSAT is time-consuming and involves several sequen-

Let $f_L(t)$ be a loading function, which is associated with the URF $g_i^j(t)$ where the indices i and j correspond to the ID of the streamline and the ID of the CDS, respectively. The discrete form of convolution operator is expressed as: $G_i^j(t) = f_L * g_i^j = \sum_{\zeta=0}^{t} f_L(t-\zeta) g_i^j(\zeta)$ where $G_i^j(t)$ is the actual BTC in response to the loading function $f_L(t)$ for the streamline i, ζ is a free variable that increases in the summation at time step intervals and t is the total simulation time.

Finally, the actual BTC for the j CDS $\bar{G}^j(t)$ is the weighted average of the individual streamline BTCs $G_i^j(t)$ e.g. $\bar{G}^j(t) = \sum_{i=1}^{Ns} v_0^i \cdot G_i^j(t) / \sum_{i=1}^{Ns} v_0^i$, where the weights are taken equal to the amount of flow that each streamline contributes to the CDS.

tial steps. However the memory requirements are relatively small, even for large problems, and more importantly the individual processes are embarrassingly parallel, i.e. little or no effort is required to separate the problem into separate tasks and almost no communication between tasks is needed.

The first step in numerical simulation is the discretization of the domain. Because of the complexity of parallel mesh generation and the lack of readily available libraries, in our framework we choose to construct a two-dimensional mesh using standard methods which can be executed on a single processor. For parallel processing, the 2D mesh is subsequently split into subdomains and the mesh is extruded in the Z direction on each process individually. To allow independent assembly on each processor without the need to exchange information besides the locally owned elements, each subdomain owns a number of ghost elements, which are elements locally owned by another processor. The next step is the matrix assembly where the conductance terms and source/receptor vectors are assembled. The distributed system is solved by the algebraic multigrid method (AMG). Initially the grids and the restriction and interpolation operators on each level are constructed. The system is then solved iteratively using an appropriate solver and preconditioner. In our framework, we propose conjugate gradient based solvers combined with algebraic multigrid methods as preconditioners (Kourakos and Harter 2014b). In cases where the

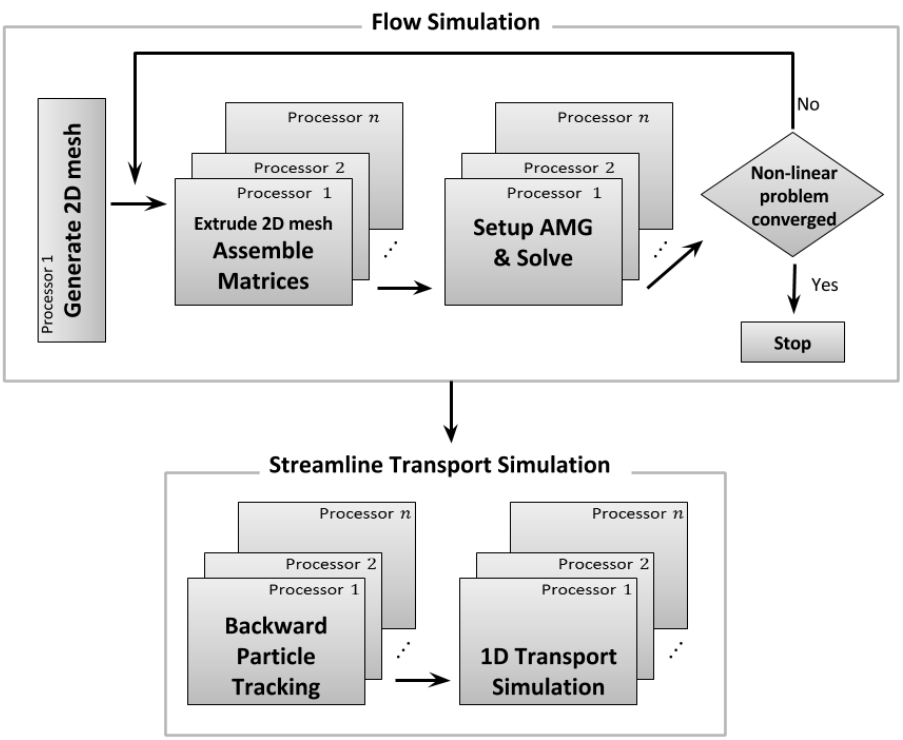

Figure 1. Schematic flow-chart of the computational tasks coded into the nonpoint source assessment simulation toolbox. The first step is a flow simulation to define the velocity distribution within the aquifer at very high resolution. The second step is a transport simulation in the three-dimensional aquifer system, which is achieved by computing nitrate or other pollutant transport along individual streamlines. The steps shown above generate so-called transfer functions that can be used within a GIS framework to generate simulated long-term contaminant histories in thousands of individual wells based on the pollutant loading history to the water table. The tool can be applied to evaluate future water quality changes due to improved management practices in selected crops, regions, or other land uses.

partial differential equations are non-linear (e.g., unconfined flow), an additional loop is needed which iterates through all steps of the flow problem until the nonlinear problem converges. In unconfined groundwater flow simulations, for each non-linear iteration, the elevation of the top layer of the grid becomes equal with the hydraulic head of the previous iteration. This results in a change of the entire conductance matrix and source/receptors vector. Therefore the system is reassembled and solved iteratively until the change in the head between two consecutive iterations is smaller than a specified threshold.

The computed head distribution is subsequently used for particle tracking. The streamline tracking simulation is a so-called embarrassingly parallel process. However, it is possible that a single streamline may span multiple subdomains and, hence, multiple processors. In cases where the available memory is able to support the entire 3D mesh, it is advantageous to join the subdomains as streamline tracking becomes easy to implement. When the problem is too large to be stored on a single processor, additional algorithmic effort is needed to transfer particles between processors. The solution of the 1D transport problem along each streamline is an independent process even on very large problems and therefore can easily be parallelized. The implementation phase, which involves convolution of loading functions with the URF computed at the transport simulation, can be parallelized seamlessly, although even the serial execution time is typically very small, despite a very large number of CDS.

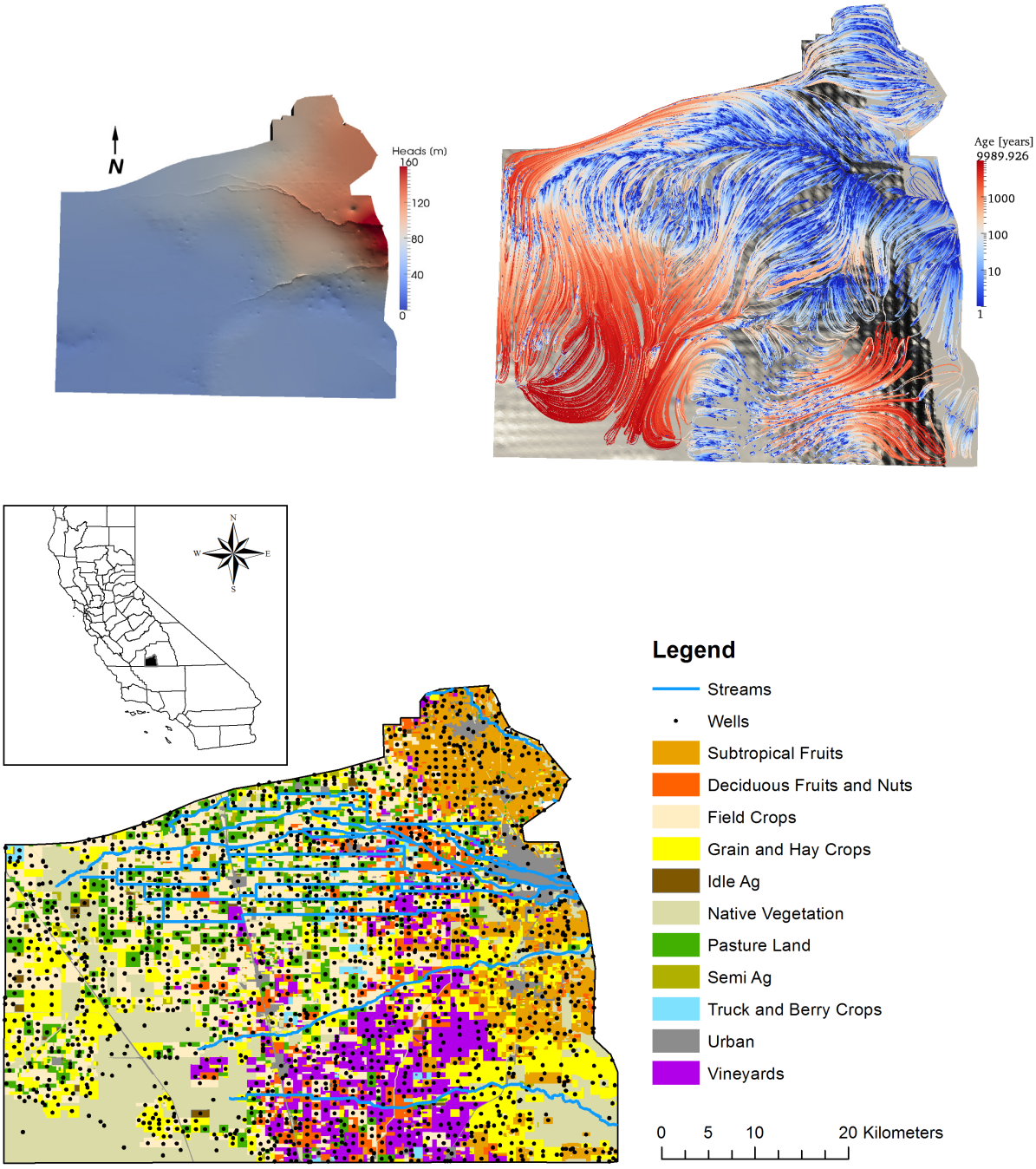

Figure 2. One application of the simulation algorithm was compelted for the Tule River basin in southern Tulare County, which features a wide range of crops, but also dairies (lower map). The flow model generates the simulated water table surface at high resolution (upper left), showing streams as recharge "walls" and large pumping wells as dotted depressions in the water table surface. Streamlines and travel time (water age, shown as the color of the streamline) are computed to all pumping wells and provide the basis for estimating pollutant transport.

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

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INTRODUCTION

Optimal fertilization practice can only be developed if knowledge of the 4 R's (right source, right rate, right place, and right time) are explicitly developed for the almond production context. To optimize nutrient use efficiency in fertigated almond, it is essential that fertilizers injected into irrigation system are provided at the optimal concentration and time to ensure that deposition patterns coincide with maximal root nutrient uptake.

OBJECTIVES

1. Determine almond root growth and phenology and characterize root distribution and nutrient uptake activity as influenced by tree nitrogen status, irrigation source, yield and plant characteristics.
2. Determine the patterns and biological dynamics (K_m, V_{max}, C_{min}) of tree nitrogen uptake and the relationship to tree demand and phenology.
3. Integrate root phenology and uptake data 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.

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

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 in 2 week basis and images will be analyzed

recording number of roots, color, diameter and length. A total of 180 root bags filled with media were installed. 80 soil solution access tubes (SSAT, a.k.a. "lysimeters") were installed at 2 depths (150 and 250 cm).

2. Fertigation method experiment

The effect of fertigation technique (pulsed, continuous, drip, microjet) was examined in a subset of trees in the same orchard as above (see Table 2 for treatments).

RESULTS AND DISCUSSION

1. Nitrate Uptake by roots

Results from this experiment are shown in Figure 1. When roots where incubated in solutions from a low range concentration of 0.05 to 0.5 mmol·l-1 of N-NO_3 (0.42 to 3.50 ppm of N-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, with no significant difference between treatments. This result suggests that N starved trees may up-regulate N uptake and can access N from lower NO_3 concentrations than trees with sufficient N content. At higher external N-NO_3 concentrations, ranging from 0.5 to 7.5 mmol·l-1 of N-NO_3 (7.01 to 14.01 ppm of N-NO_3), uptake rates significantly increased in comparison with lower external concentrations. These results suggest that roots in almond trees may be more efficient at acquiring N at low external N concentration, suggesting that continuous fertigation with low n applications is superior to split applications during the season.

Biological uptake parameters were determined using a non-linear regression approach for the low N application. V_{max} is the maximal nutrient uptake rate by the roots at a saturation nutrient concentration; C_{min} corresponds to the minimal concentration at which roots are able to absorb nutrients (below this concentration the uptake rate is 0); and K_m is a constant that represents the affinity of roots to nutrients and explains how fast the uptake rate will approach V_{max}.

Results from the minirhizotron tubes installed in this experiment are shown in Figure 3. Irrespective of year, experiment or treatments, almond roots showed a consistent growth pattern with a dual cycle, with the majority of new roots being produced at two growth phases during the year (spring and fall). Spring root growth, occurring from mid-March to June was significantly higher than the fall growth, mainly occurring from mid-September to December.

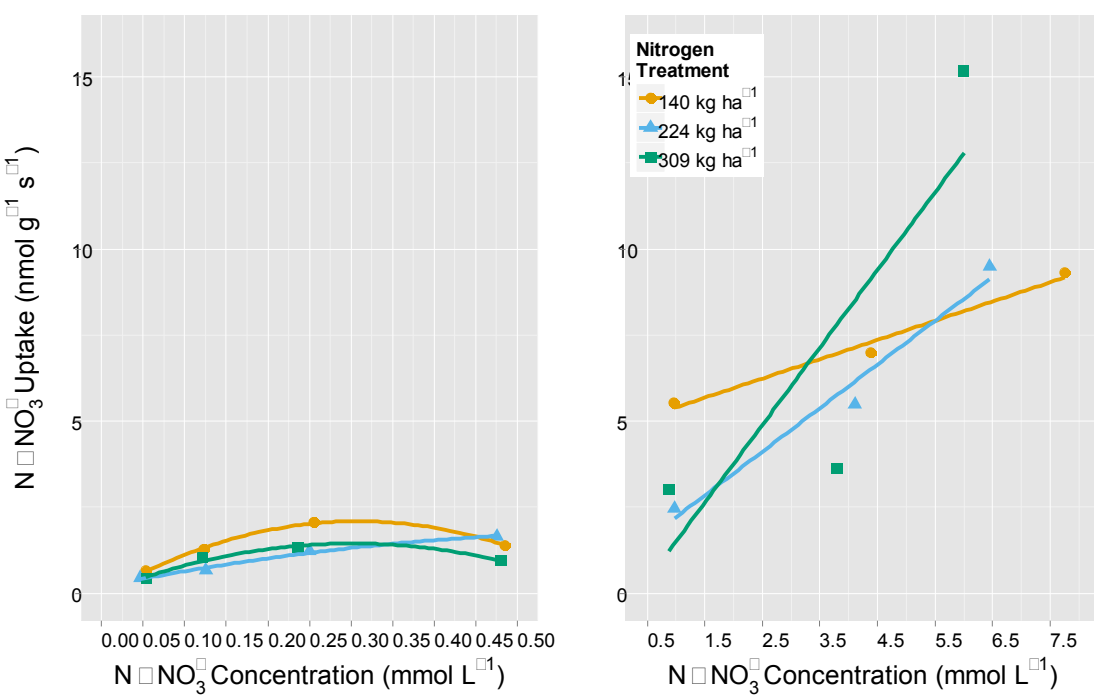

Figure 1. N-NO_3 uptake of almond roots at different N-NO_3 external concentrations

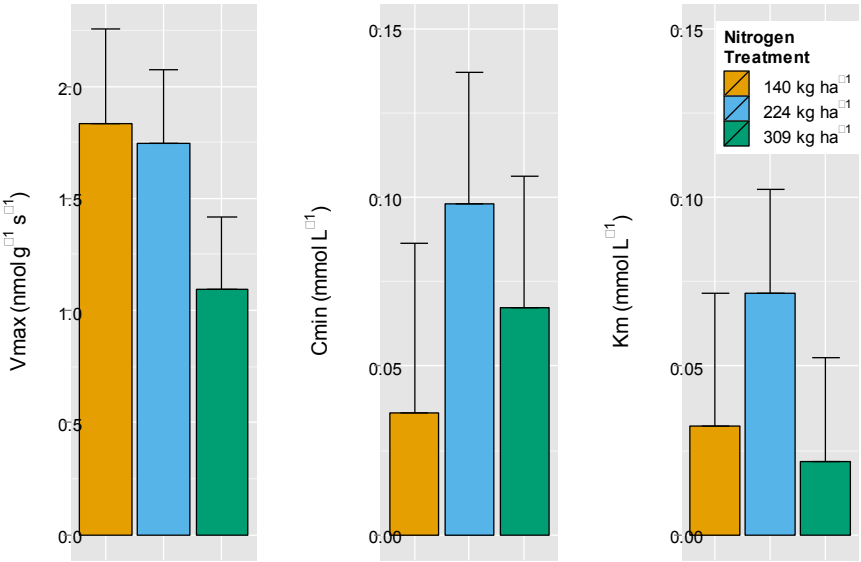

Figure 2. Almond root nutrient uptake parameters, calculated using a non-linear regression analysis.

New root growth was very limited from Jun through September when maximal carbon demand for growing nuts occurred. There was very little root growth prior to leaf out with the predominant root growth period occurring after full leaf out.

While the pattern of new root growth did not vary from year to year or between experiments, the total amount of roots produced per season varied significantly from year to year (Figure 4). In 2011 the amount of new roots produced were significantly higher than in other years and may have been due to installation disturbance that promoted root growth on 2011, this increased growth immediately following installation has been widely reported in the literature. Root growth in 2012 was significantly greater than in 2013. The reason for this is uncertain. However, it should be noted that yield in 2011 was exceptionally high yield (>4500 lbs acre) while in 2012 it was exceptionally low (900 lbs acre). The higher root growth in 2012 coincided with a very low fruit load suggesting that competition between shoots and roots defines the rate of new root growth.

Interestingly, this enhanced root growth occurred in spring, following an exceptionally high yield year, suggesting that new root growth is not dependent upon prior year carbohydrate storage. Similarly, the lower root growth observed in 2013 coincided with good fruit set further suggesting that current fruit load influences root growth.

Patterns of root growth distribution by soil depth were figured by determining the number of new roots produce per 0.2 m interval (Figure 6). There was no significant difference in root distribution or density between treatments. Despite the wide variation in the amount of roots between years (Figure 5, top graph), the percentage of roots per depth interval was similar. Virtually all the root growth is observed within 1.4 m depth, and 60-65% of the new roots are produced in between 0.2 and 0.6 m.

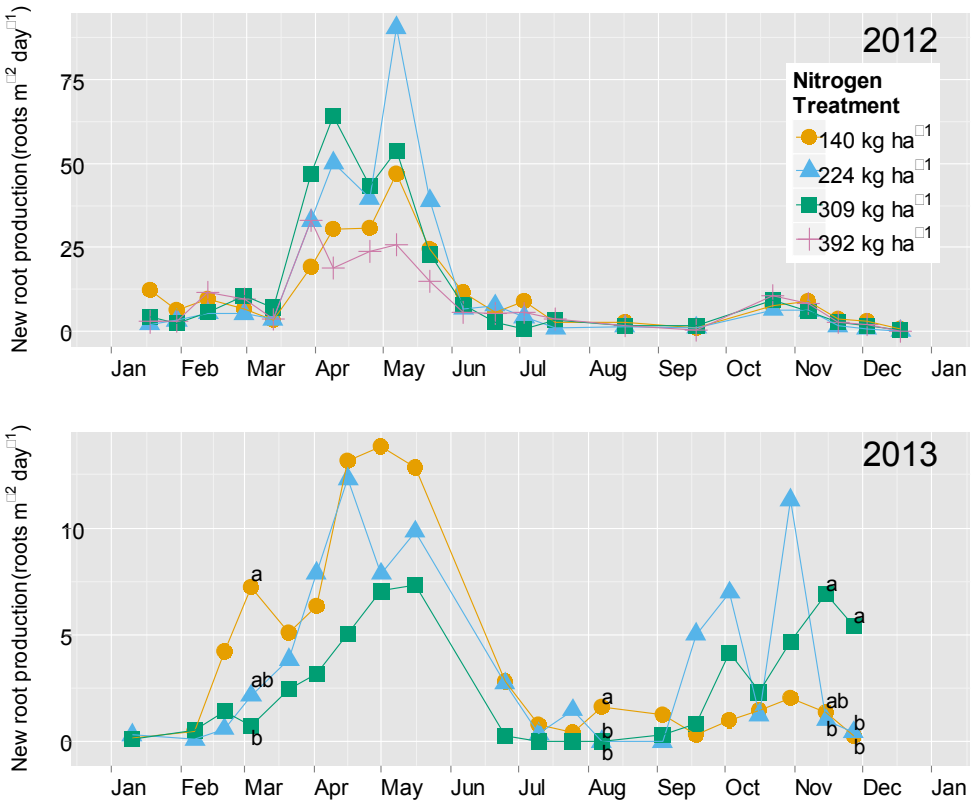

Figure 3. Number of new roots produced during the growing season in Experiment 1: N rate experiment. Note differences in scale used in these figures.

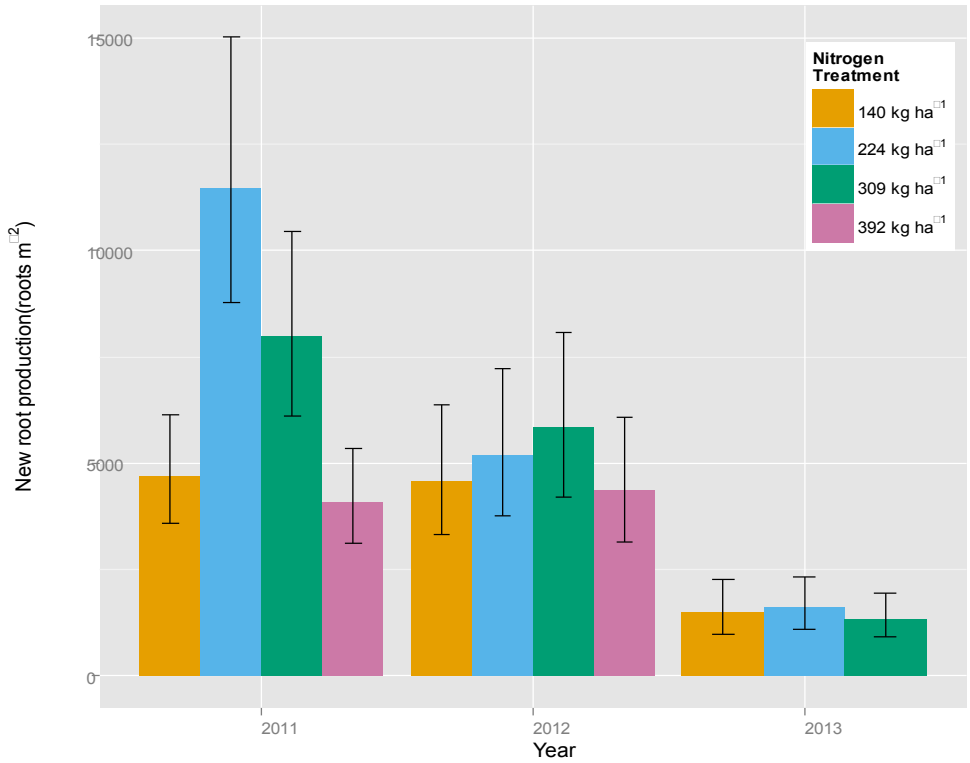

Figure 4. Total amount of new roots produced per year.

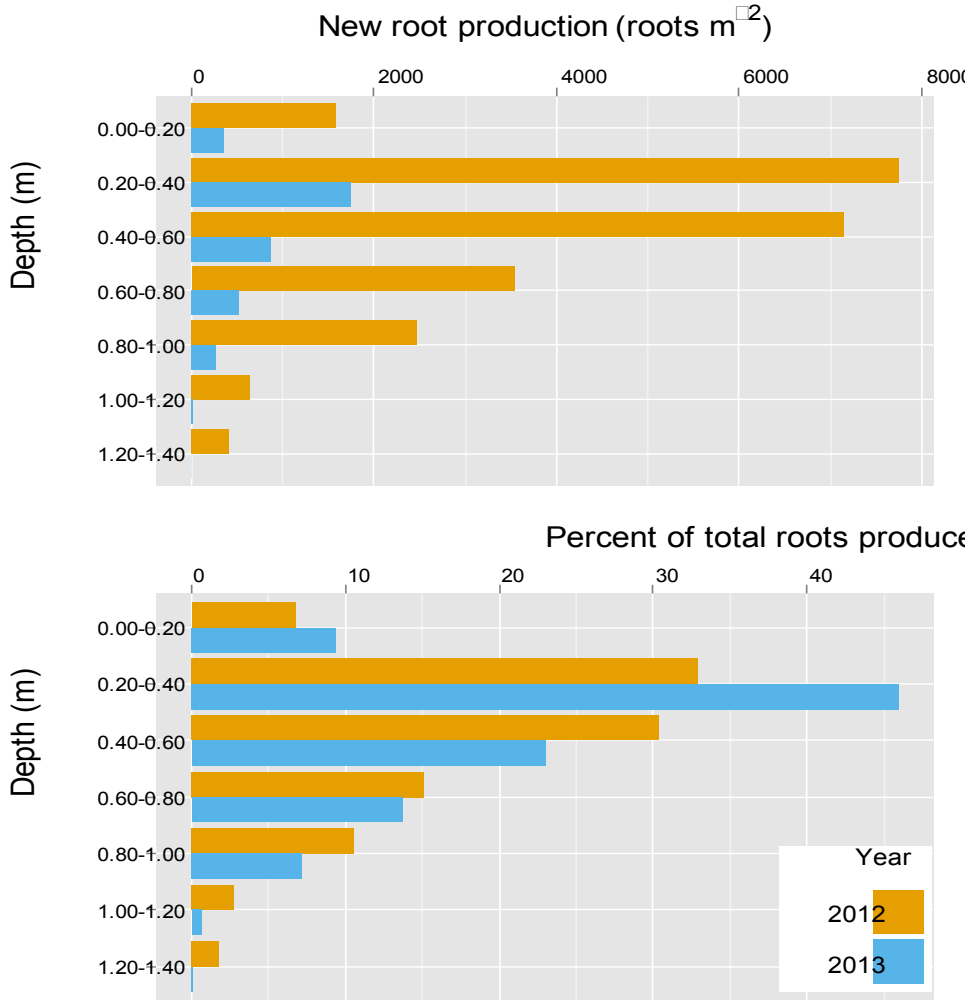

Figure 5. Vertical distributions of roots in soil depth intervals.

2. Fertigation Method

The choice of fertigation technique (continuous vs pulsed; see table 4 for further reference) had a significant effect on tree productivity only under the zero K treatment (Figure 6). Since the adoption of continuous fertigation strategy has the potential to reduce nitrate losses in comparison to traditional split N application (2-4 splits), these results suggest that the adoption of a continuous N fertigation approach will be of benefit to the industry.

N treatments and irrigation management strategies had no significant effect on root growth patterns, suggesting that nitrogen supply is not a key determinant of root growth (Figure 10).

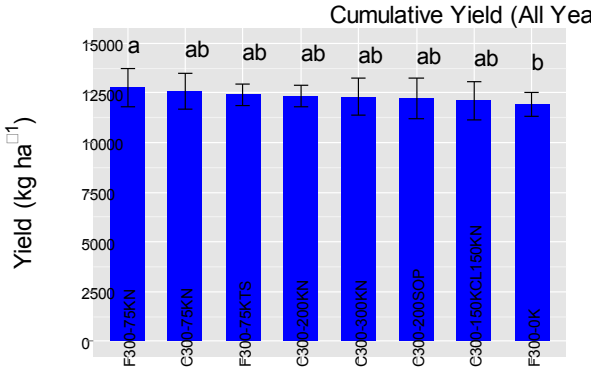

Figure 6. Effect of fertigation practices on cumulative almond yield

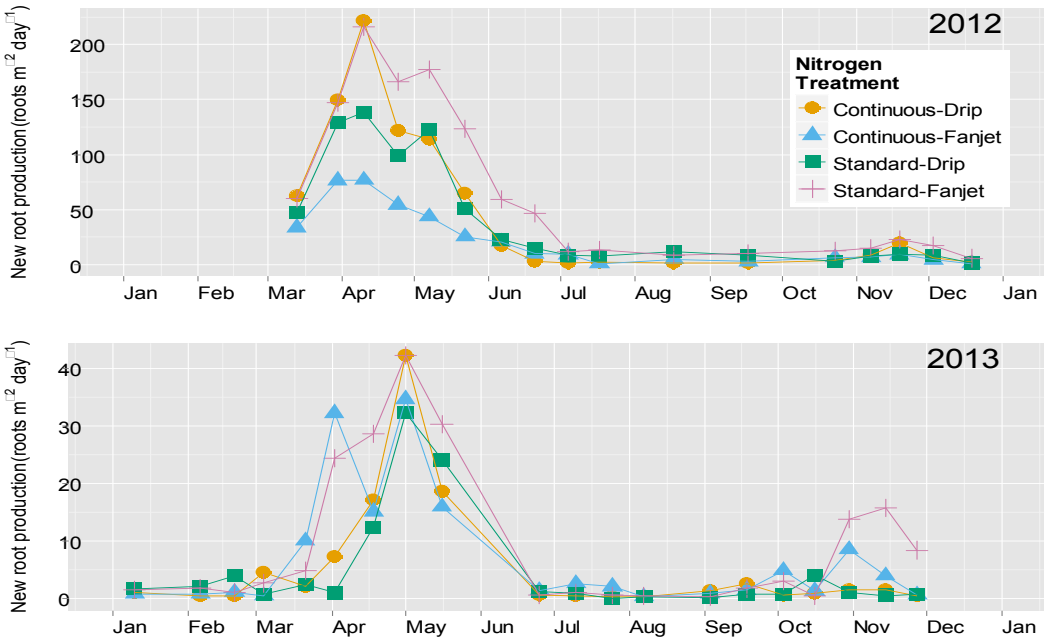

Figure 7. Number of new roots produced during the growing season in Experiment 2: Nitrogen Fertigation experiment.

Table 2. Treatment description for Experiment 2: Nitrogen Fertigation experiment.

F300-0	No K, 300 lbs N as UAN in 4 in season fertigations 20% Feb, 30% April, 30% June, 20% post-harvest.
F300-75KTS 125 SOP	200 lb K. 125 lb K as SOP band February, 75 lb as KTS and 300 lb N as UAN in 4 in season fertigations 20% Feb, 30% April, 30% June, 20% post-harvest (Grower Standard).
F300-75KN-125 SOP	200 lb K. 125 lb K as SOP band February, 75 lb as KNO3 and 273 lb N as UAN in 4 in season fertigations 20% Feb, 30% April, 30% June, 20% post-harvest.
C300-200SOP	200 lb K as SOP dissolved in gypsum mixer and 300 lbs N as UAN (total N 300), continuous application.
C300-75KN	200 lb K. 125 lb K as SOP in band February, plus 75 lb K as KNO3 and 273 lb UAN continuous.
C300-200KN	200 lb K as KNO3 and 193 lbs N as UAN (total N 300) as continuous application.
C300-300KN	300 lb K as KNO3 and 128 lbs N as UAN (total N 300) continuous.
C300-150 KCl 150 KNO3	150 lb K as KCL, 150 lb K as KNO3, 248 lbs N as UAN continuous fertigation.

ACKNOWLEDGEMENTS

Almond Board of California

Paramount Farming Company

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

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INTRODUCTION

The California Department of Food and Agriculture's Fertilizer Research and Education Program (FREP) has funded more than 160 projects since the early 1990s. For many crops, however, a comprehensive overview and synthesis of the past and current research on fertilizer use and management is incomplete or missing. In a collaborative effort between FREP and University of California Davis researchers, this obstacle to information access is being addressed by making the wealth of information on crop nutrient management from past FREP projects 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

The database of FREP-funded projects can be accessed online at: http://www.cdfa.ca.gov/is/frep/Default.aspx. Key information from approximately 145 final reports can be accessed through a user-friendly interface. Users can search for specific topics by either entering a keyword or choosing a crop type, a county, or a date range from a drop-down menu (Figure 1). From the list of projects that meet the search criteria, users can access summaries of specific projects. Links to the final report, FREP proceedings, and external sites closely related to the project are also provided. Additional projects are added to the database when the final reports are submitted to FREP.

Fertilization Guidelines

The guidelines present accurate and timely crop nutrient information in a user-friendly, visually interactive interface (Figure 2). Fertilization guidelines for ten major crops grown in California are currently available online at http://apps.cdfa.ca.gov/frep/docs/guidelines.html. Guidelines for additional crops will be uploaded to the web page on a flow basis. 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. An extensive list of references and links to sites with additional information complement the guidelines. The guidelines are a summary of research data and present a general overview of nitrogen, phosphorus, and potassium fertilization practices. They provide a basis for in-depth discussions with local farm advisors and fertilization experts about site-specific adjustments.

The latest addition to the website includes crop-specific nitrogen uptake curves, as well as data on crop nitrogen uptake and removal rates with harvested products based on research data mainly from California (Figure 3). The information provided on these pages helps making decisions about the time and rates of nitrogen applications and can be used for the preparation of nitrogen budgets.

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).

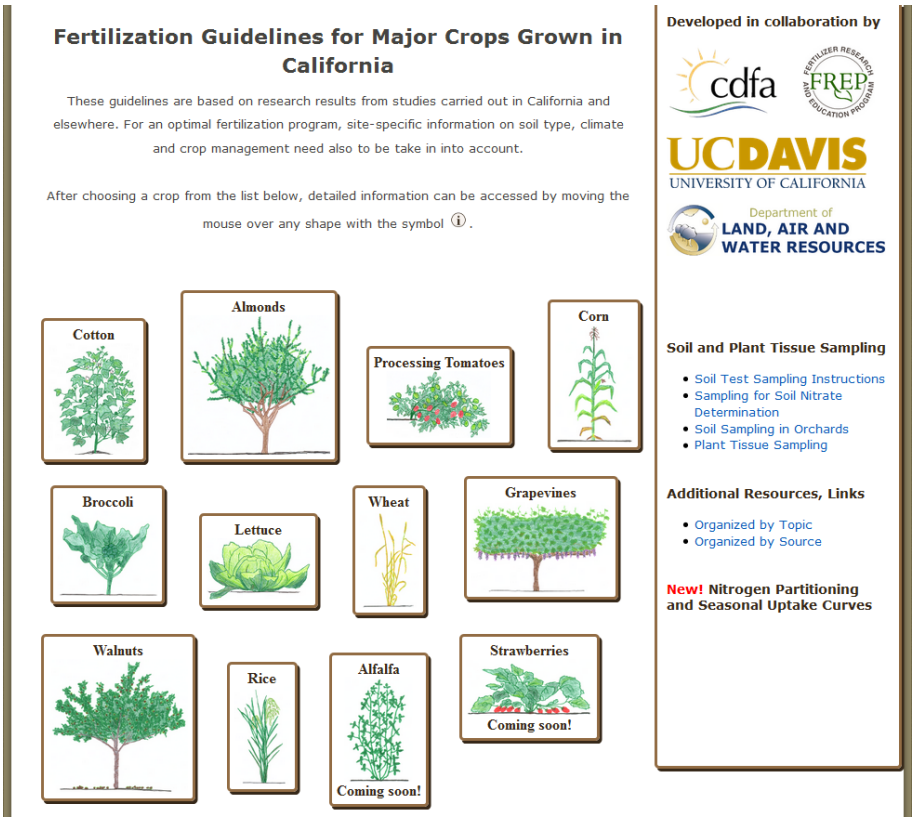
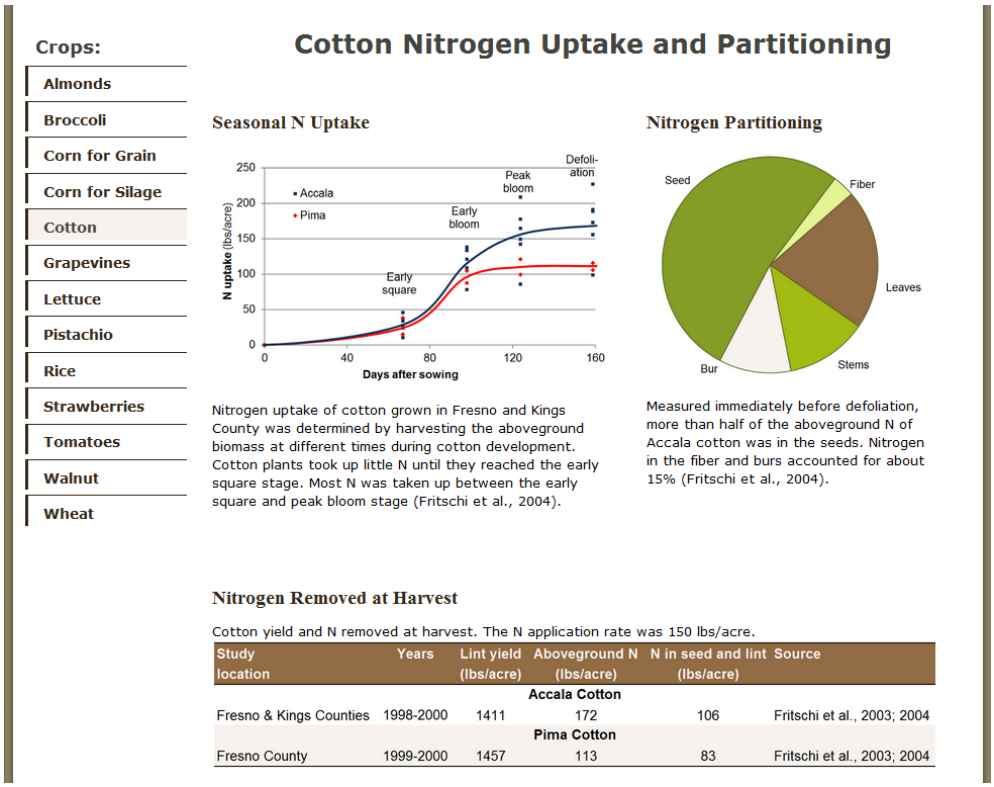


Figure 2. Screen shot of the start page for fertilization guidelines. Crop-specific guidelines can be accessed by clicking on one of the crops (online at http://apps.cdfa.ca.gov/frep/docs/guidelines.html).

Figure 3. Screen shot of the page providing information about nitrogen uptake and partitioning.



Study location	Years	Lint yield (lbs/acre)	Aboveground N (lbs/acre)	N in seed and lint (lbs/acre)	Source
			Accala Cotton		
Fresno & Kings Counties	1998-2000	1411	172	106	Fritschi et al., 2003; 2004
			Pima Cotton		
Fresno County	1999-2000	1457	113	83	Fritschi et al., 2003; 2004

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

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INTRODUCTION

Estimating in-season soil N mineralization is required to accurately prescribe fertilizer recommendations. Prescribed fertilizer rates are often based solely on tests of preseason soil inorganic N levels, such as in the pre-plant nitrate test, which ignores in season soil N mineralization. The mineralization of native soil organic N sources has been shown to provide upwards of 50 percent of crop N uptake in California agricultural soils (Kramer et al., 2002; Doane et al., 2009), making mineralized soil organic N a key pool that is often unaccounted for when making fertilizer recommendations. The mineralization of this soil organic N pool into plant-available forms of N is biologically derived, lending it a highly site-specific quality. This specificity is due to soil types and the varying structure and composition of the soil microbial community, making for difficult to predict N mineralization rates.

Biologically-based tests, i.e. incubations, based on varying activity levels of the microbial community, have been explored in order to account for this complexity, albeit with limited success. Although some of these biologically-based lab tests have proved to be better predictors of N mineralization than any currently-available chemical tests; time, space, and labor constraints prevent their widespread adoption by soil test labs. Thus, a short-term, biologically-based soil test could allow for a rapid estimation of seasonal N mineralization that is also viable in a soil test lab setting. One promising biological test has correlated N mineralization with the production of CO_2 upon rewetting of an air-dried soil (Franzluebbers 1999; Franzluebbers et al., 2000; Haney et al., 2001; Haney et al., 2008). This relationship has not yet been explored on California's agricultural soils, with their generally lower soil organic matter contents, low microbial biomass, high fertilizer N requirements, and intensive agronomic management practices.

OBJECTIVES

The overall objective of this research is to provide a quick, viable, biologically-based soil test to allow for accurate fertilizer recommendations by including estimates of in-season soil N mineralization in California soils. 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

A wide variety of soils was gathered from several of California's major crops- corn, tomatoes, and cotton. These soils were gathered across climatic, soil C content, and soil texture gradients, as well as differing management practices. These soils were 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^+), water-extractable organic C and N (WEOC/WEON), permanganate-oxidizable carbon (POXC), and dissolved organic carbon (DOC).

Long-term (105-day) incubations were conducted to measure net N mineralization. Net N mineralization at day *t* ($NMIN_t$) was calculated as the change in inorganic N ($NO_3^-+NH_4^+$) from day 0 to time *t*. The flush of CO_2 was measured in separate incubations by rewetting of air-dried soils to field capacity. Cumulative CO_2 production was measured at 6-, 24-, and 72-Hours after rewetting.

RESULTS AND DISCUSSION

Total seasonal net N mineralization ranged from 9-82 lbs N/ac. Some soils with a C:N >20 showed negative net N mineralization, or immobilization, as late as 28 days into the incubation. Overall, these immobilizing soils exhibited the lowest N mineralization values of all surveyed fields. On average, approximately 76% of the seasonal (105-day) net N mineralization was completed by day 28. This results in a strong and highly significant correlation between 28-day net N mineralization ($NMIN_{28}$) and both 56-day ($NMIN_{56}$) and 105-day ($NMIN_{105}$), as shown in Table 1. Preplant inorganic N showed no relationship to net N mineralization at days 28, 56, or 105.

The cumulative flush of CO_2 upon rewetting showed positive but weak correlations to N mineralization at any measured point during the season (Table 1). The values spanned an order of magnitude, ranging from 292-2424 µg CO_2-C/g AD soil. C mineralization was also highly variable within each field, indicating C "hotspots" greatly affecting measurements. At all time points, CO_2 showed a negative relationship with preplant N levels. The best correlation between cumulative CO_2 production and N mineralization was at 72 hours ($CMIN_{72}$) and 56 days ($NMIN_{56}$), respectively(r=0.27108, p=0.1402). It is possible that these statistically insignificant relationships can be at least partially attributed to the variable CO_2 responses.

Chemical indices were more highly correlated with N mineralization than respiration (Table 2). Both Total N and WEON were positively related with NMIN, although only WEON was significant at $p<0.05$. All measures of carbon, including WEOC:N and Total C:N, were negatively correlated with N mineralization, with DOC, Total C, and Total C:N being significant at $p<0.05$.

C mineralization proved to be less correlated with NMIN than WEON, showing that the previously shown relationship between $CMIN_{72}$ and NMIN does not hold for a wide range of California soils. The measured values of CMIN were highly variable and could be related to management, soil texture or other edaphic characteristic. This limitation would undermine the theoretical framework of CO_2

	$NMIN_{28}$	$NMIN_{56}$	$NMIN_{105}$	$CMIN_6$	$CMIN_{24}$	$CMIN_{72}$
Preplant Inorganic N	-0.02775 (0.8822)	-0.00704 (0.9700)	0.17163 (0.3559)	-0.00439 (0.9813)	-0.14888 (0.4241)	-0.25925 (0.1590)
$NMIN_{28}$	--	0.95382 (<0.0001)	0.93934 (<0.0001)	0.02399 (0.8981)	0.20470 (0.2693)	0.22544 (0.2227)
$NMIN_{56}$	0.95382 (<0.0001)	--	0.91620 (<0.0001)	-0.01602 (0.9318)	0.22159 (0.2309)	0.27108 (0.1402)
$NMIN_{105}$	0.93934 (<0.0001)	0.91620 (<0.0001)	--	0.01655 (0.9296)	0.18964 (0.3069)	0.19017 (0.3055)

Table 1. A summary of correlation coefficients between cumulative CO2 on rewetting and net N mineralization values. P-values are listed in parenthesis. All values are n=31 fields, each with 3 subsamples

	DOC	POXC	WEOC	WEON	WEOC:N	Total C	Total N	Total C:N
$NMIN_{28}$	-0.53190 (0.0021)	-0.17875 (0.1202)	-0.28499 (0.1202)	0.43382 (0.0148)	-0.12973 (0.4867)	-0.43838 (0.0136)	0.20679 (0.2643)	-0.57723 (0.0007)
$NMIN_{56}$	-0.50185 (0.0040)	-0.11943 (0.5222)	-0.24442 (0.1851)	0.46515 (0.0084)	-0.10235 (0.5838)	-0.36339 (0.0445)	0.30185 (0.0989)	-0.52744 (0.0023)
$NMIN_{105}$	-0.43305 (0.0150)	-0.19412 (0.2954)	-0.22315 (0.2276)	0.48457 (0.0057)	-0.09862 (0.5976)	-0.40179 (0.0251)	0.15668 (0.4000)	-0.50055 (0.0041)

Table 2. A summary of correlation coefficients between N mineralization and various chemical indices. P-values are listed in parenthesis. All values are *n*=31 fields, each with 3 subsamples.

being an aggregate proxy to estimate in-season N mineralization. To minimize this heterogeneous response, a labile C source was added to a subset of sampled soils and the subsequent respiration measured at 6 hours. A greater correlation between C and N mineralization values was found when using a labile C substrate than when simply rewetting the soil.

Another potential amendment to the current biologically-based test that merits further study is the altering of the prescribed WHC for the soils upon rewetting. In order to reduce the potential buffering effect of water on CO_2, CMIN can be measured at a WHC lower than field capacity. Preliminary tests on a representative subset of the sampled soils have shown an increased relationship between NMIN and CMIN at lower water-holding capacities, with the greatest sensitivity between 50-75% WHC.

This current work is promising in terms of improving correlations, but the method has not yet 1) been verified in a field setting across a wide variety of common California crops and 2) reached the capability to serve as a standalone predictor of seasonal N mineralization. Field trials are in progress on a selected set of crops in California to address the first potential research area. As the current study progresses and a more robust selection of soil management strategies, textures, and agronomic practices are included, the predictive nature of the test will be explored.

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

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INTRODUCTION

Vegetable crops produced in the desert receive large annual applications of phosphorus (P) fertilizers. Amounts of P applied to vegetable production systems often approach and exceed 200 kg P/ha, and crop recoveries of P fertilizers are generally less than 25%. While much of the added P is converted to insoluble forms in the calcareous soils of the region, some of it is carried in runoff and drainage water into receiving surface waters, causing 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 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, and 2. Compare variable rate P application to current methods and evaluate alternative economic outcomes. In the first phase of the project, we will test alternative sampling schemes. Sampling schemes evaluated will include grid sampling at various resolutions, which seek to define zones directed by other indices of in-field variability. In the second phase, we will evaluate the efficacy and economic returns to variable rate P application. Project success will be the development of economically viable protocols for the implementation of variable rate P application technologies.

DESCRIPTION

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

During 2013-2014, four research sites were established. One was iceberg lettuce in Imperial County, CA (Bard), one was broccoli in Riverside County CA (Coachella Valley), one was romaine lettuce in Yuma AZ, and one was potato in Maricopa AZ. In September we performed soil EC surveys at the first three sites as a basis for zone sampling. The last survey for potato was performed in late January. The Veris 3100 is simple to use and user-friendly for producers but the EM-38 gives higher resolution map. It is one of our objectives to evaluate these two systems as alternatives for deriving zone-based sampling schemes. An example of the electronic surveys are shown in Figure 1 for the Bard CA site.

Each production field was divided into three equal areas. For one, prescription fertilization maps would be developed based on simple grid based sampling. For another, they would be developed based on zone sampling, and for the third, P fertilizers were applied based on the growers normal practice. EC measurements were processed using the USDA-ESAP program to locate soil samples for the zone sample method based on natural variability of the soil. Immediately after these surveys, we collected soil samples for both grid and zone-based fertilizer application comparisons (Figure 2 and 3 are example sampling schemes from the Bard site).

The samples were analyzed for P and salinity in our laboratory. The salinity data is used to statistically distinguish salinity and soil texture as sources of variation in the electronic surveys. The P soil tests were used to develop P soil test maps and corresponding prescription maps (Figures 4 and 5 examples from Bard site). The grower in the Coachella Valley had a preference for liquid P fertilizer, so we used liquid P at this site. The growers in Yuma, Bard, and Maricopa preferred dry P sources, so we used dry fertilizer in these sites.

Task 2. Field testing of variable rate application (VRA) and standard grower practice.

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

Tasks 3, 4 and 5

No progress on these tasks in 2013. These were planned for 2014 and 2015. Sites in fall 2014 are already lined up for sampling in early September.

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.

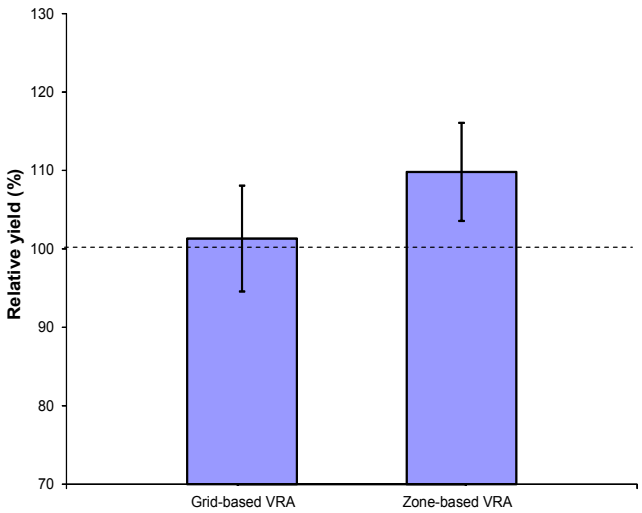
In September we performed soil EC surveys at three locations for zone sampling (Figure 1). Sites were located in Imperial County, CA (Bard), Riverside County CA (Coachella Valley) and Yuma AZ. Processed EC measurements in USDA-ESAP was used to locate soil samples for zone sample method based on natural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

Yield maps are not yet complete, but a comparison of yields show that yields in the zone and grid managed plots were generally similar to those obtained in the grower managed section of the field (Figures 6 is example from Bard). These similar yields were achieved at substantially reduced rates of P fertilizer.

ACCOMPLISHMENTS/PRELIMINARY FINDINGS

In early 2013, considerable effort was directed toward building and testing equipment for surveys and variable rate fertilizer applications. In fall 2013, field tests were implemented. Preliminary data collected during 2013-2014 show potential economic and environmental benefits to VRT fertilizer management.

In addition to working directly with growers for real time technology transfer, we conducted two formal outreach activities in 2013-2014. Field work and outreach activities are already outlined for 2014-2015.



Comparison of total relative yields from grid and zone-based fertilization schemes compared to grower practice in Bard Valley site.

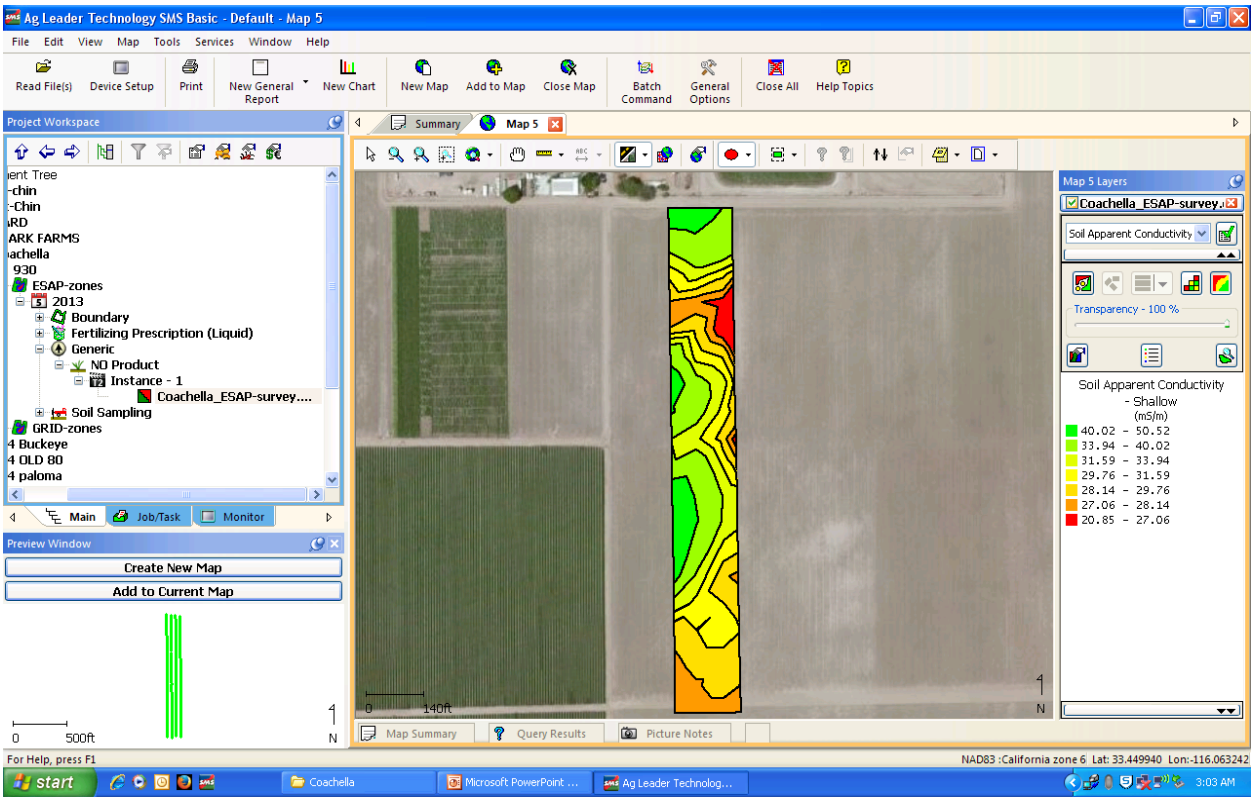
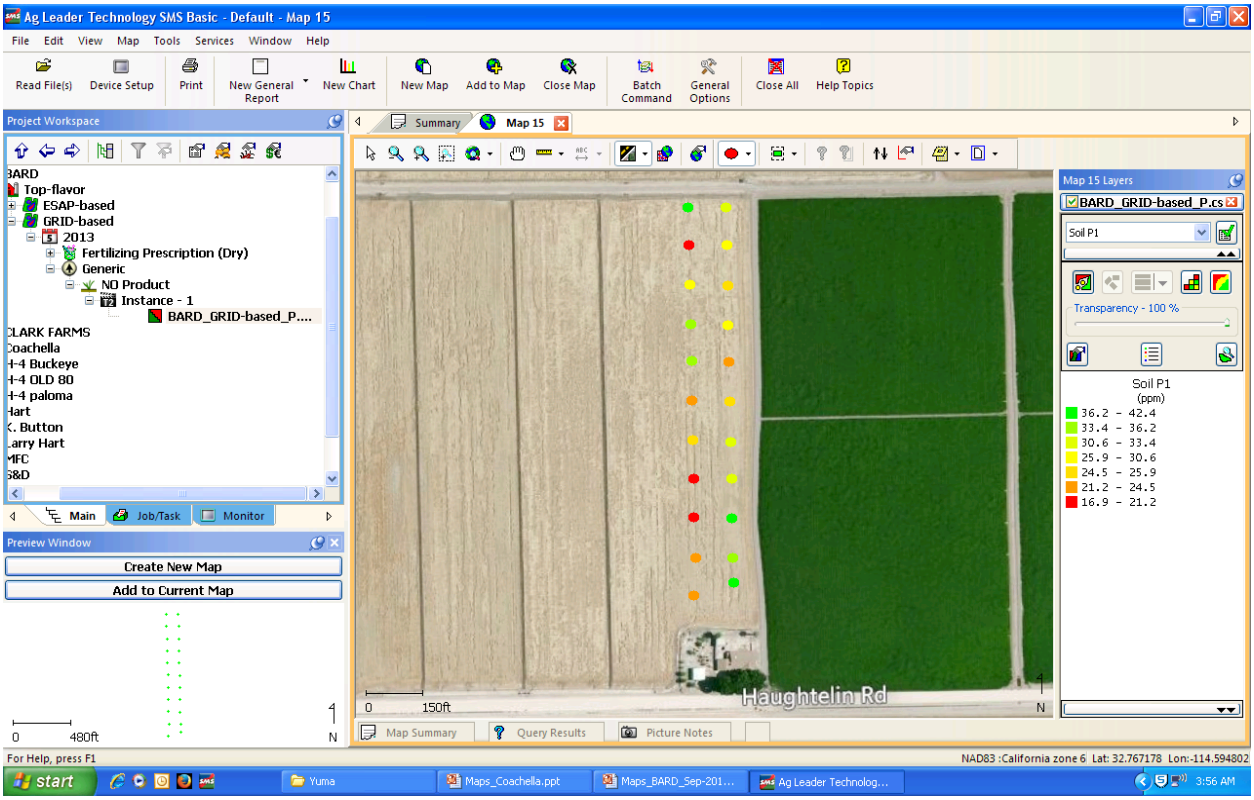


Figure 1. Results from electronic survey in zone sampling area in Bard, CA site.



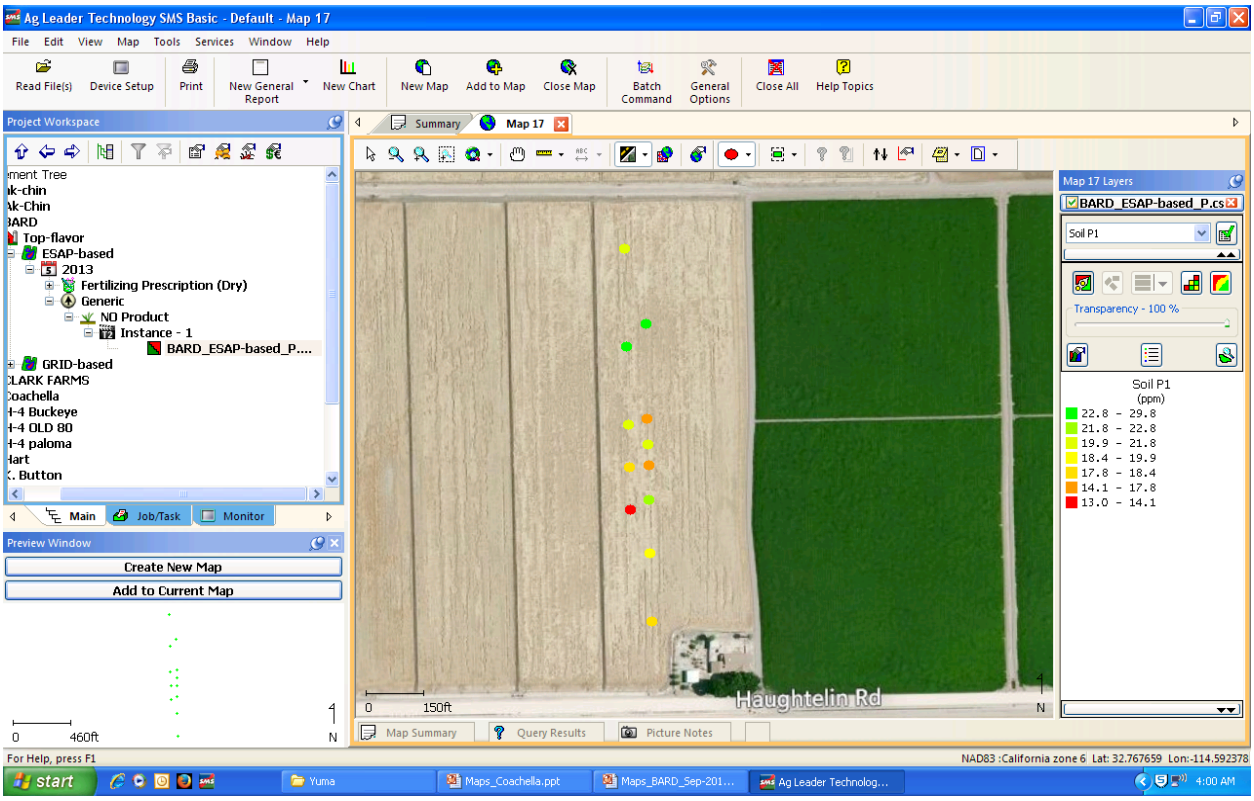
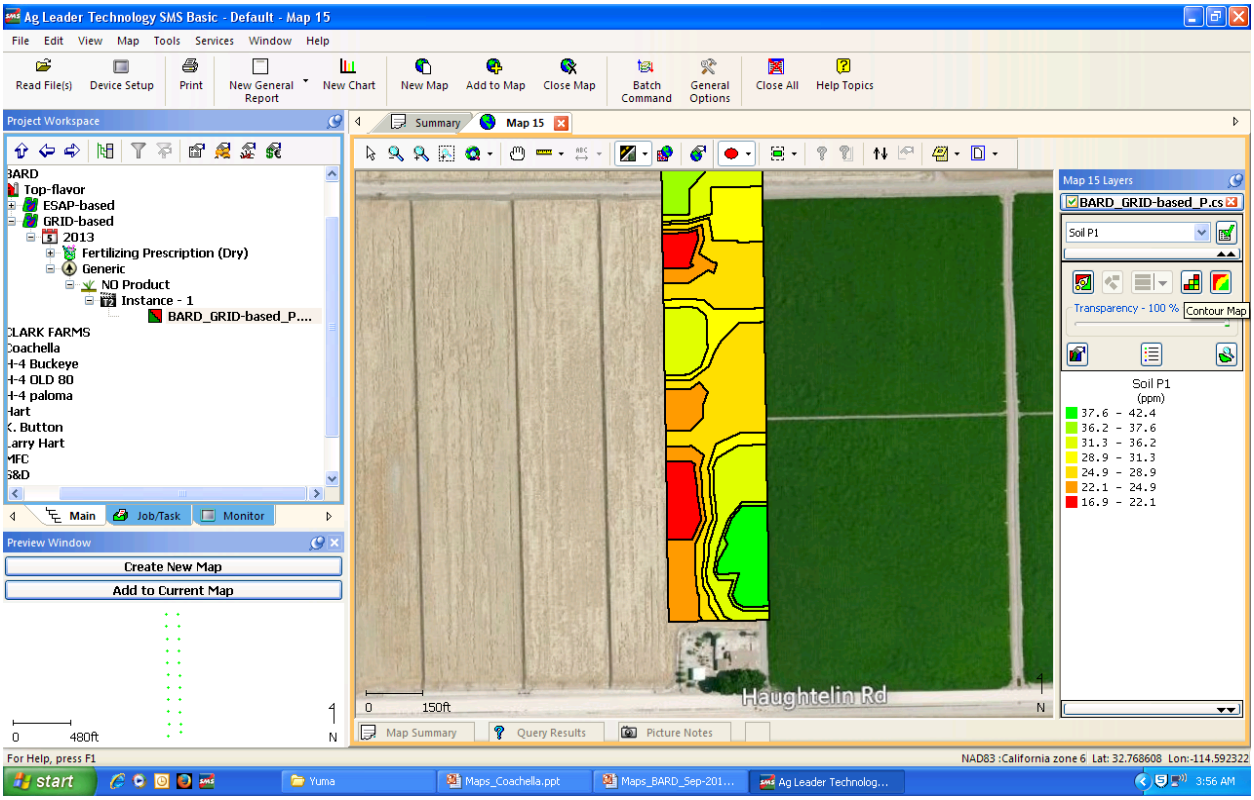


Figure 2. A comparison of grid and zone sampling schemes at the Bard, CA site.



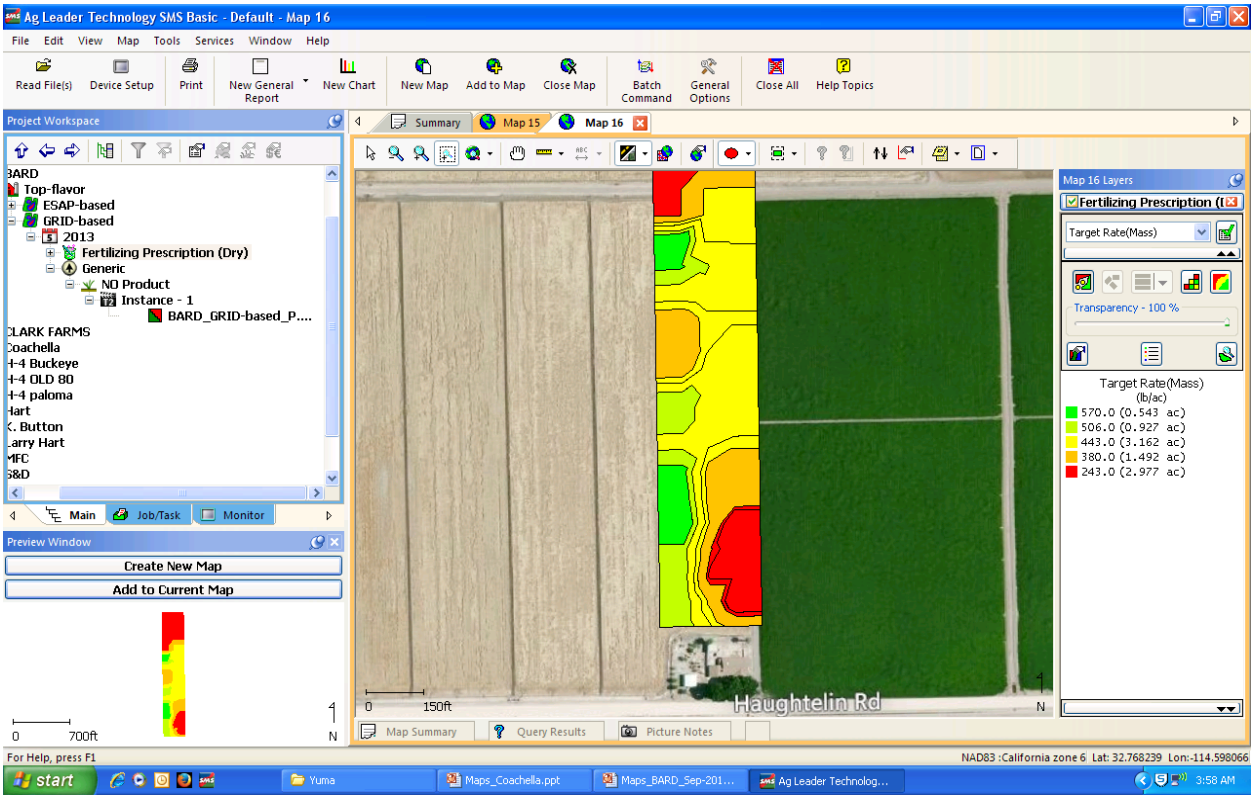
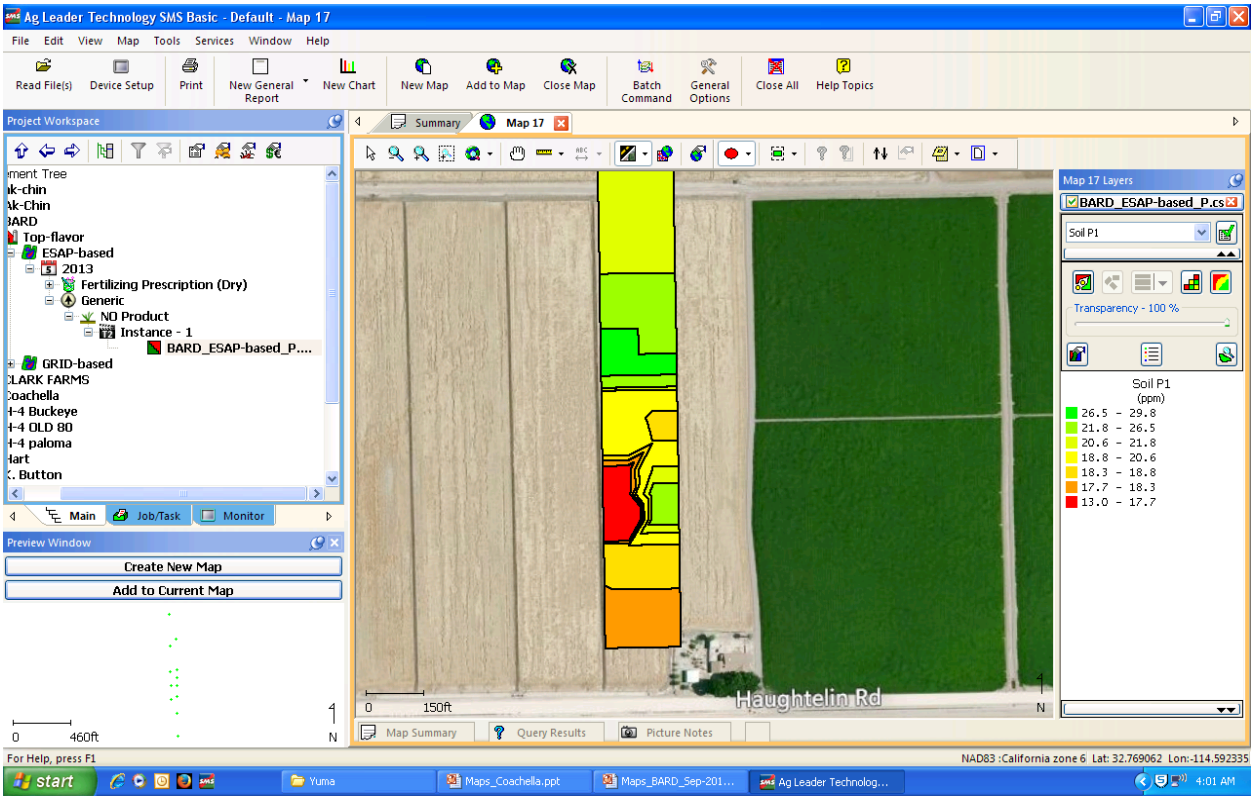


Figure 3. Interpolated soil test P values based on zone samples and corresponding prescription P fertilization map for Bard grid site.



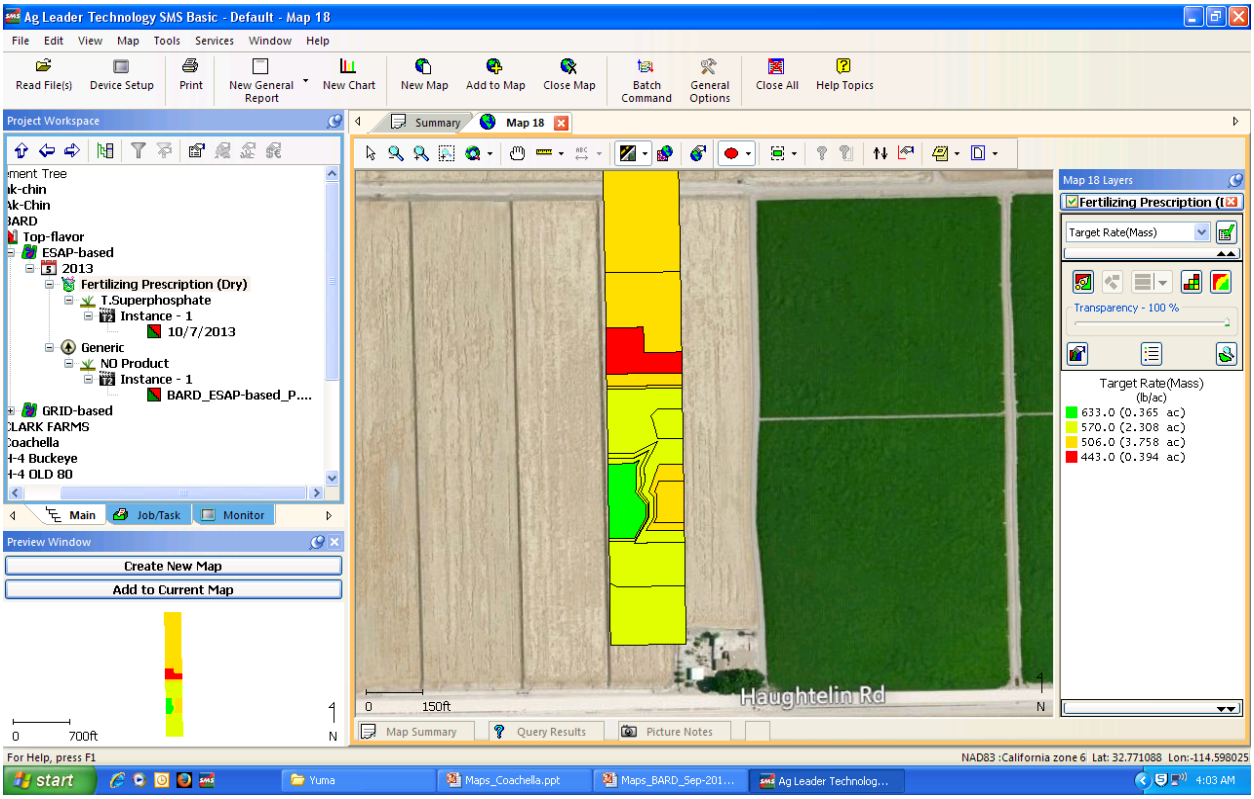


Figure 4. Interpolated soil test P values based on zone samples and corresponding prescription P fertilization map for Bard zone site.

Improving Pomegranate Fertigation and Nitrogen Use Efficiency with Drip Irrigation Systems

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INTRODUCTION

Pomegranate is an important niche crop in California because of the demand for juices with healthy bioactive compounds, mineral nutrients and high antioxidant contents. Despite this being an "ancient" crop, there are few studies that quantify the water and nitrogen requirements of a pomegranate orchard and none report on either high frequency surface drip or high frequency subsurface drip irrigation. Research has shown that well-managed surface drip (DI) and subsurface drip irrigation (SDI) systems can eliminate runoff and 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 placed SDI, is critical for effective management of N-fertigation. This project will determine the nitrogen fertilizer and water requirements and efficiency for a young pomegranate orchard.

OBJECTIVES

The objectives of this project are to determine nitrogen and water requirements of drip irrigated maturing pomegranate.

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 pomegranate.
3. Determine the effect on N leaching losses of real time seasonal nitrogen injections (N) with DI- and SDI irrigated maturing pomegranate.
4. Develop fertigation management tools that will allow the growers to achieve objective 1 and present these results to interested parties at annual field days and seminars.
5. Determine if concentrations of macronutrients (P, K, Ca, Mg) and micronutrients (Zn, Cu, Mn, Fe, B, Se) are influenced by precise irrigation/fertigation management with DI and SDI.

DESCRIPTION

This project is located on the Kearney Agricultural Research and Extension Center (KARE) and uses a 3.54-ac pomegranate orchard (*Punica granatum, L* var. Wonderful) that includes a large weighing lysimeter (Figure 1). This lysimeter is used to determine

the water use for the fully irrigated (100%) subsurface drip irrigation (SDI) with adequate nitrogen (N2) treatment and to automatically manage the hourly irrigation scheduling on the site. Water applied to the DI treatments is increased by 10% over the SDI amount 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 a 16-foot row spacing and a 12-foot in row spacing. 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-inch depth) systems with dual drip irrigation laterals, each 3.5 feet 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.

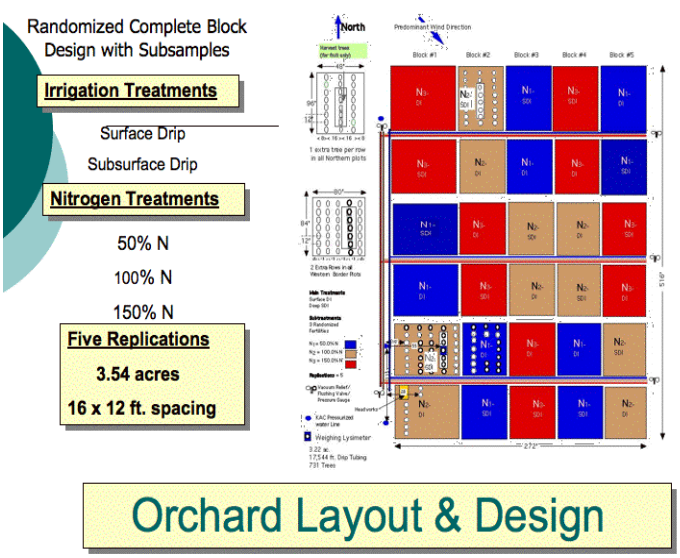

Figure 1. Orchard treatment, design and layout for surface drip irrigated (DI) and subsurface drip irrigated (SDI) pomegranate located on the Kearney Agriculture Research and Extension Center.

RESULTS AND DISCUSSION

The yearly cumulative grass reference ET (CIMIS ET_o) and the orchard evapotranspiration (ET_c), measured hourly by the weighing lysimeter, were used to develop irrigation requirements and a crop coefficient for maturing pomegranate. The 7-day averaged crop coefficient (K_c) and the 5th order polynomial regression of the 7-day averaged K_c were developed for grower's use. The equation is

$$K_c = 3e^{-10}x^4 - 5e^{-05}x^3 + 3.0347x^2 - 84013x + 9e^{+08} \quad R^2 = 0.8532$$

where x is the day of the year.

Orchard irrigations of DI and SDI were based on lysimeter measurements and were measured and recorded automatically with electronic flow meters and were used to calculate the water balance (Table 1).

Pomegranate Water Balance. Table 1 shows the components of the water balance from 2010 until July 31, 2014. Reference evapotranspiration (ET_0) was taken from the CIMIS weather station located at UC KARE. The crop water use (ET_c) was measured hourly with a large weighing lysimeter (Phene et al., 1991) and was adjusted for tree spacing. Precipitation was measured by the CIMIS weather station. Soil drainage was measured with the lysimeter and there was no runoff. The crop water requirement was applied hourly with high frequency SDI irrigation. Ten inches of rain in 2011 did not cause any drainage from the lysimeter, and none was measured since then, which implies that most of the rain and irrigation water were stored within the soil profile.

Yields, Water Use Efficiency (WUE) and Nitrogen Use Efficiency (NUE) from 2013 pomegranate harvest. Pomegranate fruits were harvested by a local commercial packer on Oct. 21 and Oct. 22, 2013. Yield samples were harvested from the five center trees of each of the five yield rows and measured for total weight and quality. Results from harvests are shown in Table 2 and indicate no significant total yield differences due to the irrigation systems or the nitrogen

Table 1. Components of the pomegranate water balance.

	Pomegranate Water Balance (in.)				
Year	ETo	Precip.	Irrig	ETc*	Drain.
2010	49.73	17.34	1.00	2.10	???
2011	50.9	10.42	8.49	9.8	0
2012	54.6	8.97	17.7	19.7	0
2013	55	3.21	24.2	26.9	0
2014**	39.3	4.77	19.5	20.9	0

2011 ETc values from 5/1 to 12/8 only.

*Lysimeter ETc adjusted for orchard spacing

**2014 Values are from January 1-July 31

treatments. To convert plot yields to t/ac, multiply by 0.0227. Total marketable fruit includes prime, superficially cracked and cracked fruit (juice fruit). Total fruit weight is the sum of all fruit weight categories. There were linear nitrogen responses for prime fruit (P =0.021) and total marketable fruit weights (P = 0.022). Contrasts between the 46 lb/ac N rate and 'other' rates were significant for prime fruit weight (P = 0.038) and total marketable fruit weight (P = 0.021).

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. Calibrated heat dissipation soil matric potential sensors (SMP CSI -229, Campbell Scientific, Logan UT) were installed in two columns of four SMP sensors each at respective depths of 24, 36, 48 and 60 inches from the soil surface. These SMPs provide the SMP feedback in the lysimeter and are used to calculate the hydraulic gradient to infer the leaching potential under high frequency SDI (H. Darcy. 1856, Phene et al, 1989). Figure 2 shows the daily average SMP from Jan. 1 to July 31, 2014. Most of the precipitation (3.96 in.) occurred from January 1 to April 9, when irrigation was started. A small rain occurred on April 26 and 27 (0.8 in.). Thereafter, irrigation was managed to maintain the SMPs within the irrigation control range of **-30 cb<SMP<-40 cb**.

Figure 3 shows calculated daily averaged hydraulic gradient (HG) from Jan. 1 to July 31, 2014 where:

$$HG = \{(SMP2 - SMP1)/ (d2-d1)\} -1 \qquad (1)$$

(d2-d1) is the difference in soil depth (cm) between the two SMPs and 1 represents the downward

Table 2. Effect of two drip irrigation methods and three levels of nitrogen injection rates on pomegranate yield attributes in October 2013.

[1] NS = not significantly different at the 5% level.

	Prime	Superficial Cracks	Cracked	Immature Green	Total		Total
Source	Weight	Weight	Weight	Weight	Marketable Fruit		Fruit Wt.
	(lb.)	(lb.)	(lb.)	(lb.)	(lb.)	(%)	(lb.)
Irrigation Method							
Surface drip	158a	291b	195a	9.3a	644a	98.6a	653a
Subsurface drip	157a	326a	196a	14.3a	679a	98.0a	693a
Prob> "F" Value	NS[1]	0.037	NS	NS	NS	NS	NS
Nitrogen Level							
N1 63 lbs/ac	132a	293a	212a	12.8a	637a	98.0a	650a
N2 149 lbs/ac	160a	313a	195a	11.2a	668a	98.4a	679a
N3 218 lbs/ac	180a	322a	179a	11.5a	681a	98.3a	693a
Prob> "F" value	NS	NS	NS	NS	NS	NS	NS
Interaction							
IM X N	NS	NS	NS	NS	NS	NS	NS

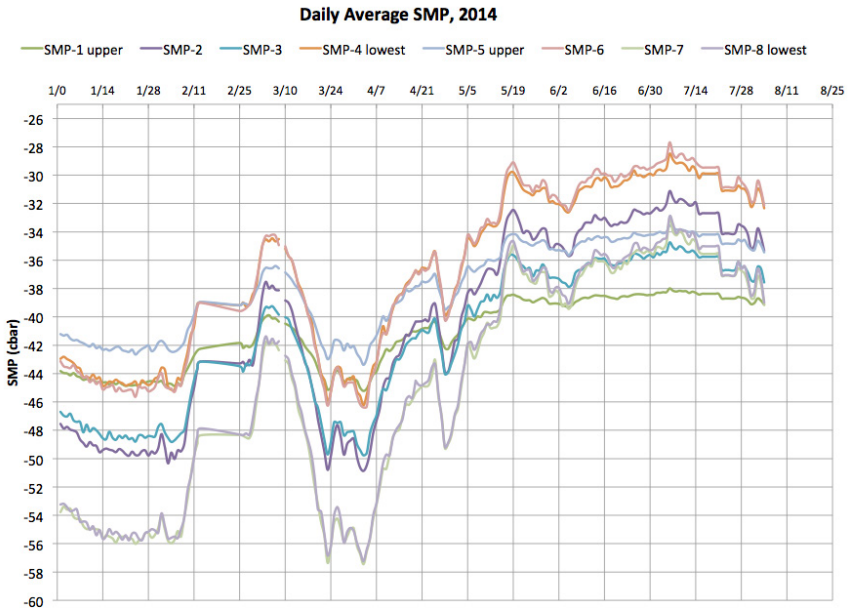

Figure 2. Daily averaged lysimeter SMPs for the four soil depths at two locations in 2014.

gravitational potential (cb/cm). HG>0 indicates upward flux and HG<0 indicates downward flux. HG-1 is the gradient from 36 to 24 in., HG-2 is the gradient from 48 to 36 in., and HG-3 is the gradient for 60 to 48 in. Results in Figure 3 indicate that the hydraulic gradients were slightly negative at the beginning of the season, mostly resulting from low ETc and precipitation. The HG's slowly rose as the trees leafed out and high frequency irrigations (0.04 in/irrigation) were applied several times per day to replace the water used by the trees. From May 14 to July 31, the SMP remained within the control range (-30 to -40 cb) and the HGs were all above -1. In equation (1), -1 is the constant gravitational potential, but because the irrigation is applied to provide ETc in real time, the gravitational potential is nearly eliminated and the HG's are essentially positive, implying no drainage from irrigation and minimal precipitation (Phene et al., 1989).

Monthly leaf tissue total Nitrogen and Carbon for 2014. Total C and N analyses were used to characterize the long term N-response to the N treatments. Results in Figure 4 show the total nitrogen in leaf tissue (%), in the six DI and SDI irrigation treatments for each of the N sub-treatments (N1, N2 and N3) from April 23 (prior to any N-fertigation) to July 8 after all of the AN-20 fertilizer had been applied to the N2 and N3 treatments.

The April and May total N samples show no significant difference between all six treatments. Thereafter, following injections of AN-20 fertilizer to the N2 and N3 treatments, these 2 treatments show greater total N trends than the N1 treatments, although not significant.

PRELIMINARY FINDINGS

Preliminary results have demonstrated the potential of high frequency SDI to provide significantly higher WUE than the high frequency DI. High Frequency SDI in the lysimeter also demonstrated the potential to maintain and minimize downward hydraulic gradient and eliminate drainage and nitrate leaching for four years. The level of applied nitrogen beyond 63 lbs/ac did not affect the yield of pomegranate. There was no yield effect from the type of irrigation system used.

Preliminary findings were presented at the Pomegranate Field Day on October 7, 2013 at the KARE research site; approximately 60 growers, UCCE advisors and irrigation industry representatives attended. Preliminary findings were presented at the FREP Conference, October 2013. Preliminary 2014 findings will be presented at the Pomegranate Field Day at the KARE research site and at the FREP Conference, both in October 2014.

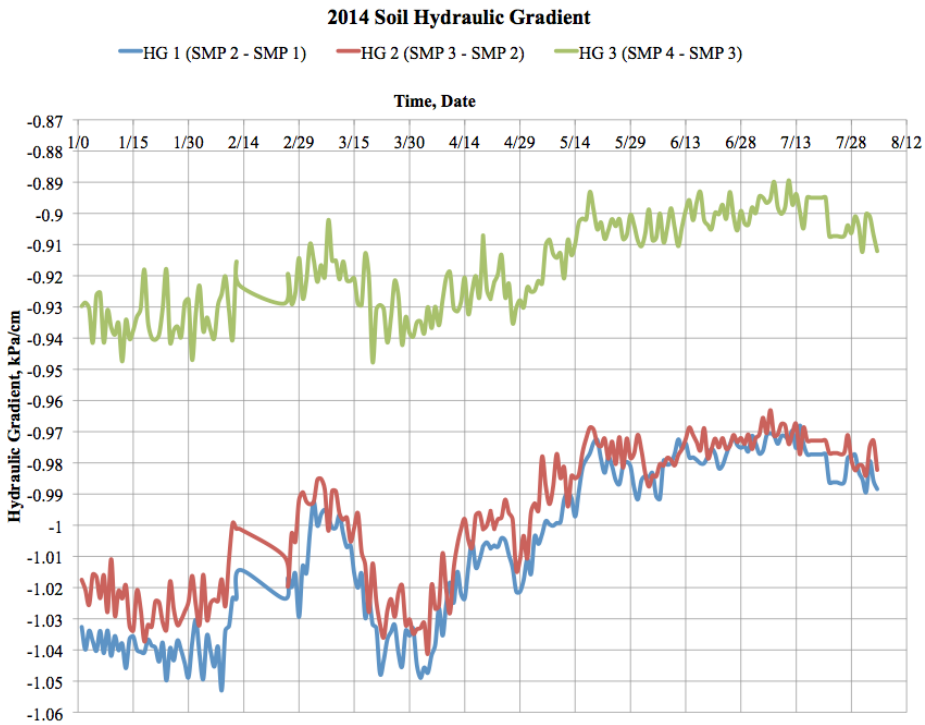

Figure 3. Daily average soil hydraulic gradients calculated using soil matric potential sensors in the lysimeter.

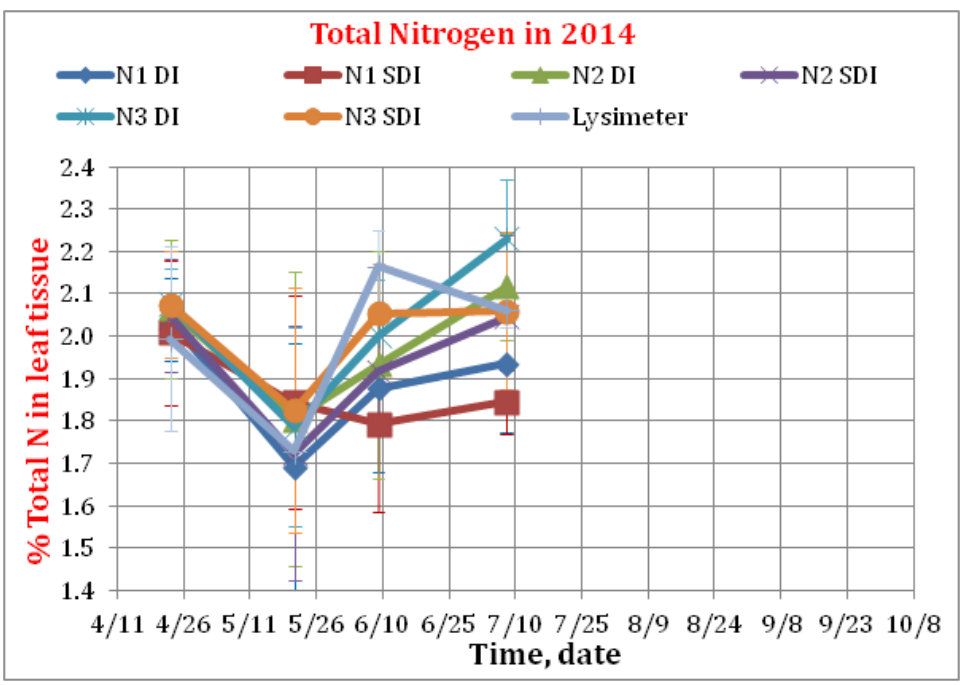

Figure 4. Monthly leaf tissue total Nitrogen for 2014.

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Dorot Valves – Solenoid & Manual valves

SDI+-- Consulting Time & equipment

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. 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).

In general, management practices that increase nitrogen use efficiency (NUE) can be expected to also reduce N_2O emissions because applied N taken up by the crop is not available to the soil processes that generate N_2O. Presently, few data of corn N use have been collected in California, and N fertilization guidelines for corn production in California are based mostly on recommendations from other regions. Thus, data on both N fertilizer use by the crop and N_2O emissions are needed. The present study takes a systems approach evaluating N_2O emissions, crop performance, N use efficiency, and potential environmental impacts with various levels of N fertilizer applications. The over-arching goal is to develop best management practices that minimize N_2O emissions without sacrificing corn yield potential.

OBJECTIVES

1. Assess annual N_2O emissions in response to a range of N fertilization rates in 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

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

Figure 1. Fertilizer side dress application.

Figure 2. Detail of injecting liquid fertilizer in bands in between corn rows.

The trials were conducted in a grower's fields in San Joaquin County in soil classified as Stockton clay. In 2013, the field had pre-plant mineral N levels of 72.4 kg N ha^{-1} in the top 60 cm, and N was added as urea ammonium-nitrate (UAN32) at 8, 139, 226 (grower's rate), 270, and 342 kg N ha^{-1}. In 2014, the pre-plant mineral N was 94 kg N ha^{-1}, and N additions were 13, 75, 164, 254 (grower's rate), and 344 kg N ha^{-1} as UAN32. The N fertilizer bands were in the bed and shoulder locations. In 2013, the corn was harvested for grain, but in 2014, silage was produced.

The N_2O flux measurements were made by placing chambers in the field for short durations (<one hour) and collecting air samples from the chambers at timed intervals. The air samples were analyzed by gas chromatography. The N_2O fluxes were calculated, using ideal gas relations, from the change in N_2O concentrations over time, chamber air temperature, chamber volume and area covered by the chamber. The daily N_2O fluxes were measured on the beds, the shoulders of the beds, and the furrows. To calculate the daily fluxes and seasonal emissions per area, the N_2O fluxes from beds, shoulders, and furrows were weighted at 65, 25, and 10 percent. The cumulative N_2O emissions were calculated by linearly interpolating between daily flux estimates. Differences between treatments were assessed using analysis of variance and standard mean separation procedures.

Yields and the total N in grain and corn biomass were measured, and the yield-scaled N_2O emissions (N_2O-N divided by grain-N per unit area) were calculated. The emission factors were calculated as the amount of N_2O-N divided the amount of fertilizer N applied (per unit area). The apparent N use efficiency was calculated as total N uptake by the corn crop divided by the amount of the total of pre-plant inorganic N and applied N (per unit area).

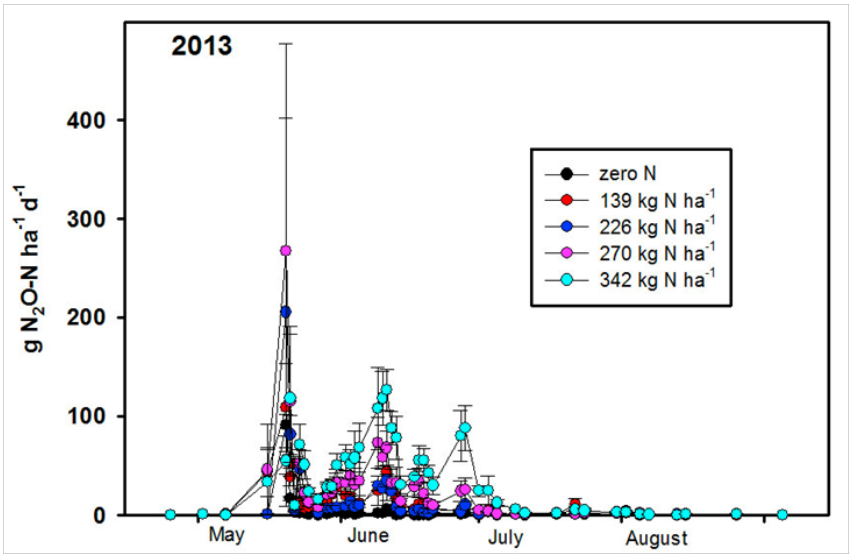

Figure 3. Daily N_2O flux during the corn growing season 2013. The standard errors are shown as line bars ($P<0.05$)(n=3).

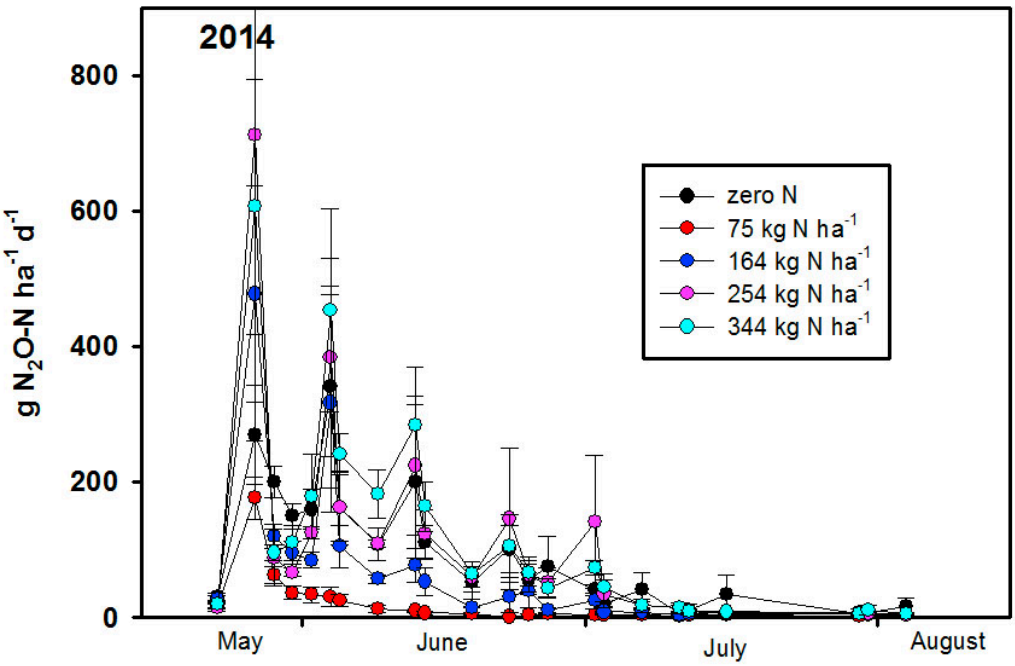

Figure 5. Daily N_2O flux during the corn growing season 2013. The standard errors are shown as line bars ($P<0.05$)(n=3).

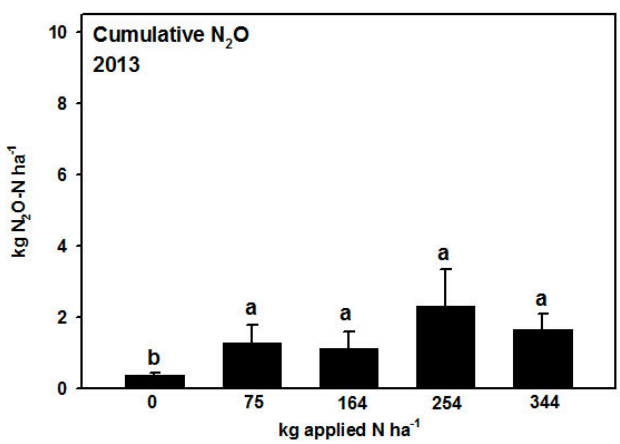

Figure 4. Cumulative N_2O emissions from May 2013 – April 2014.

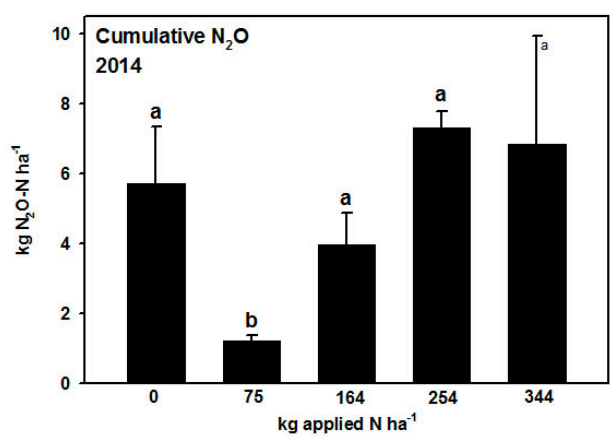

Figure 6. Cumulative N_2O emissions during the growing season 2014.

RESULTS AND DISCUSSION

The highest N_2O fluxes were observed within the first three weeks after the N fertilizer application (Figure 3).

The cumulative annual N_2O emissions for 2013-2014 did not differ among the N fertilized treatments (Figure 4). The post-harvest N_2O emissions through April 2014 during this mostly rainless winter were always low, and cumulative N_2O emissions during the post-harvest season ranged from 18-68 g N_2O-N ha^{-1} in the different treatments.

In general, the daily fluxes were higher in 2014 than in 2013 (Figure 5), but the patterns of emissions were similar among the treatments. In

Table 1. Corn grain yields, yield-scaled annual N_2O emissions (Y.s. N_2O), emission factors (EF, percentage of applied N fertilizer emitted as N_2O), and apparent nitrogen use efficiency (NUE, percentage of applied fertilizer N plus soil pre-plant nitrate content recovered in the corn biomass at harvest) in 2013. Standard errors are in parentheses. Values next to the same letters are not significantly different (P<0.05)(ns = not siginificant)(n=3).

Treatment	Yield		Y.s. N_2O		EF	NUE	
kg N ha^{-1}	Mg ha^{-1}		g N_2O-N Mg^{-1}		%	%	
8	4.2 (1.2)	c	126 (48)				
139	10.8 (0.4)	ab	136 (56)		0.92	47.6 (1.8)	a
226	9.6 (0.5)	b	124 (48)		0.49	32.0 (1.8)	b
270	10.2 (0.8)	b	239 (95)	ns	0.86	32.5 (4.7)	b
342	13.8 (1.7)	a	258 (64)		0.48	33.8 (4.1)	b

all the treatments there was a sharp peak of high emissions following the first irrigation after the sidedress N application. In the treatments with higher N applications, the fluxes continued to rise with the irrigations, although the peaks following the irrigation events decreased progressively with subsequent irrigations. This pattern was especially evident in 2014 whereas in 2013, there was one more clear N_2O emission peak in all the treatments in early June. This pattern of sustained elevated emissions in the high N application treatments (>250 kg N ha^{-1}) is likely due to the continued availability of substrate to microorganisms producing N_2O during nitrification and denitrification in those treatments.

In the lower N application treatments (<250 kg N ha^{-1}) the substrate concentration may have been lowered due to plant N uptake. Alternatively, the application of concentrated N fertilizer itself may affect microbial processes above a certain threshold (N concentration in the soil).

In 2014, the N_2O emissions in the zero-N treatment were similar in magnitude as in the three highest fertilizer N rate treatments. For unknown reasons, the ammonium concentrations were high in the shoulder positions of this treatment, so it looks like N fertilizer was added after the treatments were applied since the zero N block was on the outside of our treatment blocks. In 2014, the 75 kg N treatment had significantly lower seasonal N_2O emissions compared to any of the other treatments. The cumulative N_2O emissions were greater in 2014 than 2013 (Figure 6), and the reasons for the differences are still being investigated by comparing soil moisture, inorganic N, and temperature at the two sites.

The corn grain yields were highest in the 342 and 139 kg applied N ha^{-1} treatments, and yields did not differ among 139, 226, and 270 kg N ha^{-1} treatments (Table 1). The N use efficiency was significantly higher in the 139 kg N ha^{-1} than in the other fertilized treatments. The emission factors were below the Intergovernmental Panel on Climate Change (IPPC) default factor of 1% for direct N_2O emissions. The yield-scaled N_2O emissions did not differ among any treatments.

In 2014, the silage yields in the 344 and 112 kg N ha^{-1} were greater than in the 75 and 254 kg N ha^{-1} treatments (Table 2). The fact that yields in the zero-N plots were as high as in the fertilized treatments also implies that by mistake fertilizer N was applied in the zero N treatment. The emission factors were approximately twice as large in 2014 than in 2013.

PRELIMINARY FINDINGS

In both growing seasons, there were no clear treatment effects on corn yields, which could be the result of high native fertility in these fields. In 2013, the 139 kg fertilizer N ha-1 in addition to the 72 kg N ha-1 residual pre-plant nitrate seemed sufficient to produce adequate corn yields not statistically different from the corn yield produced after fertilizing with 342 kg N ha-1. Not surprisingly, NUE was higher than in the other treatments, whereas similar quantities of N2O were released in all the fertilized treatments. In 2014, 164 kg fertilizer N ha-1 in addition to the 94 kg N ha-1 residual nitrate were required to produce the highest yields at this site, although the 254 kg N ha-1 treatment, like the 75 kg N ha-1 treatment, also had significantly lower yields than the other treatments. In 2014, the lowest N2O emissions were recorded in the 75 kg N ha-1 (in addition to the 94 kg pre-plant nitrate N ha-1) treatment.

Table 2. Silage corn yields and emission factors (EF) in 2014. Standard errors are in parentheses. Values next to the same letters are not significantly different P<0.05)(n=3).

Treatment	Yield			EF
kg N ha-1	Mg ha-1			%
13	115 (3.9)	a		
75	103 (3.5)	b		1.65
164	112 (2.2)	a		1.56
254	102 (3.4)	b		1.69
344	115 (2.5)	a		1.99

Therefore, based on the results of this study, the recommended N rate for this site is somewhere between 211 and 258 kg N ha-1 if pre-plant nitrate levels are also accounted for. The main recommendation for growers is to assess pre-plant nitrate levels and adjust N rates accordingly.

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Optimizing the Use of Groundwater Nitrogen for Nut Crops

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INTRODUCTION

The issue of contamination of air and water with reactive forms of nitrogen (in example NO_3^-) is currently one of the most important challenges to environmental sustainability for California agriculture. A recent report (Harter et al. 2012) mandated by Senate Bill X2 1 (Perata et al. 2008) indicated over 10 percent of public water supply wells in the State exceed the maximum acceptable NO_3^- concentration level (MCL) for the US EPA designation for potable water, that agriculture fertilizer inputs account for approximately 96% of such contamination and that the problem will worsen within the foreseeable future (next several decades). The problem is greatly exacerbated in the Tulare Basin and Salinas Valley where it is estimated "57% of the population in the study area use a community public water system with recorded raw (untreated) nitrate concentrations that have exceeded MCL at least once between 2006 and 2010." (Harter et al. 2012) The agricultural community needs to be proactive in this problem and develop verifiable, best management practices to lessen groundwater nitrate (NO_3^-) contamination.

There is much supporting evidence for the above findings. Over 30 million California residents (about 85%) rely partially or fully on groundwater as a source of drinking water (State Water Resources Control Board, 2012). Nearly 2,600 California communities rely on about 8,400 community public supply wells as the main source of their drinking water. Among those, 1,662 public supply wells in 682 California communities are contaminated. In one-third of these communities the contamination is due to NO_3^- alone (206 communities with 452 NO_3^- contaminated wells). This does not include private domestic households or households on state-small and local public water systems (2-14 connections), of which as many as 40% may be contaminated with NO_3^- (Boyle et al., 2012). In regions with predominantly agricultural land, such as the Central Valley and the Salinas Valley, over 90% of GW NO_3^- pollution is estimated to originate from agricultural lands (Harter et al., 2012). Improved water and nutrient management practices are needed to lower groundwater NO_3^- contamination. These practices must account for non-fertilizer sources of N, such as that in irrigation water. Few studies have considered managing nitrate in irrigation water (pump and fertilize, P&F), but one report found that replacement of commercial fertilizer with irrigation water NO_3^- may be done at a 1:1 ratio or better (King et al., 2012).

The overarching goal of this project is to

demonstrate, validate and examine ways to optimize the utility of GW nitrogen (GWN) and to carry out a proof of concept experiment for the P&F approach for integrated N management in Almonds and Pistachio. Pump and fertilize N management will be contrasted with advanced grower practice (AGP), which consists of conventional split applications targeted to N demand and adjusted by mid-season analysis of leaf critical N, and with high frequency applications of low N concentrations (HFLN), often referred to as "spoon feed". The P&F approach rests upon the assumption that an amount of N (kg ha^{-1}) in GW (generally NO_3^--N and NH_4^+-N) is equivalent to the same amount (kg ha^{-1}) of properly managed N 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. 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 supply schedules and will generally be non-uniform through all irrigation events and thus may be differentially susceptible to leaching loss. Soil properties, irrigation management, crop N status and crop N demand will alter these dynamics. Further, the study proposes and receives supporting funds to examine water and NO_3^- dynamics in the vadose zone (rooting zone) and to GW using state of the art sensors and lysimeters for monitoring water and NO_3^- leaching.

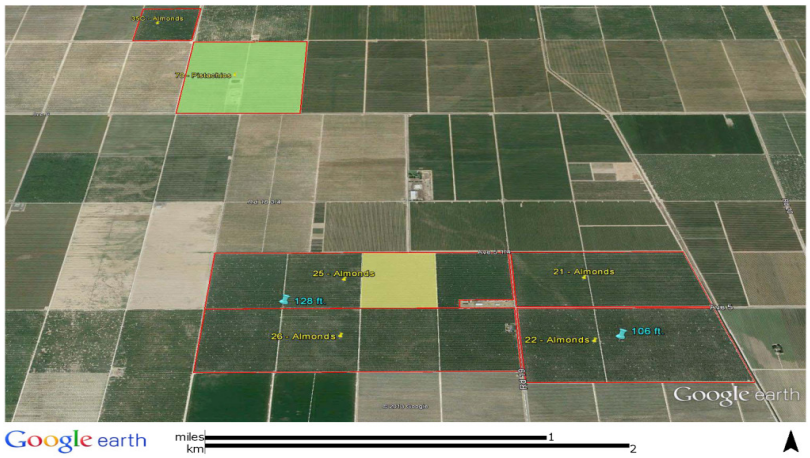

Figure 1. Selected sites highlighted in green for pistachio and yellow for almond for experiments to test the hypothesis of P&F versus AGP and HFLN fertigation. The sites are in areas SW of Madera and Turlock that have sandy soils, high infiltration rates and considered to be hydrogeologially vulnerable.

OBJECTIVES

1. Establish research and demonstration orchards for P&F, AGP and HFLN N management in pistachio and almond orchards within at least two "hydrogeologically vulnerable areas" (HVAs).
2. Utilize and validate recent developments in yield and nutrient budget N management, early season sampling and yield estimation to prescribe best management practices and contrast those practices with P&F N management treatments.
3. Characterize key biological and physical parameters relevant to the P&F concept with respect to seasonal plant-soil N mass balance
4. Monitor NO_3^- movement in the vadose zone (root zone) and extend to movement into GW.
5. Establish a proof of concept for use of stable isotopes of N and oxygen in NO_3^- ($\delta^{15}N$-NO_3^- and $\delta^{18}O$-NO_3^- (‰)) for tracer studies of NO_3^- movement under P&F versus the other practices.
6. Develop and ground validate decision support models to assist growers with optimal management of groundwater nitrogen (NH_4^+ and NO_3^-).
7. Demonstrate and proactively extend developed results, technologies relevant to on-site assessment and best management practices (BMPs) to growers.

DESCRIPTION

Research and Demonstration Orchards

An intensive search was undertaken to locate orchards appropriate to the experimental objectives of the project and with willing grower cooperators. Focus was given to the orchards bordered in red in

Figure 2. Shown (left panel) is an example of a soil pit excavated during July 2013 in order to determine location of water and salt impeding horizons, Ksat, bulk density and other soil chemical and physical parameters necessary to quantify vadose zone water and NO_3^- movement.

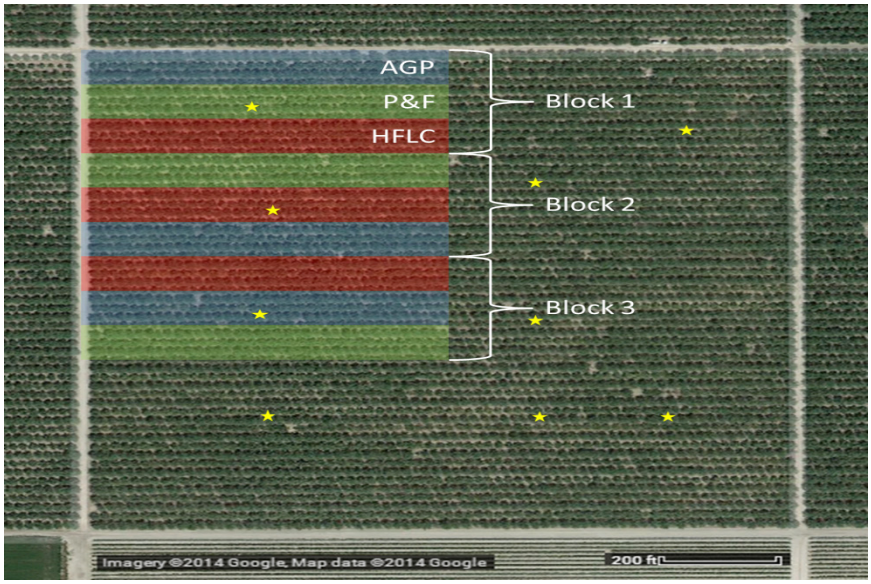

Figure 3. Basic fully replicated experimental design for both the almond and the pistachio orchards with 4 rows of trees in each treatment and three replications for each of P&F, AGP and HFLN. The treatments run the full length of the row and each star represents an intensively monitored tree (n = 2).

the lower panel of the images shown in Figure 1 and at a second site near Turlock. Soil particle size distribution analysis (texture) with depth was carried out for each site following intensive scrutiny of soil pits excavated to delineate the root zone for sensor installation (Figure 2). Nearly 200 soil samples were taken and analyzed and nitrogen analysis was done on all available orchard well water to determine suitability for the P&F treatment. From this data, two sites were established in each HVA.

The research and demonstration orchards established in each of the two HVAs (Turlock and Madera) are as depicted in Figure 3. The fully randomized complete blocks designs contain all three treatments (AGP, P&F and HFLN) and are located in the Madera (HVA1) and Turlock (HVA2) groundwater basin areas. The treatments extend the full length of the orchard rows.

RESULTS AND DISCUSSION

Fully instrumented arrays consisting of polyvinyl chloride (PVC) pipe fitted with ceramic cups for root zone monitoring, tensiometers and tensiometer electronics, data loggers and pressure transducers are used to estimate leaching rates (Figure 4, left panel). We used volumetric water content monitors for the tensiometers, custom-designed deep tensiometers that can be operated across the maximum application range (0-850 cm), irrespective of installation depth (Figure 5). This was done by installing the pressure transducer at the tensiometer cup and using a hanging water column, as opposed to conventional tensiometers where the pressure transducer is installed at the soil surface. The design was successfully tested. This new design is critical for application in irrigated systems requiring soil water dynamic measurements at significant depths (eg. > 100 cm) below the rooting zone to estimate soil water movement and potential NO_3^- leaching rates.

Figure 4. Tensiometer and lysimeter arrays established in an almond orchard within Madera HVA. Shown are (a) housing for the electronics, (b) tensiometers and deep solution samplers, (c) shallow solution samplers, and (d) solar panel to charge the battery powering the electronics in real time. The right panel shows a dositron used for N injection metering of HFLN (spoon feed) N fertigation.

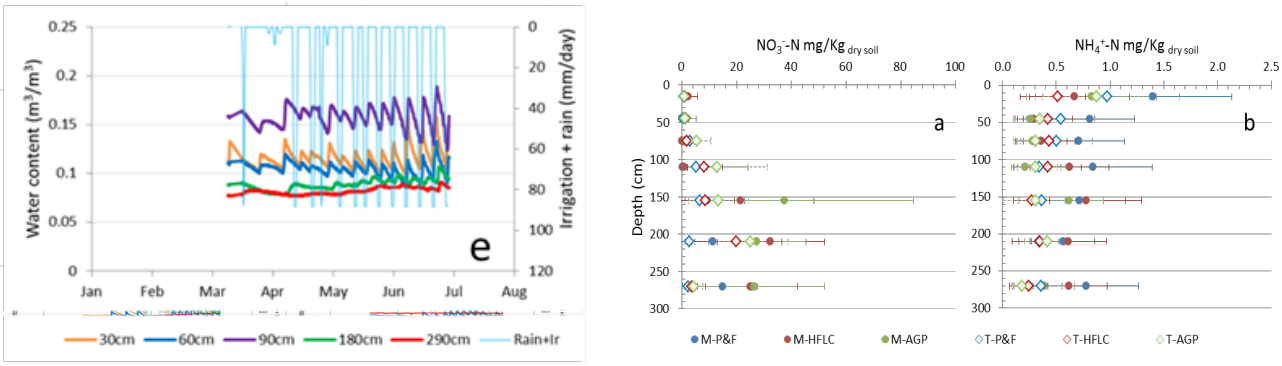

Figure 5. Shown in the left panel are real time volumetric water content measurements (m^3 m^{-3}, TDR) at 5 depths through the rooting zone. In the central and right panels are soil extractable NO_3^- and NH_4^+ concentrations (mg kg-1), respectively, for approximately the same depths.

Preliminary Findings

Continuous monitoring of changes in the volumetric water content of the sediment profile showed variation in time, reflecting irrigation events down to 180 cm depth (Figure 5, left panel). Abrupt changes in the water content were not observed below the upper profile (>180 cm) following rain and irrigation events (orange, blue and purple lines, Figure 5) but depletion of deep water (green and red lines) was observable during July and August. The water content profiles indicated rapid (~1 m h^{-1}) propagation through the loamy sand that composes the upper subsurface (blue line Figure 5, left panel). In locations where hardpan did develop, the pan significantly slowed the wetting front, such that no direct correlation between the wetting event and the water content was observed.

The soil solution NO_3^- and NH_4^+ contents (Figure 5, center and right panels) showed tremendous variation among treatments and the NH_4^+ concentrations were extremely low, as expected. The HFLN treatment (HFLC) did show some evidence of lowered NO_3^- levels at the medium depths (150-200 cm) but the results are very preliminary and will require verification in upcoming growing seasons. We anticipate it will require several seasons to resolve the impact of these treatments on GW NO_3^- dynamics.

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

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INTRODUCTION

Data from the last decade show the organic industry is on pace for a six-fold increase from initial sales in the next five years, having grown from $6.1 billion (2000) to $29 billion (2011) in sales (OTA, 2011). California is the national leader in organic farming with the highest number of organic farms, land under organic production, and organic sales (Klonsky, 2010). Despite this industry accounting for only 3% of farm-gate sales in 2008, steady growth of this sector is anticipated and signified by year-on-year growth of 8%, compared to 1% for the entire food industry in 2010 (OTA, 2011). Being an industry heavily based on trust in the "organic" brand, growth of the organic industry is partly threatened by any activity or factor resulting in potential loss of grower and consumer confidence in the integrity of the brand. One such factor is the authenticity of the organic fertilizer used to grow organic food and oversight of this remains a major challenge.

California Assembly Bill (AB) 856 (Chapter 257, Statutes of 2009), was passed to substantially increase the penalties for violation of organic fertilizer standards, require registration of all organic fertilizers sold in the state and give regulators greater authority to monitor and review organic fertilizer labels (CDFA, 2012). However, one of the challenges faced by regulators to administering this law has been the absence of a systematic protocol for regulators and product end users testing the authenticity of the organic products sold. Depending on the degree of adulteration, basic laboratory tests often fail to identify a problem. For example, analysis of nitrogen content may confirm a product label, but will not indicate the source of nitrogen (organic or inorganic).

This research provides insight into analyses that can be used to provide quality control in the production and testing of organic fertilizers and amendments.

OBJECTIVES

The major new product generated by this project is a method of detecting with high probability adulteration of organic fertilizers and other amendments by synthetic fertilizer and other chemical nutrient sources.

The following objectives guided 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. Develop a stepwise protocol test that labs and regulatory agencies can follow to identify organic fertilizers that have likely been adulterated by synthetic fertilizers.
4. Carry out blind tests with collaborating test labs to evaluate the robustness of the above protocol.
5. Disseminate the results and products of the project to potential users, such as organic fertilizer test labs and regulatory agencies.

DESCRIPTION

Synthetic and organic samples (solid and liquid) were obtained from commercial fertilizer suppliers for analysis (n = 180) (Table 1). Prior to analysis, all non-homogenous liquid samples, such as raw fish, were homogenized by mechanically shaking the sample with glass beads or steel balls. Solid samples were homogenized by grinding with a mortar and pestle, or in the case of very fibrous samples, by mechanically shaking in a steel ball mill. The following properties were measured, when appropriate: carbon content, nitrogen content, phosphorus content, carbon-13/carbon-12 isotope ratio, nitrogen-15/nitrogen-14 isotope ratio, solid content, density, dissolved organic carbon, dissolved organic nitrogen, ammonium content, and nitrate content. Ammonium content, carbon to nitrogen ratio (C/N), and nitrogen isotope ratio (δ15N) were identified as most useful for initial inspection of the database and evaluation of fertilizers. The methodologies for these analyses is presented in Table 1.

Through integration of literature and laboratory information, a systematic protocol for the detection of potential adulterants in organic fertilizer is presented (Figure 1). This protocol will assist in attaining the objectives of the California Department of Food and Agriculture Fertilizer Research and Education Program (FREP), a program within the industry-funded Fertilizing Materials Inspection Program, which include checking the truth of labeling claims and testing the compliance of the guaranteed analyses (CDFA, 2012). The rationale for the protocol is based on the most likely adulterants of products marketed as organic fertilizers being various forms of ammonia (e.g., aqua ammonia or ammonium sulfate), or possibly urea, which is itself converted to ammonium carbonate and ultimately ammonia in the presence of urease (Volk, 1959). These adulterants are favored primarily due to their low cost and high nitrogen content. Since nitrogen isotope ratio, carbon to nitrogen ratio, and ammonium content most effectively separate different classes of organic and synthetic materials, they best help indicate the presence of adulterants. Furthermore, they provide the greatest opportunity to compare with literature data, and are relatively easy to measure (and therefore most useful to a testing lab). Although not particularly investigated, adulteration through the addition of nitrate salts is also possible, but this protocol would still be able to detect this through the C/N ratios and δ15N values.

Table 1. Categories of organic fertilizers used for comparison and analysis

Unprocessed Fish	(Processed) Grain
Liquid Fish Products	Humates
Solid Fish Products	Chile Nitrate
Blood Meal	Fish / Guano
Compost and Manure	Fish / Grain
Bat Guano	Fish / Seaweed
Seabird Guano	Grain / Feather
Feather Meal	Other Blends*
Soy Meal	Urea
Cottonseed meal	Amino Acids
Bone Meal	Uric Acid
Seaweed Products	Algae

*Contained more than two components, e.g. kelp/seaweed extract, humic acid, molasses vinegar, compost, and alfalfa tea

The protocol shows a six-step systematic flowchart to follow when investigating the potential adulteration of an organic fertilizer selected in order of increasing effort and expense. This protocol minimizes the potential of incorrectly flagging a fertilizer as potentially adulterated. No single metric alone is a sufficient determinant to classify a sample as adulterated or unadulterated (Verenitch and Mazumder, 2012).

Initially, identifying the category to which a sample belongs and also knowledge of the components constituting the fertilizer is necessary in order to interpret the results of analysis and use the protocol effectively, since values that are suspect for one kind of sample may not be suspect for another kind.

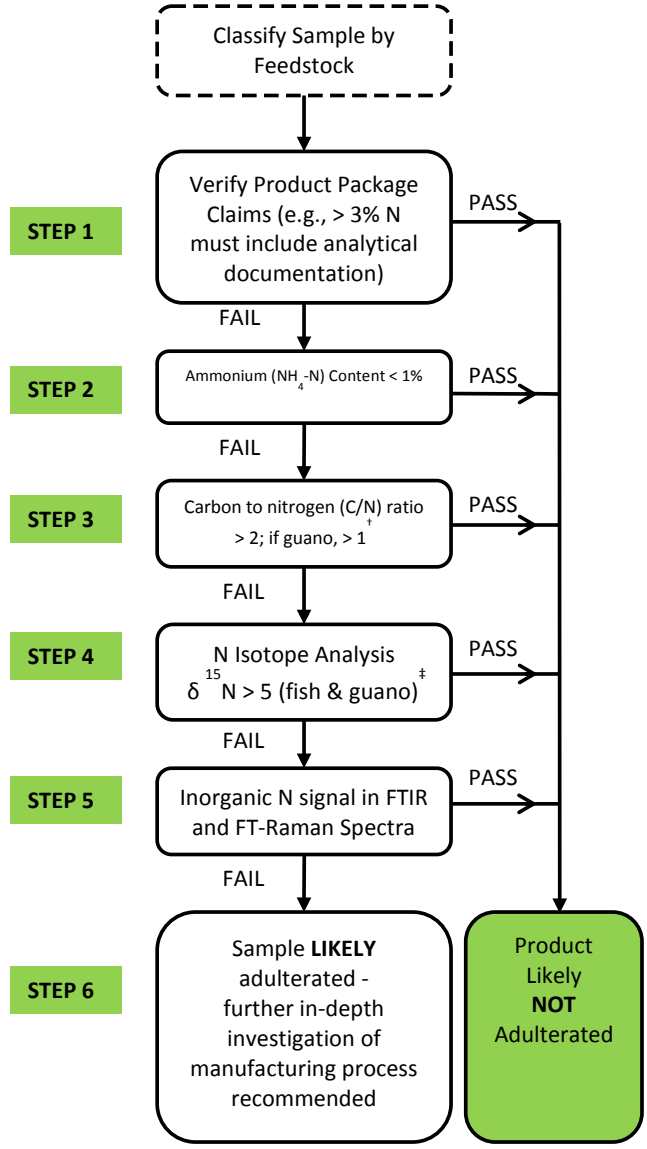
Step 1. Prior to any laboratory analysis, attention is directed toward the label and/or price of a product as a simple way to identify where to begin analytical efforts. One of the most important metrics to focus on is the nitrogen content. As stipulated by the USDA, organic fertilizers labeled as containing > 3% N must be evaluated through a material evaluation program (USDA, 2009). This program requires oversight from third party evaluators capable of verifying compliance of the component inputs (including processing and handling of the product) independent of the crop producer and fertilizer manufacturer. The suppliers of such products should have this data for their products.

Step 2. As a first analytical step to evaluating a

product, the ammonia (ammonium) content may be estimated in the field. For common, well-characterized categories of products such non-fish or guano-based fertilizers, this is an easy preliminary step toward selecting samples for further investigation. Any product in these categories found to contain more than 1% nitrogen, as ammonium (10000 mg L^{-1}) should be retained for further analysis. Setting a threshold for samples that naturally have ammonia (e.g. fish products) is more challenging, and potential adulteration of these samples can be detected by other tests in the protocol.

Step 3. The ratio of carbon to nitrogen (C:N; w/w) in any material is a good indication of how "organic" a material is. It is not necessary to check the ammonium concentration if C:N is determined. The 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 average confidence interval (CI) of the five lowest materials (i.e., seabird guano; fish guano; fish/seaweed; amino acids and other blends) is 1.28 ($P<0.01$). For guano alone, the CI at the same significance level is 1.09. Any materials that show C:N ratios below these 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 N 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, is a C:N of 1. An exception is Chile 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 Chile nitrate, questionable samples may warrant further investigating by using Step 4.

Step 4. The ratio of nitrogen-15 to nitrogen-14 (expressed as $\delta^{15}N$) is another parameter which does not fall 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 from the CI for all non-organic sources using



†Chile nitrate is an exception.
‡Seaweed, algae, and soybeans are exceptions, requires FTIR or FT-Raman analysis.

Figure 1. Flow chart of the organic fertilizer verification protocol proposed for use by test labs and regulatory agencies.

0.01 as the significance level and accounting for variations in sample size (number of values used in the calculation of each product's CI). The CI is 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 this threshold are almost certainly not adulterated. It is important to note, however, that plants that rely on symbiotic N uptake (e.g. legumes) can have $\delta^{15}N$ values as depleted as non-organic N sources. So in fertilizers where biomass from N-fixing plants has been added, it may be difficult to distinguish their

signature from that of non-organic sources.

Step 5. The two spectroscopic techniques (FTIR and FT Ramen) 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. 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. 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. The success of the spectroscopic techniques bodes well for similar analysis of solid fertilizers using near-infrared reflectance spectroscopy (NIRS), which is routinely used in plant/ forage and feed tissue analysis to determine components such as crude protein content. The liquid nature of most organic fertilizers does present a challenge for NIRS, due to water being a strong absorber of NIR light (Stuth et al., 2003).

Step 6. When a sample clearly fails all or some of the tests, adulteration is likely and warrants further investigation of the manufacturer, such as an on-site visit and examining the process of production.

CONCLUSION

There is a pressing demand for methodology to validate claims of fertilizers labeled "suitable for organic production" in order to confirm their authenticity. A standard and vigorous protocol to address this urgent need will bring transparency and authentication to the array of organic fertilizer products on the market. The systematic protocol developed through this research has the potential to be used by test laboratories and regulatory agencies to detect adulteration of organic fertilizers and soil amendments adulterated with synthetic nitrogen sources. Given the current growth of the organic industry, the importance of having a framework for detecting adulteration of fertilizer inputs cannot be understated and may be pivotal in the monitoring of the industry.

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Nitrogen Management Training for Certified Crop Advisors

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INTRODUCTION

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

OBJECTIVE

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

DESCRIPTION

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

Phase I: August 1, 2013 – December 31, 2014

This phase involves curriculum development and an initial round of trainings.

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

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

1. Modesto – January 14-15, 2014
2. Woodland – February 18-19, 2014
3. Fresno – February 25-26, 2014
4. Salinas – March 5-6, 2014
5. Tulare – March 11012, 2014

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

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

Curriculum Modification. The curriculum used in the first round of trainings will be reviewed based upon feedback from evaluations during those trainings. Modifications to the curriculum will be

considered and implemented.

Training Sessions. Three additional training sessions will be held in early 2015. Locations and times are being determined. Preliminary locations are Fresno in mid-January, San Luis Obispo at the end of February, and Sacramento in mid-March. The website we have developed will be updated regularly during this time.

Publications. A total of four publications will be created from the training materials, lessons learned from the training sessions and from additional research. The exact form of these publications is not yet determined and will depend on subject matter material and intended audience. The current intent is to produce publications for the UC ANR peer reviewed 8000 series. Depending on the subject matter and level of detail, other possible outlets include peer reviewed journals and non-peer reviewed fact sheets and reports.

RESULTS AND DISCUSSION

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

Day 1: Nutrient Management

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

Figure 1. Doug Parker, director of the California Institute for Water Resources, and Terry Stark, executive director of the California Association of Pest Control Advisers, at the Modesto training in January 2014.

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

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

At this time, training materials and videos are available on the web at ciwr.ucanr.edu/NitrogenManagement. We are in the process of creating annotated presentations to make the material more accessible for participants across trainings. We expect updated materials to be available in November.

In addition, three further trainings will take place in early 2015 in locations around the state.

Figure 2. Participants at the first nitrogen training event in Modesto, January 2014.

Figure 3. Dr. Tim Hartz presents module 3. Photo courtesy of Steve Beckley.

ACCOMPLISHMENTS

UC partnered with CAPCA to carry out the trainings. Information on the results of the 2014 trainings is provided in the table below.

Training Date	Location	Completed	No-Shows	Partial Hours	Total Registered
1/14/14 – 1/15/14	Modesto	113	0	0	113
2/18/14 – 2/19/14	Woodland	89	1	0	90
2/25/14 – 2/26/14	Fresno	111	4	1	116
3/05/14 – 3/06/14	Salinas	104	0	3	107
3/11/14 – 3/12/14	Tulare	112	7	4	123
		529	12	8	549

This project has resulted in a strong curriculum in nitrogen management that has been used to train over 500 Certified Crop Advisors, with an additional 300 expected to complete the 2015 trainings.

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

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INTRODUCTION

The primary goal of this new study is to evaluate the impacts of timing and rate of nitrogen (N) fertilizer application on optimization of wheat grain yield and protein content while reducing the potential for N leaching. The study focuses on hard and durum classes of spring wheat grown in California, and will span three years, employ two experimental approaches, and include multiple varieties and locations across California's diverse wheat agroecosystems. The work will improve our understanding of the interaction of timing and rate choices in N fertilizer management, wheat productivity, protein content, and soil profile nitrate levels post-harvest resulting from N fertilizer management strategies.

Wheat is an important commodity in California's agricultural economy, ranging from about 675,000 to almost 800,000 acres grown in recent years. For the hard and durum classes of wheat, which in 2012 comprised over 90 percent of the wheat acreage in California, achieving high protein content can impact the price that growers receive and, thereby, their profitability. For hard red spring wheat, a producer receives a premium for grain protein greater than 14% in northern California and 13% in the southern San Joaquin Valley, and a discount for wheat with less than the required grain protein (Orloff and Wright, 2011; Orloff et al, 2012). As a result, growers of the hard and durum wheat classes seek a combination of both high yield and high protein content to maximize the profitability of their crop.

Past research projects have estimated that the amount of total available N required for favorable yields, and protein ranges for hard red spring wheat are at least 1.6 lbs of total available N per bushel at lower yield levels to over 2.0 lbs total available N per bushel (or about 3 lbs N per 100 lbs of grain). In good production years, grain yields in CA can often be in the range of 3.5 to nearly 5 tons/acre. Research conducted in the 1980's by University of California researchers to improve grain protein focused primarily on moderate yielding / higher protein wheats such as Yecora Rojo (Wright et al. 2008). Newer varieties can often yield about a ton/acre higher than varieties such as Yecora Rojo, but most are lower in protein. Late-season N has been shown to improve protein, but the levels needed to consistently achieve higher protein and yield combinations are not well established for most areas of the state. Research is needed to evaluate the effectiveness of late-season N application to improve the protein content of a range of varieties with different yield and N accumulation characteristics. Wheat N studies conducted in 2012 by Orloff, Wright, and Hutmacher were consistent with earlier studies in that they demonstrated that varieties differed in N uptake and yield potential.

Since high yields are generally accompanied by low protein content, the combination of high yields and high protein content can be biologically difficult to achieve, particularly with some of the newer, higher-yielding varieties. This can serve as a significant incentive for growers to apply high rates of fertilizer N in order to increase their chances of achieving desired grain protein percentages. New research is needed to evaluate a range of N management approaches that could achieve profitable yield and protein levels while reducing the potential

for leaching losses for wheat varieties commonly grown in the state. The objectives of the proposed study are to determine the best rate and timing of split N applications to achieve economically viable high yields with desired protein content, while at the same time improving nitrogen use efficiency. Proper nitrogen fertilizer management decisions should depend on: (1) the range of crop nitrogen requirements that can achieve acceptable crop yield and quality; (2) practices that consider and improve utilization of residual as well as applied nitrogen; and (3) practices that limit or prevent nitrogen losses or excess leaching below crop active root zones.

OBJECTIVES

Primary objectives include:

1. Compare the yield and protein content of the most popular hard red, hard white, and durum spring wheat varieties in response to a range of N application treatments to determine their N-use-efficiency.
2. Evaluate N management schemes utilizing different rates and split applications of N to determine the effectiveness of pre-plant applications (front loading the system) versus delayed applications to more closely match plant uptake. The effect of these N schemes on yield and grain protein will be quantified in three different wheat production regions in California (southern San Joaquin Valley, Sacramento Valley, and northern intermountain area).
3. Determine the concentration of nitrate-N occurring at different depths in soil profiles at the end of the season as a function of N rate and application timing for various locations/ soil types to estimate nitrate accumulation or movement below the root zone and potential for deep percolation losses.
4. As information is developed in the study, present information to appropriate grower groups, consultants and industry to give opportunities for feedback and to refine concepts of workable changes in N management approaches.

Additional objectives include evaluation of soil nitrate quick tests and plant tissue tests in providing supplemental information regarding impacts of the range of fertilizer application rates and timing on soil and plant nitrogen status.

CURRENT PROGRESS

To date, five trials have been successfully implemented across three experimental regions (San Joaquin Valley, Sacramento Valley, and Intermountain Region): (1,2) a variety by nitrogen management trial in the Intermountain Region and the San Joaquin Valley sites; (3.4, 5) a multiple rates [0-300lb/acre] and multiple splits for timing of fertilizer applications [pre-plant, tillering, boot, and flowering]) in all three locations. Varieties to evaluate at each site were selected based in part on commercial suitability and based on: (1) representing the wheat classes grown in the respective study areas including durum, hard red and hard white varieties; and (2) possessing a range of yield potentials. In all cases, experimental sites with low pre-plant soil NO3-N were chosen, pre-plant soil sampling was conducted to 8 feet, trials demonstrated a measurable response to N fertilization, and, for trials that have been harvested to date, a wide range of yield and protein concentrations as a function of N rate and timing have been measured.

San Joaquin Valley - Trials described above were planted in early December and sprinkled up. In January, following tillering, two inches was applied with sprinklers. The field received 3 more 4-inch flood irrigations, with the last one being the first week in May. Both boot and flowering stage applications were followed by flood irrigations. Rainfall was not a factor. Weeds were managed with MCPA plus Express. Soil nitrate quick tests were tested three times during the growing season (including within two weeks prior to harvest) across five treatments and will be compared with soil nitrate test results from samples that will be collected in the late summer and sent through the UC Davis analytical lab. The field was harvested in mid-June. Preliminary results showed a range from 2 tons on the untreated control to 4.4 tons on the treatments with the highest nitrogen application rates and multiple applications through the growing season. Results from the yield, bushel weights and protein evaluations have not yet been analyzed. Soil cores from the surface to 8 feet depth were collected in August and will be analyzed for soil nitrate N and compared with preplant nitrate values to determine zones of soil nitrate net use and accumulation resulting from the different rate and timing treatments.

Sacramento Valley - The multiple N rate / application timing trial was planted with Patwin (hard white) in

late November to sufficient moisture and subsequent rainfall for emergence and early growth. Three inches of water was flood irrigated in late December. Tillering and boot applications of N coincided with rainfall events. Another 3 inches was flood irrigated immediately following the flowering application of N. Leaf and soil samples were taken near each N application event in a subset of the treatments. No weed control was necessary as the weed pressure was minimal. The plots were harvested on June 9. Samples have been processed for yield and protein, and preliminary analysis reveals a wide range of yield (2.1-4.6 tons) and protein content (8.0-13.2%), significant effects of both timing and rate of N application, and significant relationships between in-season plant N status and protein-yield responses. Soil samples to 8 feet were collected, post-harvest and are being processed for soil NO3-N as described for the San Joaquin Valley site.

Intermountain Region – Variety by N application rate trial and multiple N rate / application trimming trials were planted on April 14. The wheat varieties evaluated in the first trial included Yecora Rojo, Hank, WB 9668, and WB 9518. Plots were sprinkler irrigated throughout the season and water applications rates at each irrigation were recorded. Half an inch of irrigation water was applied within 24 hours of each fertilizer application to incorporate the urea fertilizer. Weeds were controlled with an herbicide tank mix of 2, 4-D and Axial. Leaf and soil samples were collected near each N application event in a subset of the treatments. The intermountain area has a later growing season than the other production areas included in this overall study. The wheat will be harvested late August so no yield or quality data are available at this time. Soil samples to 8 feet will be collected in mid- to late-September following harvest and will be processed for NO3-N content as described for the San Joaquin Valley site.

This project should provide field-based information to help judge the trade-offs between protein content and yield. The information provided by this project should improve the knowledge base for California wheat producers and regulatory agencies, better defining N applications needed to produce the most profitable crop (in terms of yield and quality), while reducing the dangers of N losses associated with possible nitrate leaching.

ACKNOWLEDGEMENTS

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

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INTRODUCTION

Water quality regulations passed by the Central Coast Regional Water Quality Control Board (CCWQCB) require growers to monitor and implement practices to improve the efficiency of applied nitrogen (N) to vegetable crops. The proposed regulations focus on nitrate loss in vegetable and other horticultural crops and in 2014 will begin to require reporting of the quantity of N applied. The regulations create the need for N uptake data for a variety of crops. Various commodity boards have funded research to address N uptake by specific commodities: There are other key commodities grown on the Central Coast that do not have support of commodity boards such as broccoli, cauliflower and cabbage. In 2009, there were 85,287 acres of broccoli, 24,334 acres of cauliflower and 6,568 acres of cabbage in the counties included in the CCRWQCB with a combined total value of $651,089,618. This project was undertaken to determine the nitrogen uptake and water use by broccoli, cauliflower and cabbage. The information generated by this project is being used to develop algorithms to model N and water use in the CropManage on-line crop management tool.

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

The project consists of a survey of well-managed, high-yielding broccoli, cauliflower and cabbage fields in Monterey County. Twenty nine evaluations were completed during the summers of 2012 to 2014 (10 broccoli; 7 cauliflower; and 12 field) and 8 evaluations were completed during the winter of 2012-13 (4 broccoli and 4 cauliflower). Fields were selected that had production practices typical for this region (i.e. direct seeded and transplanted broccoli; transplanted cauliflower and cabbage); however, new configurations are being utilized by growers and some of these were also included in the evaluations (5 line broccoli, 3 line cauliflower, and 5 line cabbage on 80 inch beds). Irrigation and fertilization practices of selected fields were also typical of the region. Fields were selected that encompass the range of microclimatic factors (e.g. Castroville to King City) and diverse soil types (sandy loams to clay loams). Crop biomass, biomass N and soil nitrate-N were measured three to four times during the growing season to measure the N uptake pattern and total N uptake. Biomass samples were collected by collecting a quantity of plants (4 to 20) or plants from a strip of bed (e.g. 10 feet) at random from four parts of the field in at each evaluation; the number of plants surveyed depended on the size of the plants. At harvest, total biomass and commercially harvested biomass and biomass N were measured. Also at harvest, total crop biomass was also analyzed for phosphorus and potassium. Fertilizer application rates and timing in each field were also recorded.

Rooting depth of the crops was measured at weekly intervals during plant establishment and then bimonthly intervals until harvest. Holes 1 to 3 feet deep were dug at 3 locations in one field of each commodity each year to identify the depth of deepest

roots. Pits were dug near harvest in one field of each commodity per year to expose a cross-section of the bed and map out the final root distribution.

Flow meters were installed at each monitored field to quantify the volume of water applied from crop establishment to harvest. The flow meters were connected to data loggers to record the length and frequency of irrigations. Infra-red canopy photos were taken every 2 weeks to develop crop coefficients for estimating crop ET. Soil moisture sensors were installed to monitor changes in soil moisture storage. This data provided an estimate the volume of drainage below the root zone.

RESULTS AND DISCUSSION

Broccoli and cabbage took up about 337 lbs N/A and cauliflower 285 lbs N/A (Table 1). Cabbage had the highest N content in the harvested portion of the biomass at 174 lb N/A; 99 and 61 lbs of N are removed in the harvested biomass for broccoli and cauliflower, respectively. Applied fertilizer averaged 182, 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.

Cabbage produced the highest overall biomass per acre (11,564 lbs/A) followed by broccoli (8,585 lbs N/A) then cauliflower (6,930 lbs N/A). 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 in all three crops.

Given the disparity in the amount of N applied to broccoli vs the amount taken up we sampled the soil down to two feet to see if we could better understand the source of the additional N. On average, at the 1-2 foot depth, there was a substantial quantity of N at the beginning of the crop cycle through midgrowth (Table 2). These evaluations may help explain why broccoli takes up more N than is routinely applied.

Growth of broccoli and cauliflower in the winter was different than summer production. Broccoli took up about 249 lbs N/A and cauliflower 273 lbs N/A. 94 and 70 lbs of N were removed in the harvested biomass for broccoli and cauliflower, respectively. Broccoli and cauliflower had 272 and 351 lbs N/A applied, respectively. Scavenging of N by these crops in winter production did not occur in the survey fields. Fertilizer applied to broccoli was only slightly in excess of uptake, but fertilizer N applied to cauliflower exceeded uptake by 78 lbs/A. Total biomass production by broccoli was 5,539 lbs/A and cauliflower was 6,490 lbs/A. Broccoli plants were much smaller in the winter, but biomass production by cauliflower was only slightly less than in the summer. Both total potassium uptake and concentration in the tissue were less in the winter than in the summer for both crops.

Crop[1]	%N total biomass	Dry biomass Lbs/A	Total uptake N/A	Fertilizer applied N/A	Scavenged from soil N/A	Unharvested residue N/A	Total K uptake lb/A
Broccoli	4.0	8,585.5	337.4	181.9	155.5	238.1	360.2
Cauliflower	4.1	6,930.5	285.1	260.0	20.7	224.3	299.9
Cabbage	3.0	11,564.5	337.5	251.1	97.1	163.5	361.6

Table 1. Summers 2012 & 2013. Above ground N/A in crop, yield components, applied fertilizer, N scavenged from soil and N in residue at harvest

Depth	Mineral N	Baseline	Early growth	Mid growth	Late growth	Harvest
1st foot	NO_3-N	46.5	23.3	12.1	8.3	6.1
1st foot	NH_4-N	2.3	2.2	2.1	2.1	1.8
2nd foot	NO_3-N	29.2	48.9	27.8	12.5	5.1
2nd foot	NH_4-N	1.1	1.4	1.5	1.13	1.4

Table 2. Average nitrate in the soil at five growth stages for each crop.

Crop	Establishment method	Number of Fields	Average Applied Water and Rainfall: Total	Irrigation Water	Rainfall	Average Crop ET
			----------	inches	----------	
Broccoli	Direct seed	11	21.2	19.0	2.2	8.6
	Transplant	3	23.1	21.0	2.1	10.4
	All methods	14	21.6	19.4	2.2	9.0
Cabbage	Direct seed	2	29.7	21.1	0.2	10.7
	Transplant	8	24.3	24.4	0.2	11.4
	All methods	10	25.2	23.7	0.2	11.3
Cauliflower	Transplant	9	15.3	12.8	2.5	6.8

Table 2. Average nitrate in the soil at five growth stages for each crop.

The overall quantity of water applied to broccoli, cabbage and cauliflower was 21.6, 25.2 and 15.3 inches, respectively and the average crop ET was 9.0, 11.3 and 6.8 inches, respectively (Table 6). Interestingly, there was higher crop ET for transplanted broccoli and cabbage than for direct seeded; we do not have a good explanation for this observation, other than the crop may achieve a larger crop canopy earlier in the crop cycle.

Canopy cover of cole crops was measured by taking overhead photos at 10 to 15 day intervals during the crop cycle using a near-infrared digital camera. Canopy cover data (Fig. 1) were fit to a developmental model proposed by Gallardo et. al. (1996):

$$\text{Canopy cover (\%)} = Gmax/(1 + \exp[A + B\times day/(Maxday*Fmax)] \quad (1)$$

where Gmax is the maximum canopy cover, *A* and *B* are fitted parameters, day is the number of days after planting or transplanting, *Maxday* is the total days between planting and the end of the crop (last harvest), and *Fmax* is the fraction of the crop cycle when the maximum canopy size is achieved. Parameters for this model were determined for broccoli, cabbage, and cauliflower grown under various planting configurations (Tables 7, 8 & 9). These models will be added to CropManage so that growers can estimate the water use of their crops using CIMIS reference ET data and a crop coefficient (Kc) calculated using the equation:

$$Kc = (0.63+1.5\,C - 0.0039C2)/100 \quad (2)$$

where Kc is the crop coefficient, ranging approximately between 0 and 1.0, and C is percent canopy cover estimated in equation 2.

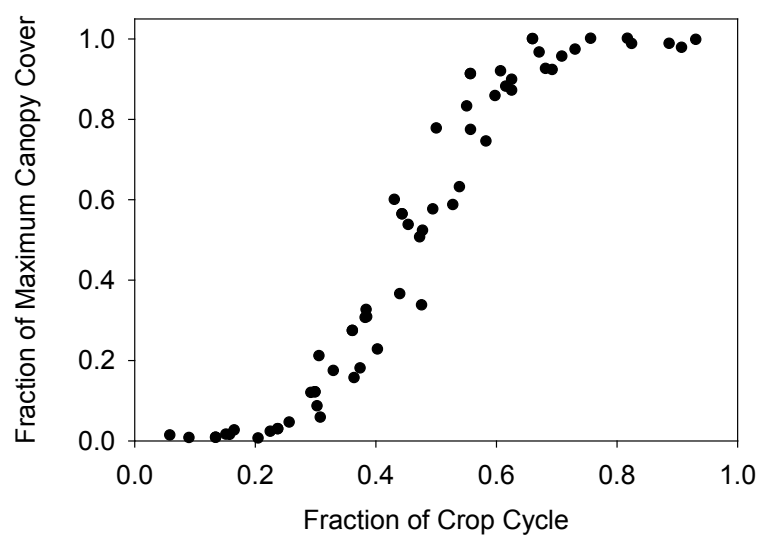

Figure 1. Canopy development of summer planted broccoli expressed as a fraction of maximum cover.

Crop description	number of sites	bed width	seedlines	Crop Cycle	Model Parameters A	B	Gmax	Fmax	Model fit R^2
	#	inches	#	days			%		
Winter, direct seeded	3	40	2	137	5.39	-7.70	89	0.96	0.87
Summer, direct seeded	6	40	2	87	6.51	-10.82	98	0.78	0.91
Summer, transplanted	1	80	5	87	5.35	-11.13	99	0.91	0.97
Summer, transplanted	2	40	2	87	3.34	-7.83	99	0.93	0.95

Table 7. Canopy cover model parameters for broccoli.

Crop description	number of sites	bed width	seedlines	Crop Cycle	Model Parameters A	B	Gmax	Fmax	Model fit R^2
	#	inches	#	days			%		
Summer, green, seeded	2	40	2	77	6.54	-10.96	95	0.81	0.80
Summer, green, transplanted	2	40	2	77	4.64	-9.69	98	0.81	0.93
Summer, green, transplanted	2	80	5	77	4.74	-10.45	87	0.79	0.95
Summer, red, transplanted	4	40	2	89	3.93	-8.09	99	0.65	0.89

Table 8. Canopy cover model parameters for cabbage.

Crop description	number of sites	bed width	seedlines	Crop Cycle	Model Parameters A	B	Gmax	Fmax	Model fit R^2
	#	inches	#	days			%		
Summer, Transplanted	3	40	1	73	4.62	-8.63	91	0.95	0.83
Summer, Transplanted	1	40	2	73	4.34	-9.25	98	1.00	0.91
Winter, Transplanted	1	40	2	128	4.88	-8.42	90	1.00	0.94
Winter, Transplanted	3	40	1	128	3.87	-6.27	66	0.93	0.94
Winter, Transplanted	1	80	3	128	4.87	-6.83	95	1.00	0.94

Table 9. Canopy cover model parameters for cauliflower.

Rooting depth of broccoli, cabbage, and cauliflower increased linearly with time, reaching maximum depths near the time of harvest (broccoli rooting depth only, Figure 2). 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.

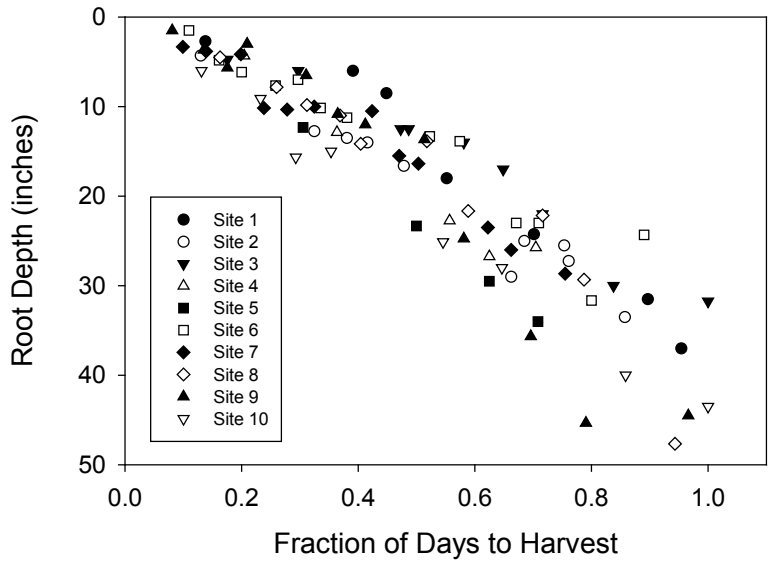

Figure 2. Rooting depth of broccoli measured in commercial fields from plant establishment to harvest.

RECOMMENDATIONS

Data from these evaluations changed the way viewed cole crops. In summer production, all of the cole crops surveyed took up more N in the crop biomass than was applied as fertilizer. Broccoli was particularly notable by scavenging over 150 lbs N/A. The scavenged N is used for crop production. About 1/3 of the nitrogen taken up by broccoli is exported in the harvested product and the remaining N is returned to the soil as crop residue. This residue has a high nitrogen content and can rapidly mineralize and be readily utilized by subsequent crops as residual soil nitrate. In this sense, the scavenged N is given a second chance for crop uptake. Preliminary evaluations of the soil nitrate-N levels indicate that broccoli and the other cole crops are accessing residual soil N from the second and third foot in the soil. This project help us to better understand that it is important to take into account residual soil N in the 2nd and 3rd foot in the soil to better understand the fertilizer needs of broccoli, as well as cauliflower and cabbage.

ACKNOWLEDGEMENTS

The California Fertilizer Research and Education Program

Overview of FREP project Assessment of Baseline Nitrous Oxide Emissions on Response to a Range of Nitrogen Fertilizer Application Rates in Corn Systems | Stockton, 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.

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

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

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 a Nutrient Budget Approach to Fertilizer Management in Almond • **Patrick Brown, 10-0039** • **Fruit, Nut, & Vine Crops**

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

Relationship of Soil K Fixation and Other Soil Properties to Fertilizer K Requirement • **G. Stuart Pettygrove, 10-0012** • **Educational & Miscellaneous**

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**

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