Sixteenth Annual

CALIFORNIA DEPARTMENT OF FOOD & AGRICULTURE

Fertilizer Research & Education Program Conference

FERTILIZER RESEARCH AND EDUCATION PROGRAM FREP

PROCEEDINGS

November 12-13, 2008 • Modesto, California

Sixteenth Annual

CALIFORNIA DEPARTMENT OF FOOD & AGRICULTURE

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FERTILIZER RESEARCH AND EDUCATION PROGRAM
FREP

November 12-13, 2008
Modesto, California

cdfa
CALIFORNIA DEPARTMENT OF FOOD & AGRICULTURE

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Introduction

CALIFORNIA DEPARTMENT OF FOOD & AGRICULTURE

Fertilizer Research and Education Program

For 15 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. Last year, FREP collaborated for the first time with the Western Plant Health Association (WPHA) to create a new conference concept that balances precise research with practical application. The success and attendance was unprecedented. This year, FREP works in partnership again with WPHA to offer another integrated agenda titled, "Fresh Approaches to Fertilizing Techniques." This 2008 event combines the 16th Annual FREP Conference with WPHA's Central Valley Regional Nutrient Seminar.

Over two full days, a panel of speakers presents ways to incorporate groundbreaking fertilizer research into agricultural methods. Presenters provide general and technical information, current research data and practical applications for four key agricultural topics: managing micro- and macronutrients; keeping nutrients in their place; understanding organic fertilizer; and managing nutrients of regional crops.

Agricultural consultants, advisors, governmental agency and university personnel benefit from the findings, and in turn pass them on to growers. FREP's commitment to outreach and education continues, constantly seeking new ways to render research results and recommendations more useful and accessible to a broad audience of agricultural professionals.

The technical summaries of findings from FREP projects presented during the conference are summarized in these proceedings.

FREP OVERVIEW

The Fertilizer Research and Education Program (FREP) 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 approximately $1 million per year for fertilizer research.

The Fertilizer Inspection Advisory Board's (FIAB) Technical Advisory Subcommittee (TASC) guides FREP activities. 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. Beginning with 2009, one or two assigned TASC members will steward each research project through completion, following the progress of the project and reviewing the required reports.

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.

The FREP TASC has laid out specific research priorities for 2009, which center on themes of fertilizer efficiency and effectiveness:

- Updating nutrient requirements
- Improving fertilizer efficiency in drip irrigated micro-irrigation systems
- Increasing fertilizer efficiency through cost-benefit analysis
- Devising innovative techniques to improve fertilizer use efficiency

Additional FREP 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.

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

Figures 1-3: FREP PROJECT FUNDING

These figures illustrate the variety of geographical regions, disciplines and commodities covered by FREP projects during the past 18 years.

Figure 1
FREP Projects by Geographic Region 1991-2008

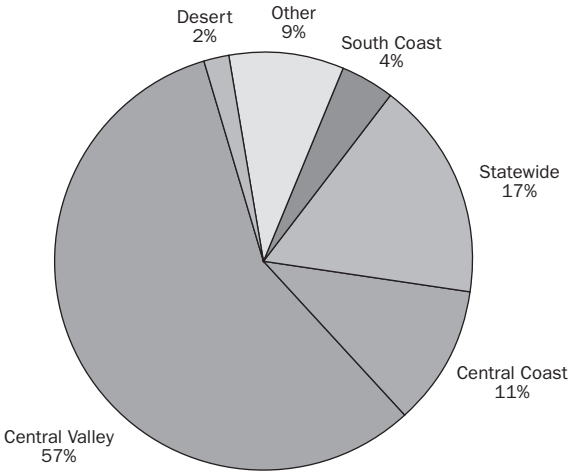


Figure 2
FREP Projects by Discipline 1991-2008

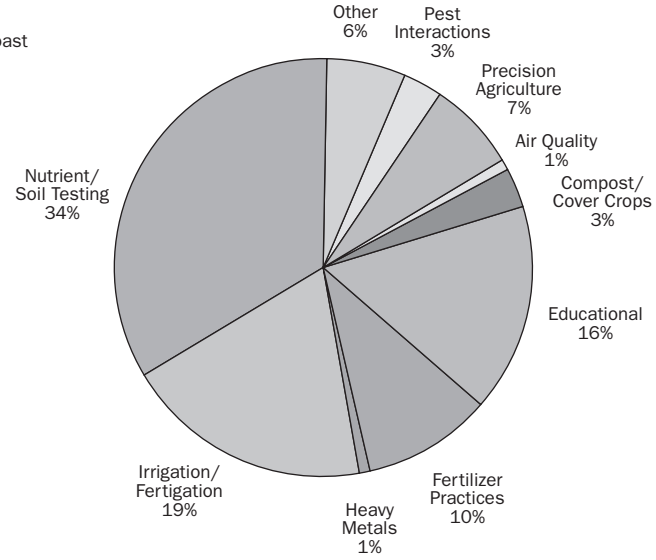
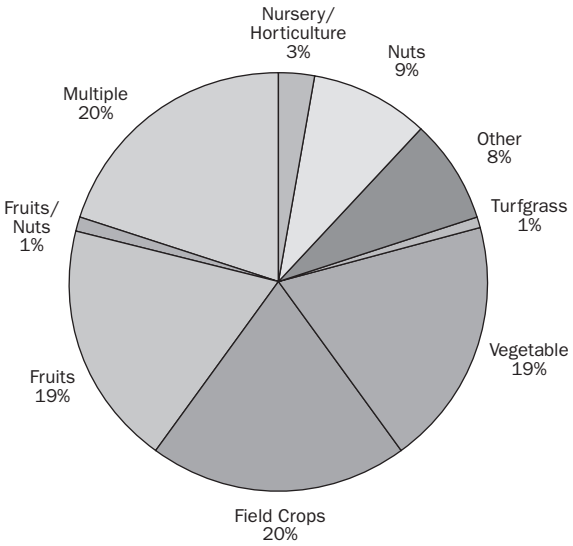


Figure 3
FREP Projects by Commodity 1991-2008



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.

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 at low or no cost by contacting the FREP office.

FREP staff collaborates and coordinates with other organizations with similar goals to extend FREP research to agricultural advisors who in turn will convey findings to farmers. Our partners include: Western Plant Health Association, California Chapter of the American Society of Agronomy; California Certified Crop Adviser Program; University of California Cooperative Extension Program; University of California Sustainable Agriculture Research and Education Program; State Water Resources Control Board Interagency Coordinating Committee; and 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 its support in providing funds for the Fertilizer Research and Education Program. Their foresight in creating FREP and their long-term commitment and dedication has been instrumental in the program's success.

We recognize the members of the FIAB TASC who review and recommend projects for funding. The professionalism, expertise and experience of David McEuen (chairman), Michael Cahn, Bob Fry, Tom Gerecke, Rob Mikkelsen, Jerome Pier, Al Vargas and Jack Wackerman have provided FREP with direction to ensure the program achieves its goals.

We thank the Western Plant Health Association as a valued partner in the "Fresh Approaches to Fertilizing Techniques" conference. Renee Pinel and Pam Emery's perspective, input and support have led to greater outreach and dissemination of FREP research findings.

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

Special recognition also goes to the leadership at the California Department of Food and Agriculture, including Nate Dechoretz, Inspection Services Division Director; Asif Maan, Feed, Fertilizer, Livestock Drugs and Egg Regulatory Services (FFLDERS) Branch Chief; and Amrith Gunasekara, Fertilizing Materials Registration and Inspection Program Manager. FREP Specialists 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 Melissa Muñoz and the rest of the FFLDERS branch support staff is also greatly appreciated.

Conference Program

Conference Program

WEDNESDAY, NOVEMBER 12, 2008

8:30–9:00 Registration and continental breakfast

9:00–9:15 Welcome
Nate Dechoretz, Director, Inspection Services Division, CDFA
Renee Pinel, President/CEO, WPHA

Facilitator
Amrith Gunasekara, CDFA

MANAGING MICRO- AND MACRONUTRIENTS

9:15–9:45 When Do We Need Micronutrients?
Mike Buttress, A&L Western Agricultural Laboratories
Keith Backman, Dellavalle Laboratory, Inc.

9:45–10:15 Comparing Sources of Micronutrient Fertilizers
Eric McGee, Bio-Gro, Inc.

10:15–10:30 Break

10:30–11:00 Getting the Best Plant Uptake of Micronutrients — Foliar- and Soil-Applied
Sebastian Braum, Yara North America

11:00–11:30 Finding the Most Cost-Effective Way of Getting Zinc into Peach and Pistachio Trees
R. Scott Johnson, UC Kearny Ag. Center

11:30–Noon Optimizing Nitrogen Availability in Cherry Growth to Obtain High Yield and Fruit Quality
Kitren Glozer, UC Davis

Noon–1:00 Lunch

KEEPING NUTRIENTS IN THEIR PLACE

1:00–1:30 How Do I Deal with Irrigation Run-off Water Quality Problems?
Larry Schwankl, UC Kearney Ag. Center

1:30–2:00 Exploring New Technologies for Increased Efficiency of Phosphate Fertilizers
Eric Ellison, J.R. Simplot Company

2:00–2:30 Developing Practical Fertility Monitoring Tools for Tomatoes
T.K. Hartz, UC Davis

2:30–2:45 Break

2:45–3:15 Using Site-Specific Fertilizer Applications in Orchards, Nurseries and Landscapes
Mike Delwiche, UC Davis

3:15–3:45 Balancing Fertilizer Application Rates with Water Quality
Protection in Strawberry Production
Tom Lockhart, Cachuma Resource Conservation District

3:45–4:00 Concluding remarks
Amrith Gunasekara

THURSDAY, NOVEMBER 13, 2008

8:30–9:00 Registration and continental breakfast

9:00–9:15 Welcome
Nate Dechoretz, Director, Inspection Services Division, CDFA
Renee Pinel, President/CEO, WPHA

Facilitator
Keith Backman, Dellavalle Laboratory

UNDERSTANDING ORGANIC FERTILIZER

9:15–10:00 Outlining Organic Fertilization — What PCAs and CCAs Should Know!
Mark Gaskell, UCCE, Santa Barbara and San Luis Obispo Counties

10:00–10:45 Comprehending the Science of Organics
Tom Ruehr, Cal Poly San Luis Obispo

10:45–11:00 Break

11:00–11:45 What Organic Nutrients Can We Use?
Rob Mikkelsen, International Plant Nutrition Institute

11:45–Noon California Certified Crop Advisers — Protecting the Environment
Allan Romander, CaCCA Program

Noon–1:00 Lunch

MANAGING NUTRIENTS OF REGIONAL CROPS

1:00–1:30 Assessing Plant Nutrient Requirements of Winegrapes
Larry Bettiga, UCCE, Monterey, Santa Cruz and San Benito Counties

1:30–2:00 Optimizing Nutritional Management in Almond and Pistachio Production
Patrick Brown, UC Davis

2:00–2:30 Keeping Up with Nutritional Requirements of Rice in a Changing Industry
Chris Greer, UCCE, Sutter, Yuba, Sacramento and Placer Counties

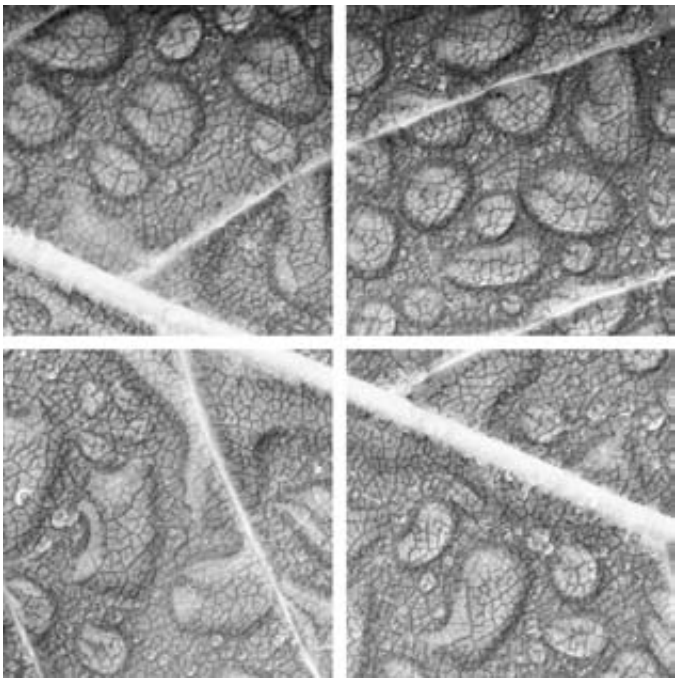
2:30–2:45 Break

2:45–3:15 Gauging the Effectiveness of Foliar Fertilizers on Citrus
Carol Lovatt, UC Riverside

3:15–3:45 Improving Phosphorus and Potassium Monitoring for Fertility Management in Alfalfa
Steve Orloff, UCCE, Siskiyou County
Daniel Putnam, UC Davis

3:45–4:00 Concluding remarks
Keith Backman

Summaries of Presented FREP Research Projects



Finding the Most Cost-Effective Way of Getting Zinc Into Peach and Pistachio Trees

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INTRODUCTION

Zinc (Zn) deficiency is a major concern in California fruit and nut orchards. Peach has been identified as particularly prone to this disorder. The problem is so widespread that foliar Zn sprays are applied on a routine basis even when no deficiency symptoms are observed. Rates of application can be very high, especially in pistachio orchards where recommendations of 40 lbs zinc sulfate/acre have been published. Since only a small fraction of the applied amount is needed to correct a deficiency, most of the Zn is simply wasted. This is both a financial burden on the grower (especially since early 2006 when zinc prices skyrocketed) and also an environmental problem that is not easy to remedy. Zinc is a heavy metal that will slowly build up in the soil and can eventually become a contaminant. Thus there is a great need to improve the efficiency of zinc foliar sprays.

In our previous FREP project that ended in 2007 (see 2007 FREP proceedings) we tested many different approaches of supplying Zn to fruit and nut trees. We concluded that foliar applications had the greatest potential for improving Zn uptake efficiency in the short term. Using a labeled ^{68}Zn isotope, we were able to show that 2% to 8% of foliarly applied Zn was taken into permanent structures of the tree. Most of these studies were conducted with zinc sulfate and experiments to compare other formulations without the ^{68}Zn label were unsuccessful due to high variability. Patrick Brown has demonstrated differences among formulations using Arabidopsis as a test plant (see 2007 FREP proceedings). For peach and pistachio plants, we have concluded that the best way to detect differences among materials is by incorporating the ^{68}Zn isotope into each formulation. Thus, the focus of this project will be on comparing the efficiency of different Zn

formulations, first on greenhouse seedlings and eventually in commercial orchards in the field. The ^{68}Zn label will be used when necessary to show differences.

PROJECT OBJECTIVES

1. To incorporate the ^{68}Zn isotope into some commonly used zinc formulations such as sulfate, EDTA chelate, oxide, amino acid or poly amine complex, citrate, lignosulfonate, fulvic acid, neutral-52%, nitrate etc.
2. To test the foliar uptake efficiency of these formulations on peach and pistachio seedlings with and without different types of surfactants.
3. To treat young peach and pistachio trees with ^{68}Zn in the field, using the best treatments from objective 2.
4. To test the most efficient Zn treatments in commercial peach and pistachio orchards.

PROJECT DESCRIPTION AND RESULTS

Working with the chemist at Monterey AgResources, we were able to incorporate the ^{68}Zn label into a Zn EDTA formulation by June 2008. Soon after, we conducted an experiment comparing ^{68}Zn EDTA with ^{68}Zn sulfate on peach seedlings in the greenhouse. The Zn analyses have not yet been completed by the Zn isotope lab. We also conducted several experiments comparing ^{68}Zn oxide with ^{68}Zn sulfate. These trials included two on peach seedlings in the greenhouse and two more on grafted nursery trees. All four experiments demonstrated that Zn sulfate is considerably more efficient than Zn oxide at supplying Zn to peach trees, whether applied to green leaves or to dormant wood. The ^{68}Zn label will be incorporated into other formulations as particularly interesting or effective materials are identified.

Significant progress was made in our procedure for testing Zn formulations, without the ^{68}Zn label, on peach seedlings growing in the greenhouse. It took two failures and a partial success before a reliable protocol was developed. In our first experiment, plants were low in Zn (12 ppm) but no deficiency symptoms were present. Different Zn formulations failed to show any improvement in growth or an increase in Zn concentration in any organ when compared to untreated control plants.

For the second experiment we made an effort to induce distinct deficiency so the symptoms could be relieved with Zn treatments. These plants tested extremely low in Zn (four ppm) but treatments showed no improvement in Zn concentration. However, there was an indication of some increase in certain growth parameters compared to untreated controls. We found growth in overall plant height was little affected by Zn treatments, but growth of lateral shoots was. In this experiment, all the Zn formulations (sulfate, EDTA, nitrate, amino acid complex and leonardite) increased lateral shoot growth by an average of 40% over untreated control plants. Unfortunately, there was substantial variability among plants so no statistical differences could be shown.

With a third experiment to tweak the procedure, the following protocol has been developed: First, many extra plants are grown, so only the most deficient are used. All are grown in sand and cotyledons are removed shortly after emergence to cut off supplies of stored Zn. Plants are then tipped to induce branching and irrigated with a 10% Hoagland solution. Once the plants are between one and two feet in height and have many short lateral shoots with very narrow leaves (typical Zn deficiency symptoms), they are ready for treatment.

In July 2008, we conducted a successful experiment following this procedure. The formulations tested were Zn sulfate, Zn EDTA, neutral Zn – 52% (combination of Zn oxide and

Zn sulfate), Zn leonardite and Zn polyamine, all applied foliarly. We also added a root-supplied treatment for comparison. After 20 days of growth, the plants were harvested and multiple measurements taken. Several measurements showed significant treatment effects, but the most sensitive was total leaf area on lateral shoots (Table 1). This parameter separated the treatments into two distinct categories. All treatments were significantly better than the untreated controls, but Zn sulfate and Zn polyamine were clearly better than the others. These materials also increased Zn concentration in new growth but not as much as the root supplied treatment.

Plans are underway to test more materials, especially those showing good results in Patrick Brown's Arabidopsis test and other interesting formulations (inexpensive, showing low phytotoxicity etc.). We will also try to induce Zn deficiency symptoms in pistachio seedlings growing in sand so a similar protocol can be followed.

CONCLUSIONS

This project is just underway, but results so far show that zinc sulfate, one of the least expensive formulations of Zn, is also one of the most efficient materials for supplying peach trees with this nutrient. Future work will continue to compare other formulations and will also test some of the same materials on pistachio. By the third year of the project we plan to evaluate the best formulations in commercial orchards.

Table 1.
Response of Zn deficient peach seedlings to foliar application of different formulations containing Zn compared to an untreated control and a treatment receiving Zn to roots through the irrigation water.

	Treatments						
			Foliar Zn Formulations				
Parameter	**Untreated Control**	**Zn to Roots**	**Sulfate**	**EDTA**	**Neutral 52%**	**Leonardite**	**Polyamine**
Plant height (cm)	57.5	57.8	53.1	56.1	56.3	53.7	54.9
Primary leaf area (cm^2/leaf)	5.8 b*	8.5 a	8.9 a	9.1 a	8.6 a	8.8 a	8.6 a
Lateral shoot length (cm)	82.0 c	129.4 ab	142.5 a	120.0 b	122.3 b	124.8 ab	143.0 a
Lateral leaf area (cm^2/plant)	65.7 c	178.1 b	273.6 a	159.6 b	159.0 b	188.9 b	241.1 a
Zn concentration in new growth (ppm)	8.1 d	18.0 a	12.4 b	8.8 d	9.9 cd	9.7 cd	11.0 bc

* Values in rows followed by different letters are significantly different from each other at p = 0.05. Rows with no letters are not significantly different.

Optimizing Nitrogen Availability in Cherry Growth to Obtain High Yield and Fruit Quality

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INTRODUCTION

Average sweet cherry yields in California (~3.4 tons/acre) are typically less than those in the Pacific Northwest (~5.5 tons/acre), due partly to insufficient chilling in some years and excessive vigor that promotes vegetative growth at the expense of reproduction. It is unlikely that current standard fertilization practices—soil-applied nitrogen (N) just after harvest—supply N in the most optimal, demand-driven timing (i.e., to meet reproductive needs without excessively promoting vegetative growth), nor is the standard practice of leaf analysis in midsummer likely to be a good indicator of N needs for subsequent season reproductive growth.

Sweet cherry bears primarily on two-year and older fruiting spurs and has a short bloom-to-ripening period for fruit development. This differs from most fruit crops, which impacts the timeframe for nutrient demand from the developing fruit as well as from the spur (vs. shoot) leaf populations that are critical for support of fruit growth. Consequently, cherry growers know little about efficiently supplying demand-driven nutrients, of which nitrogen is the most critical, and thus rely primarily on practices adopted from peach, almond, or apple orchard management. Furthermore, due to the higher chilling requirements of cherry than peach or almond, dormancy-breaking treatments in winter often are applied that further impact nutrient (particularly N) storage in, and demand by, tissues and organs. There is some indication that fall foliar application of urea may help hasten cold acclimation and reduce the incidence of bacterial canker in sweet cherry. Thus, nutritional studies in other tree crops, such as almond, do not provide optimal benchmarks for sweet cherry. For example, differences between

cherry and almond that impact nitrogen usage include potential spur lifespan (1-3 years in almond, much longer in cherry), extensive vegetative growth in cherry throughout the growing season, and leaf metabolism that appears to be nitrogen level-dependent in cherry and not in almond.

Our project will identify the periods of N demand by key cherry tissues (fruiting spurs vs. shoots) as well as N stores for spring growth, and examine the potential to optimize N supply efficiency via soil vs. foliar applications and timings. It will include the interactive effects of dormancy-breaking treatments that contain N as a component, such as CAN-17 and KNO_3. Observations on sweet cherry and peach indicate that the type of nitrogen source used to break dormancy may have carryover effects from year to year in timing of bloom, fruitfulness, and the balance of reproductive to vegetative growth. This project will investigate the potential to use appropriately timed analysis of spur N as a diagnostic measure of adequacy for subsequent reproductive growth (vs. mid-summer leaf analysis of N as a measure of adequacy for current vegetative growth).

OBJECTIVES

1. Quantify the seasonal pattern of N partitioning to sweet cherry tissues as influenced by soil and foliar applications, formulations, timing, and rootstock.
2. Determine the relationship of fruiting spur N reserves to subsequent spring spur leaf development, fruit set, and fruit growth potential.
3. Determine the impact of fall dormancy-inducing and late winter dormancy-breaking treatments on fruiting spur N reserves and early spring growth demand for N.
4. Develop recommendations to balance soil and foliar N application methods (timing and rates) to optimize annual fruit yields and quality while minimizing excessive vegetative growth.

PROJECT DESCRIPTION

Three experimental orchards were selected by rootstock (Orchards 1-3) and location (Orchards 1 vs. 2 and 3; 2 and 3 in same location). All were planted in 1998 and all are 'Bing' as the scion cultivar. Orchard 1 is on *P. mahaleb* seedling rootstock near Lodi on Acampo Sandy Loam soil; trees are planted at 13'x 18' spacing (186 trees per acre). Orchards 2 and 3, located near Linden, are, respectively, on dwarfing clonal rootstock Gisela 6 (*P. cerasus* x *P. canescens*) and Mazzard (*P. avium*) seedling rootstock. Soil at Orchards 2 and 3, which are in adjacent blocks, is Cogna Loam. Orchard 2 is planted at 14' x 17' (183 trees per acre), and Orchard 3 is planted at 12' x 16' (227 trees per acre). Trees at Orchard 1 are trained to a traditional open vase; Orchards 2 and 3 to a 'steep leader' system with three primary scaffold branches. Ten nitrogen treatments (Table 1) were assigned to each orchard with six trees per treatment in a randomized complete block design. Treatments were initiated during bloom and continued through the 2008 season. Foliar N treatments were applied by backpack mist-blower sprayer at a carrier volume (based on tree canopy volume) of 150 gallons/acre at Orchards 1 and 3 and 75 gallons/acre at Orchard 2. By February, 2009, an entire set of treatments will have been applied.

At present, we have collected dormant and growing spur and terminal shoot buds, young (fully-expanded, April) and mature (post-harvest in June, and September) spur and shoot leaves, and small fruits collected at 20 days after full bloom, prior to "pit-hardening" (Table 2). We identified the type of buds to be collected as those most representative of high seasonal demand, thus, the spur buds were those entering into the first year of bearing on two-year-old wood on

precocious mahaleb and Gisela 6 rootstocks and on three-year-old wood on Mazzard rootstock. Terminal buds from vegetative shoots were selected for tissue analysis. In each case, at least 10 buds were obtained. Shoot and spur leaves were collected from the same types of shoots, at least 10 leaves of each type.

At present, samples and data collected include N content from dormant and growing spur and vegetative buds (collected prior to and at "budswell" in February and March, respectively, and in September), young and mature spur and shoot leaves (April, July and mid-September), and small fruits collected at 20 days after full bloom (prior to "pit-hardening").

Phenological and productivity data, including full bloom date and duration of bloom, yield per tree, yield efficiency (yield/trunk cross-sectional area), and fruit quality (size, firmness, maturity, Brix and fruit removal force, or "pull force") were collected during the 2008 season. Trunk cross-sectional area (TCSA) was measured for vegetative growth, calculated from trunk circumferences taken at six inches above ground level in March and in October. Leaf area can be an indicative measure of vegetative growth and indirectly reflect N status. Leaf area was measured in April using digital image analysis (DIA) of leaf photographs (Bakr, 2005; O'Neal, 2002).

Harvest for all orchards was a single "strip pick" on June 2 at Orchard 1 and June 6 at Orchards 2 and 3. Samples of fruit were obtained at random from pickers' bins and evaluated on the day following harvest for maturity, firmness, size, stem/fruit removal force (FRF) and soluble solids. Maturity was measured by color, as per picking and grading guidelines (CDFA and California Cherry Advisory Board). Only salable mature fruit were evaluated for quality, after a 100-fruit random subsample from bin-collected fruit was evaluated for spread in maturity (by six color grades). Fruit from Orchard 1 were separated visually into the six color grades of green, straw, colorbreak (change from straw to pink), light red, dark red, and mahogany color categories by four trained evaluators using California Cherry Advisory Board color reference cards. Because of grading inconsistencies among evaluators, a Minolta CR-10 colorimeter was used for grading fruit from Orchards 2 and 3, using the same color categories on the color cards as a reference. A protocol was developed to convert CR-10 readings to the equivalent color grades. This protocol is similar to industry standards for cling peach (Slaughter and Crisosoto, 2006) and other commodity quality evaluation (Mitcham et al., 1996). Where percentage of fruit is shown for the color grades in this report, grades "green" and "straw" are combined due to very low numbers of fruit in each of these grades at harvest. Once fruit was graded thus, a subsample of 50 salable (defect-free, light red to mahogany) fruit were selected and used for fruit firmness, size, fruit removal force (FRF) and Brix determinations. Firmness and size (BioWorks FirmTech II) and FRF (Imada digital force gauge) measurements were made on individual fruits; a single Brix value was determined using juice extracted from each 50-fruit subsample.

RESULTS AND DISCUSSION

Nutrient analyses completed thus far showed no differences in total N content among treatments within each orchard and tissue type (Table 3), as might be expected for the early stages of treatment imposition. Analyses of mid-summer and September tissue samples have not yet been completed. In all orchards and treatments, percent N in both shoot buds and spur buds increased sharply from February to March with remobilization of stored nutrients at budbreak. April leaf and fruit N concentration was highest in all treatments at Orchard 2, which may be interpreted as being due to less tree volume (due to dwarfing rootstock) per unit of nitrogen

applied. Orchard 1 N values were intermediate and Orchard 3 had the lowest leaf and fruit N in April. The high vegetative vigor and large tree size at Orchard 3 may account for lower unit of N per tissue volume in all tissues. Nitrogen values for fruit from all orchards tended to be similar to that found in fully-expanded leaves, ranging from 2.9 to 4.4% N. No significant differences in N status were found within a particular organ (shoot bud, spur bud, leaf, or fruit) within a given orchard.

Shoot leaf size (Table 4) was greatest at Orchard 1, lowest at Orchard 3, and intermediate at Orchard 2. Orchard 1 tree canopies are kept very open by annual removal of large and small limbs via heavy pruning, maximizing within–canopy light distribution. Leaf area was not different among treatments within an orchard, except at Orchard 2, where leaf size also showed high variability among replicates. Spur leaf area and N content among the orchards showed similar patterns to shoot leaves, namely, the highest values were at Orchard 1, lowest at Orchard 3, and Orchard 2 intermediate.

TCSA was lowest at Orchard 2, as expected with the dwarfing and highly productive rootstock at this site (Table 5). Seasonal changes in TCSA varied greatly among trees at each site, but there were no statistically significant differences in seasonal growth due to N treatment within each orchard. Such natural variability may require the cumulative increase in TCSA over the three year period of the trial to ascertain the affects of the treatments.

The duration and date of peak bloom — recorded as "baseline data" for comparing treatment effects in future years — were: 12 days and March 24 at Orchard 1; and 11 days and March 26 at Orchards 2 and 3.

At Orchard 1, fruit was mostly dark red and mahogany at harvest (Table 6). Post-bloom N (Treatments 8 and 10) slightly delayed maturity, as evidenced by a higher percentage of fruit at "colorbreak" (changing from straw to pink fruit), and fewer dark red fruit. Firmness (Table 7) and Brix (Table 8) did not vary among treatments at this site. FRF (Table 7) was slightly reduced in Treatment 8 and highest in Treatment 10, with no clear relationship to treatment when all indices of maturity are considered. Fruit size (Table 7) was significantly different by treatment (ranging from rowsize 9.7 to 10.1), but all averaged out to row size 10, thus no practical difference in fruit size was found; weight of 25 fruit corroborated this finding of no difference among treatments (Table 8). Yield per tree among the treatments imposed prior to harvest showed no difference, nor did yield efficiency (Table 8).

At Orchard 2, fruit maturity was not different among treatments: About half of all fruit were dark red, and most of the remaining fruit were evenly found in either light red or mahogany colors. Fruit firmness, size and soluble solids were not different by treatment; FRF was statistically different among treatments, with the highest FRF in fruit that had received no N (Treatment 1) and lowest in the post-bloom treatment. However, there was overlap with results from the bloom and combination bloom, post-bloom treatments, such that a clear relationship to treatment was not apparent. There were no differences among treatments in yield or yield efficiency.

At Orchard 3, fruit maturity showed some statistical differences among treatments, with a higher percentage of fruit "salable" colors for Treatment 10, which had received both bloom and post-bloom treatments. There was no clear-cut treatment effect in any maturity or quality measure that clearly showed a treatment difference, even where statistical differences resulted. Yield and yield efficiency were not different among treatments.

Consequently, baseline data for each orchard has now been collected and it is expected that we will begin to see treatment differences as the full set of treatments is completed in the coming year.

LITERATURE CITED

Bakr, E.M. 2005. A new software for measuring leaf area, and area damaged by Tetranychus uritcae Koch. JEN 129(3):173-175.

Erez, A., Fishman, S., Linsley-Noakes, G.C. and Allan, P. 1990. The dynamic model for rest completion in peach buds. Acta Hort. (ISHS) 276:165-174.

Mitcham, B., M. Cantwell and A. Kader. 1996. Methods for Determining Quality of Fresh Commodities. Perishables Handling Newsletter Issue No. 85: 1-5.

O'Neal, M.E., D.A. Landis, and R. Isaacs. 2002. An inexpensive, accurate method for measuring leaf area and defoliation through digital image analysis. J. Econ. Entomol. 95(6):1190-1194.

Slaughter, D. and C. Crisosto. 2006. Objective Determination of Color and Firmness in Cling Peach Inspection. California Cling Peach Board Report 2006.

Table 1.
Experimental nitrogen (N) fertilization treatments applied to 'Bing' (Prunus avium) sweet cherry at three orchards in 2008, comparing standard soil application ($CaNO_3$ 15.5%N) with reduced soil application supplemented with physiologically-timed foliar[x] applications, plus impacts of dormancy induction/alleviation by nitrogenous compounds. Actual pounds N per acre shown; foliar applications of N are low-biuret urea (46% N) or PacificHort Grow Plus N (PHG+N, 15% ammoniacal N). Orchards vary by location (Lodi or Linden, CA) and rootstock (*P. mahaleb*, 'Gisela 6' or 'Mazzard' [both *P. avium*]).

Treatment[y]	Soil N post-harvest	Foliar pre-leaf fall	Foliar + Z_nSO_4 pre-leaf fall (dormancy induction)	CAN17 or KNO_3 (dormancy release)	Foliar at 10-30% full bloom/petal fall (PHG+N)	Foliar post-bloom
Timing	**June 23**	**Oct 20 + 27**	**Late Oct-early Nov**	**Jan-early Feb**	**Mar 18 or 20**	**Apr 17**
T1	90					
T2	90		20#/acre each	KNO_3, 6% w/v		
T3	90		20#/acre each	CAN-17, 25% v/v		
T4	45		20#/acre each	CAN-17, 25% v/v		
T5	45	25 + 20				
T6	45				1.12	
T7	45	25 + 20			1.12	
T8	45					2.3
T9	45	25 + 20				2.3
T10	45	25 + 20			1.12	2.3

[x] Calculated carrier volume for standard trees at Orchard 1 (Lodi) and Orchard 3 (Linden/Mazzard) = 150 gal/A; at Orchard 2 (Linden/Gisela 6), carrier volume = 75 gal/A for smaller trees on dwarfing rootstock.

Table 2.
Sampling of 'Bing' (*Prunus* avium) sweet cherry tissues at three orchards in 2008 comparing standard soil application ($CaNO_3$ 15.5%N) with reduced soil application supplemented with physiologically-timed foliar applications, plus impacts of dormancy induction/alleviation by nitrogenous compounds.

Timing [x]	Fruiting spur bud	Shoot terminal bud	Fruiting spur leaf	Shoot leaf	Fruit
Feb 28-Mar 1	X	X			
Mar 14-18	X	X			
Apr 11			X	X	X
July 17		X	X		
Sept 16	X	X	X	X	
Nov (late) – Dec (early)	X	X			

[x]Samples from Feb-March, 2008 were from all trees/treatments; for harvest data only treatments imposed during and after bloom, through harvest were sampled, as no other subsequent treatments had been imposed until after harvest.

Table 3.
Nitrogen content of 'Bing' (*Prunus* avium) sweet cherry tissues at three orchards in 2008 comparing standard soil application with reduced soil application supplemented with physiologically-timed foliar applications, plus impacts of dormancy induction/alleviation by nitrogenous compounds.

Orchard/ rootstock	%N, Feb		%N, Mar		%N, Apr		
	Buds				Leaves		Fruit
	Shoot	Spur	Shoot	Spur	Shoot	Spur	
Orchard 1/ mahaleb rootstock	1.6-1.7	1.6-1.7	2.2-2.5	2.9-3.2	2.9-3.0	3.0-3.2	3.2-3.4
Orchard 2/ Gisela 6 rootstock	2.2-2.5	2.2-2.3	2.6-3.0	2.9-3.2	3.6-4.0	3.8-4.0	3.8-4.4
Orchard 3/ Mazzard rootstock	1.3-1.4	1.3-1.5	2.4-2.5	2.4-2.6	2.6-2.8	2.8-2.9	2.9-3.0

Table 4.
Leaf area (mm^2) of 'Bing' (*Prunus* avium) sweet cherry at three orchards in 2008 comparing standard soil application with reduced soil application supplemented with physiologically-timed foliar applications. Fully-expanded leaves collected on April 11 from actively growing vegetative shoots or spurs in first year of bearing. Leaf digital images analyzed by ImageJ (vers.1.41b, http://rsbweb.nih.gov/ij/).

Orchard/rootstock and treatments	Shoot	Spur	Shoot + spur
Orchard 1: Lodi/mahaleb			
Treatment 1 (90# N, soil-applied June 23)	677 a [x]	516 a	597 a
Treatment 6 (1.12# N bloom, 45# N, June)	672 a	489 ab	580 ab
Treatment 8 (2.3# N post-bloom, 45# N, June)	661 a	491 ab	576 ab
Treatment 10 (1.12# N bloom, 2.3# N post-bloom, 45# N, June)	658 a	484 b	571 b
Orchard 2: Linden/Gisela 6			
Treatment 1	483 ab	369 a	426 a
Treatment 6	458 b	366 a	412 ab
Treatment 8	476 ab	318 b	397 b
Treatment 10	501 a	312 b	406 ab
Orchard 3: Linden/Mazzard			
Treatment 1	181 a	159 a	170 a
Treatment 6	152 a	156 a	154 a
Treatment 8	158 a	154 a	156 a
Treatment 10	163 a	151 a	157 a

[x] Means in the same column and orchard with different letters differ by Duncan's multiple range test at $P < 0.05$.
[y] Treatments evaluated represented only those differing in nitrogen application through harvest period: Treatment 1 = no N preharvest, Treatment 6 = foliar N at bloom and petal fall as Pacific Hort Grow Plus N, Treatment 8 = foliar urea applied ~1 month postbloom, Treatment 10 = bloom + petal fall + postbloom applications

Table 5.
Vegetative growth as increase in trunk cross-sectional area (TCSA, in mm^2) in 'Bing' (*Prunus* avium) sweet cherry at three orchards in 2008, comparing standard soil application ($CaNO_3$ 15.5%N) with reduced soil application supplemented with physiologically-timed foliar [x] applications, plus impacts of dormancy induction/alleviation by nitrogenous compounds. Actual pounds N per acre shown; foliar applications of N are low-biuret urea (46% N) or PacificHort Grow Plus N (PHG+N, 15% ammoniacal N). Orchards vary by location (Lodi or Linden, CA, and rootstock [*P. mahaleb*, 'Gisela 6' or 'Mazzard' (both *P. avium*)].

Orchard/rootstock		Lodi/mahaleb	Linden	
Treatment[y]			Gisela 6	Mazzard
T1	$CaNO_3$ soil June 23 (90#)	55.0 a[x]	32.2 a	42.2 ab
T2	$CaNO_3$ soil (90#), 20# each urea + zinc sulfate early Nov, KNO_3 6% w/v dormant	59.5 a	35.6 a	35.1 ab
T3	$CaNO_3$ soil (90#), 20# each urea + zinc sulfate, 25% CAN-17	50.3 a	42.3 a	28.9 b
T4	$CaNO_3$ soil (45#), 20# each urea + zinc sulfate, 25% CAN-17	61.7 a	25.9 a	44.9 ab
T5	$CaNO_3$ soil (45#), 25 + 20# urea Oct 20 + 27	57.0 a	56.7 a	52.5 ab
T6	$CaNO_3$ soil (45#), bloom + petal fall foliar (1.12#)	37.7 a	25.1 a	70.1 ab
T7	$CaNO_3$ soil (45#), 25 + 20# urea Oct 20 + 27, bloom + petal fall foliar (1.12#)	61.6 a	40.6 a	72.3 ab
T8	$CaNO_3$ soil (45#), foliar postbloom (2.3#)	58.3 a	32.5 a	53.3 ab
T9	$CaNO_3$ soil (45#), foliar postbloom (2.3#), 25 + 20# urea Oct 20 + 27	49.5 a	29.8 a	47.1 ab
T10	$CaNO_3$ soil (45#), bloom + petal fall foliar (1.12#), foliar postbloom (2.3#) 25 + 20#, urea Oct 20 + 27	68.1 a	55.4 a	76.2 a

[x] Mean separation within columns by Duncan's multiple range test, $P > 0.05$.
[Y] Calculated carrier volume for standard trees at Lodi/mahaleb and Linden/Mazzard orchards = 150 gal/A; at Linden/Gisela 6 orchard, carrier volume = 75 gal/A for smaller trees on dwarfing rootstock. Nitrogen shown as actual lb/acre in parentheses.

Table 6.
Effect of N fertilizer treatments[z] on fruit maturity (% fruit in given color) in 'Bing' sweet cherry, 2008. Salable[y] fruit are defect-free, light red, dark red and mahogany as defined by Minolta CR-10 colorimeter and California Cherry Advisory Board color card.

Orchard/rootstock and treatments	Green Straw	Color break	Light red	Dark red	Mahogany	Salabley
Orchard 1: Lodi/mahaleb						
Treatment 1 (90# N, soil-applied June 23)	1 a [x]	9 a	46 a	39 a	6 a	90 a
Treatment 6 (1.12# N bloom, 45# N, June)	1 a	4 a	45 a	46 a	4 a	95 a
Treatment 8 (2.3# N post-bloom, 45# N, June)	4 a	28 a	47 a	8 b	12 a	68 a
Treatment 10 (1.12# N bloom, 2.3# N post-bloom, 45# N, June)	6 a	15 a	45 a	30 ab	4 a	80 a
Orchard 2: Linden/Gisela 6						
Treatment 1	0 a	22 a	47 a	31 a	0	78 a
Treatment 6	0 a	25 a	49 a	26 a	0	75 a
Treatment 8	0 a	18 a	50 a	32 a	0	82 a
Treatment 10	2 a	33 a	41 a	24 a	0	65 a
Orchard 3: Linden/Mazzard						
Treatment 1	2 a	50 a	35 b	13 a	0	48 b
Treatment 6	7 a	37 ab	45 ab	11 a	0	56 ab
Treatment 8	1 a	45 ab	45 ab	9 a	0	54 ab
Treatment 10	0 a	25 b	65 a	10 a	0	75 a

[x] Means in the same column and orchard with different letters differ by Duncan's multiple range test at $P < 0.05$.
[z] Treatments evaluated represented only those differing in nitrogen application through harvest period.

Table 7.
Effect of N fertilizer treatments[z] on fruit quality [y] (size, firmness, and fruit removal force [FRF, stem 'pull force']) in 'Bing' sweet cherry, 2008. Only salable fruit were tested (salable = defect-free, light red, dark red and mahogany by colorimeter and California Cherry Advisory Board color card).

Orchard/rootstock and treatments	Firmness (g/cm^2)	Rowsize	FRF (g/cm^2)
Orchard 1: Lodi/mahaleb			
Treatment 1 (90# N, soil-applied June 23)	280 a [x]	9.7 a	626 ab
Treatment 6 (1.12# N bloom, 45# N, June)	281 a	10.0 b	606 ab
Treatment 8 (2.3# N post-bloom, 45# N, June)	285 a	10.0 b	580 b
Treatment 10 (1.12# N bloom, 2.3# N post-bloom, 45# N, June)	278 a	10.2 c	641 a
Orchard 2: Linden/Gisela 6			
Treatment 1	359 a	9.8 a	638 a
Treatment 6	361 a	9.8 a	579 bc
Treatment 8	339 a	10.0 a	541 c
Treatment 10	367 a	9.8 a	615 ab
Orchard 3: Linden/Mazzard			
Treatment 1	310 ab	9.4 b	388 a
Treatment 6	286 c	9.3 a	347 b
Treatment 8	318 a	9.5 b	399 a
Treatment 10	304 b	9.6 c	381 ab

[x] Means in the same column and orchard with different letters differ by Duncan's multiple range test at $P < 0.05$.
[y] A '10 row' cherry has a diameter of ~1" and a '9 row' cherry has a diameter of ~1.2", thus larger number for rowsize = smaller diameter fruit. Firmness measured by FirmTechII (BioWorks, Wamego, Kansas). FRF measured by Imada DS2 digital force gauge.
[z] Treatments evaluated represented only those differing in nitrogen application through harvest period: Treatment 1 = no N preharvest, Treatment 6 = foliar N at bloom and petal fall as Pacific Hort Grow Plus N, Treatment 8 = foliar urea applied ~1 month postbloom, Treatment 10 = bloom + petal fall + postbloom applications.

Table 8.
Effect of N fertilizer treatments[y] on yields and fruit quality in 'Bing' sweet cherry, 2008; trunk circumference measured at start of growing season used to calculate yield efficiency (TCSA [trunk cross-sectional area]/yield).

Orchard/rootstock and treatments	g/25 fruit	Brix	Yield/tree (kg)	Yield efficiency
Orchard 1: Lodi/mahaleb				
Treatment 1 (90# N, soil-applied June 23)	241 ax	17 a	48 a	0.094 a
Treatment 6 (1.12# N bloom, 45# N, June)	238 a	20 a	57 a	0.134 a
Treatment 8 (2.3# N post-bloom, 45# N, June)	246 a	20 a	50 a	0.100 a
Treatment 10 (1.12# N bloom, 2.3# N post-bloom, 45# N, June)	224 a	19 a	60 a	0.107 a
Orchard 2: Linden/Gisela 6				
Treatment 1	224 a	23 a	13 a	0.084 a
Treatment 6	235 a	24 a	16 a	0.093 a
Treatment 8	235 a	24 a	22 a	0.109 a
Treatment 10	228 a	25 a	16 a	0.084 a
Orchard 3: Linden/Mazzard				
Treatment 1	243 b	21 a	27 a	0.068 a
Treatment 6	260 a	21 a	30 a	0.073 a
Treatment 8	248 ab	23 a	31 a	0.085 a
Treatment 10	239 b	22 a	27 a	0.071 a

[x] Means in the same column and orchard with different letters differ by Duncan's multiple range test at $P < 0.05$.
[y] Treatments evaluated represented only those differing in nitrogen application through harvest period.

Developing 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 drip-irrigated 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.

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.

DESCRIPTION

2007

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

1. Low N fertility
2. Low P fertility
3. Adequate N and P fertility
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 P_2O_5/acre). N fertility was manipulated by varying weekly fertigation amounts.

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. NO_3-N, PO_4-P and K concentration in petiole sap
4. NO_3-N, PO_4-P and K concentration in dry petioles
5. NO_3-N, PO_4-P, and K in plant xylem flow (collected by a pressure apparatus)
6. Soil NO_3-N and NH_4-N in a composite sample of the top 8 inches of the wetted zone
7. Soil NO_3-N, PO_4-P and K in soil solution collected in the field from suction lysimeters
8. Soil NO_3-N, PO_4-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 approximately a week prior to commercial harvest stage, when >85% of fruit was red.

In addition to the UC Davis 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 maturity.

2008

The experiment at UC Davis was repeated with the same treatments, varieties and experimental design. Transplants were planted April 28. Seasonal N rate ranged from 103-286 pounds per acre, seasonal P_2O_5 rate from 0-140 pounds per acre. Additionally, three commercial fiel ds in the San Joaquin Valley were monitored. Five times during the season all the fertility measurements previously described were made; the last sampling was done approximately a week before commercial maturity.

RESULTS

Site and management details of all fields monitored are given in Table 1. Nutrient inputs were relatively consistent among the commercial fields, and bracketed the 'adequate' fertility treatment at UC Davis. All fields had relatively high total fruit yield, ranging from 45-71 tons per acre (Table 2); typically approximately 90% of total fruit yield would be marketable. Plant vigor varied among fields, ranging from 7,200-14,400 lb above-ground biomass/acre; fruit yield was highly correlated to biomass production (r = 0.92).

Analysis of 2008 samples continues, so nutrient uptake data is shown only for the 2007 fields. Total N uptake (vine and fruit) was similar in all 2007 fields, averaging approximately 220 pound per acre. P and K uptake varied substantially

among fields, ranging from 25-34 pounds P acre and 159-319 pounds K per 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.

The pattern of nutrient uptake through the season was similar in all fields; data from the UC Davis trial are illustrated in Figure 1. The majority of seasonal nutrient uptake occurred 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 UC Davis, nutrient uptake rates peaked between 4-5 pounds of N, 0.6-0.8 pounds P and 6-7 pounds K per 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 UC Davis, fruit yield of the varieties responded differently to the nutrient regimes. AB2 showed less loss of yield with low N and P fertilization than did H9780 (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 UC Davis, 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.

Definitive conclusions about appropriate soil and plant monitoring techniques cannot be drawn until analysis of all 2008 samples is complete. However, based on 2007 data, it is clear that petiole analysis for unassimilated nutrients (NO_3-N, PO_4-P) is more highly variable than leaf analysis for total N and P. Petiole analysis alone is an insufficient basis on which to make future fertigation decisions. Similarly, the stratification of nitrate in the root zone of drip-irrigated fields makes collection of a representative soil sample difficult. Given the similarity of crop nutrient uptake patterns across fields, the most efficient approach to fertigation may be to employ a fertigation template based on that uptake pattern, to be modified for field-specific conditions such as preplant soil P and K levels, and the level of soil NO_3-N present at the initiation of drip irrigation.

Table 1.
Cultural detail and fertility rates for the UC Davis and commercial fields monitored.

					Seasonal fertilizer rate (lb/acre)		
Year	Field	County	Transplant date	Variety	N	P_2O_5	K_2O
2007	UC Davis	Yolo	May 9	AB2, H9780			
	Low N				63	70	0
	Low P				173	0	0
	Adequate fertility				173	70	0
	Excessive fertility				258	140	0
	1	Yolo	April 4	H2601	169	14	24
	2	Yolo	May 1	AB5	181	14	18
	3	Yolo	May 10	AB2	186	90	33
2008	UC Davis	Yolo	April 28	AB2, H9780			
	Low N				103	70	0
	Low P				160	0	0
	Adequate fertility				183	70	0
	Excessive fertility				286	140	0
	4	Fresno	April 3	AB2	166	32	0
	5	Fresno	April 16	H2401	196	67	0
	6	Fresno	April 19	H8004	214	53	0

Table 2.
Crop productivity and nutrient uptake in the monitored fields.

		Biomass dry weight	Total fruit yield	Biomass nutrient content (lb/acre)		
Year	Field	(lb/acre)	(tons/acre)	N	P	K
2007	UC Davis[z]	10,100	58	208	34	319
	1	7,200	45	197	25	159
	2	9,500	51	243	27	194
	3	9,700	59	245	34	227
2008	UC Davis[z]	13,400	66	*		
	4	10,300	51			
	5	9,400	49			
	6	14,400	71			

[z] Mean of AB 2 and H 9780 varieties, “adequate” nutrient regime.
* Analysis still in progress.

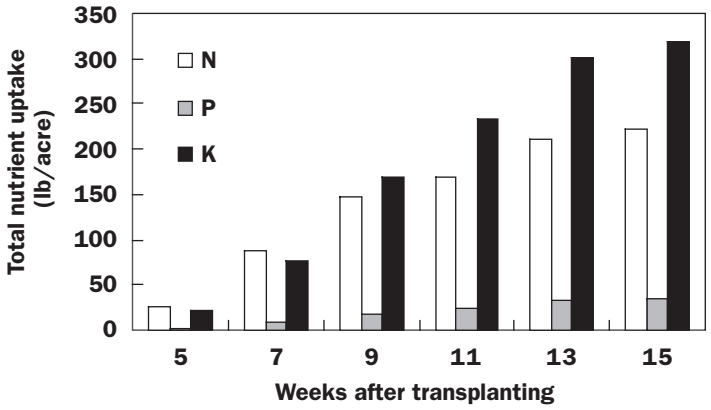

Figure 1.
Pattern of nutrient uptake over the growing season; mean of AB2 and H9780 varieties grown at UC Davis, 2007.

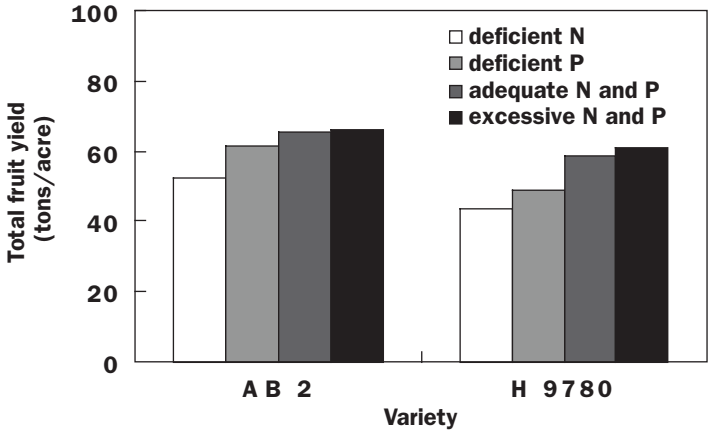

Figure 2.
Effect of fertility treatment on total fruit yield at UC Davis, average of 2007-08 trials.

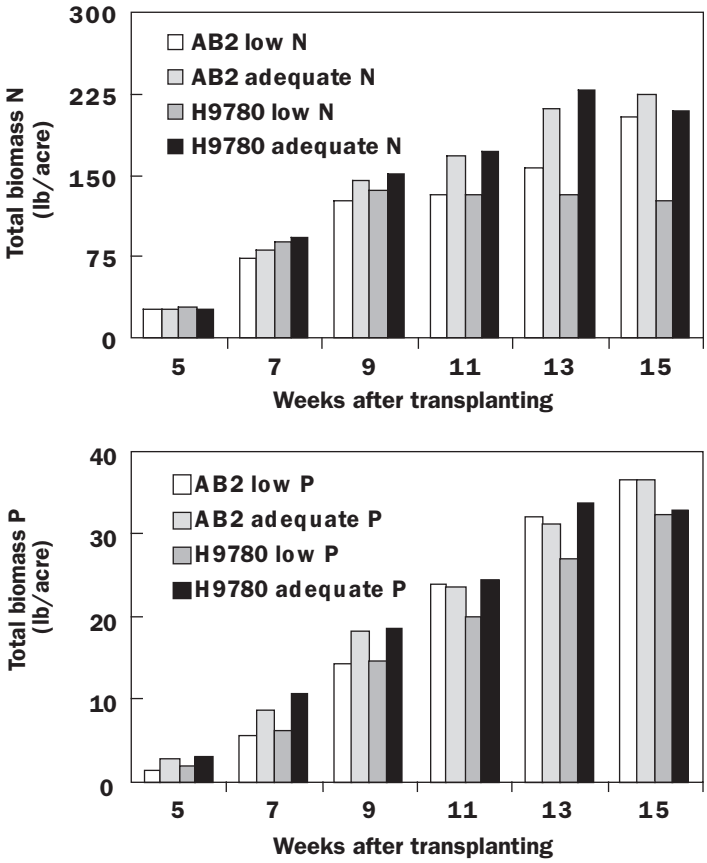

Figure 3.
Effect of fertility treatments on N and P uptake in the 2007 UC Davis trial.

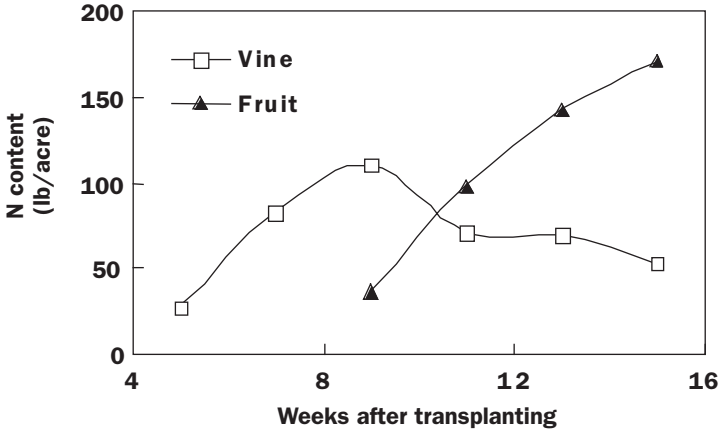

Figure 4.
Partitioning of nutrients between vine and fruit, AB2 variety at UC Davis.

Using Site-Specific Fertilization in Orchards, Nurseries, and Landscapes

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INTRODUCTION

Demand for water and fertilizer across a field can vary greatly with location, indicating that uniform application rates are either wasteful or insufficient. To complicate matters, fertigation uniformity may be adversely affected by factors such as flow time through the pipes, fertilizer diffusion in the pipes, and emitter clogging.

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 system would likely impede commercial adoption, we started 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 could 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 electrical conductivity, pressure, soil moisture, and flow sensors will allow intelligent water and fertilizer control, and automatic detection of line breaks and emitter clogging.

OBJECTIVES

Variations in plant nutrient demand and environmental regulations provide significant incentive for development of fertigation systems that allow control of water and chemicals at a resolution smaller than the entire field or nursery block. Ease of installation and simplicity of operation suggest elimination of wires from the system. Therefore, our objectives in this research project are:

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.

DESCRIPTION AND RESULTS

Wireless Design

Since this system was intended for application in orchards, landscapes, and nurseries, the wireless network had to be versatile enough to operate in many environments. Mesh networking allows messages to pass from one node to any other node in the network by routing them through intermediate nodes (Figure 1). One advantage of this system is increased network range without using high-power radios. This allows greater flexibility in node placement since interference or poor range between two nodes may be rendered moot by an alternate communication path. Another advantage is redundancy; a failed node does not disable the network since multiple routing paths exist. In the system presented here,

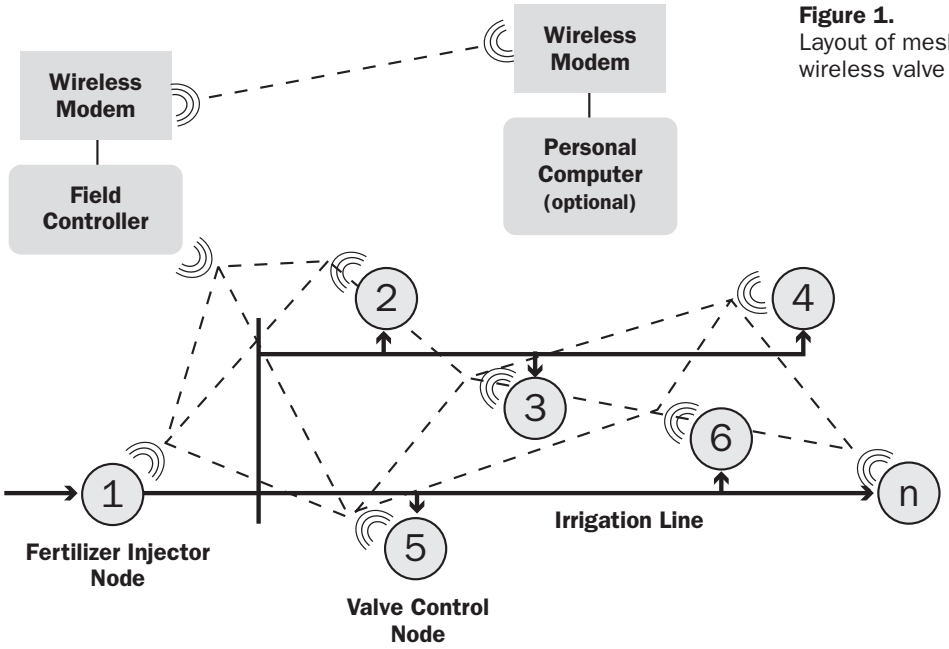

Figure 1.
Layout of mesh network for wireless valve control.

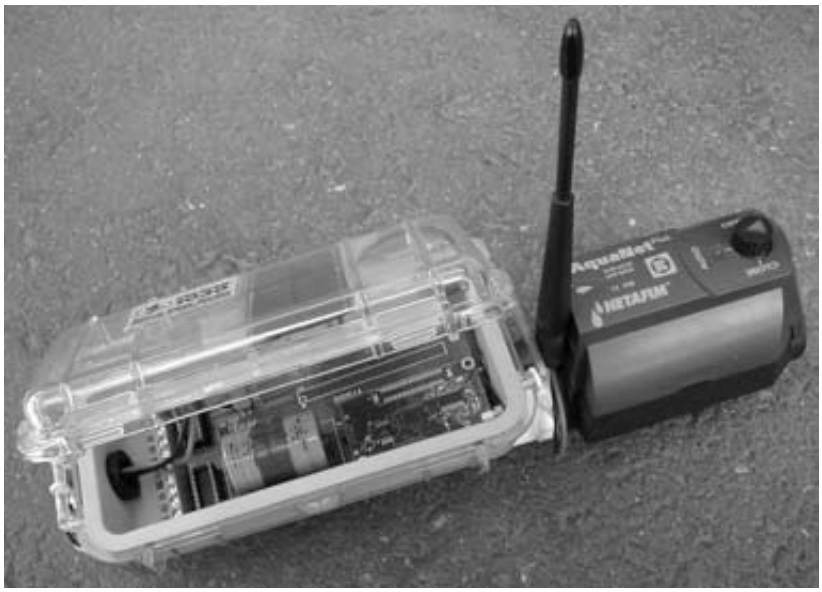

Figure 2.
Wireless valve controller with 1-inch latching valve.

an operator enters node addresses and irrigation schedules on the central field controller and they are distributed to individual nodes in the network. An optional personal computer can provide a graphical interface, but is not required to operate the system.

Hardware

A 916 MHz wireless module (MPR400CB, Crossbow Technology, San Jose, California) was adopted for our valve controller design (Figure 2). The manufacturer 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 was connected to a circuit board providing sensor inputs and valve control lines. A nickel-cadmium battery and a miniature solar panel were selected to provide continuous operation without yearly battery replacement. A latching solenoid valve (Netafim, Tel Aviv, Israel) was opened or closed with an 80 ms pulse from the battery. The wireless module was connected to a 1/2-wave dipole antenna (S467FL-5-RMM-915S, Nearson, Springfield, Virginia) for increased range.

A base node consisting of a wireless module and RS-232 gateway (MIB510CA, Crossbow Technology) was connected by serial cable to an embedded controller (TD40, Tern, Davis, California), which served as the field controller for the network of remote nodes. The field controller contained a keypad to allow entry of schedules and manual operation of the remote valves, and a liquid crystal display (LCD) for viewing status information.

Software

The mesh networking protocol (XMesh) was handled by software included with the wireless modules. Additional software was written for latching valve actuation, a software real-time clock, schedule storage and execution, and external sensor measurement. Each remote

node in the network was programmed with a unique address between 1 and 9999. External sensors and internal voltages were measured every 10 minutes and transmitted to the field controller. Closed-loop fertigation control using conductivity sensors and flow meters is being developed. Closed-loop irrigation control based on soil moisture measurements and fault detection based on pressure measurements were tested in previous work and will be added to these units in future software revisions.

Wireless Range and Function

Maximum one-hop radio range was tested using the base node and one remote node. The wireless nodes were tested with 1/4-wave whip antennas and 1/2-wave dipole antennas. Tests were conducted under visual line-of-sight conditions (open field) and obstructed conditions (young peach orchard with four-meter-high canopy) with the nodes on the ground or elevated one, two, or three meters on a wooden stake. The results (Table 1) showed that mean range varied greatly depending on the node configuration and the test environment. Orchard range was difficult to measure due to erratic connectivity near the maximum range. In some cases, the remote node could be moved a few centimeters between two locations with full and zero signals. This illustrates the value of a mesh network, which provides multiple paths of communication. To achieve a one-hop range of 100 meters would, in the conditions tested here, require a dipole antenna mounted slightly higher than one meter or a whip antenna mounted slightly higher than two meters. In general, elevating a node with whip antenna by one meter improved range as much as adding a dipole antenna. Ground level units would require about 20- to 30-meter spacing to ensure adequate wireless connectivity. Extrapolation of these results for range estimation in other fields or orchards is difficult since the conditions would likely be different in each location.

Table 1.
Radio range under various conditions.

View	Antenna	Elevation (m)	Mean Range (m)
VLOS[1]	Whip	0	20.9
		1	67.6
		2	97.8
		3	205.2
	Dipole	0	32.7
		1	92.8
		2	192.6
		3	241.1
Orchard	Whip	0	21.7
		1	46.9
		2	94.0
		3	119.4
	Dipole	0	30.0
		1	83.2
		2	128.4
		3	145.9

[1]Visual line-of-sight

The general functionality of network messaging was tested by sending valve, time, and schedule commands to the remote nodes in a mesh network. Eight remote nodes were placed close to the base or in distant locations that forced them to create a multi-hop mesh network. Each node acknowledged commands, returned correct clock values, and properly opened or closed a valve. This indicated that the mesh network was operating correctly, although there were a few instances where nodes did not respond on the first attempt. This always occurred after moving the nodes to a new location or early in the re-routing test. In all cases, waiting several minutes allowed the network to stabilize and operate correctly. The average time between command and acknowledgment at the base was 2.2 seconds for a one-hop message, 5.6 seconds for a two-hop message, and 9.3 seconds for a three-hop message, giving a mean of 2.7 seconds per hop. Over the time frame of an irrigation cycle, such

delays in communication are negligible. In a re-routing test, one node in the path to the furthest node was turned off. After several minutes of no response, subsequent messages were successfully routed along the new path, showing the self-healing properties of a mesh network.

Proper schedule execution required the remote nodes to maintain the correct date and time during operation. However, the internal clock was subject to inaccuracy because of crystal frequency drift. A simple test was done to measure the amount of daily clock drift. To start, the clock of the embedded controller was set to the nearest second on a reference clock. The clocks of two remote nodes were set by radio transmission of the current time stored on the embedded controller. Over eight days, the clocks of the embedded controller and the two remote nodes were queried and compared to the reference time. The average clock drift per day was calculated. A linear regression of the embedded controller data gave an average lag of 0.4 seconds per day. A linear regression of the combined data of Nodes 1 and 2 gave a lag of 6.3 seconds per day of operation. If uncorrected for several weeks, scheduled irrigations or sensor

Figure 3.
Electrical conductivity probe with threaded body for installation on fertigation line.

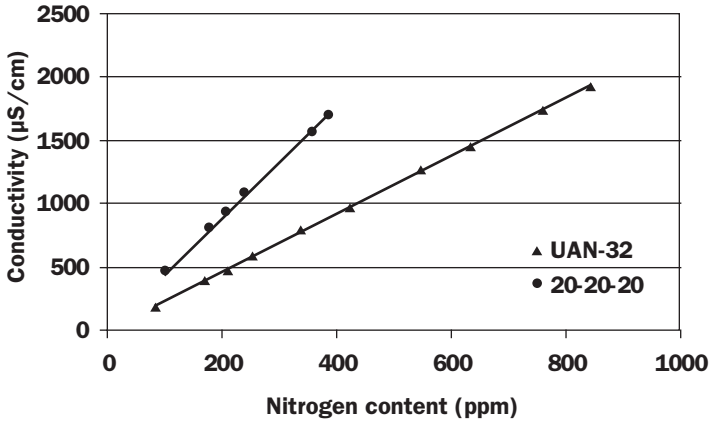

Figure 4.
Electrical conductivity of fertilizer solutions with known nitrogen concentration.

measurements would occur minutes later than expected. To ensure the embedded controller and remote nodes maintained synchronized clocks, the remote nodes were updated with a new time stamp each day.

Energy Management

Current consumption of the remote nodes was measured during wake/sleep power cycling, radio operations, sensor measurement, and valve operation. To extend battery life, nodes were in sleep-mode most of the time and only used the radio when data transfer was required. This power-cycling feature was included with the wireless module software. The total charge consumption of a node was estimated to be 6.76 mA · h per day. NiCd batteries self-discharge at 15-20% per month, which for the 170 mA · h battery used here, was about 29.75 mA · h per month (1 mA · h per day). Node charge consumption and battery self-discharge has to be balanced by solar panel charge production in order to ensure continuous operation of the valve controller.

Tests of solar panel performance yielded a charge production of 26.0-81.3 mA · h in direct sunlight and 6.5-13.7 mA · h in shade. Full sunlight on a daily basis would overcharge the battery, whereas full shade on a daily basis might not provide adequate energy to recharge it. A solar panel disconnect feature will be used to ensure continuous node operation without battery degradation from overcharging. Intelligent energy management by the node software will help ensure battery consumption remains low during extended periods of poor solar panel output. Theoretically, the 170 mA · h NiCd battery used here should be able to supply a 7.76 mA · h per day load (node and self-discharge) for 22 days. In testing, this duration was not achieved. A node without solar panel operated for just over 13 days before its battery voltage fell below 7.2 V, and finally to 3.5 V after a total of 17 days.

Fertigation Control

As valves open and close in a spatially variable irrigation system, water pressure and flow rate will change. 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 individually controlled blocks or emitters at different rates or times, fertilizer travel times could be difficult to predict. Electrical conductivity (EC) sensors in the irrigation line will allow the wireless network to locate the fertilizer head and tail by the change in conductivity as the fertilizer passes through. Using fertilizer-specific calibrations, the actual concentration of fertilizer could also be determined. This information will be used to adjust fertigation timing at each control valve in real time.

A simple two-pin EC probe (CDH-712, Omega Engineering, Stamford, Connecticut) with threaded body was selected for ease of installation into an irrigation system (Figure 3). The probe has a 0 to 2,000 µS/cm range. This will be suitable for nurseries and greenhouses with frequent fertigation using general fertilizer injected at about 100 to 450 ppm nitrogen. A greater range sensor will be needed for orchard and vineyard fertigations which typically use higher concentrations of nutrient (up to 10,000 ppm nitrogen) and operate less frequently. The conductivities of two fertilizer solutions were measured at known concentrations of nitrogen: Urea-Ammonium-Nitrate-32% (UAN-32) and a general NPK fertilizer (20-20-20). Liquid UAN-32 alone has a nitrogen concentration of 421,789 ppm (mg/L). Solutions of known concentration were made by dilution in distilled water, which has a conductivity of 0 µS/cm. Quantities of 20-20-20 were weighed on a laboratory scale and dissolved in distilled water to create solutions of known nitrogen concentration (ppm, mg/L) based on the fact that the fertilizer is 20% nitrogen by weight. The measured conductivity was a linear

function of nitrogen concentration (Figure 4). Calibration equations will be programmed into the wireless nodes allowing them to measure the nitrogen concentration of the injected fertilizer stream during fertigation. Accurate measurements will also require the nodes to regularly recalibrate themselves to use the baseline conductivity of the irrigation water. For example, tap water in our laboratory had a measured conductivity of 520 µS/cm.

WORK IN PROGRESS

Twenty wireless valve controllers have been manufactured and will be deployed to nurseries and landscapes for field testing. Sensors will be connected to the nodes for monitoring water pressure, soil moisture level, or other parameters. We will test site-specific fertigation control in a UC Davis orchard microsprinkler system or other suitable location. We will also complete an economic feasibility analysis to determine at what level a wireless system would be economically viable for a grower. We are in continued communication with Crossbow, the wireless module manufacturer, to promote commercialization of the techniques developed under this grant.

ACKNOWLEDGEMENTS

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Balancing Fertilizer Application Rates with Water Quality Protection in Strawberry Production

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INTRODUCTION

The Santa Maria Valley has high nitrate concentrations in ground water and surface water. Several wells have up to 70 ppm of nitrate. Many surface water samples have been measured in excess of 45 ppm, the EPA drinking water standard for nitrate. The Central Coast Regional Water Quality Control Board (RWQCB) Conditional Ag Waiver of 2004 (waiver) requires farmers to develop farm water quality management plans (farm plans) to document existing and implement additional management practices in order to reduce and clean up runoff which leaves their property. We are trying to develop tools to help farmers comply with water quality regulations and reduce some costs related to inputs. A great advantage to this work has been the farmer cooperators that we have been working with. We have set up two fertilizer trials in commercial strawberry fields.

One trial had three rates of preplant fertilizer, 0, 80 and 160 pounds of nitrogen (N) as 18-8-13 slow release fertilizer. We added a total of 44 pounds of N through the drip system. The 80-pound treatment was the most promising to the farmer, though we did not see significant differences in yield among the treatments. This year we are going to repeat the preplant treatments, lower the rates of preplant N to 0, 65 and 130 pounds, and have three different weekly injection rates. The weekly injection rates will be 2.5, 5, and 10, with total midseason additions of 20, 40 and 80 pounds of N per acre.

The second trial had tree rates of pre-plant compost, equivalent to 0, 10 and 20 tons of compost per acre and then three, six, and 12 pounds of N injected per week for 25 weeks. We did not see a difference in yield related to compost but we did see a direct relationship between weekly N rates and boxes of strawberries produced. The injectable organic N sources are expensive and are more problematic going through the drip lines than conventional N sources. This year's trial will focus on three different injectable N sources and the same three weekly N rates.

There are around 100 growers in Santa Maria that are farming on 40 acres or less and speak mostly Spanish. Many of them have requested assistance in developing irrigation and nutrient management plans. We have had two large group strawberry production meetings with this group, where the fertilizer trials were visited and discussed. We have had several small group meetings where we have discussed irrigation and nutrient management concepts. We are providing a "follow-up" assistance to this group, where we try to help them utilize some of the technology from the fertilizer trials on their farms. Many have applied one-half of the preplant fertilizer compared to last year. An outline of the farm planning information that we are offering to these farmers is given below.

DESCRIPTION

Our approach is to develop a farm water quality management plan tool box. The tool box consists of an irrigation compartment and nutrient management plans.

The steps in the irrigation compartment look like this:

1 Irrigation mobile lab evaluations for distribution uniformity (DU).

- Our mobile lab technicians perform a catch-can experiment and take pressure readings throughout the field to determine a field's DU. The DU is a measure of how evenly water is applied over the entire field.

  DU_{lq} = Average low quarter H_2O depth ÷ average H_2O depth in all elements

2 Determine the amount of nitrate and salt in the irrigation water.

- Nitrate procedure: Dip an EM Quant® nitrate test strip into the water for one second, shake off excess solution, and wait 60 seconds. Estimate nitrate concentration using the color chart provided. Nitrate-N content (consider as fertilizer, if >10)
- The strip reading gives units of NO3- in parts per million (ppm).
- ppm NO_3- ÷ 4.43 = ppm NO_3-N
- ppm NO_3-N x 1 inch x 0.227 = pounds of NO_3-N per acre-inch of water applied

  Example: Nitrate strip reading from well water = 100 ppm NO_3-÷ 4.43 = 22.5 ppm

  - 22.5 ppm NO_3-N x 1 inch of H_2O x 0.227 = 5 lbs NO_3-N per acre-inch of water applied.

  Salinity is measured with an electrical conductivity meter and if the electrical conductivity of irrigation water (EC_w), is high, then utilize a leaching fraction. For strawberries, an ECw of 0.7 can limit production by 10%.

  A leaching fraction is an application of an amount of irrigation water greater than the plant root zone will hold. The salt is pushed out of the plant root zone by a leaching fraction. Remember that N fertilizers act as salts, and leaching fractions should be put on before fertilizer application rather than immediately after.

Example: If one inch of water is required to fill the plant root-zone and the farmer applies 1.2 inches of water in order to push the salts out of the plant root-zone, then the 0.2 extra inches of water is considered the leaching fraction.

3 Develop an irrigation schedule.

- Determine the soil's infiltration rate and water holding capacity from USDA soil survey report, by interviewing the farmer, and by performing on-site soil probing and observations.
- Determine the amount of flow that the well can produce in gallons per minute produced by the pump from flow meter or interviewing farmer and observations.
- Calculate how many minutes or hours of drip irrigation are required to add one inch of water.
- Relate inches of water applied to depth of water penetration.
- Train the farmer to determine soil moisture by feel and/or install and train him to utilize tensiometers, the strawberry beds are irrigated so frequently that low range tensiometers are necessary, these measure the soil moisture tension at a range of 0 to 50 centibars.
- Discuss timing of leaching fractions and fertilizer injections, and the relationship between the two.

An irrigation evaluation of drip systems also includes a water analysis for Fe concentration and bicarbonates in order to determine causes of emitter plugging.

The steps in the nutrient management plan compartment look like this:

4 Determine crop's nitrogen requirement.

- Assist the farmer in determining how much nitrogen to apply over the entire season. Information sources include the Western Fertilizer Handbook; University of California, Davis; private agricultural lab recommendations; private consultants; and fertilizer trials with UC Cooperative Extension.

5 Take a preplant soil sample.

- Soil sample ten or more subsamples per management unit.
- Send to a lab for analysis and recommendations.
- Discuss the lab's recommendations with the farmer in relation to the N requirement and the field salinity and previous crop conditions.

6 Determine preplant fertilizer requirement.

- Define a site-specific preplant fertilization program to be applied before the plastic mulch is applied. Once the plastic mulch is in place, the only means of getting significant fertilizer to the plants is by injecting through the drip system.

  Electrical conductivity of the soil extract is represented by EC_s. If $EC_s \geq 1.0$, then sprinkle irrigate for up to 12 hours, in order to leach the salts. Sprinkle before the plastic covers the beds.

  Strawberries grow best at a pH of 6.8 or lower (slightly acidic condition). If the soil pH is higher than 6.8, then apply bulk sulfur, or Tiger Sulfur® at preplant. The field may need additional pH adjustment

midseason, and if so, then inject calcium thiosulfate CaS_2 through the drip system.

Phosphorus (P) and micronutrients do not leach so it is best if they can be applied 100% at preplant.

Potassium (K) can be applied 100% at preplant, or 50% preplant and then the remaining 50% injected through drip system at mid-season.

A portion of the crops N requirement can be applied preplant, from 20% to 50% of the amount determined under Step 4 above. The remainder should be injected through the drip system.

7 Define a mid-season fertilizer program.

- All midseason amendments must be injectable through the drip system, since the plastic mulch bed covers prevent other soil application methods.

8 Conduct mid-season soil nitrate quick test.

- The farmer can determine when to begin nitrogen injections by soil sampling in the plant root zone. He should pull 10 subsamples from the plant root-zone and then perform the soil nitrate quick test.

  If test strip reads ≥50 ppm nitrate, then he doesn't need to add N fertilizer; if <50, consider an injection of N fertilizer.

  Time irrigations so that any leaching fractions occur before fertilizer injections, as discussed above under Step 2.

Here is an example of a nitrogen budget for a strawberry crop:

The farmer determines that his crop requires 160 pounds of N, 30 pounds of P and 120 pounds of K for the entire season.

He decides to apply 50% of the N as a slow release (18-8-13) before planting.

Apply = 445 pounds of 18-8-13 fertilizer to add 80 pounds of N, 35 pounds of P and 57 pounds of K.

The remaining 80 of pounds N, 0 pounds of P, and 63 pounds of K will be made with midseason injections.

Potassium nitrate (KNO_3-N) is equivalent of a 13-0-46 that is water soluble. A solution would weigh about 12 pounds per gallon and every gallon would contain 1.5 pounds of N and 5.5 pounds of K. Injecting six midseason applications of two gallons per acre of KNO_3-N would deliver 18 pounds of N and 66 pounds of K.

CAN-17 is a commonly used material. It weighs about 12 pounds per gallon and contains 17% N and therefore contains about two pounds N per gallon. The remaining 62 pounds of N could be applied as CAN-17. He could make seven injections of five gallons CAN-17 per injection per acre, which would deliver a total 70 pounds of N per acre.

9 Assess mid-season salt buildup.

- Salts accumulate quickly in the strawberry beds. We can perform a quick test for ECs on the soil pulled for a soil nitrate quick-test described above. If ECs >1.0, then apply a drip irrigation that includes a leaching fraction as described under Step 2 above.
- Injections of calcium thiosulfate (CaS_2) or soluble gypsum ($CaSO_4$) prior to the leaching fraction irrigation is also a practical way to reduce salinity in the plant root-zone.

There are some additional tools that we are considering in our fertilizer trials:

- Leaf and petiole sampling and quick analysis with the Horiba Cardy® meter.
- Soil suction lysimeters are being used to sample the leachate below the root zone.
- Varying cut-back dates, and injectable fertilizer rates for a secondary fresh market.

CONCLUSION

In summary, there is one toolbox and the irrigation and nutrient tools are tightly linked. Poor DU in a drip system equals poor DU for all of the fertilizer injected through it. Nitrate-nitrogen moves wherever the water moves and if that is past the root zone, then that nitrogen is lost. Fertilizer costs are increasing, water quality regulations are tightening, and the price that a farmer gets for a box of strawberries is about the same as it was five years ago. The tools are not new, merely crop specific adaptations and customization of basic soil, plant and water sampling and evaluation. The concepts utilized and developed here in strawberries can also be useful in other row-crop production systems.

Developing a Nutrient Budget Approach to Fertilizer Management in Almond

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INTRODUCTION

There are many different approaches to nutrient management in crops that range from the simple to the sophisticated. In its simplest iteration, nutrients are applied based upon results of leaf analysis and comparison with established "critical values" (CVs). In this approach, leaf nutrient analysis provides only an indication of adequacy or deficiency but does not provide any specific information on the appropriate rate or timing of any fertilizer response. CVs are an inadequate approach to nutrient management in a high value species. Not only is the collection of a representative leaf sample difficult, and generally collected too late in the season to respond, our degree of confidence in the existing CVs is limited and most importantly the results provide no specific information on how to respond. An alternative approach, which is widely used in high value agricultural enterprises such as animal production, aquaculture, greenhouse vegetable and flower production, and increasingly in agronomic crops, is to use knowledge of growth and development to derive nutrient demand curves that guide the timing and quantity of nutrient applications. In these approaches, growth models, estimates of daily nutrient intakes, knowledge of nutrient bioavailability and the interactions between nutrients and other inputs are integrated to ensure that nutrient supply does not limit growth and that profitability is maximized by avoiding excess applications.

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

OBJECTIVES

1. Develop a phenology- and yield-based nutrient model for almond.
2. Develop fertilizer response curves to relate nutrient demand with fertilizer rate and nutrient use efficiency.
3. Determine the effectiveness and nutrient use efficiency of various commercially important N and K fertilizer sources.
4. Validate current CVs and determine if nutrient-ratio analysis provides useful information to optimize fertility management.
5. Develop and extend an integrated nutrient BMP for almond.

DESCRIPTION

Tree nutrient demand is being determined by measuring nut development, nut nutrient content, and total nut biomass in 100 trees at four sites (Arbuckle, Salida, Madera and Bakersfield) in eight- to nine-year-old microsprinkler-irrigated almond orchards of good productivity planted to Nonpareil (50%) on uniform rootstock in soils representative of the region. Leaf samples have been collected in April, May, June, July, and October. Tissue determination for the major elements (N, P, K, S, Ca, Mg, B, Zn, Fe, Mn,and Cu) in all the collected nut samples and leaf samples is being processed by the Department of Land, Air and

Water Resources (DANR) analytical laboratory at University of California, Davis. Tree yield and quality attributes have been collected from all individual trees. All nutrient and biomass data will be cross-referenced to individual tree yield, phenology, environment and other variables to develop a phenology- and yield-based nutrient model for almond.

In a second experiment, a large experimental fertilizer response trial has been set up in an eight-year-old orchard, 50% Nonpariel and 50% Monterey. Experimental plots have been replicated under fan-jet and drip irrigation systems. Fifteen individual trees and their immediate 30 neighbors have been considered as a single uniformly treated unit with all measurements taken on the central six Nonpareil trees individually. A total of 128 experimental units of 15 trees have been treated, and from this, 768 individual trees will be monitored for yield, nut growth and development and full nutrient status. A fertigation system has been installed and a digital flow meter has been employed to provide well controlled doses of fertilizer during five fertigation events. Basal sulphate of potash (SOP) application was made in early February and fertigation was done in February, April, June, August, and October. The total experimental area is 100 acres.

The twelve treatments include four rates of N (125, 200, 275, 350 pounds per acre, all other elements held constant) applied through UAN-32; 3 rates of K (100, 200, 300 pounds per acre, applied as 60% SOP basal and 40% KTS fertigated; all other elements held constant), plus four contrasting rates of CAN-17, one KCl and one SOP treatments. Effectiveness of each treatment will be determined by changes in leaf tissue analysis, yield, and soil residual N and K over a three- to five-year period.

Leaf samples have been collected in April, May and June, July, and October. Tissue determination for the major elements (N, P, K, S, Ca, Mg, B, Zn, Fe, Mn and Cu) in all the collected nut samples and leaf samples is being processed by the DANR analytical laboratory at UC Davis. Tree yield and quality attributes have been collected from all individual trees. All nutrient and biomass data will be cross-referenced to individual tree yield, phenology, environment and other variables to develop a phenology- and yield-based nutrient model for almond.

RESULTS AND DISCUSSION

Currently the first four rounds of tissue sampling have been completed at four sites and results of tissue analysis from DANR laboratory are pending. Nuts have been harvested and yield has been determined for individual trees as well as for total numbers of experimental trees in all replication of every treatment. Once tissue analysis reports are available, data will be analyzed and a model of nutrient uptake will be developed. Average yield of treatments under fan-jet (Table 1) and drip (Table 2) is given below. These data are reported here as in-field dry whole fruit weight per tree average, pending completion of crack-out. At 25% kernel weight, yield range is from 3,300 to 3,600 pounds per acre kernel weight. Statistical analysis of kernel yield, development of phenology models and analysis of tissue nutrient levels and relationship with yield will be completed in the coming months. In the coming years this project will be supplemented with additional orchards, ground-based aerial and satellite sensing and advanced modeling approaches as a component of a USDA grant that has been received to further support this project.

Table 1.
Average yield of 15 trees, fan-jet section

Treatments	Replications						Total Average
	1	2	3	4	5	6	
	Yield (Lb)	Yield (Lb)	Yield (Lb)	Yield (Lb)	Yield (Lb)	Yield (Lb)	
Treatment A: N 125lb/ac, K 200lb/ac (UAN)	145	140	143	154	144		145
Treatment B: N 200lb/ac, K 200lb/ac (UAN)	146	157	145	160	148		151
Treatment C: N 275lb/ac, K 200lb/ac (UAN)	150	144	158	159	155	152	153
Treatment D: N 350lb/ac, K 200lb/ac (UAN)	142	133	170	174	156		155
Treatment E: N 125lb/ac, K 200lb/ac (CAN)	114	137	136	161	162		142
Treatment F: N 200lb/ac, K 200lb/ac (CAN)	141	142	141	172	164		152
Treatment G: N 275lb/ac, K 200lb/ac (CAN)	135	187	157	155	153	144	155
Treatment H: N 350lb/ac, K 200lb/ac (CAN)	132	135	143	164	155		146
Treatment I: N 275lb/ac, K 100lb/ac (UAN, SOP, KTS)	148	142	137	141	155		145
Treatment J: N 275lb/ac, K 300lb/ac (UAN, SOP, KTS)	129	146	171	156	154		151
Treatment K: N 275lb/ac, K 200lb/ac (UAN, SOP)	129	146	155	173	153	149	151
Treatment L: N 275lb/ac, K 200lb/ac (UAN, KCl)	136	150	140	155	146	147	146

Each value is the sum of yields measured on six individual harvested trees plus nine pooled trees (15 total per replicate per treatment)

Table 2.
Average yield of 15 trees, drip section

Treatments	Replications						Total Average
	1	2	3	4	5	6	
	Yield (Lb)	Yield (Lb)	Yield (Lb)	Yield (Lb)	Yield (Lb)	Yield (Lb)	
Treatment A: N 125lb/ac, K 200lb/ac (UAN)	169	146	150	176	155		159
Treatment B: N 200lb/ac, K 200lb/ac (UAN)	155	149	167	174	156		160
Treatment C: N 275lb/ac, K 200lb/ac (UAN)	165	173	184	170	159	157	168
Treatment D: N 350lb/ac, K 200lb/ac (UAN)	173	163	188	169	153		169
Treatment E: N 125lb/ac, K 200lb/ac (CAN)	170	145	163	165	155		160
Treatment F: N 200lb/ac, K 200lb/ac (CAN)	159	157	173	139	163		158
Treatment G: N 275lb/ac, K 200lb/ac (CAN)	166	158	169	177	167	170	168
Treatment H: N 350lb/ac, K 200lb/ac (CAN)	169	151	163	180	159		164
Treatment I: N 275lb/ac, K 100lb/ac (UAN, SOP, KTS)	166	156	172	190	164		170
Treatment J: N 275lb/ac, K 300lb/ac (UAN, SOP, KTS)	173	159	157	181	176		169
Treatment K N 275lb/ac, K 200lb/ac (UAN, SOP)	157	164	163	173	162	170	165
Treatment L N 275lb/ac, K 200lb/ac (UAN, KCl)	162	171	158	178	164	173	168

Developing Leaf Sampling and Interpretation Methods for Almond

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INTRODUCTION

In tree crop production in California, leaf sampling and critical value analysis represents the primary tool for fertilizer decision making (Brown and Uriu, 1996). Ninety percent of growers and consultants participating in the recent CDFA-FREP-funded focus groups on nutrition and subsequent surveys of growers, felt that University of California (UC) Critical Values (CVs) were not appropriate for current yield levels, were not useful early in the season and did not provide sufficient guidance for nutrient management. Two explanations for this observation are possible: 1) the current CVs are limited in application and are possibly incorrect; or 2) there are systematic errors in the manner in which critical values are used. While it is not known if UC CVs are incorrect (this will be verified), it is known that they have not been validated for early season use and it is clear that there has been a systematic error in the way leaf sampling and CVs have been used. We conclude that the "problem" with current CVs is not that they are necessarily wrong, but that they

do not account for within-field, within-canopy, between-season or within-season variability. A vast majority of growers also noted that CVs are of no use early in the season when in-season adjustments could still be made, and many noted that even if a sound leaf sample is taken that the analysis cannot be used to determine a specific fertilization response.

This project aims to correct this situation by developing new approaches and interpretation tools that better quantify field and temporal variability, are sensitive to yield and provide for in-season monitoring and fertilizer optimization in almond. This project will also offer the unique opportunity to verify current CVs and determine the utility of nutrient ratios as a diagnostic tool.

OBJECTIVES

1. Determine the degree to which leaf nutrient status varies across a range of representative orchards and environments.
2. Determine the degree to which nutrient status varies within the canopy and within the year.
3. Validate current CVs and determine if nutrient ratio analysis provides useful information to optimize fertility management.
4. Develop and extend an integrated nutrient best management practice (BMP) for almond.

DESCRIPTION

A large-scale survey of within-field, between-field, within-tree and between-organ nutrient concentration and variance will be conducted in mature almond orchards. The interaction between yield and nutrient status will be determined at four sites on >600 individual trees.

All trials have been initiated in eight- or nine-year-old microsprinkler-irrigated (one drip-irrigated) almond orchards of good to excellent productivity planted to Nonpareil (50%) in soils representative of the region and a large percentage of almond acreage. At experiment completion, trees will have reached 11 or 14 years old (after three or five years), representing their most productive years.

For each of four almond sites (Arbuckle, Salida, Madera, Bakersfield), plots are a 10- to 15-acre contiguous block. Both leaf and nut samples will be collected at five times during the season, selected from 114 trees in each plot for a period of three to five years. Sample collection will be spaced evenly over time from full leaf expansion to one month post-harvest. As a phenological marker, days past full bloom and stage of nut development will be noted. Light interception, trunk diameter, and individual yields of these trees will also be measured.

Table 1.
2008 Sampling schedule for each site.

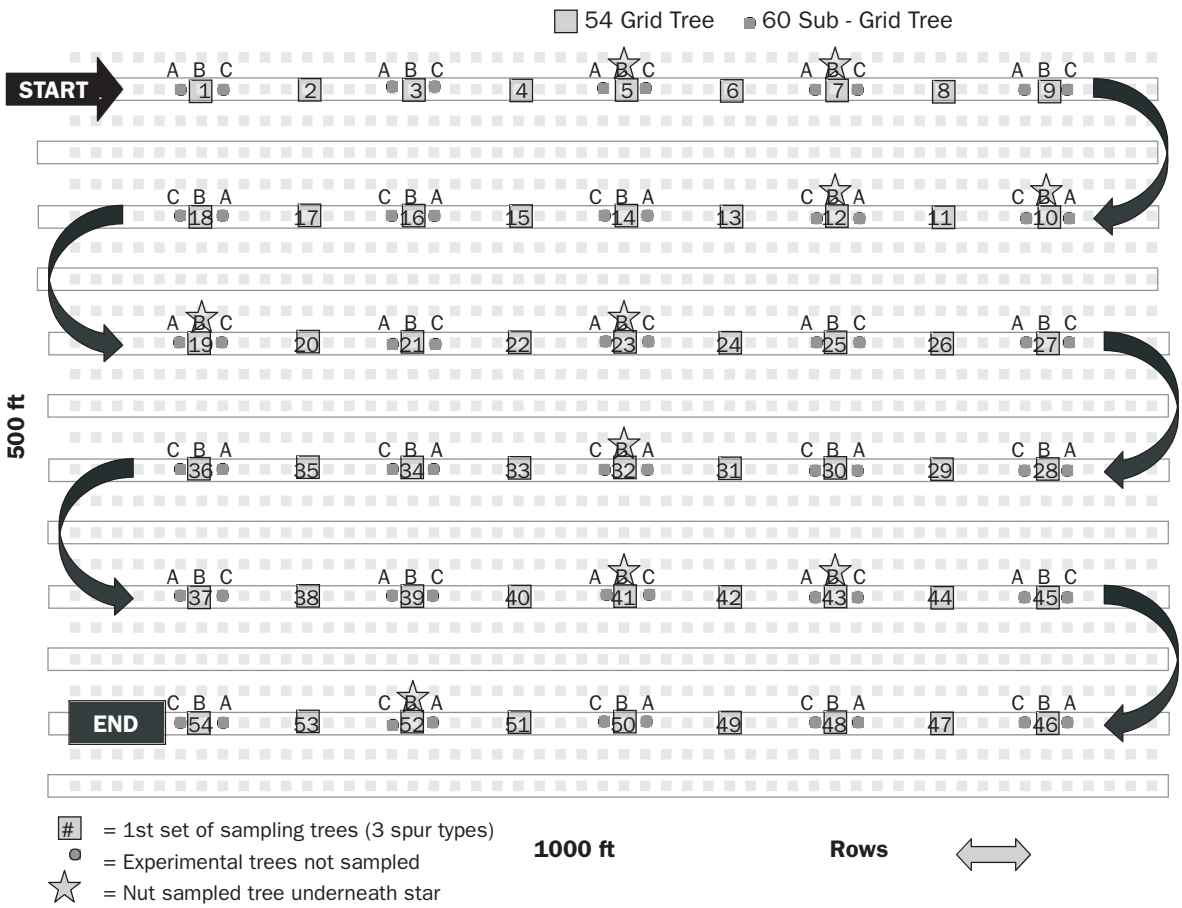
	1*	2	3	4	5	6**	
Sample Type	**Apr 6**	**May 12**	**Jun 16**	**Jul 26**	**Aug 20**	**Oct 10**	**Total**
Non-fruiting spur leaves	30	114	114	30	0	30	318
Fruiting spur leaves–1 nut	30	30	30	30	0	30	150
Fruiting spur leaves–2+ nuts	30	30	30	30	0	30	150
Nut sample	10	10	10	10	10	0	50
Total	100	184	184	100	10	90	668

*April 6 sampling date is based on estimated date of full leaf expansion.
**October 10 sampling date is one month past harvest of final site (harvest date average of four sites).

Standard leaf sampling protocol will be carried out on exposed, non-fruiting spurs, as well as collecting leaves from fruiting spurs with one and multiple fruit to explore different sampling methods (Table 1). Composite nut samples will be collected from each site. Both leaf and nut samples will be processed by researchers prior to being sent to the Department of Land, Air and Water Resources (DANR) analytical laboratory at University of California, Davis.

With the guidance of Richard Plant, a leading agronomic statistician, an extensive grid-sampling protocol has been established at each site using techniques developed for geographic information systems (GIS). At 54 grid points uniformly distributed across a 10- to 15-acre block of trees, May and July leaf nutrient status, light interception, trunk diameter and tree yield will be determined in each Nonpareil tree. At 30 of these grid points, the nutrient status and yield

Figure 1.
Plot map (same for all sites) used for this project. It gives the layout of the experiment as it is in the orchard at each of the four sites. The 54 grid trees listed are the main trees of the study being sampled a total of five times throughout the growing season. The 60 sub-grid trees were sampled from only twice during the season and serve the purpose of assessing nutrient content and yield of trees neighboring those from the main grid pattern.



of two neighboring Nonpareil trees will also be collected as independent data points. Initially, non-fruiting spur leaves in exposed positions will be selected for these samples; however, depending on the early results, sampling protocols may be adjusted. Two statistical techniques, "nugget sampling" and "modified Mantel," will be used. This approach allows for partitioning of variance in nutrient status due to environment, due to genetic variability and "random" variability and allows for determination of the interactions and dependencies between nutrition and yield and the nature of spatial variability within an orchard.

Overall, this experiment will collect far more samples (2,672 samples from 456 individual trees), analyzed for more nutrients (N, K, P, S, Ca, Mg, B, Zn, Mn, Fe) than ever performed before and will collect the individual tree yields associated with each of these samples. This detailed approach is designed to provide the foundation statistical information needed to guide fertilizer practice for the foreseeable future.

RESULTS AND CONCLUSIONS

This experiment commenced in 2008, and results of only the first of the nutrient sampling dates and field yields have been determined. Full analysis of yield x nutrient status and within-tree and between-tree variability and interaction between yields and nutrient relationships will be conducted in the coming months prior to the 2009 season. Yields at all sites were very good to excellent (Table 1).

Table 1.
Field pick-up weights on per-tree and per-acre basis.

Location	Arbuckle	Salida	Madera	Bakersfield	All Sites
Lbs./tree	129.2	173.1	126.1	128.6	139.3
Lbs./acre	12,794.0	15,581.0	12,612.0	14,919.0	13,977.0
Tons/acre	6.40	7.79	6.31	7.46	6.99

Guaging the Effectiveness of Foliar Fertilizers on Citrus

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INTRODUCTION

Foliar fertilization can meet the plant's demand for a nutrient at times when soil conditions (low temperature, low soil moisture, pH, salinity) render soil-applied fertilizers ineffective. Thus, foliar fertilization is an effective method for correcting soil deficiencies and overcoming the soil's inability to transfer nutrients to the plant. Nutrients, especially phosphate, potassium and trace elements can become fixed in the soil and unavailable to plants. Applying nutrients directly to leaves, the major organ for photosynthesis, ensures that the plant's metabolic machinery is not compromised by low availability of an essential nutrient. It is important to note that foliar-applied fertilizers of phloem-mobile nutrients are translocated to all parts of the tree, including the smallest feeder roots. Foliar fertilizers reduce the potential for accumulation of nutrients in soil, run-off water, surface water (streams, lakes and the ocean), and groundwater (drinking water supply), where they can contribute to salinity, eutrophication and nitrate contamination, all of which have serious consequences on the environment and humans. Thus, foliar fertilization provides advantages over traditional soil-applied fertilizer and should replace soil-applied fertilizer, at least in part, in crop best management practices (BMPs).

Three problems impede adoption of foliar fertilizers:

1. Not all nutrients are taken up through the foliage and, even if taken up, some nutrients are not phloem mobile. Thus, *a priori* knowledge (research) is necessary to know which nutrients are taken up through the leaves of a specific crop in order to develop a foliar fertilization program. This information is not always available to growers and the lack of information compromises a grower's ability to discern which foliar fertilizers are worth using and when to apply them.
2. Standard leaf analyses do not always show the expected increase in nutrient concentration. This can be due to poor nutrient uptake, but also can result from excellent uptake

and utilization by tissues not sampled (new shoots, stems, roots and especially fruit). Conversely, leaf analyses can give false positive information regarding foliar fertilization. Some foliar-applied nutrients persist in the wax of the leaf cuticle. Thus, if the leaves analyzed are not washed properly, a false high reading will be obtained. Frequently, it is considered sufficient to merely demonstrate that a nutrient applied as a foliar fertilizer is taken up. To do this, leaves are typically analyzed within a short period of time after the fertilizer is applied to the foliage. Whereas this approach may confirm that uptake has occurred, benefits of the application are largely presumed.

3 Rates of foliar fertilizer are typically lower than soil-applied fertilizer, but application of foliar fertilizer can be more expensive, especially if a grower does not own his own sprayer. Tank mixing multiple fertilizers and/or pesticides to save a trip through the orchard can cause negative interactions that reduce efficacy or cause negative effects on plant metabolism, such as the negative effect on yield of the avocado due to the interaction between foliar-applied N and B (Lovatt, 1999). Growers have been proactive in protecting the environment, but with the high cost of fertilizer in general, foliar fertilizers must be proven to be effective for growers to be willing to incur the expense of using them. An improved methodology to evaluate the effectiveness of foliar fertilizer is required. We propose that the only acceptable standard by which to measure effectiveness of foliar fertilizer is a resultant yield benefit and net increase in grower income.

The key to achieving a yield benefit and net increase in grower income is properly timing the foliar application of fertilizer to key stages of crop phenology when nutrient demand is likely to be high or when soil conditions are known to restrict nutrient uptake. For citrus and avocado tree crops, this approach is in contrast to applying foliar fertilizers at the standard time of 1/3- to 2/3-leaf expansion (March), which targets foliage with a thin cuticle and large surface area and only result in yields equal to those attained with soil-applied fertilizer (Embleton and Jones, 1974; Labanauskas et al., 1969). With demonstration that foliar fertilization strategies can be used to increase yield parameters and grower net income with reliability by properly timing their application (Lovatt 1999), growers will replace soil-applied fertilizer, at least in part, with foliar fertilizer, improving fertilizer efficiency and protecting the environment.

Winter prebloom foliar applications of low-biuret urea or potassium phosphite (a form of P [HPO_3^{-2}] readily taken up by leaves and translocated through trees to the roots [Lovatt and Mikkelsen, 2006]) have been shown to increase yield, yield of commercially valuable large size fruit and total soluble solids (TSS) of sweet oranges (*C. sinensis*) (Albrigo, 1999; Ali and Lovatt, 1992, 1994; Lovatt, 1999); when combined, the yield effects are additive (Albrigo, 1999). Use of urea and potassium phosphite in Clementine mandarin (*C. reticulata*) production in Morocco produced similar beneficial yield results (El-Otmani et al., 2003a, b). Application of potassium phosphite in May (during the cell division stage of fruit development) and again in July (at maximum peel thickness, which marks the end of the cell division stage of citrus fruit development) or a single application of urea in July increased the yield of large size 'Frost nucellar' navel orange fruit (*C. sinensis*) (Lovatt, 1999). Fruit size of 'Sunburst' tangerine (*C. reticulata* x *C. paradisi*) was increased with foliar application of potassium nitrate (KNO_3) at dormancy (February), post-bloom (~April) and exponential fruit growth (July-August) (Boman, 2002).

Foliar application of potassium sulfate (K_2SO_4) at the post-shooting stage of banana (*Musa spp.*) increased yield, fruit quality and post-harvest shelf-life (Kumar and Kumar, 2007). Foliar-applied potassium during cantaloupe (*Cucumis melo*) fruit development and maturation improved fruit market quality by increasing firmness, sugar content, and nutritional value through increased beta-carotene, ascorbic acid and K concentrations in the edible flesh (Lester et al., 2007).

For avocado, canopy applications of B or urea-N just prior to avocado inflorescence expansion (cauliflower stage of inflorescence development), significantly increased the number of viable ovules, increased the number of pollen tubes that reached the ovules, and increased yield (Lovatt, 1999). Earlier (bud break) applications were not effective, later (full bloom) applications were intermediate in effect. B is also known to stimulate cell division and increase fruit set and fruit size of many crops, even seedless fruit, and even when leaf analyses indicate B is adequate.

For all cases cited above, proper timing of the foliar fertilizer application was a factor in increasing commercial yield or improving fruit quality parameters, including increased fruit size. Moreover, these results were attained even though the crops were not deficient based on standard nutrient analysis for the crop.

We propose to conduct this research with Clementine mandarin (*Citrus reticulata* Blanco), for which little fertilizer research has been conducted in California. Thus, the results of this project will not only establish the feasibility of using a yield benefit and net increase in grower income as a new methodology for evaluating the effectiveness of foliar fertilizers, but also will provide California Clementine mandarin growers with fertilization practices to improve crop production that are efficient and protect the environment. In addition, CDFA-FREP provides the visibility required to make the benefits of this approach known to researchers and growers of other crops.

OBJECTIVES

To test the efficacy of properly timed foliar-applied $ZnSO_4$, Solubor-B, urea-N and phosphite-P+K fertilizers to increase 'Nules' Clementine mandarin fruit number, size, and/or quality and increase grower net income and, thus, to demonstrate that a yield benefit and net increase in grower income should be the only acceptable standard for evaluating the effectiveness of foliar applied fertilizers.

Thus, the specific objectives are to test the efficacy of the following fertilizers applied to the foliage at the times specified:

1. N (23 pounds per acre, urea [46% N, ≤ 0.25% biuret]) with K and P (0.64 gallons per acre, potassium phosphite [0-28-26]) applied winter prebloom to increase flower number, fruit set and yield, without reducing fruit size, and to increase total soluble solids (TSS) and TSS:acid.
2. Zn (one pound per acre, $ZnSO_4$ [36% Zn]) at 10% anthesis in the southwest tree quadrant (SWTQ) to increase fruit set and yield, without reducing fruit size.
3. B (1.3 pound per acre, Solubor [20.5% B]) at 10% anthesis in the SWTQ to increase total yield and yield of commercially valuable large size fruit.
4. K and P (0.49 gallons per acre, potassium phosphite [0-28-26]) in May and July to increase yield of commercially valuable large size fruit, without reducing total yield, and to increase TSS and TSS:acid.
5. N (23 pound per acre, urea [46% N, ≤ 0.25% biuret]) at maximum peel thickness to increase yield of commercially valuable large size fruit, without reducing yield, and to increase TSS and TSS:acid.

6 K (25 pounds KNO_3 per acre) at dormancy (February), post bloom (~April) and summer fruit growth (July-August) to increase the yield of commercially valuable large size fruit (Boman, 2002). Fertilizer rates are based on application in 250 gallons water per 100 trees per acre so that can be adjusted for application to individual trees.

DESCRIPTION

The research will be conducted in a commercial orchard of bearing 'Nules' Clementine mandarins located near Fowler. Treatments above (1-6), a soil-fertilized control (standard grower practice) (Treatment 7) and a foliar-fertilized (2/3-leaf expansion) control for each fertilizer (ZnSO4, low-biuret urea-N, potassium phosphite-P+K, and Solubor-B above (Treatments 8-12) will be applied to 16 individual 'Nules' Clementine mandarin trees (replications) per treatment in a randomized complete block design (192 data trees).

This research starts in October, at which time we will initiate treatments to determine the optimal time for applying low-biuret urea to the foliage of 'Nules' Clementine mandarin to increase flowering fruit set and yield (November 15, December 15, January 15, or February 15). Starting in early March the orchard will be visited every two weeks to monitor and record tree phenology in order to apply the foliar fertilizer treatments at the proper time each year. Starting at the beginning of June, five average size fruit will be collected from around each of 20 randomly selected trees in the buffer rows every two weeks. Fruit diameter and peel thickness will be measured to determine when maximum peel thickness occurs each year. In September, 40 spring flush leaves from non-fruiting terminals will be collected, processed and analyzed for N, S, P, K, Mg, Ca, Fe, Mn, B, Zn, and Cu by atomic absorption spectrometry and inductively coupled plasma atomic emission spectrometry. In October the time of color break and TSS:acid will be determined. Annually, at harvest in November, treatment effects on yield, fruit size distribution (packout) will be determined using an in-field fruit sizer. A subsample of 100 fruit per tree will be used to determine fruit diameter, peel thickness, color and external peel quality by my lab. A second subsample of 25 fruit per tree will be used to determine fruit weight, juice weight, percent juice, TSS, percent acidity, TSS:acid by the UC Lindcove REC analytical lab. A cost-benefit analysis will be calculated. Cumulative treatment effects on yield parameters will be determined with each successive harvest. The effectiveness of the treatments averaged across two years and three years of the study will also be determined. With each successive set of harvest data, alternate bearing index (ABI = [Year 1 yield - Year 2 yield] ÷ [Year 1 yield + Year 2 yield]) will be calculated for each treatment. In Year 3, treatment effects on ABI for the three years of the study will be determined. All data will be statistically analyzed using the General Linear Model procedure of SAS.

RESULTS AND CONCLUSIONS

The proposed research is scheduled to start in October 2008. Thus, there are no results at this time.

LITERATURE CITED

Albrigo, L. G. 1999. Effects of foliar applications of urea or Nutri-Phite on flowering and yields of Valencia orange trees. Proceedings, Florida State Horticultural Society.

Ali, A.G. and C.J. Lovatt. 1992. Winter application of foliar urea. Citrograph 78:7–9.

Ali, A. G. and C. J. Lovatt. 1994. Winter application of low-biuret urea to the foliage of 'Washington' navel orange increased yield. Journal of the American Society of Horticultural Science 119:1144-1150.

Boman, B.J. 2002. KNO_3 foliar application to 'Sunburst' tangerine. Proceedings, Florida State Horticultural Society 115:6-9.

El-Otmani, M., A. Ait-Oubahou, F.-Z. Taibi, B. Lmfoufid, M. El-Hila, and C. J. Lovatt. 2003a. Prebloom foliar urea application increases fruit set, size, and yield of Clementine mandarin. Proceedings, International Society of Citriculture 1:559–562.

El-Otmani, M., A. Ait-Oubahou, H. Gousrire, Y. Hamza, A. Mazih, and C. J. Lovatt. 2003b. Effect of potassium phosphite on flowering, yield, and tree health of 'Clementine' mandarin. Proceedings, International Society of Citriculture 1:428–432.

Embleton, T.W. and W.W. Jones. 1974. Foliar-applied nitrogen for citrus fertilization. Journal of Environmental Quality 3:388-392.

Kumar, A.R. and N. Kumar. 2007. Sulfate of potash foliar spray effects on yield, quality and post-harvest life of banana. Better Crops 91(2):22-24.

Labanauskas, C.K., W.W. Jones and T.W. Embleton. 1969. Low residue micronutrient sprays for citrus. Proceedings, first International Citrus Symposium 3:1535-1542.

Lester, G.E., J.L. Jifon and W.M. Stewart. 2007. Foliar potassium improves cantaloupe marketable and nutritional quality. Better Crops 91(1):24-25.

Lovatt, C. J. 1999. Timing citrus and avocado foliar nutrient applications to increase fruit set and size. HorTechnology 9:607-612.

Lovatt, C.J and R.L. Mikkelsen. 2006. Phosphite fetilizers: What are they? Can you use them? What can they do? Better Crops 90:11-13.

Summaries of Other Ongoing FREP Research Projects

Evaluating Humic Substances Used in Commercial Fertilizer Formulations

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INTRODUCTION

The potential benefits of using humic acids in agriculture have been the subject of a substantial body of research. Among the benefits claimed have been improved seed germination, stimulation of root growth and soil microbial activity, enhanced nutrient uptake, chelation of micronutrients, and stimulation of crop growth and yield. Many commercial fertilizer formulations containing humic substances are currently being marketed. While the bioactivity of humic substances has been well documented in solution culture or hydroponic experiments, very few studies showing positive crop response to humic acid have been conducted in representative agricultural soils. This project is systematically examining the effects of commercial humic acid formulations when applied to such soils. Using laboratory, greenhouse and field experiments, humic acid effects on soil microbial activity, early growth, nutrient uptake, and yield of lettuce and processing tomato will be documented.

OBJECTIVES

1. Quantify the effects of humic acid materials used in commercial fertilizer formulations on soil microbial activity, early growth, nutrient uptake, and crop yield.
2. Determine whether crop response to humic acid materials is soil-specific.

DESCRIPTION

Five commercial humic acid formulations (Table 1) have been evaluated in greenhouse, laboratory and field experiments. For the greenhouse experiment four field soils were collected, two from the San Joaquin Valley and two from the Sacramento Valley. The soils chosen had been in typical row crop/vegetable crop rotations, and all had low P availability (< 15 ppm bicarbonate extractable (Olsen) P); other physiochemical properties are given in Table 2. The soils were air-dried and blended for uniformity. Plastic pots of one-liter volume were partially filled with 750 g of soil. To simulate a banded preplant fertilizer application, a band of liquid was applied to the soil surface and covered by an additional 250 grams of soil. The humic acid materials, with and without P fertilizer (liquid 10-34-0),

were compared to a P-fertilized control and an untreated control receiving neither humic acid nor P fertilizer. Application rates simulated field rates of two pounds active ingredient (a.i.) per acre for the humic materials and 50 pounds P_2O_5 equivalent per acre for all fertilized treatments.

Ten seeds of 'Green Towers' romaine lettuce were sown in each pot, in a line one inch above and one inch to the side of the humic acid/fertilizer band. The seeds were covered with a thin layer of sand, and placed in a greenhouse. The pots were wetted on November 2, 2007. After germination, the pots were thinned to one representative plant/pot. The experimental design was randomized complete block, with five replicate pots of each soil x treatment combination. The greenhouse was maintained at 75/70°F day/night. Watering was done daily with a calcium nitrate solution containing 100 ppm N. Whole plants were harvested on December 19 (47 days after sowing). The plants were oven-dried, weighed, ground and analyzed for P content.

A laboratory incubation experiment was conducted to evaluate the effects of the humic acid formulations on soil microbial activity, and microbial community structure. Two agricultural soils were selected, one a low organic matter soil from the San Joaquin Valley, one a higher organic matter soil from the Salinas Valley; physiochemical characteristics are given in Table 3. The soils were air-dried, passed through a five-millimeter screen, and blended for uniformity. One hundred grams of dry soil was placed in glass jars of one-liter volume. The soil was wetted to field capacity moisture content by adding water alone, P fertilizer solution, humic acid solution, or a solution containing both humic acid and P fertilizer. The concentrations of P and humic acids were calculated to represent the concentration of these materials in a banded application of 20 pounds P_2O_5 and two pounds a.i. humic acid per acre. Four replicate jars of each humic acid/P fertilizer combination per soil were prepared along with unfertilized and P-fertilized controls. Once wetted, the jars were sealed and placed in a 77°F chamber for seven days. After three and seven days samples of the headspace air were removed from the jars and analyzed for CO_2 concentration; from these data the milligrams of carbon mineralized by microbial activity was calculated. At the end of seven days, the jars were removed from the chamber, and 50 grams of wet soil removed from each jar. These soil samples were analyzed for phospholipid fatty acid (PLFA) analysis by gas chromatography. This technique provides a profile of the active microbial communities in the soil (fungi, bacteria, etc.).

A drip-irrigated field experiment was conducted at University of California, Davis. A field of silt loam soil with an Olsen P value of 12 ppm was prepared with 60-inch wide raised beds. On April 18, 2008, a pre-transplanting banded application of fertilizer was applied four to five inches deep, offset approximately one inch from the bed center. The treatments applied included each of the humic acid formulations at both a one- and three-pound a.i. rate applied with 10-34-0 fertilizer, a P-fertilized control and a no P control. In all treatments receiving P fertilization, 70 pounds P_2O_5 per acre were applied. The humic acid materials were thoroughly blended with the 10-34-0 before application to simulate commercial use. The control not receiving P fertilization received preplant N equivalent to that contained in the 10-34-0 fertilizer. The field was transplanted with Heinz 9780 processing tomato plants on April 24. The experimental design was randomized complete block with five replications; individual single row plots were 100 feet long. One month after transplanting, four whole plants per plot were harvested, dried and analyzed for P concentration. At commercial maturity, the plots were mechanically harvested and marketable yield determined.

RESULTS

P fertilization had a profound influence on lettuce growth in all soils (Table 4); unfertilized treatments in Soils 1 and 2 were severely P-limited; however, only in Soil 3 did the addition of a humic acid formulation with P fertilizer increase lettuce growth above that of P fertilization alone. In the absence on P fertilization, no humic acid formulation increased lettuce growth in any soil. Similarly, humic acids did not increase lettuce P uptake (Table 5). In the incubation experiment P fertilization stimulated soil microbial activity in both soils, while humic acids caused a small but statistically significant stimulation only after seven days, and only in the lower organic matter soil (Table 6). In that low organic matter soil, humic acids increased the detectable amounts of phospholipid fatty acids that are correlated with fungi, bacteria and actinomycetes (Table 7). In the higher organic matter soil, the application of humic acids was not stimulatory; in fact, the P-fertilized control had higher PLFA levels than the humic treatments.

In the field experiment P fertilization increased early plant growth, plant P concentration and fruit yield (Table 8). However, humic acids did not improve any aspect of crop performance compared with the P-fertilized control.

Table 1.
Commercial humic acid products being tested.

Humic formulation	Humic acid content	Form	Manufacturer
Actagro Humic Acid	10%	Liquid	Actagro, LLC
Actagro Liquid Humus	11%	Liquid	Actagro, LLC
Organo Liquid Hume	6%	Liquid	Black Earth Humates, Ltd.
Quantum-H	6%	Liquid	J.R. Simplot Co.
ESP-50	50%	Powder	Earthgreen Products, Inc.

Table 2.
Physiochemical properties of the soils used in the greenhouse experiment.

Soil attribute	Soil 1	Soil 2	Soil 3	Soil 4
Location	Fresno County	Fresno County	Yolo County	Yolo County
Texture	Sandy clay loam	Clay loam	Loam	Loam
CEC (meq/100 g)	18.9	23.6	19.3	21.7
Olsen P (ppm)	3.0	5.0	12.0	10.0

Table 3.
Physiochemical properties of the soils used in the laboratory incubation experiment

Soil attribute	Soil 1	Soil 2
Texture	Sandy clay loam	Loam
pH	7.8	7.9
Organic matter (%)	0.8	2.46
Olsen P (ppm)	7.0	59.0
NO_3-N (ppm)	23.0	8.0

Table 4.
Effect of humic acid formulation and P fertilizer on lettuce plant dry weight, greenhouse experiment.

	Lettuce dry weight (g/plant)			
Treatment	**Soil 1**	**Soil 2**	**Soil 3**	**Soil 4**
Actagro Humic Acid	0.19 b[z]	0.43 b	0.86 d	1.37 b
Actagro Liquid Humus	0.19 b	0.44 b	0.96 d	1.24 b
Organo Liquid Hume	0.28 b	0.52 b	0.92 d	1.03 b
Quantum-H	0.26 b	0.61 b	0.81 d	1.10 b
ESP-50	0.36 b	0.65 b	0.91 d	1.29 b
Actagro Humic Acid + P	1.64 a	1.72 a	3.44 a	2.96 a
Actagro liquid Humus + P	1.73 a	1.87 a	3.28 ab	2.78 a
Organo Liquid Hume + P	1.91 a	1.52 a	3.44 a	2.99 a
Quantum-H + P	1.67 a	1.91 a	3.02 abc	2.49 a
ESP-50 + P	1.91 a	1.48 a	2.63 c	3.20 a
P alone	2.08 a	1.89 a	2.69 bc	2.74 a
No humic acid or P	0.21 b	0.50 b	0.79 d	1.06 b
Contrasts				
Humics alone vs. humics + P	**	**	**	**
Humics + P vs. P alone	ns	ns	*	ns
Humics alone vs. no humics or P	ns	ns	ns	ns

[z] mean separation within columns by Duncan's multiple range test, $p < 0.05$.
[ns], *, ** not significant at $p < 0.05$, or significant at $p < 0.05$ or 0.01, respectively.

Table 5.
Effect of humic acid formulation and P fertilizer on lettuce P uptake, greenhouse experiment.

	Lettuce P uptake (mg/plant)			
Treatment	**Soil 1**	**Soil 2**	**Soil 3**	**Soil 4**
Actagro Humic Acid	0.36 b[z]	0.82 c	1.91 c	4.28 c
Actagro Liquid Humus	0.42 b	0.93 c	2.06 c	3.81 c
Organo Liquid Hume	0.51 b	1.11 c	1.90 c	3.10 c
Quantum-H	0.55 b	1.18 c	1.83 c	3.20 c
ESP-50	0.80 b	1.43 c	2.05 c	3.55 c
Actagro Humic Acid + P	6.72 a	6.40 ab	19.85 a	14.60 b
Actagro liquid Humus + P	6.52 a	6.74 ab	19.72 a	16.95 ab
Organo Liquid Hume + P	7.35 a	6.08 ab	17.68 a	16.63 ab
Quantum-H + P	6.59 a	7.04 a	18.80 a	14.96 b
ESP-50 + P	7.38 a	5.48 b	12.76 b	20.57 a
P alone	7.52 a	6.56 ab	15.66 ab	15.39 b
No humic acid or P	0.48 b	1.03 c	1.68 c	2.80 c
Contrasts				
Humics alone vs. humics + P	**	**	**	**
Humics + P vs. P alone	ns	ns	ns	ns
Humics alone vs. no humics or P	ns	ns	ns	ns

[z] mean separation within columns by Duncan's multiple range test, $p < 0.05$.
[ns], *, ** not significant at $p < 0.05$, or significant at $p < 0.05$ or 0.01, respectively.

Table 6.
Effects of humic acid formulation and P fertilization on soil microbial activity (mg carbon mineralized / jar), incubation experiment.

	Soil 1		Soil 2	
Treatment	**3 days**	**7 days**	**3 days**	**7 days**
Actagro Humic Acid	2.22 b[z]	4.27 c	6.27 e	8.86 e
Actagro Liquid Humus	2.34 b	4.06 c	6.50 de	9.36 d
Organo Liquid Hume	2.23 b	3.90 c	6.58 d	9.27 de
Quantum-H	2.24 b	3.93 c	6.25 e	8.84 e
ESP-50	2.29 b	4.19 c	6.29 de	8.91 de
Actagro Humic Acid + P	2.84 a	5.69 b	7.35 c	10.77 bc
Actagro liquid Humus + P	2.48 a	5.84 b	7.52 bc	11.06 ab
Organo Liquid Hume + P	2.85 a	5.83 b	7.90 a	11.26 a
Quantum-H + P	3.04 a	6.30 a	7.26 c	10.56 c
ESP-50 + P	3.04 a	5.89 ab	7.84 a	11.24 a
P alone	2.86 a	5.45 b	7.71 ab	11.22 a
No humic acid or P	2.32 b	3.99 c	6.40 de	9.12 de
Contrasts				
Humics alone vs. humics + P	**	**	**	**
Humics + P vs. P alone	ns	**	ns	ns
Humics alone vs. no humics or P	ns	ns	ns	ns

[z] mean separation within columns by Duncan's multiple range test, $p < 0.05$.
[ns], *, ** not significant at $p < 0.05$, or significant at $p < 0.05$ or 0.01, respectively

Table 7.
Effects of humic acid formulations and P fertilization on the amount of phospholipid fatty acids detectable in soil (nmol / g dry soil), incubation experiment.

		Phospholipid fatty acids detected (nmol/g dry soil)			
Soil	**Treatment(s)**	**Total**	**Fungi**	**Bacteria**	**Actinomycetes**
1	All humic acids alone	26.3	5.7	13.8	1.46
	All humic acids + P	29.1	6.3	15.2	1.57
	P alone	22.0	4.4	11.6	1.27
	No humics or P	14.9	2.6	8.0	1.09
Contrasts					
Humics alone vs. humics + P		*	ns	*	ns
Humics + P vs. P alone		**	*	**	*
Humics alone vs. no humics or P		**	**	**	**
P alone vs. no humics or P		**	**	**	ns
2	All humic acids alone	54.7	11.9	30.5	3.05
	All humic acids + P	51.4	11.9	28.7	2.89
	P alone	59.3	13.6	33.0	3.32
	No humics or P	54.3	12.4	30.3	3.10
Contrasts					
Humics alone vs. humics + P		ns	ns	ns	ns
Humics + P vs. P alone		**	**	**	**
Humics alone vs. no humics or P		ns	ns	ns	ns
P alone vs. no humics or P		ns	ns	ns	ns

ns, *, ** not significant at $p < 0.05$, or significant at $p < 0.05$ or 0.01, respectively.

Table 8.
Effect of humic acid formulations and P fertilization on processing tomato early growth, plant P concentration and marketable fruit yield, field experiment.

Treatment	Humic acid rate (lb a.i./acre)	Plant dry weight (g)	Plant P concentration (% dry weight)	Mkt. fruit yield (tons/acre)
Actagro Humic Acid	1	21.0 ab[z]	0.46 a	50.6 ab
Actagro Liquid Humus		23.2 a	0.40 b	48.9 ab
Organo Liquid Hume		20.5 ab	0.39 b	51.4 a
Quantum-H		23.1 a	0.44 ab	48.2 ab
ESP-50		22.8 a	0.40 b	49.0 ab
Actagro Humic Acid	3	20.9 ab	0.43 ab	47.4 ab
Actagro liquid Humus		21.4 ab	0.44 ab	51.0 ab
Organo Liquid Hume		23.6 a	0.40 b	52.3 a
Quantum-H		20.8 ab	0.45 a	50.2 ab
ESP-50		21.6 ab	0.40 b	51.9 a
P alone		21.7 ab	0.39 b	51.4 ab
No humic acid or P		17.4 b	0.34 c	46.4 b
Contrasts				
Humic @ 1 lb vs. 3 lb rate		ns	ns	ns
All humic treatments vs. P alone		ns	ns	ns
All P treatments vs. no P control		**	**	*

[z] mean separation within columns by Duncan's multiple range test, $p < 0.05$.
[ns], *, ** not significant at $p < 0.05$, or significant at $p < 0.05$ or 0.01, respectively.

Can a Better Tool for Assessing 'Hass' Avocado Tree Nutritional 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 U.S. market, which now receives fruit from Mexico, Chile, New Zealand, Australia, Dominican Republic, Peru and Ecuador (Figure 1) and soon South Africa and Brazil.

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 (Razeto and Granger, 2001; Razeto et al., 2003; Razeto and Salgado, 2004), 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.

OBJECTIVES

The specific objectives of this project are as follows:

1. To determine the sensitivity of the flower, entire inflorescence, and fruit peduncle to differences in tree nutrient status.
2. To determine if the nutrient concentrations of the tissues above are related to fertilizer rate and to yield parameters.
3. To 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.

DESCRIPTION

Tissues will be collected as follows: Entire inflorescence at the cauliflower stage and at full bloom; flowers at full bloom; and 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), 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 best management practice (BMP) N vs. BMP NPK and 0.8x N vs. 0.8x NPK in both July and August at a new research site in Santa Barbara. Tissue will be analyzed for N, S, P, K, Mg, Ca, Fe, Zn, Mn, B, Cu, and Cl. At harvest, yield (number and kilogram of 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 number of research sites, sampling dates and different tissues sampled, we have a huge and complex set of data. Different statistical analytical techniques are being used to mine this data set. For simplicity, results from one of our research orchards are presented here to provide an example of the information obtained. In this example, we used harvest data and peduncle tissue and standard leaf samples (Embleton et al., 1973) nutrient analyses. Using correlations and regression analyses, we determined which nutrients in each tissue significantly positively or negatively influence each yield parameter, i.e., total yield in kilograms and number of fruit per tree, and fruit size distribution based on packing carton fruit sizes. Packing carton fruit sizes are based on grams per fruit, as follows: size 84 (99 to 134 grams); size 70 (135 to 177 grams); size 60 (178 to 212 grams); size 48 (213 to 269 grams); size 40 (270 to 325 grams); size 36 (326 to 354 grams); and size 32 (355 to 397 grams).

For significant relationships, an equation predicting how the yield parameter will change with a change in the tissue concentration of the nutrient was generated. Using stepwise regression analyses, we can predict the most important combination of nutrients for each yield parameter. In this statistical analysis of the data, we found no significant relationships between leaf nutrient concentrations and total yield or fruit size. In contrast, there were significant relationships between the nutrient concentrations in peduncle tissue and yield parameters. For example, 98% of the variation in total yield for the trees in this orchard was explained by peduncle concentrations of four nutrients (in order of importance) Cu + N + Mn + B ($P = 0.0002$). Similarly, 86% of the variation in the yield of commercially valuable fruit of packing carton sizes 60 + 48 + 40 could be explained by four different nutrients (in order of significance) Ca + Zn + Mg + N ($P = 0.0233$). For small size fruit of packing cartons size 84 + 70, 98% of the variation in yield was due (in order of significance) to Cu + P + B + Mn ($P = 0.0002$). As suspected, 'Hass' avocado tree nutrient status related to high total yield is also related to a high yield of small size fruit. Keep in mind examples are from only two tissues sampled on one date in a single orchard.

It is anticipated that the results of our research will identify a tissue(s) and a time(s) of analysis that is responsive to fertilizer treatment, related to tree growth and yield parameters and predictive of yield. With these results, an annual tissue sampling strategy can be developed to provide avocado growers with a more sensitive tool to better manage their fertilizer inputs and reduce costs, while increasing yield, fruit size, fruit quality and net profit and protecting the environment from fertilizer over-use.

LITERATURE CITED

Crowley, D.E. 1992. Soil fertility and the mineral nutrition of avocado: the physical, chemical, and biological properties of soil and their importance in the culture of avocado. California Avocado Development Organization and The California Avocado Society, Circular No. CAS-92/1, 26 p.

Crowley, D.E. and W. Smith. 1996. Zinc fertilization of avocado trees. HortScience 31:224-229.

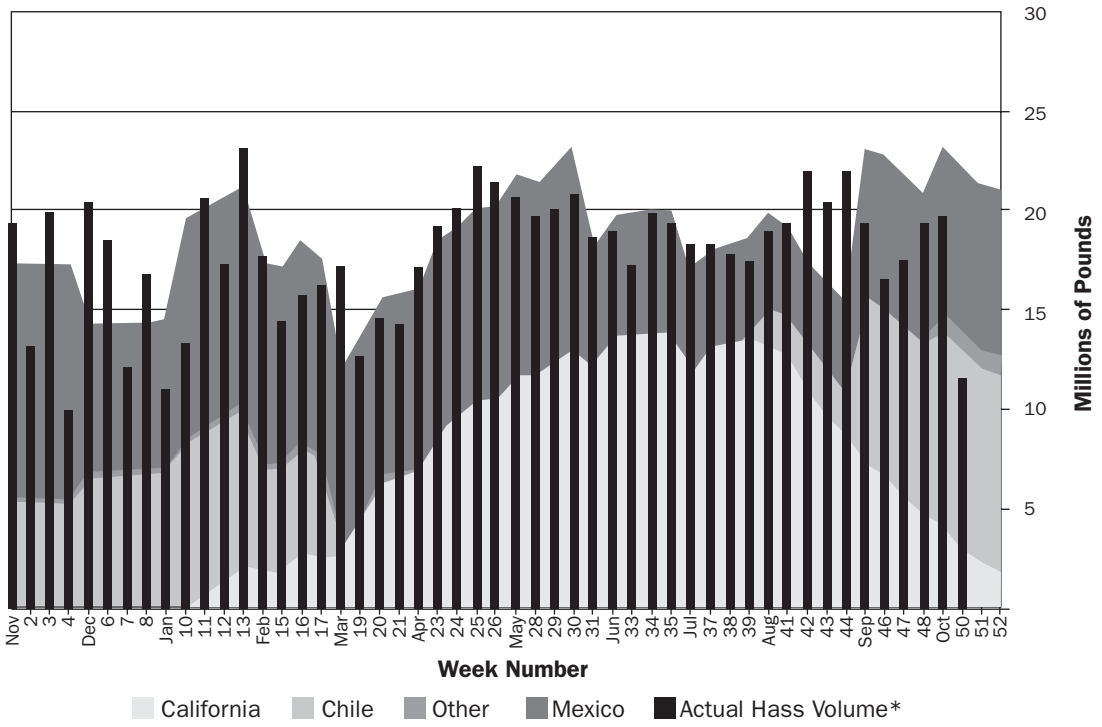
Lovatt, C.J. and G. Witney. 2001. AvoResearch 1(3):1-4, 11.

Razeto, B. and C. Granger. 2001. Análisis químico del pendúnculo del fruto y la inflorescencia, posibles herramientas de diagnóstico nutricional en palto (*Persea americana* Mill.), p. 73. In: Resúmenes. 52º Congreso Agronómico de Chile, Quillota, Chile.

Razeto, B., C. Granger, and T. Fichet. 2003. Análisis de diferentes tejidos como indicadores del nivel de boro en el árbol de aguacate (*Persea americana* Mill.). (Analysis of different tissues as indicators of boron level in avocado [*Persea americana* Mill.]). Proceedings, V World Avocado Congress 1:359–363.

Razeto, B. and J. Salgado. 2004. The influence of fruit peduncle as indicators of nitrogen status of the avocado tree. HortScience 39(6):1173–1174.

Figure 1
'Hass' avocado fruit (in millions of pounds) arriving weekly from Chile, Mexico and other countries into the U.S. and competing with California grown avocados in the U.S. markets.



**Chile and Mexico figures represent arrivals into U.S. market. All other figures reflect Avocado Marketing Research and Information Center (AMRIC) shipment volume.*

Data designed by Gwen Peterson, AMRIC

Developing Certified Crop Adviser Specialty Certification and Continuing Education in Manure Nutrient Management

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INTRODUCTION

Under waste discharge requirements adopted by the Central Valley Regional Water Quality Control Board (Order No. R5-2007-0035), all dairy producers must implement nutrient management plans (NMP). The NMPs must be developed and signed by Certified Crop Adviser (CCA) or other certified professionals. The technical standards for the NMPs include unprecedented annual nitrogen loading limits for each field, and the regulation requires a detailed monitoring and reporting program including manure, plant, soil, and water sampling and analyses. We are collaborating with the California Certified Crop Adviser (CCA) board to train crop management professionals in the agronomic aspects of manure management to enable them to better serve the dairy industry.

OBJECTIVES

1. Produce a manure and crop nutrient management curriculum in the form of educational modules to be made available on the internet in downloadable format. Additionally the modules will be formatted for use in short courses or workshops both initially and in continuing education.
2. Develop a set of multiple choice questions and an accompanying set of performance objectives on manure nutrient management suitable for use by the California Certified Crop Adviser program in the state CCA examination.
3. Conduct workshops for crop management professionals on crop nutrient management and dairy manure use in the Central Valley

region. The workshops will target CCAs, NRCS technical service providers (TSPs) and USDA Natural Resource Conservation Service (NRCS) staff who are certified planners of comprehensive nutrient management plans.

ACCOMPLISHMENTS

As of September 2008, accomplishments are the following:

1. Development of curriculum materials begun with technical bulletins in preparation on the topics shown in the following table:

a	Introduction to dairy manure tech guide series
b	Potential environmental impacts of dairy manure applications to cropland
c	Regulatory aspects of dairy manure nutrient management
d	USDA cost-share programs related to dairy manure recycling
e	Dairy manure properties
f	Manure sampling and analysis
g	Estimating manure N availability
h	N cycling and losses from the soil
i	Soil testing and estimating soil N availability
j	Crop N Requirements and harvest removal
k	Legume N credit for crops following alfalfa
l	Plant sampling
m	Irrigation water N testing
n	Whole farm N balance and actions to address imbalance
o	Nutrient management planning and budgeting with examples
p	Dairy infrastructure requirements for agronomic nutrient management
q	Irrigation system performance basics
r	Lagoon water calculations
s	Sources of information

2. A workshop was conducted in May 2008 at three locations in the Central Valley. A total of 205 persons attended, including 67 CCAs and 18 USDA NRCS staff members. Continuing education units (3.5 units in the nutrient management category) were awarded to the CCAs. A total of seven new handouts were produced for this workshop series, not including PowerPoint presentations.
3. A bank of 20 questions on manure nutrient management is in preparation for use by the California Certified Crop Adviser program in its 2009 examination.
4. A two-day workshop will be conducted in two locations in the fall of 2008 to cover more detailed aspects of nutrient management planning for crops using dairy manure.

ACKNOWLEDGEMENTS

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List of Completed FREP Research Projects

To view the full final reports, please visit the California Department of Food and Agriculture's Fertilizer Research and Education Program website at www.cdfa.ca.gov/is/fflders/frep.html; or, you may contact the program at frep@cdfa.ca.gov, (916) 445-0444 to obtain printed copies.

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