

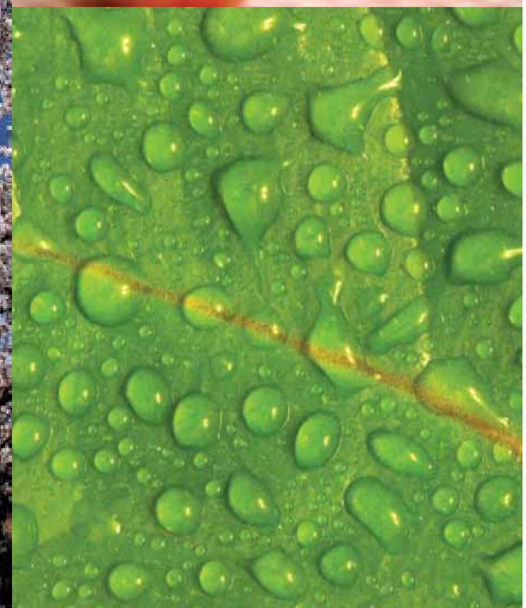

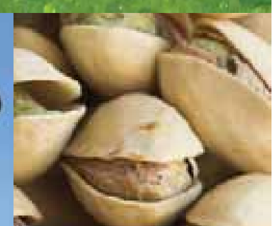

15TH

FIFTEENTH ANNUAL

FERTILIZER RESEARCH & EDUCATION PROGRAM CONFERENCE

PROCEEDINGS

NOVEMBER 27–28, 2007
TULARE, CALIFORNIA

FREP

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CALIFORNIA DEPARTMENT OF FOOD & AGRICULTURE

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TABLE OF CONTENTS

INTRODUCTION

FERTILIZER RESEARCH AND EDUCATION PROGRAM

For 14 years, the California Department of Food and Agriculture's (CDFA) Fertilizer Research and Education Program (FREP) has presented its pioneering fertilizer research at annual conferences. Agricultural consultants and advisers, and governmental agency and university personnel have benefited from the findings, and in turn have passed them on to growers when and where applicable.

FREP's commitment to outreach and education continues. We constantly seek new ways to render research results and recommendations more useful and accessible to an even broader audience of agricultural professionals.

So for this year's conference, FREP has taken a different tack. We teamed up with the Western Plant Health Association (WPHA). Together, we explored a new conference concept, looking through each other's eyes for creative ideas to balance the precise with the practical. We came up with "Fresh Approaches to Fertilizing Techniques" – an event that combines the 15th Annual FREP Conference with WPHA's Central Valley Regional Nutrient Seminar.

Expanded to two days, the conference features a panel of speakers who show how groundbreaking fertilizer research can be integrated into agricultural methods. Presenters provide general and technical information, current research data and practical applications for each of five key agricultural topics:

- Micronutrients
- Foliar fertilizer application
- Water management and fertigation
- Plant nutrient and soil assessment tools
- Manure management

Those who attend the conference will hear the full program of technical and practical application presentations. Contained in this booklet are the technical summaries of findings from FREP projects presented during the conference, plus other ongoing FREP research.

FREP OVERVIEW

The Fertilizer Research and Education Program funds and coordinates research to advance the environmentally safe and agronomically sound use and handling of fertilizer materials. FREP serves a wide variety of agriculturalists: growers; agricultural supply and service professionals; university extension and public agency personnel; consultants, including certified crop advisers (CCAs) and pest control advisers (PCAs); and other interested parties.

FREP was established in 1990 through legislation with support from the fertilizer industry. The California Food and Agricultural Code Section 14611(b) authorized a mill assessment on the sale of fertilizing materials to provide funding for research and education projects that facilitate improved farming practices and reduce environmental effects from the use of fertilizer. The mill assessment generates close to $1 million per year for fertilizer research.

FREP is guided by the Technical Advisory Subcommittee (TASC) of the Fertilizer Inspection Advisory Board (FIAB). This subcommittee includes growers, fertilizer industry professionals, and state government and university scientists.

FREP COMPETITIVE GRANTS PROGRAM

Each year, FREP solicits suggestions for research, demonstration, and education projects related to the use and handling of fertilizer materials. FREP strives for excellence by supporting high quality research and education endeavors that have gone through a rigorous statewide competitive process, including independent peer review. The TASC reviews, selects and recommends to the FIAB funding for FREP research and education projects.

The growing concern of nitrate contamination in ground and surface water from fertilizer use was FREP's initial research focus. In recent years, FREP's research funding has expanded to include agronomic efficiency in the management of nutrients.

Today, FREP's key research area goals include the following:

- Crop nutrient requirements—determining or updating nutrient requirements to improve crop yield or quality in an environmentally sound manner.
- Fertilization practices—developing fertilization practices to improve crop production, fertilizer use efficiency or environmental impact.
- Fertilizer and water interactions—developing and extending information on fertigation methodologies leading to maximum distribution uniformity while minimizing fertilizer losses.
- Site-specific fertilizer technologies—demonstrating and quantifying applications for site-specific crop management technologies and best management practices related to precision agriculture.
- Diagnostic tools for improved fertility/fertilizer recommendations—developing field and laboratory tests for predicting crop nutrient response that can aid in making fertilizer recommendations.
- Nutrient/pest interactions and nutrient/growth regulator interactions—demonstrating or providing practical information to growers and production consultants on nutrient/pest interactions.
- Education and public information—creating and implementing educational activities that will result in adoption of fertilizer management practices and technologies that improve impaired water bodies. Types of activities include:
  - On-farm demonstrations that demonstrate to growers improved profitability reduced risk or increased ease of management.
  - Programs to educate growers, fertilizer dealers, students, teachers, and the general public about the relationships between fertilizers, food, nutrition, and the environment.
  - Preparation of publications, slide sets, videotapes, conferences, field days, and other outreach activities.
- Additional areas that support FREP's mission, such as air quality, tillage, crop rotation, economics of fertilizer use, and cropping systems.

In addition to the above, specific FREP research priorities for 2008 are the following:

- Improving nitrogen and phosphorus efficiency in high production systems with consideration to environmental quality.
- Determining nutrient requirements for high-value specialty crops or emerging new crops in highly environmentally sensitive areas.
- Developing best management practices (BMP) for reducing residual soil nitrate.

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

Funding is generally limited to $50,000 per year for up to three years; however, large, multi-disciplinary projects may be considered at higher funding levels.

Figures 1–3: FREP Project Funding

These figures illustrate the variety of geographical regions, disciplines, and commodities covered by FREP projects during the past 17 years.

Figure 1

CDFA FREP Projects by Location: 1990–2007

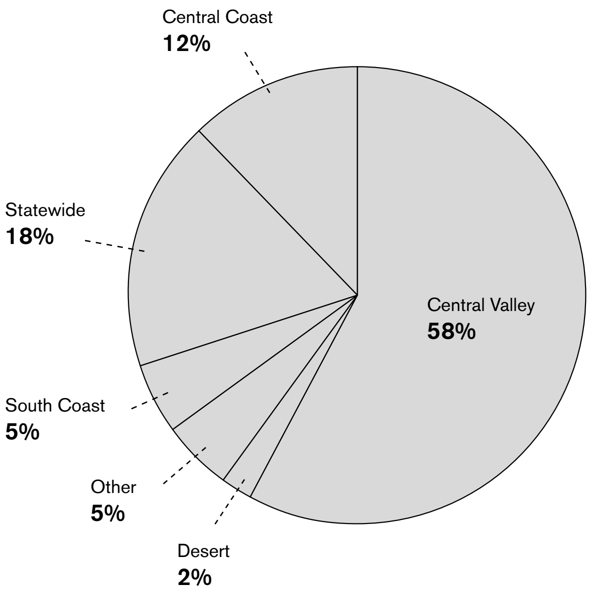


Figure 2

CDFA FREP Projects by Discipline: 1990–2007

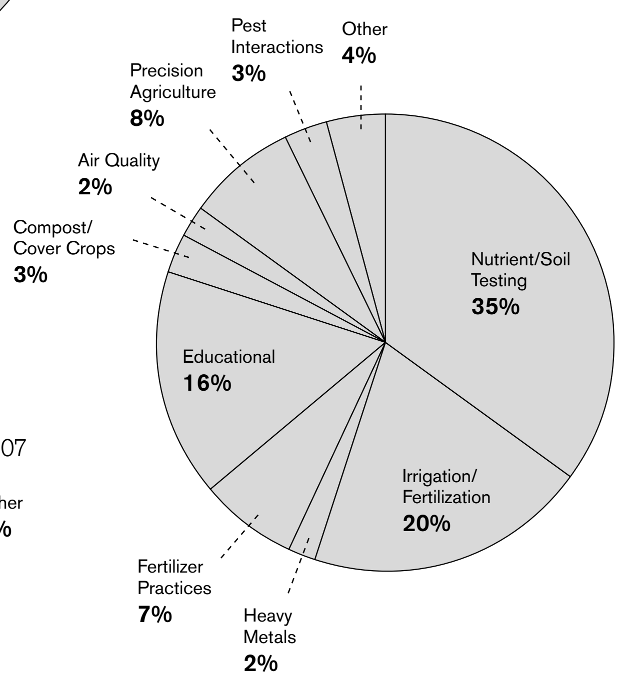
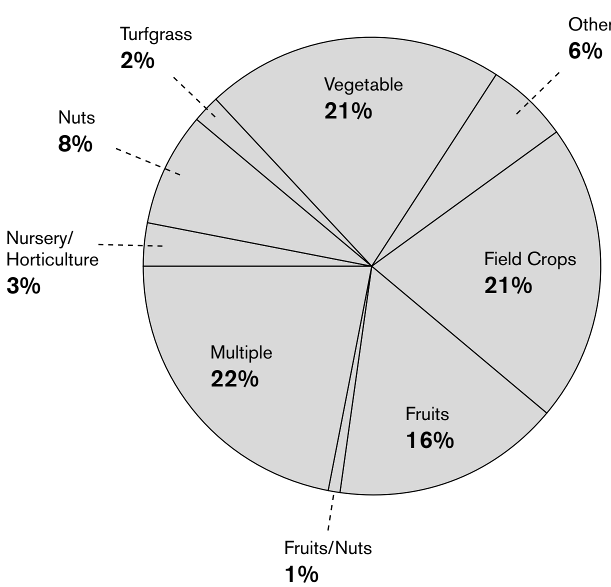


Figure 3

CDFA FREP Projects by Commodity: 1990–2007



FREP EDUCATION AND OUTREACH

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.

This is reflected in significant support (16%) to relevant education and outreach projects (Figure 2). FREP has also funded a number of projects designed to increase the agricultural literacy of students in K-12.

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 by contacting the FREP office.

In today's world of limited budgets, we know we must work with others to achieve our objectives. To that end, FREP staff collaborates and coordinates with other organizations that have similar goals. Our partners include:

Western Plant Health Association

California Chapter of the American Society of Agronomy

California Certified Crop Adviser Program

University of California Cooperative Extension Program

University of California, Sustainable Agriculture Research and Education Program

State Water Resources Control Board, Interagency Coordinating Committee

Monterey County Water Resources Agency

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.

ACKNOWLEDGMENTS

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 also 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 Tom Beardsley, Michael Cahn, Bob Fry, Tom Gerecke, David McEuen, Rob Mikkelsen, Jerome Pier, Al Vargas and Jack Wackerman have given FREP its drive and direction to ensure the program achieves its goals.

We especially thank the Western Plant Health Association as a valued partner in this year's conference. Renee Pinel and Pam Emery's perspective, input and support have given FREP new eyes and new ideas for greater outreach potential of FREP research findings.

Others deserving mention are the project leaders and cooperators, as well as numerous professionals who peer review project proposals and thus enhance the quality of FREP's work.

Special recognition also goes to the leadership at the California Department of Food and Agriculture, including Nate Dechoretz, Inspection Services Division Director; Asif Maan, Feed, Fertilizer, Livestock Drugs and Egg Regulatory Services (FFLDERS) Branch Chief; and Kent Kitade, FFLDERS Program Supervisor. Kelsey Olson and Carolee Riley are credited for their invaluable role in the publication of this proceedings booklet and coordination of this year's conference. Additional help from Avnee Jivabhai and the branch's support staff is also greatly appreciated.

CONFERENCE PROGRAM

NOVEMBER 27, 2007

8:30–9:00 Registration and continental breakfast

9:00–9:15 Welcome
Nate Dechoretz, Director, Inspection Services Division, CDFA
Renee Pinel, President/CEO, Western Plant Health Association

MICRONUTRIENTS—Not Such a Minor Story

9:15–10:00 Principles and Uses of Micronutrients in Tree Crops
Patrick Brown, University of California, Davis

10:00–10:30 Micronutrient Interactions—Do's and Don'ts
Sebastian Braum, Yara North America

10:30–10:45 Break

10:45–11:15 Improving the Efficiency of Zinc Applications to Peaches and Pistachios
R. Scott Johnson, UC Kearny Agricultural Center

11:15–11:45 Identification and Correction of Micronutrient Deficiencies in Nut Crops
Bob Beede, UC Cooperative Extension, Kings Co.

11:45–12:15 Emerging Products—A Look Forward
Rob Mikkelsen, International Plant Nutrition Institute

12:15–1:15 Lunch

FOLIAR FERTILIZER APPLICATION—The View from on Top

1:15–1:45 Foliar Fertilization—Why? What? When?
Carol Lovatt, University of California, Riverside

1:45–2:15 Use of Foliar Applicants
Patrick Brown, University of California, Davis

2:15–2:45 Break

PLANT AND SOIL ASSESSMENT TOOLS—Their Variance and Value

2:45–3:15 Is California's Non-nutritive Standards for Fertilizers Protective?
Andrew Chang, University of California, Riverside

3:15–3:45 Can a Better Tool for Assessing 'Hass' Avocado Tree Nutrient Status be Developed? –A Feasibility Study
Carol Lovatt, University of California, Riverside; Ben A. Faber, UC Cooperative Extension, Ventura County; and Richard Rosecrance, California State University, Chico

3:45–4:15 Value and Limitations of Tissue Analysis as a Fertilizer Management Tool in Annual Crops
Tim Hartz, University of California, Davis

NOVEMBER 28, 2007

8:30–9:00 Registration and continental breakfast

9:00–9:15 Welcome
Nate Dechoretz, Director, Inspection Services Division, CDFA
Renee Pinel, President/CEO, Western Plant Health Association

WATER IN FERTILIZATION MANAGEMENT—New Stream of Consciousness

9:15–9:45 Where Does Our Water Come From?
Brandon Souza, Agricultural Water Management Council

9:45–10:15 Managing Limited Water Supplies on the Farm
Blake Sanden, UC Cooperative Extension, Kern County

10:15–10:30 Break

10:30–11:00 Wireless Valve Control Network for Fertigation Control and Monitoring
Mike Delwiche, University of California, Davis

11:00–11:30 Effect of Cover Crops and Conservation Tillage on Agricultural Runoff and Quality
William Horwath, University of California, Davis

11:30–12:00 Practical Tips on How to Improve Drip Quality and Micro-irrigation
Larry Schwankl, UC Kearney Agricultural Center

12:00–1:00 **Lunch**

1:00–1:15 California Certified Crop Advisers—Delivering a Total Approach to Crop and Environmental Management through IPM and Nutrient, Soil, Crop and Water Management
Allan Romander, California Certified Crop Adviser Program

MANURE MANAGEMENT—The Latest Scoop

1:15–1:45 Organic Product Regulatory Update
Renee Pinel, President/CEO, Western Plant Health Association

1:45–2:15 Manure—The Facts!
Bob Fry, Natural Resources Conservation Service, USDA

2:15–2:30 Break

2:30–3:00 Constructing Monitor Wells on Dairies
Thomas Harter, University of California, Davis

3:00–3:30 Manure and Regulations Piled Higher and Deeper—How Can CCAs Help California's Dairy Producers?
Stuart Pettygrove, University of California, Davis

12

SUMMARIES OF PRESENTED FREP RESEARCH PROJECTS

EXPLORING AGROTECHNICAL AND GENETIC APPROACHES TO INCREASE THE EFFICIENCY OF ZINC RECOVERY IN PEACH AND PISTACHIO ORCHARDS

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INTRODUCTION

Zinc (Zn) deficiency is a serious problem in the San Joaquin Valley. The symptoms on peach and pistachio trees, particularly young vigorous trees, are commonly seen. As a result, it has become fairly routine for growers to apply Zn (usually foliarly) every year to their orchards. Often very high rates are used, but only a small percent of that applied is taken up by the tree. Thus, Zn can slowly build up in the soil over time and has the potential of becoming a contaminant. Therefore, there is a need to improve fertilization techniques by increasing Zn uptake efficiency.

Multiple approaches are proposed to increase the efficiency of fertilizer zinc recovery following both soil and foliar applications. The first approach is to modify soil pH in small areas of the root system to increase soil zinc availability. A second approach is to use cover crops efficient at mobilizing soil Zn, thus making it more available to the trees. The third approach rests upon preliminary data suggesting that other Prunus rootstocks may be more efficient soil zinc scavengers than "Nemaguard", the rootstock currently in use for most peach and nectarine orchards. Finally, we will use labeled zinc (68Zn) with both greenhouse seedlings and field trees to study the efficiency of zinc uptake and its distribution throughout the tree from foliar applications. The effects of rate, formulation, additives and timing will all be investigated.

OBJECTIVES

1. Assess the feasibility of alternative zinc application methodologies to increase the efficiency of zinc recovery by using soil applications to acidify and stimulate root proliferation in a limited portion of the soil volume.
2. Evaluate the potential of using zinc efficient cover crops to mobilize soil zinc and make it more available to tree roots.
3. Evaluate an experimental peach rootstock that appears to have greater capacity for zinc uptake from soil than rootstocks currently in commercial usage.

4 Compare the efficiency of zinc uptake into the woody tissues of peach trees before, during and after leaf abscission in the fall.

5 Evaluate the distribution of zinc throughout young peach trees (especially to the roots) from a fall foliar application.

RESULTS AND DISCUSSION

2007 is the final year of this three year project. Dozens of individual experiments have been conducted and some are still underway. The original five objectives of this study have been addressed and conclusions drawn. In pursuing the objectives, other related questions arose and we designed experiments to address those questions as well. Some of these experiments will likely continue for several more years. Below is a brief summary of each set of experiments associated with the five original objectives.

Soil Acidification (Objective 1)

Acidifying the soil in an 18" deep hole next to a mature peach tree increased leaf manganese, iron and copper but not zinc. Leaf Zn concentration was only increased by adding a pound of zinc sulfate to the hole (see 2006 report). Such an approach would not provide an economical method for correcting zinc deficiency. We have concentrated instead on an approach with newly planted trees—adding a "root bag" to the planting hole. Zinc deficiency is quite a common problem in the first few years of vigorously growing peach trees.

In 2005, we added root bags containing 100g urea, 100g sulfur and 0, 10 or 50g zinc sulfate to newly planted peach trees at the UC Kearney Agricultural Center. Each bag was wrapped with cheesecloth for easy handling. The highest rate of zinc sulfate increased summer leaf Zn levels and both rates increased dormant shoot Zn (see 2006 report). However, the trees were quite weak and these treatments did not increase growth compared to the untreated control. Our next step was to apply the technique to vigorously growing commercial plantings.

In 2006, we added root bags to two commercial orchards at the time of planting. Both orchards were well managed and grew vigorously. The treatments had no effect on growth through two seasons. In one orchard, the root bags slightly increased leaf Zn in both 2006 and 2007. In the other orchard, where some Zn deficiency symptoms were observed and leaf Zn levels were below the deficiency threshold of 15 ppm, no improvement in leaf Zn was measured (Table 1). Although this technique shows promise, we have concluded it is inadequate for correcting Zn deficiency in young peach trees.

Companion Crops (Objective 2)

Barley and other graminaceous species release molecules called phytosiderophores from their roots that help extract Zn and Fe from the soil. When another crop is planted with the barley, its Zn and Fe uptake can also be improved if its roots are in close proximity to the barley roots. We tried this approach by planting winter barley in the rows next

	TREATMENT		
SITE 1	**CONTROL**	**ROOT BAG** (150g Zn Sulfate)	
7/06 Leaf Zn (ppm)	**20.1 b***	**24.3 a**	
7/07 Leaf Zn (ppm)	**18.6 b**	**21.6 a**	
1/07 Trunk circ (cm)	**16.3 a**	**15.1 a**	
SITE 2	**CONTROL**	**ROOT BAG** (50g Zn Sulfate)	**ROOT BAG** (150g Zn Sulfate)
7/07 Leaf Zn (ppm)	**11.6 a**	**12.0 a**	**11.4 a**
1/07 Tunk circ (cm)	**13.1 a**	**14.3 a**	**13.7 a**

Table 1
The effect of adding root bags to the planting hole of newly planted peach trees. Each bag contained 150g sulfur, 150g urea and 50 or 150g zinc sulfate. Trees were planted in the early spring of 2006.

* Values in rows followed by different letters are significantly different from each other at p = 0.05.

to some three-year-old peach trees, but could not measure any increase in leaf Zn. We felt it was probably because the roots of the two species were not close enough together. In the fall of 2005 we planted barley directly under some Springcrest peach trees that were showing minor Zn deficiency symptoms. Spring and summer leaf samples and dormant shoot samples were taken and analyzed for Zn. None of these samples showed an increased in Zn content where Nemaguard was used as the rootstock (Table 2). Another rootstock did respond and will be discussed in the next section. We have concluded that using barley as a companion crop is not a viable approach to correcting Zn deficiency in peach trees on Nemaguard rootstock.

Rootstocks (Objective 3)

Rootstocks clearly differ in their ability to extract nutrients from the soil. Nemaguard is notoriously poor at taking up zinc, thus leading to the deficiency problems this project has attempted to address. Other rootstocks, such as Hiawatha, have shown substantially greater zinc uptake (see 2005 FREP report). In 2007 we demonstrated that the zinc levels in trees on another rootstock could be manipulated to a much greater extent than on Nemaguard. In the barley experiment described above, we tested the concept on two recently patented rootstocks, Controller 5 and Controller 9, as well as Nemaguard. Controller 5 showed a substantial increase in dormant shoot Zn levels when barley was planted as a companion crop (Table 2). The other two rootstocks showed no response. In another experiment with these same three rootstocks we tried to increase tree Zn levels with two applications of zinc sulfate to the soil through a low volume irrigation system. Once again, Controller 5 responded to the fertilization treatment while the other two rootstocks did not (Table 2).

Looking at all our experiments which have attempted to manipulate root uptake of Zn, we have been unable to find an economically viable approach to correcting Zn deficiency with Nemaguard as the rootstock. The long-term solution to this problem is to develop new rootstocks which have a much greater ability to take up zinc from the soil.

Foliar Studies (Objectives 4 and 5)

Our emphasis in 2007 was on foliar Zn applications. We have conducted over a dozen experiments, most of them involving 68Zn labeled zinc sulfate and zinc oxide materials. Many of these experiments were conducted in a greenhouse where we have developed a protocol using small peach seedlings. Space does not allow a full description of each experiment, but our major conclusions to date are summarized below:

1. So far we have found the period of greatest zinc uptake to be in early fall. Young trees in the field were able to take up between 7% and 8% of the 68Zn in a labeled zinc sulfate solution painted on the leaves in mid September. About half of the zinc taken up moved into the roots during the dormant season. The rate was equivalent to about 2 lbs zinc sulfate (36% Zn) per 100 gals water. Our largest uptake rate with seedlings in the greenhouse has been about 3%. One experiment conducted on dormant shoots showed less than 5% uptake of Zn. Thus, our current conclusion is that the most efficient time for applying zinc is in the fall. Not only is there greater uptake, but there is also a larger target than the dormant (no leaves) or spring (less leaves) periods and growers are generally less concerned about phytotoxicity. We currently have a couple of experiments in progress to determine the best timing (early vs. late fall) and rate (1 to 15 lbs zinc sulfate/100 gals) for this practice.
2. Zinc is taken up much more efficiently from a zinc sulfate solution than from a zinc oxide suspension. In one experiment, solutions (or suspensions) of these two zinc sources were painted on dormant shoots of grafted nursery trees growing in pots in the greenhouse. Zinc oxide is very insoluble and residue was clearly visible on and around the buds. To try and get some of this into solution, rain was simulated by lightly misting the shoots on five separate occasions. Even under these conditions, only 0.1% of the applied zinc oxide was detected in the new growth. By contrast, fifteen times more zinc was supplied by the zinc sulfate solution (1.5% uptake). We are continuing to research zinc oxide since field studies have shown it is able to correct zinc deficiency in many plants. Perhaps, it slowly supplies zinc over a long period of time or may need certain additives or environmental conditions to work most effectively.

3 Besides the zinc oxide and zinc sulfate experiment mentioned above, we have also tested other formulations including chelates, amino acid and fulvic acid complexes, lignosulfonates and nitrates. Unfortunately, since we have not had materials with the 68Zn label, we have not been able to show statistical differences among the various formulations. We have talked with several zinc fertilizer companies and plans are currently underway to incorporate the 68Zn label into some of their products. This will give us a much more powerful tool to compare the uptake efficiencies of different zinc fertilizers.

4 This project also includes pistachios and several experiments have been initiated. The one completed experiment has demonstrated that zinc does not move within a pistachio tree as well as it does in peach. In young grafted trees that were actively growing, the zinc moved into nearby older leaves but not readily into the growing shoot tip or roots. Compared to peach, the total uptake was about the same but distribution throughout the plant was quite different. In our peach experiments, we have always shown significant movement into shoot tips and often into roots. Thus it will probably be more of a challenge to effectively supply zinc to pistachio trees. We are currently developing a seedling protocol similar to the greenhouse peach system that has worked so well. We have also treated some young trees with fall foliar applications of zinc sulfate to see if zinc moves out of senescing leaves and into roots as we have demonstrated with peach.

5 The scientific literature reports beneficial effects of adding certain surfactants and other additives to foliar nutrient sprays. We have experimented with several that have looked particularly promising. Specifically, there are some silicone-based surfactants that greatly reduce surface tension of the solution. Some scientists have hypothesized this could allow the solution to enter stomates directly. Another material called lecithin has been reported to separate cuticle platelets on the surface of leaves and thus allow more nutrients to penetrate inside. Finally, urea has been reported to increase uptake of zinc and other heavy metals by directly penetrating the cuticle and carrying nutrients along. We have conducted a series of experiments to test these materials under a range of conditions. To date, we have not measured a benefit from any of these surfactants in either peach or pistachio. We still have a few more ideas to test before drawing final conclusions.

6 By conducting a study of zinc sulfate rates on peach seedlings, we have determined the most efficient rate to be about 400 ppm Zn. Both

	TREATMENT	
ROOTSTOCK	**CONTROL**	**BARLEY**
Nemaguard	**19.3 a***	**22.4 a**
Controller 5	**29.4 b**	**42.8 a**
Controller 9	**26.1 a**	**22.8 a**
ROOTSTOCK	**CONTROL**	**Zn SULFATE FERTIGATION**
Nemaguard	**21.8 a**	**24.3 a**
Controller 5	**33.5 b**	**45.0 a**
Controller 9	**22.3 a**	**26.5 a**

Table 2
The effect on dormant shoot Zn of planting barley under trees or adding zinc sulfate (25 lbs/acre) to the irrigation water of peach trees on three different rootstocks. Springcrest was the variety for the barley experiment and O'Henry for the fertigation trial.

* Values in rows followed by different letters are significantly different from each other at $p = 0.05$.

lower and higher rates showed a lower percent uptake. This is equivalent to a field rate of about 1 lb zinc sulfate per 100 gals, considerably less than the rate typically applied in the fall to peach trees. We are currently repeating this rate trial on potted trees growing outside with leaves nearing senescence. This information will help us revise recommendations for fall applications and hopefully improve the efficiency of this common practice.

CONCLUSION

We have explored many different approaches of increasing the efficiency of zinc applications to fruit and nut trees. In general, our attempts at improving soil uptake of Zn have not been very successful, particularly with Nemaguard as the rootstock. Some new experimental rootstocks are much better at extracting Zn from the soil and could provide a long-term solution to zinc deficiency in peach trees. Results from our experiments with foliar applications of 68Zn have been very encouraging. We have made significant progress towards identifying the most efficient rate and timing for zinc sulfate sprays, and determining whether additives can help. We are currently developing plans to incorporate the 68Zn label into other formulations so similar experiments can be conducted.

DEVELOPMENT OF A MODEL SYSTEM FOR TESTING FOLIAR FERTILIZERS, ADJUVANTS AND GROWTH STIMULANTS

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INTRODUCTION

Foliar fertilization and the application of foliar stimulants, adjuvants and other non-pesticide materials (foliar chemicals) have become a central practice of many agricultural producers. Our understanding of these products is, however, remarkably poor and for the majority of foliar fertilizers used in California agriculture there is very little information on nutrient uptake, nutrient use efficiency, nutrient transport or the application conditions that optimize efficiency and return on investment.

Foliar chemicals are used for a number of reasons; some have a clear physiological and production rationale while others are of doubtful utility. Valid reasons for the use of foliars include the correction of low nutrient availability in soils (e.g., Fe deficiency in high pH soils), overcoming excessive nutrient demand during fruit growth, reduced nutrient uptake during reproduction, targeted fruit quality enhancement and the need to ensure time-critical delivery of nutrients to specific tissues (B to flowers and fruit, Ca to fruit). In Pistachio, foliar sprays are common and used for any number of purported benefits from correction of deficiencies to "optimization" of plant growth and reduction of alternate bearing (though real evidence for this effect is lacking). Unfortunately, there are also many products on the market that have very little clear physiological rationale and limited research support.

Determination of the relative nutritional effectiveness and physiological impact of the wide variety of foliar nutrient formulations available in the market for field and horticultural crops is an experimentally complex, time consuming and inexact science. For many growers, farm advisors, consultants and sales persons making recommendations on the use of the plethora of available foliar materials represents a tremendous challenge. Additionally, for companies that have produced quality, effective products, there is great difficulty in separating their product from those that are less effective.

Current approaches to determining the effectiveness of a particular nutrient formulation are crude and time consuming and do not easily allow for the determination of the biological or environmental factors that determine formulation effectiveness. Studies such as this are typically conducted in the field with the incumbent limitations on environmental control, replicability and reproducibility. Given the very significant degree of uncontrolled variability in field experimentation it is often very difficult to determine the true effectiveness of a product and misleading results can easily be obtained. Field experimentation rarely provides adequately robust information to truly determine the physiological basis underlying a superior material or approach, without this information, results of experiments cannot serve as good predictors of the effectiveness of an approach under different field conditions.

Our goal is to develop a quick and easy system for testing foliar chemicals and to use that system to determine the most effective commercially available products.

PROJECT OBJECTIVES

1. Develop a model system for testing the efficacy of a broad range of foliar materials.
2. Conduct tests of materials of greatest relevance to growers under standardized and manipulated environmental conditions.
3. Identify materials of greatest efficacy and define application conditions for optimal efficiency.
4. Conduct developmental research to develop targeted formulations.

PROJECT DESCRIPTION

A model system has been developed that allows for rapid replication, careful environmental control, precise foliar nutrient applications and intelligent sampling protocols to determine true nutrient use efficiency. The test-plant system (Arabidopsis) has a short 45-60 day life cycle (cultivar dependent) and a very distinct vegetative/floral transition period. Plants were grown in a controlled environment growth chamber in a system that prevents the inadvertent contact of foliar fertilizers with soil. The rapid growth of the test plant allows us to determine both the degree of uptake and the movement of the foliar chemical within the plant. With this system established we have now commenced a series of investigations of many commonly used foliar products.

RESULTS AND CONCLUSIONS

Five separate experiments have been completed to verify the efficacy of a range of common Zn foliar fertilizer products. Mixtures of commercial and single salt products were tested. The following results are preliminary and as such trade materials names have been removed and replaced with generic terms. All materials were applied at the same rate of applied Zn; as costs of materials and application rates vary with all of these materials, no implication of economic efficiency is included here. Due to subtle differences in application techniques and experimental duration, a comparison of absolute numerical values between experiments is not appropriate. Here we have contrasted replicate experiments using a relative ranking that represents the degree to which the material differed from the control treatment within the same experiment. Treatments with different rankings within a single experiment differ significantly ($p>0.05$).

While not all materials were replicated in all trials it is clear from Table 1 that there is a remarkable consistency in materials ranking between replicate experiments. Formulations differ in their efficacy from highly effective to no difference from the non-treated control.

Following the completion of the Zinc experiments, trials of K and Ca will be commenced.

	RANKED EFFICACY			
Experiment	4	3	2	1
No applied Zn	1	1	1	1
Zn-Oxide	1	1		
Zn-Phosphate	2			
Zn-Oxide	2			
Neutral Zn			2	1
Zn Nitrate (A)	3	2		
Zn Organic (A)			3	1
Zn Sulfate	2	2	4	2
Zn Organic (B)		2	4	3
Zn Bio-org (A)	3	4		
Zn Bio-org (B)	4	4		
Zn Bio-org (C)	4	4		
Zn Bio-org (D)	4	4		
Zn Bio-org (E)	3	5		
Zn Nitrate/Urea	4	4		
Zn Bio-org (F)	4	5	5	3
Zn Chelate		5	5	4

Treatments with different rankings within a single experiment differ significantly ($p>0.05$).

Results of these first trials suggest the system provides highly reproducible results that can effectively determine relative efficacy of different materials. We believe that the plants and system used here may result in greater degrees of movement than would occur in hard-leaved species such as Almond and Pistachio; thus, these results may overemphasize the relative efficacy of the better products.

IS CALIFORNIA'S NON-NUTRITIVE STANDARDS FOR FERTILIZERS PROTECTIVE?

22

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INTRODUCTION

California Code of Regulations, Title 3-Plant Industry, Article 1-Standards and Labeling, Section 2302-Non-Nutritive Standards regulates the contents of potentially harmful As, Cd, and Pb of fertilizers and micronutrient supplements sold in California. It stipulates that

> For each percent available phosphate (P2O5), the fertilizing material shall not exceed the following concentrations of non-nutrient metals: Arsenic, 2 ppm; Cadmium, 4 ppm; Lead, 20 ppm.

Similar rules apply to the micronutrient supplements.

The numerical limits in the promulgated rules were based on outcomes of a risk-based assessment on potential human health of As, Cd, and Pb due their presence in these materials (1998). In the process, assumptions were made as to the background concentrations in the soils and the parameters in projecting over time losses through surface runoff and plant uptake of the As, Cd, Pb in receiving soils. Is California's non-nutritive standards for fertilizers protective? A lack of comprehensive and realistic field-based data casts doubts on the appropriateness of the regulation.

PROJECT OBJECTIVES

1. Assess the appropriateness of the soil-solution partition coefficients, K_d, that were used in the CDFA risk-based study to estimate the As, Cd, and Pb losses through surface runoff and leaching and the plant uptake factors *(PUF)* that were used in the CDFA's risk-based study on the plant accumulation of As, Cd, and Pb by food plants grown in California cropland soils through examinations of existing data, laboratory experiments, and field testing.
2. Address the appropriateness of the non-nutrition rules in California's fertilizer regulations, based on the assessment.

PROJECT DESCRIPTION AND RESULTS

During the course of the study, a series of laboratory experiments, computer-based modeling, and field investigations were conducted. More than 1,200 soil samples were collected at the identified locations of 50 California benchmark soils and in seven major vegetable production regions across California and analyzed for total concentrations of As, Cd, Pb, P, and Zn in which the P and Zn contents of the soils were indicators of P fertilizers and micronutrients inputs, respectively.

In selected locations, plant tissue samples were also collected at the time of soil sampling. These paired samples were used to establish distribution coefficient that is the ratio of total elemental concentration in soil vs. elemental concentration in corresponding soil solution (i.e., $K_d = C_{solution}$ (mg l-1)/C_{total} (mg kg-1) and the *PUF* that is the ratio of elemental concentration of plant tissue vs. the total elemental concentration of the corresponding soil or soil solution (i.e., $PUC_{total} = C_{plant}$ (mg kg-1)/C_{total} (mg kg-1) or $PUC = C_{plant}$ (mg kg-1)/$C_{solution}$ (mg kg-1)). The California portion of the USDA Soil Survey trace element dataset for soils and plant tissues was used to verify the outcomes from the data described above (Holmgren et al., 1993). PC-based mathematical models were developed. Laboratory and field experiments were conducted to calibrate the processes included in the modeling. Simulations were conducted to project the long term accumulation of As and Cd in California cropland soils under various fertilizer quality and management scenarios.

Under the field growing conditions, the K_d and *PUF* for any food crop did not appear to be constant with respect to the element, plant species, or soils of concern. Instead, the field obtained values for these two parameters followed the lognormal distributions and the range of the distributions appeared to be rather wide. The K_d and PUF_{total} employed for the CDFA risk-based study of As, Cd, and Pb uptake by food plants were similar in magnitudes, covered roughly the same ranges, and followed the lognormal distributions as those data we obtained independently from the field samplings. Since this is the case, we expect the outcomes of CDFA's risk-based assessment on the maximum tolerable threshold for As, Cd, and Pb in the fertilizers to be comparable to the outcomes if the K_d and *PUF* were obtained based on the conditions of production fields in California. We conclude that the K_d and *PUF* used in the previous referenced study were appropriate.

CONCLUSIONS

1 The soil to solution partitioning coefficient, K_d, is an important parameter in assessing the environmental and health risks of potentially toxic metals in cropland soils. We examined the K_d, for As, Cd, and Pb in P fertilizers and cropland soils in the laboratory based on the conventional extraction of 1:10 soil to water ratio (w/v). In soils treated with P fertilizer and micronutrients, solution/solid phase partition of As, Cd, and Pb were comparable to those indigenous of the soils unless the amounts added became excessive.

2 Ideally, K_d, the ratio of the total (C_{total}) and solution concentrations ($C_{solution}$) of trace element in soil, is determined under the field moisture conditions. In reality, the soil solution concentration is represented by the concentration in extracts of a given soil to water ratio. We used cadmium as an example to demonstrate the uncertainties in determining the soil solution Cd concentrations, thus the K_d because the soil solution concentration varied with the soil to water ratio. Results of extraction experiments showed that extracting the soils at the soil to water ratio of 1: 1 (w/v) was most representative of the field moisture contents and provided the most consistent results. Under this circumstance, the Cd concentration in soil solution tends to be probabilistic and follows a normal distribution. The probability density functions for K_d were established. If K_d is characterized in probabilistic terms, the risks of environmental and health harms of trace elements in the soils may be more appropriately assessed.

3 We assessed the K_d and *PUF* based on soil and plant tissue samples obtained from croplands in California. Under the growing conditions of production fields, the K_d and *PUF* for any food crops did not appear to be constant with respect to the element, plant species, or soils confirming the laboratory findings. Instead, the field obtained values of these two parameters followed generally the lognormal distributions and the range of the distributions appeared to be rather wide. The K_d and *PUF* employed for the CDFA's risk-based study of As, Cd, and Pb uptake by plants were similar in magnitudes, covered roughly the same ranges, and followed the lognormal distributions as those we obtained from the field samples. Since this is the case, we expect the outcomes of the risk-based assessment on the maximum tolerable thresholds for As, Cd, and Pb in the fertilizers and micronutrients to be comparable to the

outcomes if K_d and *PUF* were obtained from data representing the conditions of production fields in California.

4 In soils, As, Cd, Pb in solution phase may be surface adsorbed or immobilized and precipitated into mineral phases and vice versa. These processes take place simultaneously and for K_d, they must be considered at the same time. We described the reaction kinetics by a two-site model combining linear instantaneous model for the surface adsorption and first order reaction kinetic model with forward and backward reaction constants for the immobilization and precipitation of the mineral phase. We developed the mathematical models and used the batch Cd adsorption experiments with two California soils to test the validity of the model. The method allowed us to distinguish the trace elements that are surface adsorbed and precipitated and determine the K_d and the precipitation and dissolution constants simultaneously.

5 A more reasonable approach to assess the impacts of trace element inputs on cropland soils is through the mass balance of trace elements in the soil profile. Based on the information obtained in the previous studies, we updated the model parameters of the mass balance model developed in the previous study and used the Monte Carlo simulations to assess CDFA's trace elements thresholds for fertilizers and micronutrients. Under the normal crop practice, applications of P fertilizers meeting California's trace element standards for fertilizers will result in gradual reduction of As and increase of Cd in the receiving soils over 100 years of continuous cultivation. The amounts of changes were considerably smaller than applying P fertilizers meeting the trace element thresholds of the regulations in Oregon and Washington and those recommended by APPFRO. Removal by plant uptake has the greatest impact in the mass balance of trace elements in soils.

6 Based on the outcomes of the model simulation, we designed a field experiment to examine the plant uptake of the trace elements under the growth conditions of field production. In this case Cd uptake by romaine lettuce was used as the example. The soil solution Cd concentrations the soils remain relatively constant throughout the plant-growing season. At a given stage of growth, the rate of Cd uptake by Romaine lettuce plants is related to the soil solution Cd concentrations according to the Michaelis-Menton kinetics model. However, the maximum influx rates J_{max} obtained in this manner would decrease with the length of the growing period. A second order kinetic model by integrating the time factor was developed to simulate the cumulative plant uptake of Cd over the growing season:

$$C_{plant}(t) = C_{Solution}.PUF_{max} \cdot e^{-b \cdot t}$$

where C_{plant} and $C_{solution}$ refer to the Cd content in plant tissue and soil solution, respectively, $.PUF_{max}$ represents the uptake potential at time zero and b is a kinetic constant related to plant growth. The plant uptake factor, *PUF,* which is defined as the ratio of Cd in plant tissue to that in soil solution, follows the similar trend to that of C_{plant}. The data from the field experiment showed that the Cd naturally occurring in the P fertilizers and Cd spiked P fertilizers were different. On a per unit total soil Cd basis, the absorption by Romaine lettuce were much higher for the indigenous Cd than the spiked Cd of the P fertilizers. This mathematical model is general and may be universally applicable to the assessment of uptake by other plant species or of other trace elements.

We improved the trace element model by coupling the trace element mass balance with the water flow algorithms of HYDRUS-1D to account for trace element distributions in the soil profiles. In the modified model, the simulated soil profile is discretized into a number of uniform adjoining sections. In each section, the same scheme as defined in the previous model was adopted. The external inputs are sorted into three categories. Inputs from atmospheric deposition and with irrigation water are added to the top element of the soil profile. Discrete sources from fertilizers, micronutrient and waste disposal are added uniformly to the plow layer. The model allows simulating plant root growth and distribution along the soil profile and the solute transport is simulated with the convective-dispersive equation. The model not only allows studying the pools and fluxes of trace element in cropland soils, but also assessing the distribution of trace elements along the soil profile.

CAN A BETTER TOOL FOR ASSESSING 'HASS' AVOCADO TREE NUTRIENT STATUS BE DEVELOPED? – A FEASIBILITY STUDY

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INTRODUCTION

California avocado growers must increase yield, including fruit size, and/or reduce production costs to remain competitive in the US market, which now receives fruit from Mexico, Chile, New Zealand, Australia, South Africa, Peru and other countries. Optimizing the nutrient status of the 'Hass' avocado (*Persea americana* Mill.) is a cost-effective means to increase yield, fruit size and quality, but the California avocado industry has no reliable diagnostic tool relating tree nutrient status with yield parameters. For the 'Hass' avocado of California, experiments for only N, Zn and Fe have been conducted to determine the optimal leaf concentration for maximum yield (Crowley, 1992; Crowley and Smith, 1996; reviewed in Lovatt and Witney, 2001). Alarmingly, leaf N concentration was not related to yield (Lovatt and Witney, 2001). Optimum ranges for nutrients other than N, Zn and Fe used for interpreting leaf analyses for the 'Hass' avocado are borrowed from citrus and, thus, are not related to any avocado yield parameter. Moreover, since optimal ranges for most nutrients are not known, current ranges for N, Zn and Fe are likely inaccurate, since they were determined under conditions where availability of one or more nutrients might have limited yield.

The project's objective is to test the feasibility of using tissues that have frequently proven more sensitive and reliable than leaves to diagnose deficiencies of the 'Hass' avocado sufficiently early that corrective measures would have a positive effect on yield parameters during the current year, not just the following year. Based on results obtained by avocado researchers in Chile, it is highly likely that peduncle and/or inflorescence tissue will meet the criteria essential for an effective diagnostic tool for 'Hass' avocado fertility fertilizer management in California. However, it must be noted that additional research would be required to develop the broader database required to have confidence in the relationship between nutrient concentrations in peduncle and/or inflorescence tissue and yield or fruit size than would be provided by the two data sets that will be obtained in this proposed two-year study. Hence, this is a feasibility study designed to determine whether a better tool for assessing 'Hass' avocado tree nutrient status can be developed.

PROJECT OBJECTIVES

1. Determine the sensitivity of the flower, entire inflorescence, and fruit peduncle to differences in tree nutrient status.
2. Determine if the nutrient concentrations of the tissues above are related to fertilizer rate and to yield parameters.
3. Determine if differences in tissue nutrient concentrations related to yield can be detected sufficiently early to be corrected before they impact yield, fruit size or fruit quality in the current year.

PROJECT DESCRIPTION

Tissues will be collected as follows: entire inflorescence at the cauliflower stage and at full bloom; flowers at full bloom; peduncle of young fruit in June-July (which is before exponential increase in fruit size and June drop of the current crop, start of mature fruit drop and transition from vegetative to reproductive growth); and in November at the end of the fall vegetative flush. Sample collection is repeated the following year. Standard leaf collection will be in September each year. Samples will be collected from 16 individual 'Hass' avocado trees on the diagonal across orchards (with different but known rootstocks) located in Pauma Valley, Irvine, Santa Paula (high N and B site), San Luis Obispo and from trees receiving BMP N vs. BMP NPK and 0.8x N vs. 0.8x NPK in both July and August at a new research site in Carpinteria. Tissue will be analyzed for N, S, P, K, Mg, Ca, Fe, Zn, Mn, B, Cu, and Cl. At harvest, yield (number and kg fruit), fruit size distribution and fruit quality will be determined per tree. The project is a success if one, or more, tissue (a) is sensitive to differences in tree nutrient status, (b) has a nutrient content related to fertilizer rate and yield, fruit size and quality, and (c) reveals nutrient deficiencies sufficiently early that correction will improve yield in the current year.

RESULTS AND CONCLUSIONS

The research was initiated with the start of funding in July 2007. Due to the freeze, orchards that we had planned to use had to be replaced with new ones. The first sampling date was September, the standard time for collecting avocado leaves for analysis. At this time, we also collected fruit peduncles for nutrient analysis for comparison with leaf analyses. Due to the short period of time since the research was initiated, we have no results to report at this time.

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DEVELOPMENT OF PRACTICAL FERTILITY MONITORING TOOLS FOR DRIP-IRRIGATED VEGETABLE PRODUCTION

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INTRODUCTION

The conversion to drip irrigation is revolutionizing the California vegetable industry. At the current rate of conversion, as much as half the acreage of the major fruiting crops will be in under drip irrigation within five years. This has important ramifications for fertility management. The higher yield potential, and the ability to respond to changing nutrient demands, makes more intensive nutrient monitoring in drip culture both useful and economically justifiable.

Optimizing nutrient management with drip irrigation will require both a detailed knowledge of crop nutrient uptake patterns, and the ability to monitor and interpret in-season nutrient status in both soil and crop. Currently, insufficient data is available on crop nutrient uptake by growth stage for these important crops under high yield, drip-irrigated conditions. Nutrient monitoring has historically centered on preplant soil testing, and in-season whole leaf or petiole analysis. With the advent of widespread drip irrigation there is interest in exploring other approaches such as soil solution monitoring or petiole sap analysis (for both macro- and micronutrients). Unfortunately, recent research from around the country has cast doubt on the reliability of these analytical tools as in-season fertigation guides. This project was undertaken to develop accurate nutrient uptake and partitioning data under high yield drip-irrigated conditions, and to provide a critical assessment of a range of crop and soil nutrient monitoring options.

PROJECT OBJECTIVES

1. Develop crop nutrient uptake and partitioning curves for drip-irrigated processing tomato across a range of field sites.
2. Evaluate and calibrate practical soil and plant monitoring tools to guide fertility management.

PROJECT DESCRIPTION

A drip-irrigated processing tomato trial was transplanted May 9 at University of California, Davis (UCD). Four fertility regimes were compared:

1. Low N fertility
2. Low P fertility
3. Adequate N and P fertility ('appropriate' fertility management)
4. Excessive N and P fertility

Each fertility regime was replicated three times; two common processing tomato varieties (AB2 and Heinz 9780) were grown in all plots, in a split plot design. P fertility was manipulated by varying the preplant P application (from 0 to 140 lb P2O5/acre). N fertility was manipulated by varying weekly fertigation amounts; seasonal N application ranged among treatments from 63 - 258 lb N/acre.

Beginning at early flower growth stage the plots were intensively sampled every two weeks for nutrient status, with the following measurements taken:

1 Whole plant macro- and micronutrient content
2 Whole leaf macro- and micronutrient concentration
3 NO3-N, PO4-P and K concentration in petiole sap
4 NO3-N, PO4-P and K concentration in dry petioles
5 NO3-N, PO4-P, and K in plant xylem flow (collected by a pressure apparatus)
6 Soil NO3-N and NH4-N in a composite sample of the 0-15 inch depth in the wetted zone
7 Soil NO3-N, PO4-P and K in soil solution collected in the field from suction lysimeters
8 Soil NO3-N, PO4-P and K in soil solution collected by centrifugation of composite samples of the 0-15 inch depth in the wetted zone

The final sampling was done a week prior to commercial harvest stage, when > 85% of fruit was red.

In addition to the UCD trial, three commercial processing tomato fields in the Sacramento Valley were monitored. In each field three areas were monitored separately for replication. Four times during the season all the fertility measurements previously described were made; the last sampling was done 7-10 days before commercial harvest. Site and management details of all fields monitored are given in Table 1.

RESULTS AND CONCLUSIONS

All fields had high total fruit yield, ranging from 45-59 tons/acre (Table 2). Total N uptake (vine and fruit) was similar in all fields, averaging approximately 220 lb/acre. P and K uptake varied substantially among fields, ranging from 25-34 lb P/acre and 159-319 lb K/acre. Differences in P uptake were due primarily to P fertilizer application (all fields had reasonably low soil test P); differences in K uptake were primarily due to soil factors, since K fertilizer application was minimal in all fields.

Table 1. Site and management details for 2007 fields.

				SOIL FERTILITY (PPM)		SEASONAL FERTILIZER RATE (lb/acre)		
FIELD	**TRANSPLANT DATE**	**VARIETY**	**SOIL TEXTURE**	**OLSEN P**	**EXCHANGE K**	**N**	**P_2O_5**	**K_2O**
UCD	May 9	AB2, H9780	loam	11	220			
Low N						63	70	0
Low P						173	0	0
Adequate fertility						173	70	0
Excessive fertility						258	140	0
1	April 4	H2601	loam	4	114	169	14	24
2	May 1	AB5	clay loam	16	138	181	14	18
3	May 10	AB2	clay loam	11	110	186	90	33

The pattern of nutrient uptake through the season was similar in all fields; data from the UCD trial are illustrated in Figure 1. The majority of seasonal nutrient uptake occurs during the period between early fruit set and the ripening of early fruit (approximately week 5 through week 11). In the final month of the season nutrient uptake rates decline substantially. At UCD, nutrient uptake rates peaked between 4-5 lb N, 0.6-0.8 lb P and 6-7 lb K/day in the 'adequate' fertility treatment. Uptake rates in the "excessive" fertility treatment were only marginally higher; of the extra fertilizer applied in the excessive treatment beyond that applied in the "adequate" treatment, only approximately 40% of the N and 10% of the P was taken up by the plant.

At UCD fruit yield of the varieties responded differently to the nutrient regimes. AB2 showed only a minor loss of yield with low N and P fertilization, while with H9780 yield loss to both low N and low P was substantial (Figure 2). AB2 was apparently more effective at recovering nutrients from the soil than was H9780, as evidenced by N and P uptake in the low fertility treatments being closer to that in the adequately fertilized plots (Figure 3).

Partitioning of nutrients between vine and fruit showed a consistent pattern (Figure 4). In all fields, vine nutrient content peaked at about full bloom growth stage, and declined as fruits developed and ripened. Even in the excessively fertilized treatment at UCD, vine N/P/K content declined substantially as the fruit load developed. Not surprisingly, nutrient concentration in all vegetative tissues declined quickly after fruit bulking began. The rate of this decline varied among fields, particularly with respect to K.

Additional monitoring will be done in 2008, and the value of the various monitoring techniques will be evaluated using the combined data from both years.

Table 2
Crop productivity and nutrient uptake in monitored fields, 2007.

ᶻ mean of AB2 and H9780 varieties, 'adequate,' nutrient regime

	BIOMASS DRY WT	TOTAL FRUIT YIELD	BIOMASS NUTRIENT CONTENT (lb/acre)		
FIELD	**(tons/acre)**	**(tons/acre)**	**N**	**P**	**K**
UCD[z]	**10,100**	**58**	**208**	**34**	**319**
1	**7,150**	**45**	**197**	**25**	**159**
2	**9,530**	**51**	**243**	**27**	**194**
3	**9,670**	**59**	**245**	**34**	**227**

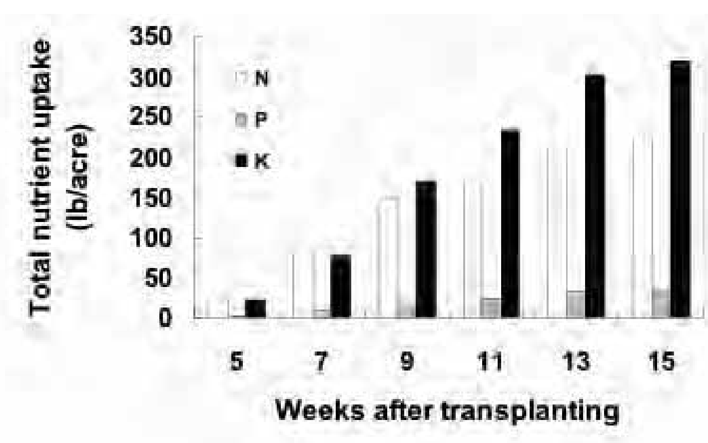

Figure 1
Pattern of nutrient uptake over the growing season; mean of AB2 and H9780 varieties grown at UCD.

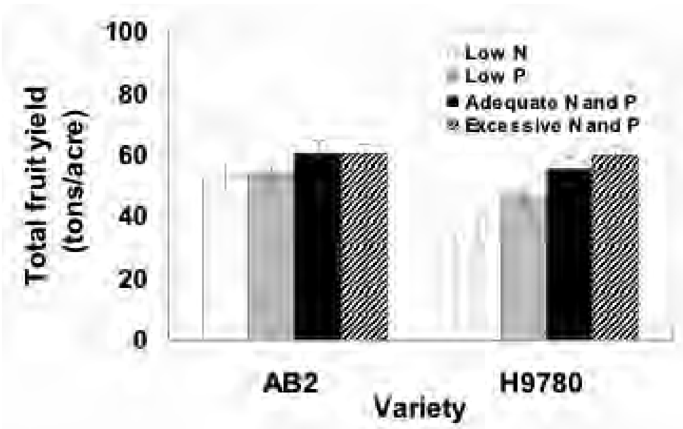

Figure 2
Effect of fertility treatment on total fruit yield, UCD trial.

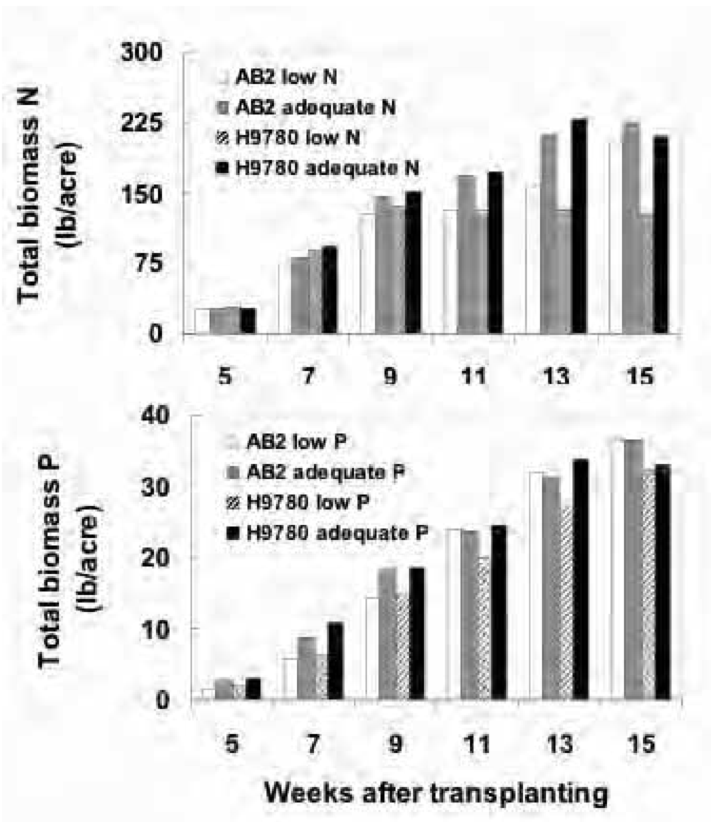

Figure 3
Effect of fertility treatments on N and P uptake in the UCD trial.

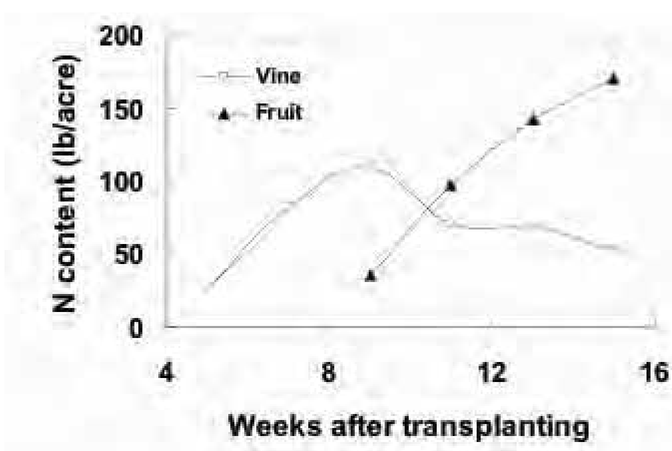

Figure 4
Partitioning of nutrients between vine and fruit, AB2 variety at UCD.

WIRELESS VALVE CONTROL NETWORK FOR FERTIGATION CONTROL AND MONITORING

32

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INTRODUCTION

Precision management of irrigation and fertigation in orchards, nurseries, and landscapes is compromised by traditional sprinkler and drip systems, which are designed for uniform water and nutrient delivery and ignore the reality that demand often varies across fields and between individual plants. To complicate matters, fertigation uniformity may be adversely affected by factors such as flow time through the pipes and emitter clogging. Orchards, nurseries, and landscapes each have unique problems related to water and fertilizer management.

Orchards are high value permanent crops, commonly irrigated and fertigated using drip or microsprinklers. Differences in soil type and topography can affect the rate of infiltration and runoff. Another problem with modern fertigation systems is that growers sometimes inject fertilizer for only a short portion of the irrigation cycle (i.e., 1-2 hr). Recent research has shown that fertilizer may not reach the furthest emitters for as long as 45 minutes, indicating that some trees are not likely receiving enough nutrient. Emitter clogging and irrigation line damage further compound the problem of delivering water and fertilizer. Nurseries deal with continually changing inventory and must comply with environmental regulations limiting runoff and fertilizer leaching. Plants of differing size may be irrigated from the same source, so some will receive too much water and fertilizer while others will receive too little. In landscape operations, irrigation control also is important since a significant amount of California's available water is used for turf grass and ornamentals. Optimizing water delivery can conserve water and prevent fertilizer leaching and runoff.

We began considering these problems by developing a precision microsprinkler system for orchards under a previous FREP research project. Small valves located at each individual tree controlled the delivery of water and fertilizer. Recognizing that power and communication wires in the previously developed systems would likely impede commercial adoption, we initiated development of a wireless network for site-specific management. Wireless communication and solar power will eliminate the use of wires and will improve ease of installation and reduce problems associated with long-range wired communication and damage from animals and machinery. Larger valves will be used to control flow to multiple sprinklers or drip emitters (e.g., laterals) or smaller valves will control flow to individual plants or trees (e.g., each microsprinkler). Individual valve schedules will be different in order to match differing water and fertilizer requirements and can easily be changed to accommodate replants, disease, growth, or seasonal changes. Data from pressure and flow sensors will allow intelligent water and fertilizer control and automatic detection of line breaks and emitter clogging.

PROJECT OBJECTIVES

1. Develop general operating strategies for spatially controllable fertigation to allow application of prescribed amounts of fertilizer at specific locations.
2. Design a wireless valve controller network to simplify the implementation of precision fertigation.

PROJECT DESCRIPTION

Fertigation Control

As valves open and close in a spatially variable irrigation system, water pressure and flow rate will change. A suitable fertilizer injection system will be needed to maintain the proper concentration of dissolved fertilizer. In large fertigation systems we will also need to consider the time it takes for dissolved fertilizer to reach each emitter. When attempting to deliver fertilizer to blocks or emitters at different rates or times, standard operating procedures may not apply.

One possibility for providing spatially variable control is to analyze the hydraulics of the irrigation system and develop an equation to predict flow through each branch of the fertigation lines based on the location of emitters and whether they are on or off. This would require information about the pump, irrigation piping, emitter sizes, etc. Under ideal conditions, equations would be able to determine the location of the fertilizer head and tail at any given time after initiation of fertilizer injection. Since field conditions are never ideal and frequently change, sensors will likely be needed in addition to, or instead of, flow equations. Electrical conductivity (EC) sensors in the irrigation line will detect the fertilizer head and tail as it passes through various points in the irrigation system. This information will be used to adjust fertigation timing at each control valve in real time. Tests are now being planned with the microsprinkler system from our previous project to evaluate one or more of these control methods before integration with the wireless valve control network.

Wireless Design

Since this system is intended for application in orchards, greenhouses, landscapes, and nurseries, the wireless network (Figure 1) must be versatile enough to operate in many environments. Mesh networking will allow messages to pass from one node to any other node in the network by routing it through intermediary nodes. This technique allows increased network range without using high power transceivers. Another advantage is redundancy. A failed node will not disable the entire network since multiple routing paths exist between nodes. The operator will enter schedules on the field controller,

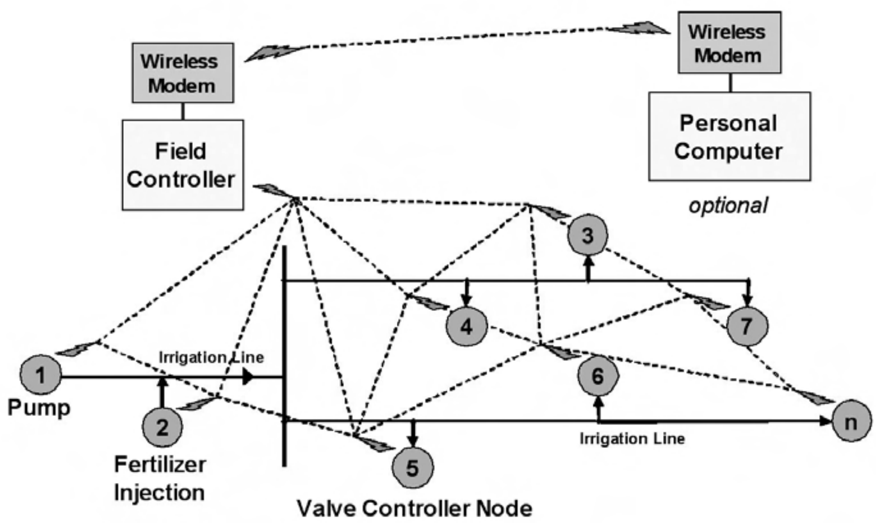

Figure 1
Layout of wireless valve network.

and they will be distributed to the pump controller, injector controller, and valve controller nodes in the network. Sensors that monitor parameters such as soil moisture, temperature, or humidity could also be used for automatic triggering of irrigation and fertigation events. An optional personal computer will provide a graphical interface, but will not be required to operate the system.

The first generation prototype for a wireless microsprinkler was designed using commercially available demonstration boards (Figure 2a) (http://www.microchip.com). The network communication protocol was handled by the company's implementation of the Zigbee wireless networking standard (http://www.zigbee.org). After initial testing, we found that the Zigbee communication protocol did not support the battery-powered routing feature needed for a truly low-power wireless network. In our second generation design, we selected smaller, low-power wireless modules which were designed specifically for battery-powered mesh networking (http://www.moteiv.com) (Figure 2b). Testing of the mesh network showed that sending messages from the field controller to the valve controllers was not as reliable or efficient as expected.

A 900 MHz low-power wireless module (Crossbow Technology, San Jose, CA, USA) was adopted for the third generation design (Figure 3a). These modules were selected because the mesh networking software is robust and the company is interested in developing products for agricultural monitoring and control, thus providing a good opportunity for collaboration and increased likelihood of future commercialization. The wireless module, along with a 7.2 V nickel-cadmium battery, 200 mW (13.4 V, 15 mA) solar panel, and valve switching circuitry, are connected to a prototype circuit board from Crossbow Technology. The components are housed in a clamshell-style polycarbonate enclosure. The valve controllers have been used to operate 1-inch and 1/8-inch latching valves. A field controller contains a keypad to allow entry of schedules and manual operation of the remote valves, and a liquid crystal display (LCD) for viewing status information (Figure 3b).

RESULTS

Wireless Communication

When powered, the valve controller nodes automatically begin the process of forming a mesh network. This network allows messages

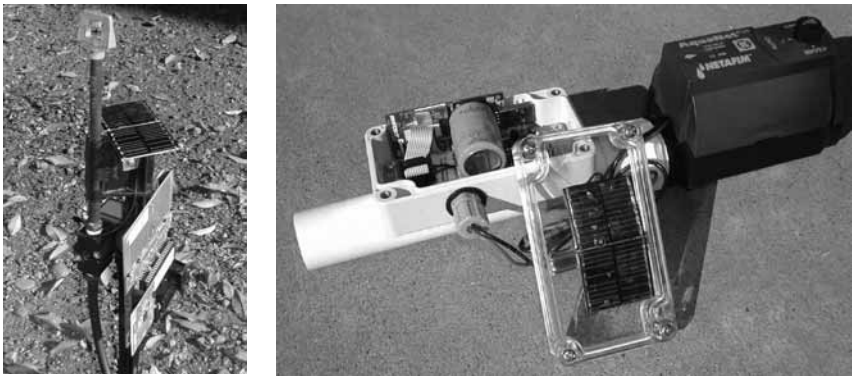

Figure 2 a, b
First and second generation wireless valve controllers.

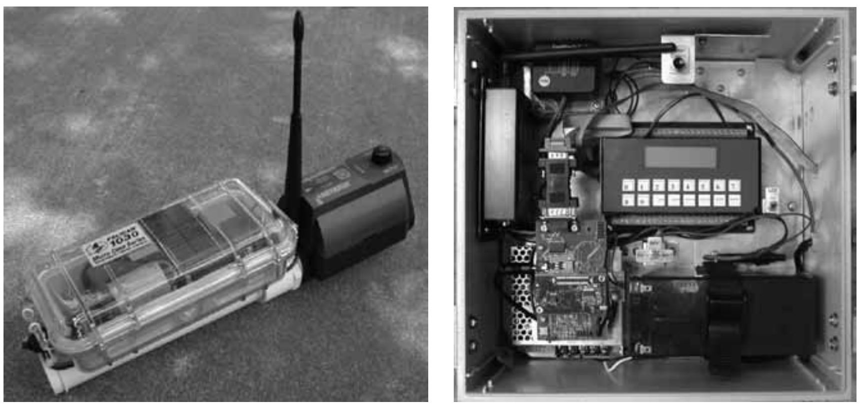

Figure 3 a, b
Third generation wireless valve controller and field controller.

to be passed from node to node in order to improve communication range and reliability. Commands (e.g., open or close valve) entered on the field controller keypad are transmitted to a valve controller with a particular address. The receiving valve controller executes the command provided in the message and then transmits an acknowledgement back to the field controller. Currently, this only acknowledges that the command was executed, but does not confirm, for example, that the valve actually opened properly. This feature will be explored in a later phase of development. In our tests, each node properly opened or closed the connected latching valve using an 80 ms pulse from the battery (2 A peak current).

Maximum one-hop radio range was tested under several different conditions. The wireless nodes were tested with quarter-wave whip antennas (included with the wireless modules) and half-wave dipole antennas. When using the whip antennas, nodes were tested alone and enclosed in the polycarbonate enclosure (requiring the antenna to be bent). The dipole antenna was mounted on the exterior of an enclosure and connected to the wireless module inside. The nodes were tested under visual line-of-sight conditions (VLOS, open field) and obstructed conditions (young peach orchard) with the nodes on the ground or elevated on a non-metallic support above ground level. For each case, two or more tests were completed. The results (Table 1) showed that range varied greatly depending on the node configuration and the test environment. Some test cases were combined if the resulting range was very similar. To obtain satisfactory range in most conditions will require a dipole antenna and mounting of the nodes a half meter or more above ground level.

Energy Management

The valve controller node has a measured radio current of 15 mA and a sleep current of about 80 µA (radio off). To extend battery life, nodes must be in sleep-mode most of the time and only use the radio when data transfer is required. This power-cycling feature is included with the wireless module software. The nodes spend most time in sleep-mode and synchronously wake every 128 ms to listen for radio activity from neighbors. If no activity is detected, the node returns to sleep. If the node were to send or receive radio messages every three minutes, the total battery consumption would be approximately 6.6 mA-h per day. This energy use must be balanced by solar panel energy production in order to ensure perpetual operation of the valve controller. Solar panel performance was tested in full sunlight and full shade conditions. A data logger recorded open-circuit voltage in full sunlight and output current from the panel through a 10 Ω load resistor for 19 days. Peak voltage was 12.7 V and peak current was about 15 mA in full sun and 1.5 mA in shade. Integration of current over time yielded a daily production of 52 to 81 mA-h in full sun and 6 to 10 mA-h in shade. Based on these tests, the solar panel should produce adequate energy for continuous operation.

Solar charging of the Ni-Cd battery was checked using two valve controllers, one with a solar panel and one without. They were placed outside in an open area for nine sunny days and set to transmit data messages every 15 seconds (higher rate than normal). These messages were logged every two minutes (Figure 4). The data collected included battery voltage and temperature inside the enclosure. It is evident by the voltage peaks that the solar panel charged the battery each day. However, the daily voltage low-point started to decrease after

Table 1
Radio range under various conditions.

VIEW	ANTENNA	ELEVATION (m)	ENCLOSED	MEAN RANGE (m)
VLOS	whip	0.5	No	51
Orchard	whip	0.5	No	23
VLOS	whip	0.5	Yes	33
Orchard	whip	0.6	Yes	16
VLOS/Orchard	whip	0	Yes/No	7
VLOS	dipole	0.8	N/A	98
Orchard	dipole	0.8	N/A	72
VLOS	dipole	1.7	N/A	217
VLOS/Orchard	dipole	0	N/A	32

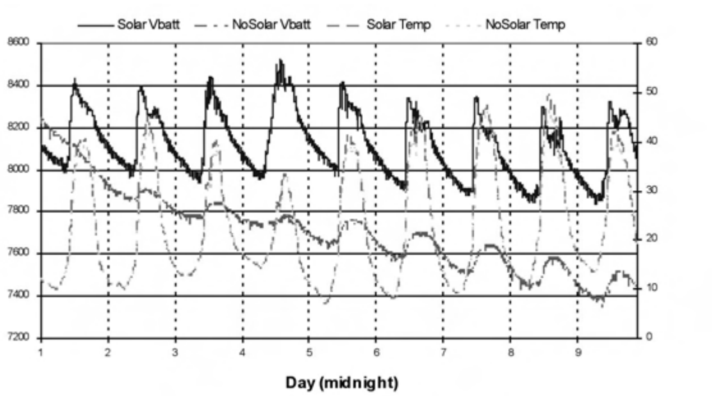

Figure 4
Battery voltage and temperature inside valve controller enclosures over 9 days.

Day 5. It appears that this was due to excessive heating of the enclosure. A daytime temperature over 40°C resulted in a reduced battery voltage the following morning. This is possibly due to poor battery charging at high temperatures. Improved insulation or shielding of the enclosures will be necessary to protect the circuit and battery. Small voltage fluctuations were also seen for the non-solar node. These were due to changes in battery voltage and resistance during daily temperature variation.

CONTINUING WORK

We are beginning lab testing of methods for fertigation control with a spatially variable system. Results from these experiments will guide the design of field tests. The nodes will be programmed for stand alone operation using wirelessly transmitted schedules. Extended tests under sunlight, shade, and overcast skies will be conducted to determine the reliability of solar-powered battery charging and energy management schemes. Sensors will be connected to the nodes for monitoring water pressure, soil moisture level, or other parameters. Nodes will be deployed in the field and used to test fertilizer control and fault detection strategies. Since this system has potential applications in orchards, nurseries, greenhouses, and landscapes, the wireless controllers will be tested in as many different environments as possible. We will also complete an economic feasibility analysis to determine at what level a wireless system would be economically viable for a grower.

ACKNOWLEDGEMENTS

This research was supported by CDFA-FREP, the Slosson Research Endowment, and the California Association of Nurseries and Garden Centers.

EFFECTS OF COVER CROPPING AND CONSERVATION TILLAGE ON SEDIMENT AND NUTRIENT LOSSES TO RUNOFF IN CONVENTIONAL AND ALTERNATIVE FARMING SYSTEMS

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INTRODUCTION

Conservation tillage, winter cover cropping, and post-sediment traps provide options to growers to address runoff and minimize nutrient and sediment losses from agriculture land. These practices have been to address runoff related issues in other regions of the United States. In California, less is known of the effectiveness of these practices in addressing runoff. Conservation tillage (CT) and cover cropped (CC) systems can lead to improved water quality through enhanced infiltration. Sediment traps act to increase retention and holding time thus promoting infiltration and capturing sediment. It is the intent of this study to assess the usefulness of these practices to address runoff and water quality concerns for California.

This project was a three-year effort to quantify relationships between tillage, CC, fertility management, runoff, and nutrient losses from irrigated soils in Northern California. We established a network of automated water samplers at the long-term UC Davis Sustainable Agricultural Farming Systems (SAFS) site and in grower fields. The network of automated samplers provides yearround monitoring of surface runoff to determine the effectiveness of CT and CC in minimizing runoff quantity and improving runoff quality. Runoff volume and water quality parameters including turbidity, suspended sediment, phosphate, inorganic nitrogen, total dissolved nitrogen and phosphorous, dissolved organic carbon, and pesticides were determined.

PROJECT OBJECTIVES

1. Quantify discharge from research plots and grower fields to compare alternative management practices with conventional ones.
2. Quantify non-point source pollutions (NPSP) concentrations and loads in discharge.
3. Inform farmers, policymakers, and the general public about the usefulness of cover crops (CC) and conservation tillage (CT) in addressing nutrients losses.

MATERIALS AND METHODS

The SAFS research site is located in Northern California's Sacramento Valley (38° 32' N, 121° 87' W, 18m elevation) on the former Long-term Research on Agricultural Systems (LTRAS) now the Russell Ranch Sustainable Agriculture Facility at the University of California, Davis. The alluvial soils are classified as Yolo silt loam (fine-silty, mixed nonacidic, thermic Typic Xerorthents; USDA taxonomy) and Rincon silty clay loam (fine, smectitic thermic Mollic Haploxeralfs; USDA taxonomy).

Cooperating growers were located within ten miles of the SAFS site. All farming systems had at least a ten-year history of management except that split plot tillage treatments were initiated in 2003.

CT management in all systems is defined as a tillage practice that leaves at least 30% crop residue on the soil surface and/or reduces ST practices by 40%. In contrast to the ST system, CT beds are not listed in the fall. However, like ST management, CT fields are left fallow in the NCC system while the CC and OCC systems use a legume CC. The SAFS plots were a two-year rotation of processing tomato (*Lycopersicum esculentum*) and corn (*Zea mays*).

We monitored the storm seasons starting in December 2004 and ending in April 2006. During the 2004-2005 storm season, runoff data collection at the SAFS research site used a catchment (sump) system to channel furrow runoff. At the end of each rain event, a grab sample was taken for analysis and then the sump was emptied.

On both grower fields, runoff was sampled by datalogger-equipped auto-samplers to assess the affects of CC-ST and NCC-CT with respect to NCC-ST treatments. Runoff was determined with an area/velocity sensor combined with frequent water sampling. In 2003-2004 and 2004-2005, data was also collected from a post sediment trap located at the end of field of a NCC-ST treatment. Grower field data was collected during both storm and irrigation seasons.

SYSTEM	TREATMENT	TILLAGE	SAFS	GROWER A	GROWER B
Conventional	Fallow (NCC)	Standard (ST)			
Conventional	Fallow (NCC)	Conservation (CT)			
Alternative	Cover Crop (CC)	Standard (ST)			
Alternative	Cover Crop (CC)	Conservation (CT)			
Alternative	Organic (OCC)	Standard (ST)			
Alternative	Organic (OCC)	Conservation (CT)			

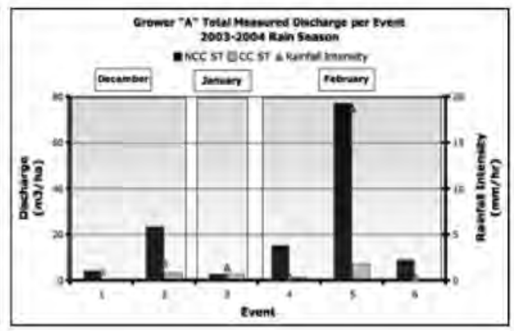
Table 1
Summary of systems, treatments, and tillage practices used on the experimental plots and two growers' fields in the Sacramento Valley, California.

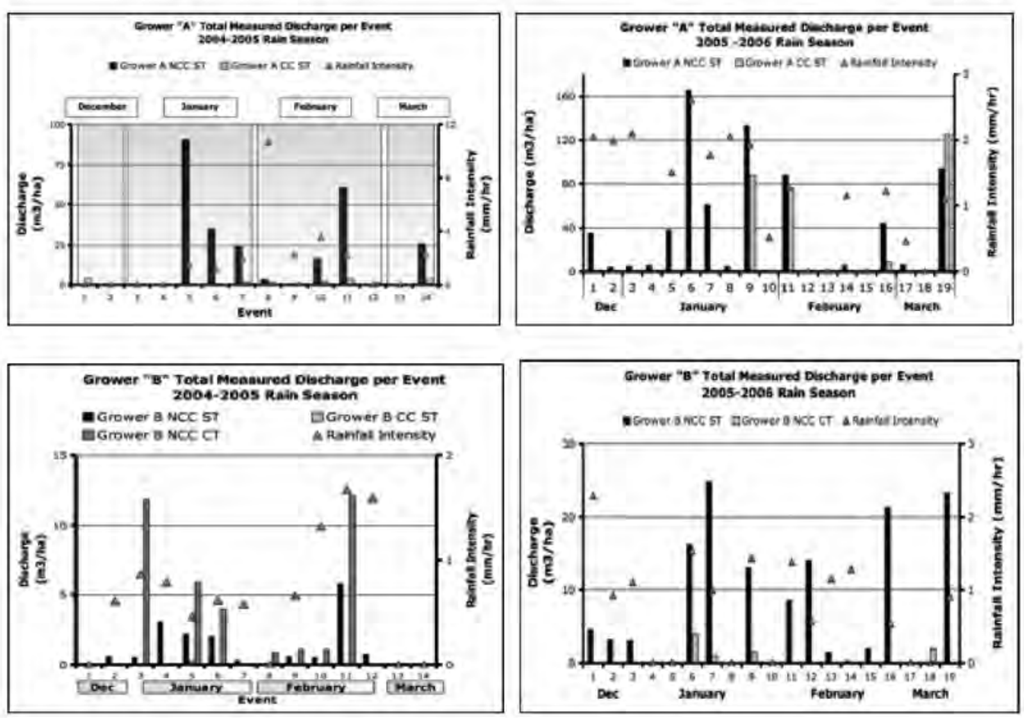
RESULTS AND DISCUSSION

The following are the major findings of our research. We show only the grower field data to provide an example of field scale runoff phenomenon. SAFS data will be shown during the oral presentation to highlight differences between conventional and organic management. Figure 1 shows discharge characteristics from grower fields. The affect of CC on Grower A fields is to significantly reduce runoff. The affect of CC on Grower B fields was minimal. The effect of CT on runoff is variable. Runoff on CT soils is dependent the residue load contributed by the previous crop where tomato CT combination similar runoff to NCC-ST fields (SAFS data not shown).

Tables 2 and 3 show loads of water quality constituents examined on grower fields. In all cases for Grower A and B the total amount of water quality constituents represent less than 1% of N and P from fertilizer inputs. The effect of cover crop on Grower A was to significantly reduce output of water quality constituents. There was little effect

Figure 1. Comparison of event volume weighted discharge as a percentage of rainfall for two Yolo County tomato growers over three storm seasons. In addition to discharge, rainfall intensity for each event is represented by the light-colored triangles. At the Grower "A" farm, NCC ST was compared to CC ST for all three seasons of the project. At the Grower "B" farm, NCC ST was compared to NCC CT and CC ST in 2004-2005. For 2005-2006 NCC ST was compared to just NCC CT.





Grower	Year	Management System	Tillage	TSS kg/ha	Phosphate g/ha	DOP g/ha	NO3-N g/ha	NH4-N g/ha	DON g/ha	DOC g/ha
A	2003 - 2004	Conventional (NCC)	ST	84 (±2.02)	0.82 (±0.18)	7.75* (±0.51)	4.11 (±0.36)	0.70 (±0.13)	47.66 (±1.38)	81.88 (±1.41)
		Cover Cropped (CC)	ST	2* (±0.22)	0.09* (±0.04)	0.12* (±0.06)	0.69* (±0.12)	0.25* (±0.08)	2.40* (±0.26)	8.08* (±0.44)
A	2004 - 2005	Conventional (NCC)	ST	45* (±0.59)	3.42 (±0.26)	.	85.13* (±1.01)	5.57* (±0.48)	.	110* (±1.46)
		Cover Cropped (CC)	ST	1* (±0.11)	0.30* (±0.06)	.	23.44* (±0.84)	0.19* (±0.08)	.	11.48* (±0.33)
A	2005 - 2006	Conventional (NCC)	ST	83* (±0.73)	5.26* (±0.16)	3.31* (±0.14)	143* (±1.05)	16.75* (±0.35)	46.98* (±0.44)	184* (±0.98)
		Cover Cropped (CC)	ST	16 (±1.07)	27.46 (±1.06)	18.49 (±0.90)	148 (±2.90)	17.81 (±1.23)	98.41* (±2.41)	654 (±5.84)

Table 2
Grower A volume-weighted seasonal average load for all three storm seasons where data was collected. The fields were exactly the same in 2003-2004 and 2004-2005. In 2005-2006, the treatments switched fields so that, although the same two fields were still being compared, the treatments flip-flopped. For example, the 2003-2004 NCC ST treatment became the CC ST treatment.

Grower	Year	Management System	Tillage	TSS mg/L	Phosphate mg/L	DOP mg/L	NO3-N mg/L	NH4-N mg/L	DON mg/L	DOC mg/L
B	2004- 2005	Conventional (NCC)	ST	2543 (±3.66)	0.39 (±0.04)	.	0.33* (±0.03)	0.04* (±0.02)	.	3.47 (±0.08)
		Cover Cropped (CC)	ST	249 (±1.68)	0.78 (±0.09)	.	3.45 (±0.25)	0.35 (±0.11)	.	7.36 (±0.30)
		Conventional (NCC)	CT	1863* (±4.59)	0.18* (±0.03)	.	2.12* (±0.21)	0.03* (±0.02)	.	4.19* (±0.23)
B	2005- 2006	Conventional (NCC)	ST	3546 (±2.88)	0.45* (±0.03)	0.23* (±0.04)	1.48* (±0.09)	0.02 (±0.01)	1.21* (±0.09)	2.29 (±0.08)
		Conventional (NCC)	CT	1982 (±6.52)	0.24 (±0.04)	0.15 (±0.07)	0.95 (±0.22)	0.04 (±0.03)	0.37 (±0.05)	3.28 (±0.25)

Table 3
Volume weighted average concentration sampled from two consecutive storm seasons. Grower B is a tomato farmer in Yolo County, California. The 2004-2005 fields included three treatments. A fallow, standard tillage system (NCC ST), a cover cropped, standard tillage system (CC ST), and a conservation tillage system (NCC CT). Conservation tillage is defined as a practice that leaves at least 30% residue cover or reduces tractor passes by at least 40% of conventional practices. The NCC ST field was the same for 2004-2005 and 2005-2006 but the NCC CT fields were different in the two years of trials.

of the CT or CC on Grower B fields. The data show that the affect of CT and CC depends on soil type, crop history and landscape characteristics such as slope.

CONCLUSIONS

1 On fields prone to winter runoff, cover crops significantly reduced runoff. Cover crops had little effect on fields with a low tendency to produce runoff.

2 The effect of conservation tillage was not uniform and produced mixed results. One reason for the mixed results is that conservation tillage is broadly defined being implemented either as leaving 30% or greater residue cover on the soil surface or a 40% reduction in tillage passes. Therefore, conservation tillage either increased or decreased winter runoff with no clear trend attributed to soil type.

3 The quality of water in agricultural runoff was generally within EPA drinking water guidelines for both winter and summer events except for total suspended solids. Generally, less than 1% of applied fertilizers were found as inorganic or organic constituents in runoff annually.

4 Conservation tillage had comparable yields to conventional tillage using the same fertilization practices within the same farming system (i.e., conventional, organic), data not shown. The main exception was for organic management where we found conservation tillage to be incompatible with manure amendments that are required to be soil incorporated to provide nitrogen to crops.

5 Conventionally managed systems generally had higher yields of corn compared to CC and organic management. Tomato yields were similar among all systems regardless of source of fertilizer nitrogen, tillage or cover crop management (data not shown).

In conclusion, there is no universal prescription to reduce winter runoff except for the use of cover cropping on fields prone to runoff. We therefore recommend that a system of classification be developed to assess field runoff vulnerability to target fields prone to winter runoff. However, farmers who cover crop may experience significant delays in spring crop establishment putting them at a competitive disadvantage compared to growers whose fields are not prone to runoff and do not need to cover crop.

CONSTRUCTING MONITORING WELLS ON DAIRIES

PROJECT LEADER

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INTRODUCTION

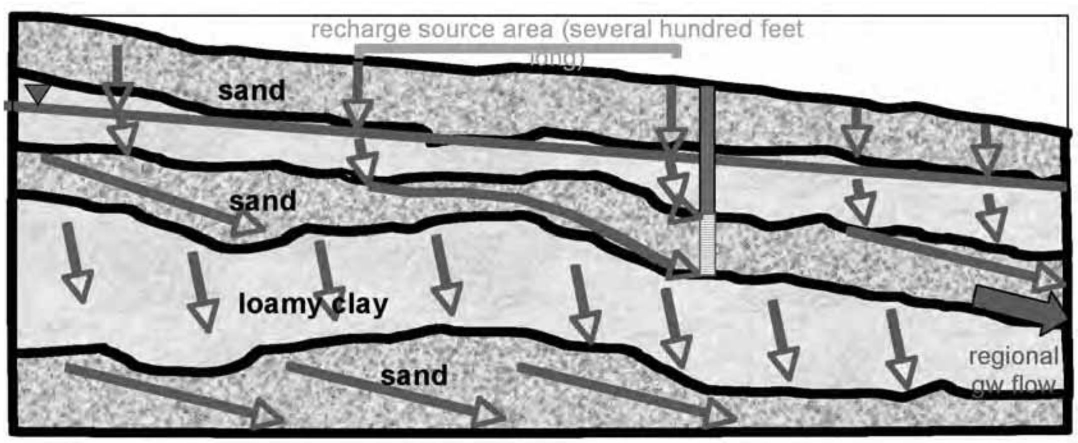
Regulatory programs frequently require monitoring of first encountered (shallow-most) groundwater for purposes of determining whether an actual or potential, permitted or incidental waste discharge has had or will have a degrading effect on groundwater quality. Traditionally, these programs have focused on the monitoring of incidental discharges from industrial sites. Increasingly, sources with an implied groundwater recharge are subject to monitoring requirements. These recharging sources include, for example, land application of municipal, food processing, or animal waste to irrigated cropland. An example of such a program is the new Waste Discharge Reporting Guidelines for Dairies in California's Central Valley, the country's most important dairy region.

Groundwater monitoring of a recharging source requires a different approach to groundwater monitoring than traditional (incidental source) monitoring programs. Furthermore, the shallow groundwater aquifer targeted for compliance monitoring commonly consists of highly heterogeneous unconsolidated alluvial, fluvial, lacustrine, glacial, or subaeolian sediments of late tertiary or quaternary age. Particularly in arid and semi-arid climates, groundwater is also frequently subject to significant seasonal and interannual groundwater level fluctuations that may exceed ten feet seasonally and several tens of feet within a three- to five-year period. The current approach to monitoring well design, which typically places a twenty-foot screen at the water level encountered at the time of drilling, is often inadequate to represent the recharge water quality from the source to be monitored.

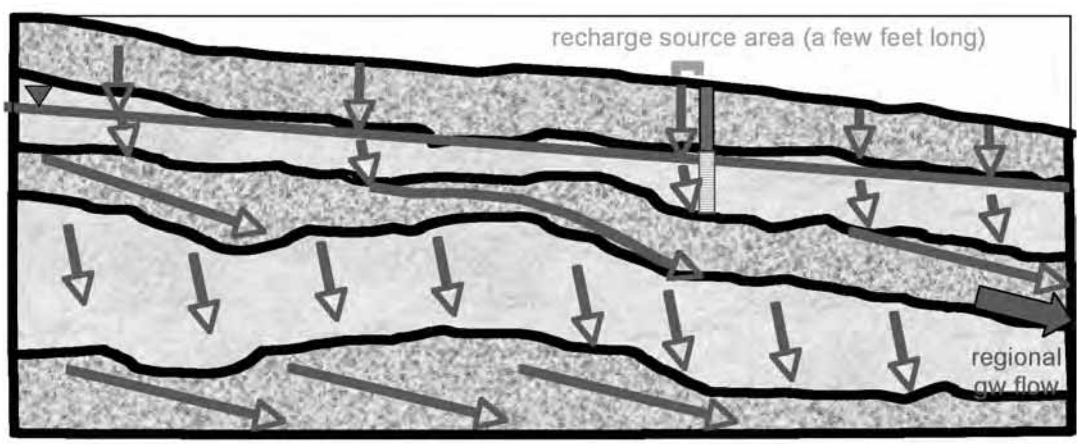
PROJECT OBJECTIVE AND DESCRIPTION

We present a hydrodynamically rigorous approach to designing groundwater monitoring wells for recharging sources under conditions of aquifer heterogeneity (Figure 1) and water level fluctuations (Figure 2) and present the application of this concept to monitoring confined animal farming operations (CAFOs) with irrigated crops located on alluvial fans with highly fluctuating, deep groundwater table. The well design is based on prior knowledge of anticipated water level fluctuations and on borehole log information obtained during drilling (either a detailed geologic log, or a—typically less expensive—so-called "E-log"). To accommodate varying water levels, a nested well or cluster-well approach may be required. We are currently testing this design on several dairies in the southern San Joaquin Valley.

Figure 1
Monitoring in Heterogeneous Aquifer

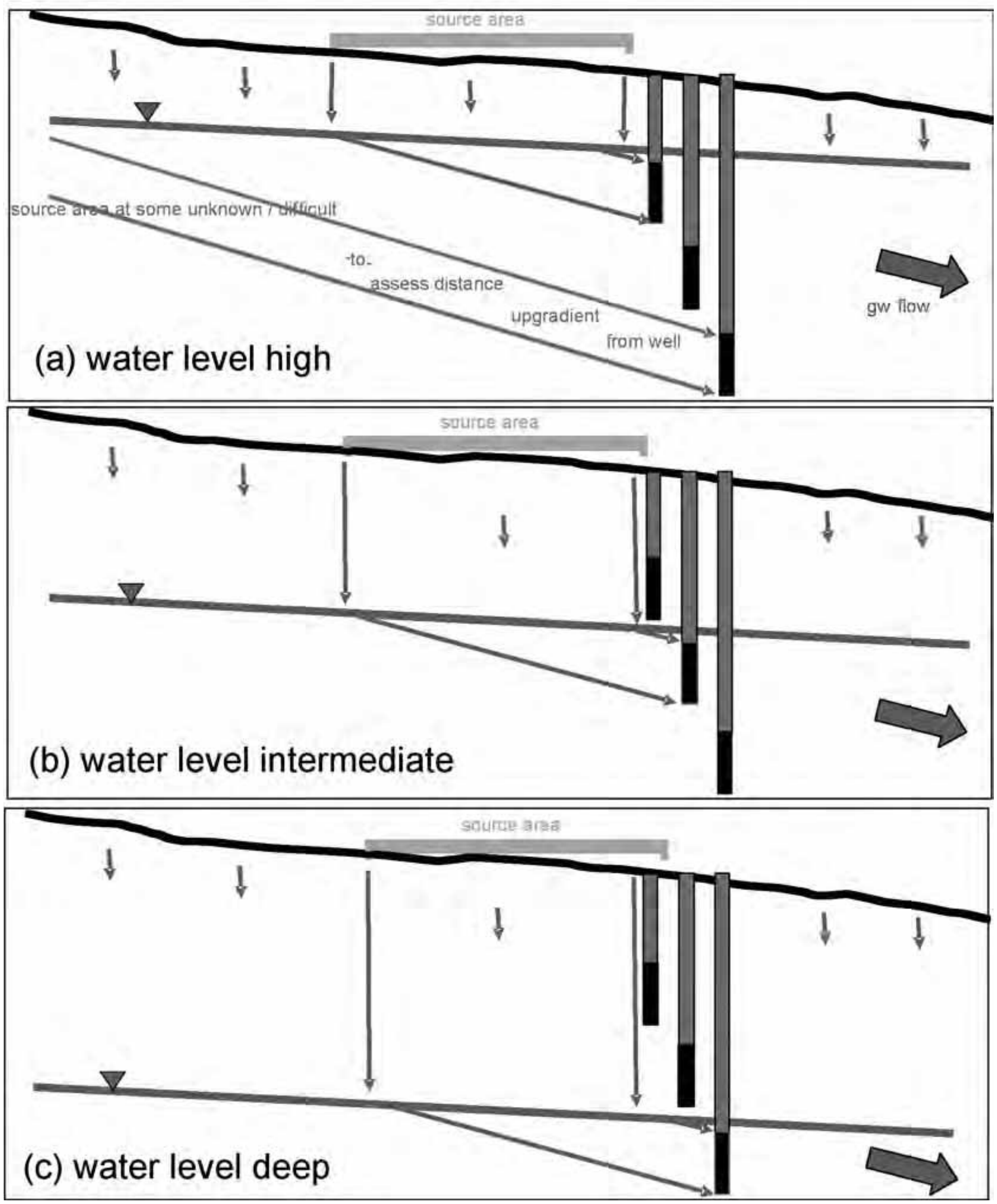


(a) The well screen (length ~ 20') is located in the first significant sand layer below the water table. While possible a few tens of feet below the actual water table, this well intersects the recharge from a significant portion of the intended source area.



(b) The well screen (length ~ 20') is located at the water table (typical installation), but not intersecting sand layer. The screen intersects a silt/clay layer with low conductivity and nearly vertical leakage flow to the sand layer. The corresponding source area of the monitoring well is only a few feet long and not representative of a (field-/ lagoon-sized) source area.

Figure 2
Monitoring a Dynamic Water Table



46

SUMMARIES OF OTHER ONGOING FREP RESEARCH PROJECTS

UPDATING OUR KNOWLEDGE AND PLANNING FOR FUTURE RESEARCH, EDUCATION AND OUTREACH ACTIVITIES TO OPTIMIZE THE MANAGEMENT OF NUTRITION IN ALMOND AND PISTACHIO PRODUCTION

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INTRODUCTION

There is a growing consensus among University of California (UC) faculty and farm advisors, consultants and growers that the UC-established critical values for determination of almond and pistachio nutrient status and the methods used to manage fertilization in these crops may be outdated or underutilized. In the absence of viable and well-regarded stand-ards and guidelines for nutrient management, growers do not have the resources needed to use fertilizers wisely.

PROJECT OBJECTIVES AND DESCRIPTION

Our goal is to survey current practices, concerns and needs in almond and pistachio nutrition, collate existing information and best management practices and design a new research and extension initiative to increase the efficiency of fertilizer usage and guide subsequent nutrition research and education programs. To meet this goal, we conducted small focus groups with industry stakeholders and used the information we gathered to form the content of surveys we distributed to approximately 1800 randomly selected almond growers and 300 pistachio growers throughout California.

RESULTS AND CONCLUSIONS

This experiment is ongoing and results are not yet tabulated, most of the following text describes the project objectives and how they were accomplished. Results will be presented at the November FREP conference.

In December 2006 and January 2007, we conducted a total of six focus group interviews with selected almond and pistachio stakeholders to identify current practices, concerns and needs in almond and pistachio nutrition management. Each focus group was comprised of between eight and twelve participants, and each session lasted ninety minutes. Focus groups were moderated by trained facilitators and participants' answers were noted by trained transcribers as well as recorded on tape. At the end of each focus group, the transcriber read the group's notes aloud to give participants the opportunity to add to or clarify what had been said.

We synthesized information from the focus groups by categorizing participants' responses in order to identify "saturated" concepts, in which the same idea was expressed by participants in numerous focus groups. Based on the results of the focus groups, we designed surveys to distribute to randomly-selected almond and pistachio growers in order to provide us with statistically sound, quantitative answers to our questions of growers' current practices, concerns, and needs in the field of plant nutrition. The surveys are 15 pages long and contain 37 questions. An online version is at http://education.ucdavis.edu/research/nutsurvey.

From a database of approximately 6000 almond growers, we randomly selected 1800 growers to whom we mailed surveys in early July 2007. We mailed surveys to 300 pistachio growers; since there is a smaller population of pistachio than almond growers in the state, we chose to conduct a census of the entire population of pistachio growers, so no random selection of names occurred.

As of September 8, 2007, we had received 650 responses from almond growers and 100 pistachio responses. This is a very good response rate and is adequate for a statistically sound analysis.

Remaining tasks will include collating and analyzing survey and workshop findings to produce a rigorous analysis of current practices, needs and constraints; designing an extension initiative to increase the efficiency of fertilizer usage and guide the development of new nutrition research and education programs; and presenting the results at Almond Board and Pistachio Commission year-end meetings as well as at CDFA and other appropriate meetings.

IMPROVING WATER-RUN NITROGEN FERTILIZER PRACTICES IN FURROW- AND BORDER CHECK-IRRIGATED CROPS

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INTRODUCTION

Injection of N fertilizers in irrigation water is a common practice in the western United States. The main limitation of this practice is the potential for spatial non-uniformity of N application rates, which can lead to crop N deficiencies in some parts of the field and wasted N and nitrate leaching losses in other areas. The obvious way to maximize uniformity of N applied in the irrigation water is to make the irrigation itself as uniform as possible. Methods for doing this in surface gravity irrigation systems (e.g., reducing field lengths or compacting furrow bottoms) are well known but can be costly or difficult for farmers to implement and are effective only in some situations.

A method for improving N uniformity in surface gravity irrigation systems that does not depend on improved water distribution uniformity is to delay the start of fertilizer injection until the water has advanced some distance across the field. This avoids fertilizer application on the upper end of the field early in the irrigation during the period of the most rapid infiltration. This practice has some possible drawbacks, but it has not been widely tested.

Another potential contributor to poor distribution of N during fertigation in surface gravity systems is the loss of N as volatile ammonia when anhydrous ammonia (AA) is used. Being the lowest-cost fertilizer per unit N, AA is often applied to lower-value field crops such as corn and sudangrass. A few older studies concluded that loss of N by volatilization during AA fertigation in furrow-irrigated fields was usually not significant; but other researchers have shown that losses depend on several factors (temperature, wind, etc.) and can be substantial.

During the past three summers, we have conducted tests of the delayed injection method in commercial row crop fields. We have observed some improvement in N distribution uniformity. We also have observed losses of N—apparently due to ammonia volatilization—in all eight of the test fields where AA was used. In all cases, this contributed to spatial non-uniformity of the N application. In a few cases, the loss appeared to be high enough to justify the use of a more expensive, non-volatilizing N fertilizer.

OBJECTIVES

1. Investigate the relationship of timing of water-run fertilizer injection to N application uniformity.
2. Determine the role of ammonia volatilization in non-uniformity of water N application.
3. Develop recommendations for N fertilizer injection timing and publish the information for use by growers and the fertilizer industry.

PROJECT DESCRIPTION

Since the beginning of the project in 2005, we have conducted experiments in eight commercial corn fields that were being fertigated with anhydrous ammonia. These tests were conducted during the farmers' regular irrigations and with commercial fertilizer tank set-ups provided by each cooperating farmer's retail supplier. In addition, in a corn field in 2006 and in two bean fields in 2007, we conducted similar experiments using urea-ammonium nitrate (UAN) solution fertilizer. All experiments were done when plants were small (< 24 inches tall) to facilitate visual monitoring of the irrigation water advance, even though more typically, growers will fertigate when the corn is at a more advanced stage of growth.

Length of monitored fields ranged from 900 to 2000 feet. At each field, we collected data from one or two furrows during a single irrigation event or set, and this was repeated on two successive days, resulting in two or three data sets at each field. During each day's set, a different fertilizer injection rate and timing was used, thus providing an evaluation of the delayed injection strategy under similar crop and soil conditions. Measurements included water flow rate (using flumes in individual furrows or a flow meter) and water advance times at 100-foot intervals. Also at 30- to 60-minute intervals, we collected furrow water samples at the point where water entered the furrow and at five to seven additional locations along the length of the furrow. These samples were stored on ice, then refrigerated until they could be analyzed for ammonium (AA samples) or Kjeldahl N and nitrate (UAN samples)

For the delayed fertilizer injection treatments, we delayed opening the fertilizer tank valve until irrigation water had advanced 50% to 75% of the distance across the field. We attempted to adjust the application rate so as to achieve the same N rate (30-50 lb N/acre) for all treatments in a field. We did this by increasing the fertilizer flow rate for shorter injection periods. However, this required some guesswork, and we were not often successful in achieving the same target N rate on successive irrigation sets in a field. At the two UAN-fertilized bean fields in 2007, we used our own small fertilizer injection system, hoping to have a side-by-side comparison of different injection timings during the same set; however problems were encountered with the equipment, and data are still being analyzed.

RESULTS

Results for 2005 and 2006 were presented in earlier reports (see proceedings of the 2005 and 2006 Fertilizer Research and Education Program Conference and the 2006 California Plant and Soil Conference). Analysis of the 2007 data is in progress, and only partial results are shown here.

In 2007, at the one site where anhydrous ammonia (AA) was used this year (Colpien loam, pH 7.7, 1250-foot field length), we observed a decrease in ammonium concentration in the water as it advanced across the field. Over the three days with different AA injection rates and timings, the N concentrations at a distance of 1100 feet from the head of the field were 23-32% lower than at the head of the field (Figure 1), even after allowing time for the fertilizer to "catch up" with the advancing water front in the delayed injection treatments. This is similar to observations in 2005 and 2006. The very high pH of the water during the fertigation (pH 9.5-10.0 vs. pH~7 before injection was started) is convincing evidence that the decrease was due to ammonia volatilization.

Additionally, as in past years, we observed a water temperature increase of 10-15˚F over the length of the field. An example from one day is shown in Figure 1(a). Other researchers have documented the impact of temperature on the rate of ammonia volatilization. The non-uniformity in NH_3 concentration due to volatilization will be added to the effect of non-uniform water application (not yet evaluated) to determine the final N spatial distribution pattern. Our experiments were all conducted when the corn was 24 inches tall or less. It is possible that when the plants are taller and the plant canopy is completely closed, there will be slower ammonia volatilization due to less air movement and the more complete shading of the furrow. To investigate this possibility, in 2007, we collected water samplesfrom several late-season corn fields that were being fertigated with AA. Samples from the bottom ends of fields showed lower concentrations of N than the top ends, with differences similar to that observed in our early-season corn experiments. However, this does not address the possibility that in tall corn fields, plant leaves absorb some of the volatilized NH_3.

Also in agreement with the past years' observations, the 2007 measurements show that fertilizer injected after water has advanced halfway or more across a field quickly catches up to the advancing water. In one of the 2007 UAN-fertigated bean field furrows, about 2.5 hours were required for the water to advance 1500 feet. A pulse of UAN fertilizer started late in the irrigation took only about 20 minutes to reach full strength at the 1500-foot mark.

DISCUSSION OF DELAYED INJECTION STRATEGY

Our measurements in 2005 and 2006 suggest that the delayed application strategy can result in improved N distribution uniformity. In considering whether to adopt this practice, growers will need to weigh the potential benefits (more uniform application of N and a reduced quantity of fertilizer N likely needed) against the higher level of management required. Specifically, the delayed injection method requires that someone turn on and turn off the fertilizer tank once during each irrigation set; also it will be necessary to adjust the fertilizer tank valve setting to compensate for the shorter length of the injection period. Regarding this last point, a simplified approach would be to run the fertilizer for some fixed number of hours per irrigation set regardless of the actual length of the set or water advance rate, which may vary from set to set.

We note that many farmers think of set times as the frequency of "moving" or changing water from one set to the next. Water is typically changed at intervals related to irrigation personnel labor shifts, e.g., 8 or 12 hours. To develop more N-efficient and accurate fertigation, farmers need also to consider the length of time required for water to advance to the end of the field and the opportunity time, i.e., the actual number of hours water is present for infiltration in different parts of the field. This will be even more important if the delayed fertilizer injection strategy is to provide any advantage.

An additional consideration with anhydrous ammonia (but not with urea or UAN solution fertilizer) is the need for training and a religious adherence to safety protocols if the grower or irrigator will be turning fertilizer on and off or adjusting the rate controller. With conventional continuous injection of anhydrous ammonia, the fertilizer supplier can handle all or most of the tank set-up tasks and controller adjustment. But with the delayed injection procedure, the farmer or a farm employee will have to be more involved with this.

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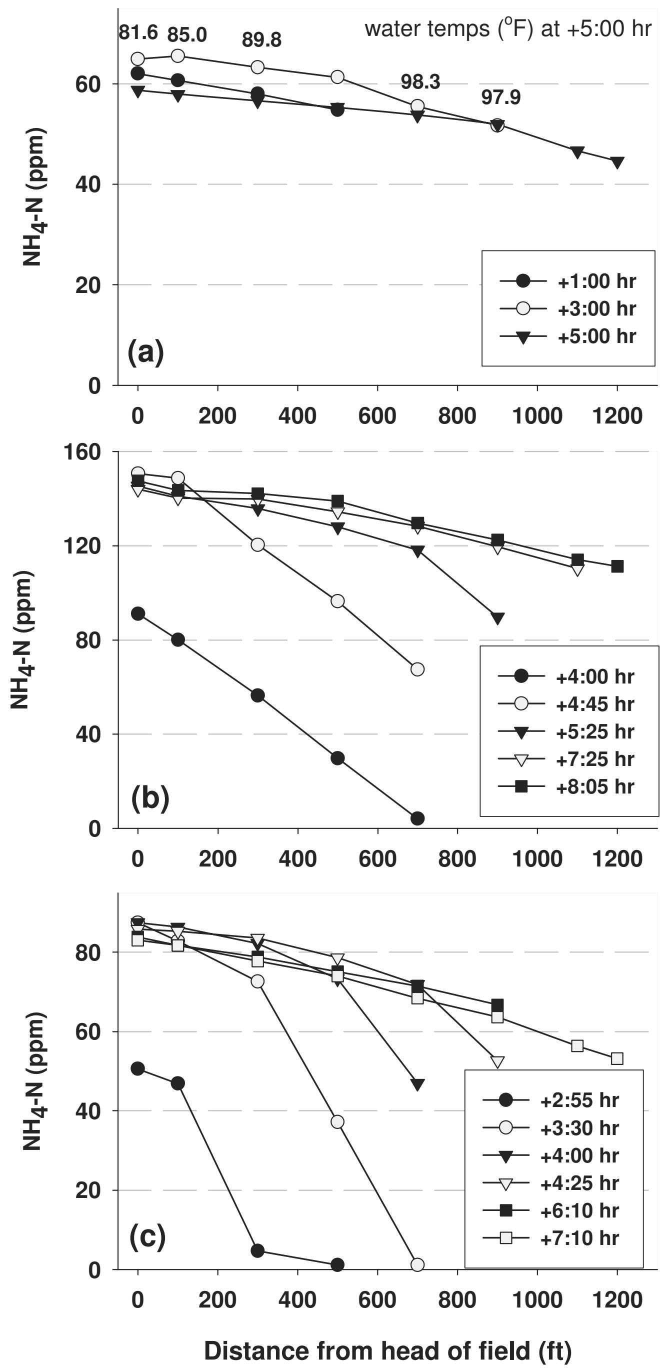
Figure 1
Ammonium N concentrations in furrow water during anhydrous NH_3 fertigations on three successive days with (a) continuous injection, or (b) and (c) injection delayed until water advanced to 720-750 ft. Hours shown in legend indicate time elapsed since start of irrigation.



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