PROCEEDINGS

Fourteenth Annual

Fertilizer Research & Education Program Conference

FREP

NOVEMBER 29, 2006
MONTEREY, CALIFORNIA

Fourteenth Annual

Fertilizer Research and Education Program Conference

November 29, 2006
Monterey, California

Sponsored By

California Department of Food and Agriculture

Western Plant Health Association

California Certified Crop Advisor Program

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Front and Back Cover Photography
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Sacramento, CA

Publication Design
Maitri Graphics
Sacramento, CA

Printing
Copeland Printing
Sacramento, CA

FREP

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FERTILIZER RESEARCH AND EDUCATION PROGRAM INFORMATION

The Fertilizer Research and Education Program (FREP) provides growers and the fertilizer industry with cost-effective ways to improve the efficient use of fertilizers that minimize environmental impacts. FREP serves growers, agricultural supply and service professionals, extension personnel, public agencies, consultants, and other interested parties. FREP is entirely funded from a mill tax on the sale of commercial fertilizers in the State of California, which in turn has provided grants to fund more than 100 research and educational projects over the past 16 years.

FREP was created in 1990 through legislation with support from the fertilizer industry. The California Food and Agricultural Code Section 14611(b) allows CDFA to impose the mill assessment on sales of fertilizers to provide funding for research projects that facilitate improved farming practices, reducing nitrate contamination of groundwater, as well as any environmental impacts.

Initially, the growing concern of nitrate contamination from ground and surface water from fertilizers was FREP's focus. This involved identifying and prioritizing the most nitrate-sensitive groundwater areas in California and working with public agencies, growers, and industry to develop and promote effective ways to reduce nitrate contamination from fertilizers. FREP continues to fund research on reducing nitrate contamination of groundwater, as well as many of California's important environmentally sensitive cropping systems.

CURRENT FREP FUNDING PRIORITIES

- Projects that determine or update nutrient requirements to improve crop yield or quality in an environmentally sound manner will be considered. Projects may include: research on crop nutrient uptake; the amounts, timing, and partitioning of nutrients removed from the soil; effects of soil chemistry on nutrient uptake; establish or update soil or tissue nutrient level thresholds used to determine fertilizer application timing and/or amounts; and the role of balanced nutrition in improving crop yield/quality.

- Projects that develop fertilization practices to improve crop production, fertilizer use efficiency or environmental impacts will be considered. Projects may include: research on slow-release fertilizers; foliar nutrient management; timing and effectiveness of fertilizer applications; new fertilizer technologies; and nutrient movement in differing soil types, cropping systems, and application methodologies.

- Projects that develop and extend information on fertigation methodologies leading to maximum distribution uniformity and minimizing fertilizer losses will be considered. Other approaches that will reduce ground and surface water contamination or improve the efficiency of fertilizing materials with respect to water management will also be considered.

- Demonstrate and quantify applications for site-specific crop management technologies and best management practices related to precision agriculture. Projects may include: development of fertilizer yield response and utilization models based on spatial and temporal variability; identify and quantify environmental interactions (soil quality issues, soil type characteristics, soil fertility or irrigation variability) and economic relationships.

- Field and laboratory tests for predicting crop nutrient response that can aid in making fertilizer recommendations. New techniques and diagnostic tools for monitoring soil and plant nutrient status are also encouraged. Field correlation studies may also be appropriate.

- Projects may demonstrate or provide practical information to growers and production consultants on nutrient/pest interactions. Pests may include insects, weeds or diseases.

- Educational and public information projects:
  - On-farm demonstrations of proven practices and technologies within FREP goals to encourage their adoption in California, with priority areas

given to impaired water bodies.
- Education training of fertilizer management in areas with impaired water bodies.
- Programs to educate growers, fertilizer dealers, students, teachers, and the general public about the relationships between fertilizers, food, public health, and the environment.
- Preparation of publications, slide sets, videotapes, conferences, field days, and other outreach activities.

- Other projects that support FREP's mission, such as air quality, tillage, crop rotation, economics of fertilizer use, and cropping systems will be considered.

FIGURES 1-3: FREP PROJECT FUNDING

These figures illustrate the variety of geographical regions, commodities, and disciplines covered by FREP projects over the past 16 years.

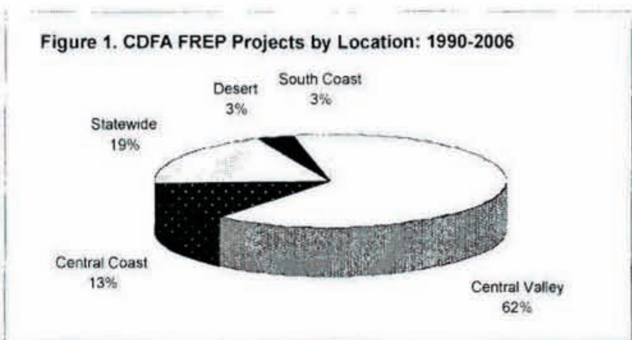

Figure 1. CDFA FREP Projects by Location: 1990-2006

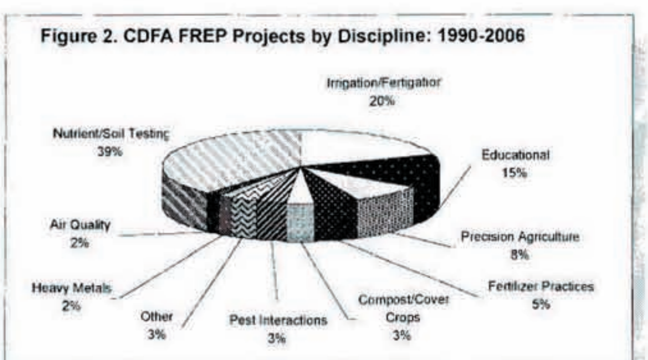

Figure 2. CDFA FREP Projects by Discipline: 1990-2006

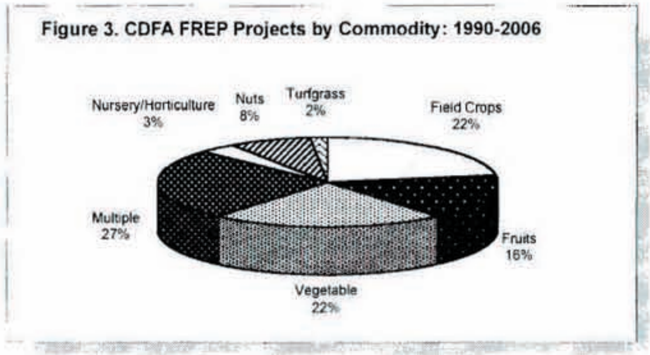

Figure 3. CDFA FREP Projects by Commodity: 1990-2006

EDUCATION AND OUTREACH

One of FREP's primary 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 FREP support (15%) of relevant education and outreach projects (Figure 2). FREP serves a broad audience, including growers, agricultural supply and service professionals, extension personnel, public agencies, consultants, Certified Crop Advisers, Pest Control Advisers, and other interested parties. Proceedings from the annual FREP conference are disseminated throughout the year to interested members of the agricultural community. FREP has also funded a number of projects designed to increase the agricultural literacy of students in the K-12 setting. In today's world of limited budgets, we know we must work with others to achieve our objectives. To that end, FREP staff collaborates and coordinates with other organizations with similar goals. Our partners include:

- The Western Plant Health Association
- California Chapter of the American Society of Agronomy
- California Certified Crop Adviser Program
- California Association of Pest Control Advisers
- Monterey County Water Resources Agency
- University of California, Sustainable Agriculture Research and Education Program
- State Water Resources Control Board, Interagency Coordinating Committee
- University of California Cooperative Extension Program

ACKNOWLEDGMENTS

We would like to acknowledge the support of the fertilizer industry in providing funds for the program. Their foresight

in creating FREP and their long-term commitment and dedication has been instrumental in the program's success.

We would also like to recognize the members of the Fertilizer Inspection Advisory Board Technical Advisory Subcommittee, who review and recommend projects for funding. Tom Beardsley, Michael Cahn, Bob Fry, Tom Gerecke, David McEuen, Rob Mikkelsen, Jerome Pier, Al Vargas, and Jack Wackerman have been invaluable in helping to ensure FREP's success. Their dedication to the program and professionalism is greatly appreciated. The members of the Fertilizer Inspection Advisory Board are also acknowledged for their enthusiastic support and ongoing commitment to the program.

We also greatly value the input and support received from the Western Plant Health Association. Others deserving mention include the project leaders and cooperators, as well as the dozens of professionals who review project proposals and help enhance the quality of FREP's work.

Special recognition also goes to the leadership at the California Department of Food and Agriculture, including Nate Dechoretz, Director of the Division of Inspection Services; Asif Maan, Branch Chief of the Feed, Fertilizer, and Livestock Drugs Regulatory Services Branch (FFLDRS), and Kent Kitade, FFLDRS Program Supervisor. Lacey van Exel and Natalie Krout are recognized for their invaluable role in the publication of the *Proceedings* and the success of the FREP Conference. Additional help from the Branch's support staff is also appreciated.

Soil-solution Partitioning of Trace Elements in Cropland Soils of California: Estimating the Plant Uptake Factors of As, Cd, and Pb

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Introduction and Project Description

Energy, water, nutrients, and pesticides are essential elements of the modern day crop production systems. Inputs of these elements are needed to sustain successful harvests and maximize the economical gains.

Sustainability

In the past 20 years, the National Water Quality Inventories concluded that the nation's water quality has not experienced significant improvement due to the nonpoint-source water pollution, and consistently identified agriculture as the single most important source of nonpoint-source pollutants in the nation's water bodies. Soil is the medium that supports crop production and modulates water and nutrient movements. It also performs important ecological functions of being the primary medium in which biogeochemical cycling of elements takes place, the major sink for global atmospheric fallout of trace metals, and the ultimate receptor of wastes. In this regard, the amounts and timing of the crop production inputs are important, and potentially toxic substances may be inadvertently introduced into the soils through this pathway. When the capacity of soil to modulate the mass flows and to attenuate the toxic pollutants is exceeded, the excess will adversely affect the down downstream water bodies. More importantly, the soil is the starting point of the terrestrial food chain. Substances entering the soil through this pathway may be transported along the food chain to harm unsuspected consumers of the harvests. The sustainability of agricultural production systems should not be judged simply by the soil's ability to yield profitable crops. It should also consider the potential environmental harm caused by the agricultural production such as erosivity of soils, ground and surface water quality, air quality, and food quality.

Trace Elements in Fertilizers

Fertilizers are essential inputs for crop production. They are a blend of substances from varieties of sources containing the active ingredients. Under conventional practices, natural minerals, synthesized chemicals, industrial by-products and wastes, even materials classified as hazardous wastes may be found in fertilizers, as the regulations require only a guarantee on the contents of active ingredients. These natural minerals and waste-derived ingredients may contain essential elements, such as iron or zinc, that qualify them to be marketed as a fertilizer, but they often contain non-beneficial and potentially toxic elements that are inherent of the wastes. Fertilizers derived from natural sources may also contain undesirable substances. For example, the phosphate rocks, the primary stock for P fertilizers, vary in Cd concentration that can range from essentially nil to an excess of 500 mg kg^{-1} P. Arsenic and lead are also common contaminants of the fertilizers and micronutrients. In 1996, the Heavy Metals Task Force of the California Department of Food and Agriculture surveyed fertilizers marketed in

California and showed that the contents of potentially toxic elements of arsenic, cadmium, and lead could vary from essentially nil to several thousand mg kg^{-1} (Table 1).

Table 1. Arsenic, Cadmium, and Lead Contents of Fertilizers and Fertilizer Ingredients in California, 1996.

Category	Arsenic (mg kg^{-1})	Cadmium (mg kg^{-1})	Lead (mg kg^{-1})
Phosphate	0.1 – 85	n.d.* to 3,734	n.d.* to 595
Minerals	n.d.* to 4,950	n.d.* to 500	n.d.* to 62,800
Blends	0.1 to 155	n.d.* to 200	n.d.* to 4,650
Sewage Sludge	0.1 to 15	1.1 to 20	4.5 to 151

*n.d. denotes element not detected

Similar results were found when fertilizers and blending ingredients were surveyed in the State of Washington (Bowhay, 1997).

Risk-based Assessment and Fertilizer Regulations

In 1997, CDFA conducted a risk-based assessment on human health due to exposures to arsenic, cadmium, and lead in fertilizer and/or micronutrient applications on cropland (CDFA, 1998). Through this process, CDFA established the maximum permissible limits for As, Cd, and Pb in fertilizer products that are used in food production. Subsequently, the numerical limits derived from this study were adopted as a part of the fertilizer regulations in California (California Code of Regulations, Title 3, Sections 2302 and 2303). Environmental risk assessment has become a commonly employed procedure for establishing numerical limits in the fertilizer regulatory processes (TFI, 2000; USEPA, 2000; AAPFCO, 2002). The fertilizer regulatory agencies in California (http://www.cdfa.ca.gov/is/fert/), Oregon (http://www.oda.state.or.us/dbs/heavy_metal/search.lasso), and Washington (http://www.wa.gov/agr/PestFert/Fertilizers/ProductDatabase.htm) now track and publish the levels of non-nutritive substances in fertilizer and/or micronutrient products registered for sale.

In the risk assessments, ideally, the plant uptake factors (PUF) are estimated by the soil solution concentration. PUF (l kg^{-1}) is defined as the ratio of plant tissue concentration (mg kg^{-1}) vs. soil solution concentration (mg l^{-1}). The soil solution concentrations normalize the availability of trace elements to plants across soils of various physical and chemical properties. In the risk-based assessment conducted by CDFA (1998), the plant tissue concentrations were estimated by the total metal concentration in the soils, using data obtained from the published technical literature, as the K_d values were not readily available for cropland soils. The total metal content of the soils was not an accurate and consistent parameter in estimating the transfer of metals from soils to the plants, as the availability of the element in the soils may be affected by soil properties such as pH, organic matter content, and cation exchange capacity. The uncertainties of the plant uptake factors that were employed in this risk assessment could introduce significant errors in the final outcomes. The values of K_d and PUF are susceptible to measurement uncertainties, even obtained under the most realistic situation. In addition, they must be generalized across different soil and plant species and management alternatives to represent scenarios often encountered in realistic situations. Ideally, K_d and PUF should be characterized in the probabilistic terms. In this manner, the outcomes of risk assessment may account for uncertainties in parameterization.

Project Objectives

In this project, the issues raised during the processes of developing the fertilizer regulations in California were addressed in the following manner:

1. Survey to determine the As, Cd, and Pb concentrations of cropland soils in California.
2. Characterize the K_d and PUF of cropland soils in California.
3. Develop a trace metal mass balance computer model to estimate metal accumulation in soil and plants due to fertilizer applications.

Results

Arsenic, Cadmium, and Lead Concentration of Soils

During the course of this investigation, 50 benchmark soils of California were sampled in 2002 and their As, Cd, and Pb contents were compared to those sampled in 1965. The outcomes showed that the background levels of these three elements in California soils have not changed significantly over time.

In the meantime, the vegetable growing soils in seven production areas were sampled to determine the influence of fertilizer applications on the soil's As, Cd, and Pb contents.

In the majority of the cases, the As, Cd, and Pb levels of the cropland soils remained at the baseline levels. The trace metal contents of soils in a few cases have exceeded the baseline levels. However, the elevated levels were attributed to diffused sources not related to the fertilizer applications (Tables 2 and 3).

Table 2. Role of Phosphorus Fertilizers on Arsenic, Cadmium and Lead Contents of Cropland Soils in California

Production Region	Arsenic	Cadmium	Lead
Oxnard and Ventura Area	Baseline	P Fertilizer	Diffuse Sources
Santa Maria and San Luis Obispo Valley	Diffuse Sources	Diffuse Sources	Diffuse Sources
Colusa/Glenn County	Diffuse Sources	Baseline	Baseline
Fresno	Baseline[1]	Baseline	Baseline
Coachella Valley	Baseline	Diffuse Sources	Baseline
Imperial Valley	Baseline	Diffuse Sources	Baseline
Monterey/Salinas Valley	Baseline	Diffuse Sources	Diffuse Sources

[1]*While remaining in the baseline range, the arsenic contents of soils showed a rising trend.*

Table 3. Role of Micronutrients on Arsenic, Cadmium and Lead Contents of Cropland Soils in California

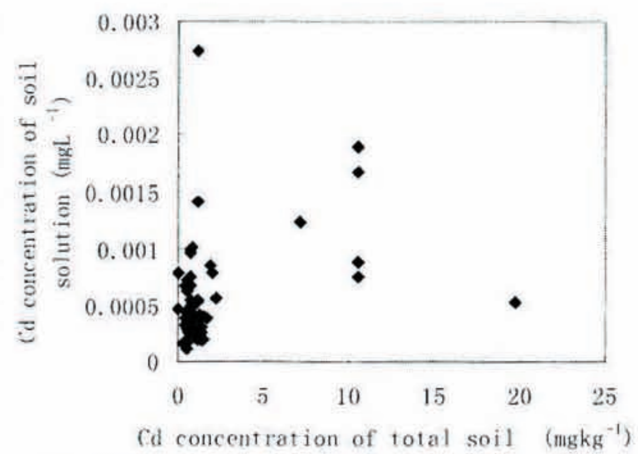
Production Region	Arsenic	Cadmium	Lead
Oxnard and Ventura Area	Baseline	Diffuse Sources	Diffuse Sources
Santa Maria and San Luis Obispo Valley	Diffuse Sources	Diffuse Sources	Diffuse Sources
Colusa/Glenn County	Diffuse Sources	Baseline	Baseline
Fresno	Baseline[1]	Baseline	Baseline
Coachella Valley	Baseline	Diffuse Sources	Baseline
Imperial Valley	Baseline	Diffuse Sources	Baseline
Monterey/Salinas Valley	Baseline	Diffuse Sources	Diffuse Sources

[1]*While remaining in the baseline range, the arsenic contents of soils showed a rising trend.*

Characterization of Partition Coefficients (K_d) and Plant Uptake Factor (PUF)

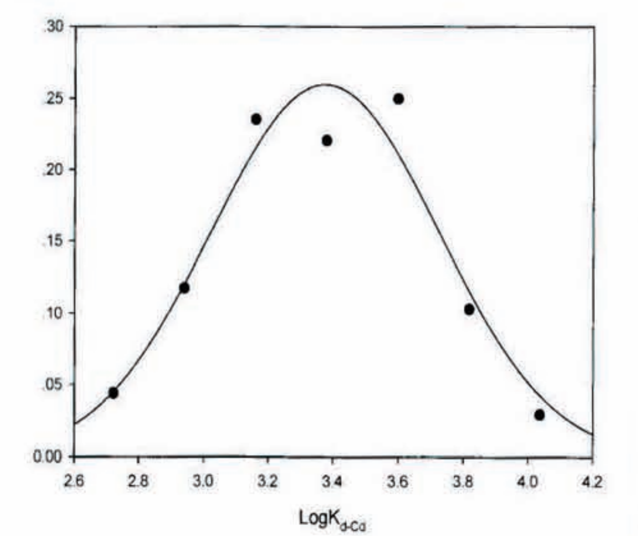
The solution phase concentration of As, Cd, and Pb in the California cropland soils did not appear to be related to their respective total contents (Figure 1).

Figure 1. Solid vs. Solution Phase Concentrations of Cd in California Cropland Soils



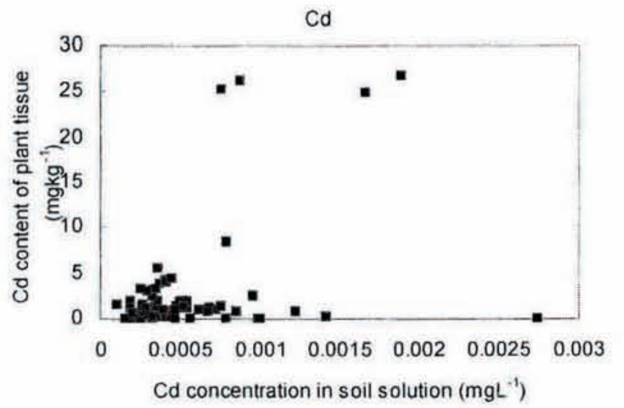
As a result, the K_d of the same element could vary by 5 to 6 orders of magnitude. In this regard, the data may be treated as a random distribution. The skewed scattering pattern may be described by a log-normal probability distribution (Figure 2).

Figure 2. Log-normal Probability Distribution of K_d for Cd in California Soils



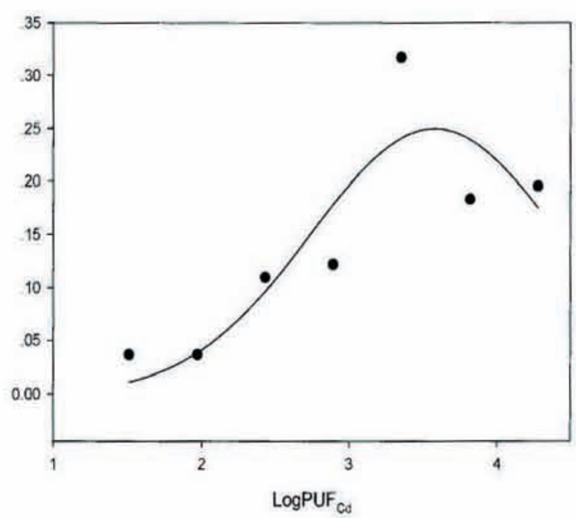
The As, Cd, and Pb concentrations in the plant tissue also were not related to the soil solution concentrations of the respective element (Figure 3).

Figure 3. Soil Solution Cd vs. Plant Tissue Cd of crops grown in California



Again, the date scattering pattern may be considered to follow a random distribution and described by a log-normal distribution (Figure 4).

Figure 4. Log-normal Probability Distribution of PUF of crops grown in California

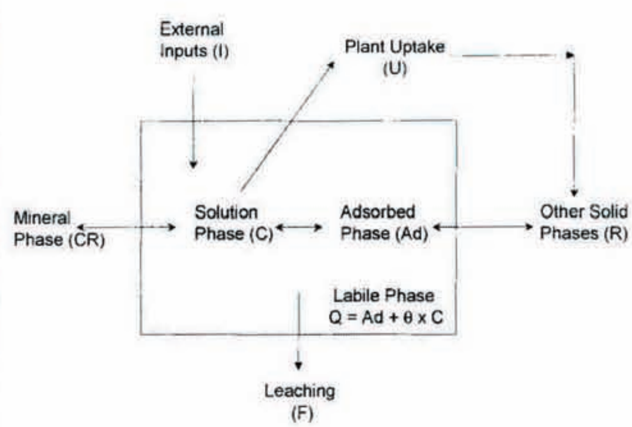


Trace Metal Mass Balance Model

A mass balance model is developed to assess trace element transformations in the root zone of irrigated cropland soils that are receiving routine P fertilizer and micronutrient applications. It assumes that the trace elements present in the root zone are distributed in the soil solution and four solid phases, namely the inorganic mineral, surface adsorbed, organic, and residual phases (Figure 1). A PC-based algorithm is developed to solve the equation, and the mass balances of As and Cd in California cropland soils are simulated for 100 years using this model.

Cropland soils in California typically contain 7.7 and 0.22 mg kg^{-1} of As and Cd and receive 30 and 13 g $ha^{-1}yr^{-1}$ of As and Cd inputs through application of P fertilizers and irrigation water. It appears, according to the model simulations, that the cropping practices do not have a significant effect on the total As content of the soils. However, the total Cd content of cropland soils may rise steadily over the 100-year simulation period. Results show that the total As and Cd content of the cropland soils will change from 7.7 to 7.6 and 0.22 to 0.35 mg kg^{-1}, respectively, over the 100-year simulation period. The outcomes of the simulations also showed that regulated As and Cd levels were not expected to result in excessive accumulation of these elements in the cropland soils and the harvested crops.

Figure 5. Schematic Depiction of the Trace Element Mass Balance Model



Conclusions

1. The As, Cd, and Pb contents of the cropland soils in California have not been adversely affected by the fertilizer applications and for the majority of them, the As, Cd, and Pb contents remained at the baseline levels.
2. The solid and solution phase partition (K_d) and the plant uptake factor (PUF) of As, Cd, and Pb for cropland soils in California do not appear to be constants. Instead, the K_d and PUF may be described by the log-normal probability distributions through which the uncertainties of estimating the soil accumulation and plant tissue concentrations of As, Cd, and Pb in cropland soils may be quantified.
3. Mass balance calculations indicated that fertilizers meeting the current maximum permissible As and Cd levels would not expect to result in excessive accumulation in receiving soils and in plant tissue. There was not sufficient data of lead to produce a reliable estimate. Judging on the K_d and PUF determined, we expected the fertilizers meeting the permissible Pb level to be the same as As and Cd.

Wireless Network for Site Specific Fertilizer Application

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Introduction

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

Orchards are a high value permanent crop, commonly irrigated and fertigated using drip or microsprinklers. Differences in soil type and topography can affect the rate of infiltration and runoff. For example, avocado orchards suffer from extreme variation in elevation. When applied uniformly, water and fertilizer can leach in light textured soils and pool in heavy soils or at low elevations. Another problem with modern fertigation systems is that growers sometimes inject fertilizer for only a short portion of the irrigation cycle (i.e., 1-2 hr). Recent research has shown that fertilizer may not reach the furthest emitters for as long as 45 minutes, indicating that some trees are not likely receiving enough nutrient. Conversely, increasing fertigation time to satisfy the most distant trees might over-fertilize others. Emitter clogging and irrigation line damage further compound the problem of delivering water and fertilizer.

Nurseries deal with continually changing inventory and must comply with environmental regulations limiting runoff and fertilizer leaching. Poor irrigation and fertilization uniformity causes over-application or under-application to plants throughout the nursery. Some nurserymen control their valves manually, which can waste water if not continuously monitored. Plants of differing size may be irrigated from the same source, so some will receive too much water and fertilizer while others will receive too little. Excessive runoff and leaching can be managed by capture and recycle systems, but this is expensive and not feasible for all nurseries.

In landscape operations, irrigation control also is important since a significant amount of California's available water is used for turf grass and ornamentals. Optimizing water delivery can conserve water and prevent leaching and runoff. Many commercial controllers have been developed in order to optimize water delivery by using reference evapotranspiration. These systems can reduce over-watering, but they only address the scheduling aspect of irrigation management and do not help with problems such as varying soil types, elevation, and diverse water requirements for all plants in a single installation.

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. The system was successfully used to irrigate trees for specific durations, to apply a specific volume of water at each tree, and to irrigate in response to soil water demand. Automated fault detection was used to check for damaged drip lines and clogged or damaged emitters. Recognizing that power and communication wires in the previously developed systems will likely impede commercial adoption, we initiated development of a wireless network for site-specific management. Wireless communication and solar power will eliminate the use of wires and will improve ease of installation and reduce problems associated with long-range wired communication and damage from animals and machinery. We will develop a simple and inexpensive wireless valve control system that can operate in multiple environments and is easy to install without added wiring. Larger valves will be used to control flow to multiple sprinklers or drip emitters (e.g., laterals) or smaller valves will control flow to individual plants or trees (e.g., each microsprinkler). Individual valve schedules will be different in order to match differing water and fertilizer requirements and can easily be changed to accommodate replants, disease, growth or seasonal changes. Using feedback from pressure and flow sensors, it will be possible to improve water and fertilizer application accuracy over that of fixed-duration irrigation. An added benefit is that these sensors will provide information to automatically detect line breaks, emitter clogging, and similar problems.

Objectives

To continue the development of site-specific fertilizer application methods, we have submitted a new proposal to FREP with the following objectives:

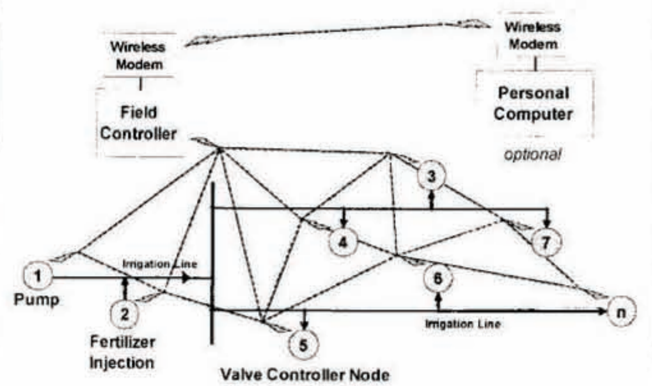
(1) Develop general operating strategies for spatially controllable fertigation to allow application of prescribed amounts of fertilizer at specific locations.
(2) Design a wireless valve controller network to simplify the implementation of precision fertigation.

Project Description

System Design

Work has already begun on the wireless valve controller network. The three tasks required to accomplish this objective are (i) design an intelligent valve controller capable of low-power, stand-alone operation, and wireless communication; (ii) develop a communication network to link the valve controllers with a central field controller; and (iii) develop improved control strategies for applying water and fertilizer. Since this system is intended for application in orchards, greenhouses, landscapes, and nurseries, the wireless network (Figure 1) must be versatile enough to operate in many environments. Mesh networking will allow messages to pass from one node to any other node in the network by routing it through intermediary nodes. This technique allows increased network range without using high power transceivers. Another advantage is redundancy. A failed node will not disable the entire network since multiple routing paths exist between nodes. The operator will enter schedules on the field controller, and they will be distributed to the pump controller, injector controller, and valve controller nodes in the network. Sensors that monitor parameters such as soil moisture, temperature or humidity could also be used for automatic triggering of irrigation and fertigation events. An optional personal computer will provide a graphical interface, but will not be required to operate the system.

Figure 1. Layout of wireless valve network.



The first generation prototype for a wireless microsprinkler was designed using commercially-available demonstration boards (Figure 2) (http://www.microchip.com). A latching solenoid valve was used to control water and fertilizer flow through the emitter since it requires only a brief pulse of energy to open or close. A buzzer was connected to the microcontroller for audible feedback during node operation. A solar panel on top of the stake will charge an onboard battery for continuous operation without battery replacement, though this feature is not yet implemented. Another demonstration board was connected to the field controller to allow communication on the wireless network. 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.

In our second generation design, we selected smaller, low-power wireless modules from Moteiv (http://www.moteiv.com) (Figure 3). These boards were designed specifically for battery-powered mesh networking and have been used to operate 1-inch and 1/8-inch latching valves (Figure 4).

Figure 3. Second generation design with module using wireless mesh communication.

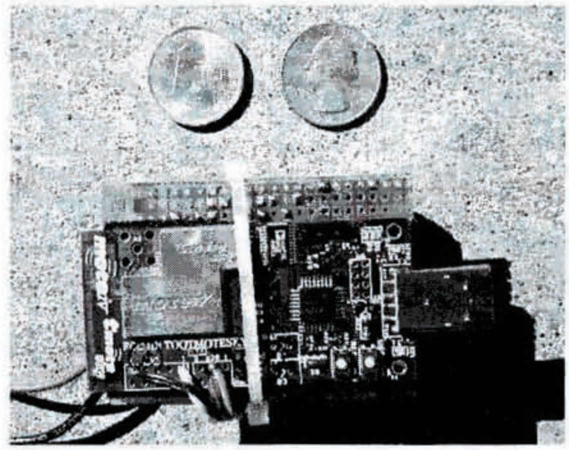


Figure 2. First generation prototype microsprinkler node.

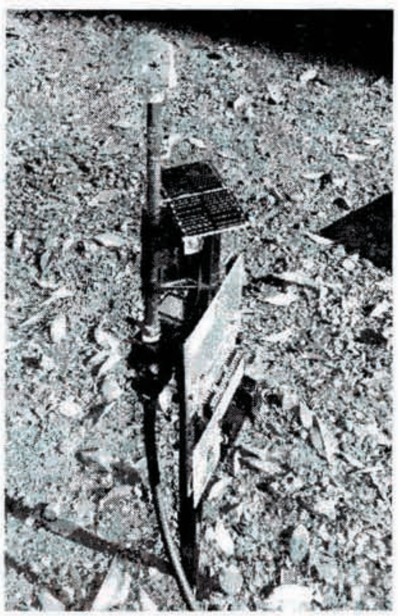
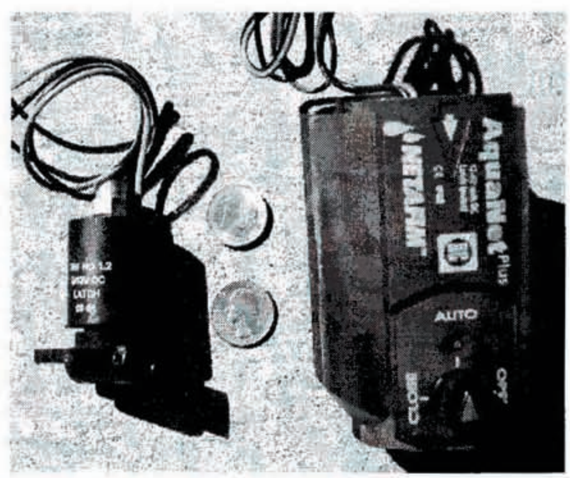


Figure 4. Latching solenoid valves with 1/8" or 1" ports for irrigation/fertigation control.



Initial Results and Continuing Work

For both first and second generation designs, communication between the field controller and two nodes was tested. Each node properly responded to commands to open or close its valve. Radio transmission range under visual line-of-sight conditions was about 100 ft using the printed antennas on the demonstration boards. Improved range could be achieved by using a wire antenna. To extend battery life, nodes sleep most of the time and only use the radio when data transfer is required. The second generation design used only one-fifth as much energy during sleep compared to the first generation prototype. Ultimately, the nodes must use less energy on average than is produced by the solar panel which recharges the battery. The solar panel output was tested in full sunlight and full shade conditions. Sunny conditions produced five to seven times more energy than shaded conditions. Under shaded conditions, just enough energy was produced to allow 30 minutes of daily radio communication. Careful monitoring of radio-use and solar panel production will be needed to ensure uninterrupted node operation.

Pending support for the new project, we plan to start work on general operating strategies for a spatially variable fertigation (objective 1) and complete the wireless network design (objective 2). The nodes will be programmed for standalone operation using wirelessly transmitted schedules. Extended tests under sunlight, shade, and overcast skies will be conducted to determine the reliability of solar-powered battery charging and energy management schemes. Sensors will be connected to the nodes for monitoring water pressure, soil moisture level or other parameters. Nodes will be deployed in the field and used to develop fertilizer control and fault detection strategies. Since this system has potential applications in orchards, nurseries, greenhouses, and landscapes, the wireless controllers will be tested in as many different environments as possible. We will work with growers to improve their water and fertilizer use efficiency and minimize runoff and leaching.

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

Determination of Nursery Crop Yields, Nutrient Content, and Water Use for Improvement of Water and Fertilizer Use Efficiency

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Introduction

There is increasing interest in the development of fertilizer and irrigation best management practices for commercial nurseries. Some of the information necessary for the development of BMPs for nurseries is available. For example, some information about water and nitrogen requirements of 1-gallon container nursery stock has been published, and a few studies have addressed questions about the effects of fertilizer N form, concentration, frequency of delivery, and the effects of plant development on nutrient uptake. Although such studies yield much useful information, they are not well suited to provide general guidelines for fertilizer management of the immense range of nursery crops in California. This project was undertaken to provide the nursery industry with basic information about the quantities of nitrogen, phosphorus, potassium, and water needed by their crops.

Objectives

1. Determine the NPK uptake of 75 container-grown ornamental crops at commercial maturity.
2. Measure water use of these crops at key stages of development and relate values to reference evapotranspiration.
3. Estimate and prepare recommendations for overall crop water and fertilizer needs based on values obtained from preceding objectives.

Description

A wide range of nursery crops were grown in the Environmental Horticulture outdoor nursery on the UC Davis campus. Plants were fertilized with a complete controlled-release fertilizer or with a complete liquid feed fertilizer. Fresh and dry weights and NPK contents of the roots and shoots of propagules and finished crops were determined. Evapotranspiration was monitored throughout crop production. Data for Years 1-3 are presented here.

Results and Discussion

Year 1

Daily water use of the one-gallon sun and shade crops grown in Year 1 varied with weather conditions and crop age. Water use of plants grown in full sun did not exceed 250 mL/day on any day, and usually was less than 200 mL/day. Water use of plants grown under shade cloth never exceeded 200 mL/day, and usually was less than 150 mL/day. The crop coefficients for crops grown in full sun ranged from 0.9-1.8 (based on water use relative to ET_o for the soil surface area), but seasonal changes in k_c never exceeded 0.29 for a particular shrub species. The values were generally lower for shade-grown species, but remained relatively constant over time for only two of the species. For the other shade-grown species, k_c increased by as much as 0.73 as plants increased in size.

Applied fertilizer rate (low and high rates recommended by the manufacturer) had no significant effect on yields, and these woody species did not appear to have luxury consumption of the macronutrients analyzed. Dry weights and tissue nutrient concentrations of finished plants are presented in Table 1. Four species (Aucuba, Camellia, Dietes, and Juniperus) grew slowly and had relatively small dry weight gains. Tissue nitrogen concentrations were acceptable in all species, but P was low in several species and K was unusually low in Camellia. Camellia took up extremely small amounts of N and no measurable amounts of P or K during the growing season (Table 2). Among the species with more normal growth, N uptake ranged from 70 mg by Aucuba to 598 mg by Lavandula (Table 2). P uptake among most species was between 30-50 mg, but uptake by Aucuba, Camellia, Dietes, and Juniperus was 11 mg or less. K uptake also varied widely.

Table 1. Dry weight and tissue N, P, and K concentrations in whole plants (shoots plus roots) from 1-gallon containers at commercial maturity in Year 1 experiment.

Species	Dry wt. (g)	N (%)	P (%)	K (%)
Acorus 'Ogon'	25.1	2.87	0.39	3.73
Aucuba japonica 'Variegata'	4.3	2.37	0.19	1.56
Camellia x 'Winter's Star'	5.2	2.07	0.15	0.64
Dietes vegeta	8.6	1.95	0.21	2.19
Hydrangea macrophylla 'Nikko Blue'	24.0	2.20	0.23	2.12
Juniperus scopulorum 'Moonglow'	11.6	2.12	0.15	1.45
Lantana 'Pink Caprice'	29.7	2.04	0.17	1.89
Lavandula dentata	32.4	2.05	0.19	1.92
Nandina domestica	26.4	1.65	0.15	1.00
Weigela florida 'Variegata Nana'	14.6	2.53	0.30	1.70

Table 2. Total N, P, and K uptake of plants in 1-gallon containers between planting and harvest in Year 1 experiment.

Species	N (mg)	P (mg)	K (mg)
Acorus 'Ogon'	529	53	716
Aucuba japonica 'Variegata'	70	3	22
Camellia x 'Winter's Star'	42		
Dietes vegeta	132	11	141
Hydrangea macrophylla 'Nikko Blue'	449	41	459
Juniperus scopulorum 'Moonglow'	138	5	108
Lantana 'Pink Caprice'	565	44	525
Lavandula dentata	598	54	557
Nandina domestica	411	33	240
Weigela florida 'Variegata Nana'	311	32	196

Cumulative water use (transpiration plus evaporation) ranged from about 11-15 liters for most species (Table 3). The maximum ratio of N uptake to total water use was 56 mg/l, and the average value was 25 mg/l.

Table 3. Cumulative water use and calculated minimum liquid feed [N] (based on ratio of total N uptake and total water uptake) in Year 1 experiment.

	Low fertilizer rate		High fertilizer rate	
Species	Water use (l)	[N] (mg/l)	Water use (l)	[N] (mg/l)
Acorus 'Ogon'	11.6	36	13.0	49
Aucuba japonica 'Variegata'	7.8	11	7.2	7
Camellia x 'Winter's Star'	7.5	8	7.1	2
Dietes vegeta	11.7	10	11.1	14
Hydrangea macrophylla 'Nikko Blue'	12.7	38	11.1	38
Juniperus scopulorum 'Moonglow'	11.5	10	11.8	13
Lantana 'Pink Caprice'	17.9	27	18.6	34
Lavandula dentata	15.3	32	13.3	56
Nandina domestica	10.6	31	10.6	47
Weigela florida 'Variegata Nana'	15.4	22	15.0	18

Year 2

The experiments in Year 2 were focused on herbaceous species and were grown in containers ranging in size from 4-inch to 1-gallon, depending on species. The yields differed significantly among species, and the applied fertilizer rate affected yields and nutrient content in Coleus, Cosmos, and Pepper plants (Table 4). Average yield for all species fertilized at the high recommended rate was 14.4 g, compared to 13.3g for plants fertilized at the low recommended rate.

Shoot N, P, and K concentrations were significantly different among species, and tissue N concentrations were affected by fertilizer concentration, but shoot K and P concentrations were affected only by species (Table 5). The lower N and K concentrations in plants fertilized at the low fertilizer rate could account for the lower yields observed at that fertilizer concentration, although NPK concentrations were within the published acceptable ranges for all species except Pepper (and perhaps Cosmos, for which no published data are available).

The highest quantity of N uptake was 883 mg by Cosmos plants (Table 6). Average N uptake was 346 mg at the low fertilizer rate and 446 mg at the high rate. Fertilizing at the high recommended rate resulted in greater N uptake by Coleus, Cosmos, Impatiens, Nepeta, Pepper, and Perovskia, but only Coleus, Cosmos, and Pepper plants responded with higher yields.

Table 4. Dry weight (g) of finished plants in Year 2 experiment.

	Low fertilizer rate			High fertilizer rate		
Species	**Shoot**	**Root**	**Total**	**Shoot**	**Root**	**Total**
Angelonia	12.7	1.30	14.0	12.0	1.14	13.1
Calibrachoa	10.6	0.69	11.3	8.0	0.52	8.6
Caryopteris 'Longwood Blue'	14.4	0.85	15.3	14.6	0.69	15.3
Coleus 'Tilt A Whirl'	6.9	1.06	8.0	10.1	1.10	11.2
Cosmos 'Sonata Pink'	20.7	2.16	22.9	25.5	2.56	28.1
Geranium 'Flamingo'	19.9	2.09	22.0	21.9	2.07	24.0
Impatiens 'Double Ole Rose'	7.7	0.75	8.5	7.4	0.64	8.1
Lavender 'Munstead'	7.0	0.55	7.6	6.1	0.63	6.7
Nepeta 'Dropmore'	16.4	1.69	18.1	20.2	1.29	21.4
New Guinea Impatiens 'Bonfire Orange'	5.5	0.79	6.3	5.8	0.95	6.7
Penstemon 'Red Rocks'	10.3	0.33	10.6	9.2	0.28	9.4
Pepper 'Sweet California Wonder'	11.3	4.39	15.7	16.1	5.62	21.7
Perovskia atriplicifolia	11.7	0.79	12.5	12.3	1.04	13.4

Table 5. Whole shoot nutrient concentrations (% dry weight) of finished plants in Year 2 experiment.

	Low fertilizer rate			High fertilizer rate		
	N	**P**	**K**	**N**	**P**	**K**
Species	**(%)**	**(%)**	**(%)**	**(%)**	**(%)**	**(%)**
Angelonia	3.10	0.43	2.48	3.29	0.49	2.70
Calibrachoa	3.46	0.42	3.37	3.46	0.42	3.35
Caryopteris 'Longwood Blue'	3.79	0.45	2.52	3.97	0.49	2.69
Coleus 'Tilt A Whirl'	3.66	0.74	4.17	3.98	0.67	4.30
Cosmos 'Sonata Pink'	2.26	0.46	3.13	3.65	0.57	4.34
Geranium 'Flamingo'	2.69	0.56	3.16	2.81	0.60	3.38
Impatiens 'Double Ole Rose'	3.56	0.62	4.15	4.28	0.63	4.41
Lavender 'Munstead'	3.13	0.41	4.17	3.21	0.42	4.41
Nepeta 'Dropmore'	3.62	0.45	3.60	3.97	0.45	3.75
New Guinea Impatiens 'Bonfire Orange'	3.09	0.58	3.29	3.42	0.62	3.15
Penstemon 'Red Rocks'	2.89	0.49	3.17	2.93	0.50	3.03
Pepper 'Sweet California Wonder'	2.62	0.52	3.78	3.20	0.45	4.25
Perovskia atriplicifolia	3.10	0.56	3.88	3.61	0.59	4.09

Table 6. Whole plant nutrient uptake of finished plants in Year 2 experiment.

	Low fertilizer rate			High fertilizer rate		
	N	**P**	**K**	**N**	**P**	**K**
Species	**(mg)**	**(mg)**	**(mg)**	**(mg)**	**(mg)**	**(mg)**
Angelonia	393	54	304	391	57	310
Calibrachoa	370	45	292	259	35	220
Caryopteris 'Longwood Blue'	545	65	365	581	71	401
Coleus 'Tilt A Whirl'	220			380		
Cosmos 'Sonata Pink'	388			883		
Geranium 'Flamingo'	214			264		
Impatiens 'Double Ole Rose'	468			552		
Lavender 'Munstead'	204	26	257	186	24	228
Nepeta 'Dropmore'	596	74	588	803	91	747
New Guinea Impatiens 'Bonfire Orange'	114			148		
Penstemon 'Red Rocks'	287	48	306	255	48	259
Pepper 'Sweet California Wonder'	345			654		
Perovskia atriplicifolia	356	65	430	445	73	517

The calculated ratio of N uptake: water uptake over the course of the experiment indicates that most of these herbaceous species readily take up about 100-150 mg N/l, 20 mg P/l, and 120-150 mg K/l (Table 7). Luxury consumption of N occurs in most of the species tested.

Evapotranspiration did not exceed 250 ml/day, and usually was less than 150 mL/day. Cumulative water use ranged from 1.6 l for New Guinea Impatiens to 3.9 l for Impatiens (Table 7). Only Geranium, Cosmos, Nepeta, and Perovskia, the crops with the greatest leaf area, exceeded ET_o. The crop coefficient, k_c, tended to increase as plants matured. For most species, k_c did not increase dramatically until the week of harvest. Values in the first 2 weeks after planting ranged from 0.2 to 0.6 (based on water use relative to ET_o for the area occupied by each plant). At commercial maturity, k_c ranged from 0.4 for New Guinea Impatiens to 1.5 for Cosmos.

YEAR 3

Plants in Year 3 were grown in 1-gallon pots using UC Mix as the potting medium and fertilized with half-strength or quarter-strength Hoagland's solution with each irrigation. Yields differed among species, but the fertilizer rate only affected the yield of Hemerocallis (Table 8).

Shoot N, P, and K concentrations and total uptake were significantly different among species and fertilizer rates (Tables 9 and 10). The crops for which fertilizer rate affected shoot N were Aptenia, Euonymus, Gazania, Hemerocallis, Lagerstroemia, Miscanthus, Pachysandra, Parthenocissus, Phalaris, Prunus, and Pyracantha coccinea. The higher fertilizer rate also increased shoot P in Pachysandra and Parthenocissus, and increased shoot K in Aptenia, Armeria, Gazania, Pachysandra, and Phalaris.

The highest quantity of N uptake was 1.25 g, by Hemerocallis plants (Table 10). Average N uptake was 379 mg at the low fertilizer rate and 530 mg at the high rate. P uptake averaged 77 and 100 mg at the low and high fertilizer rates, and average K uptake was 490 and 615 mg. It is important to note, however, that only the yield of Hemerocallis was affected by fertilizer uptake.

The calculated ratio of nutrient uptake: water uptake over the course of the experiment indicates that, except for Hemerocallis, all of these crops achieve acceptable yields at ratios of about 50 mg N/l, 20 mg P/l, and 50 mg K/l (Table 11). Aptenia apparently took up K at a ratio well in excess of the concentration applied, but yield was not affected significantly in this experiment.

Phalaris had the highest average rate of water use at 398 ml/day, and the highest water use on any single day was 602 ml, by Phalaris. The overall average for daily evapotranspiration was 150 ml, but values ranged from 77 to 398 ml. Cumulative water use ranged from 6.3 l for Spiraea to 16.6l for Hypericum (Table 11).

Table 7. Cumulative water uptake and calculated minimum liquid feed NPK concentrations (based on ratio of total NPK uptake and total water uptake) in Year 2 experiment.

	Low fertilizer rate				High fertilizer rate			
Species	Water Use (L)	N (mg/l)	P (mg/l)	K (mg/l)	Water Use (L)	N (mg/l)	P (mg/l)	K (mg/l)
Angelonia	3.1	128	17	99	3.4	116	17	92
Calibrachoa	2.7	138	17	109	2.7	97	13	83
Caryopteris 'Longwood Blue'	3.1	174	21	117	3.2	184	23	127
Coleus 'Tilt A Whirl'	2.0	112	22	123	2.1	179	29	186
Cosmos 'Sonata Pink'	3.3	119	23	164	3.5	253	37	295
Geranium 'Flamingo'	2.1	103	17	126	1.7	158	21	165
Impatiens 'Double Ole Rose'	3.8	123	28	143	3.9	142	33	167
Lavender 'Munstead'	2.3	89	11	112	2.1	87	11	107
Nepeta 'Dropmore'	4.1	146	18	144	3.6	224	25	208
N.G. Impatiens 'Bonfire Orange'	1.6	73	14	77	1.6	93	16	79
Penstemon 'Red Rocks'	3.1	92	15	98	2.7	93	18	95
Pepper 'Sweet California Wonder'	2.6	133	24	155	2.9	223	29	232
Perovskia atriplicifolia	3.4	103	19	125	3.4	130	21	151

Table 8. Dry weights (g) of liners and commercially mature plants in the Year 3 experiment.

Scientific name/cultivar	Common Name	Liner	Harvest DW Low Rate	Harvest DW High Rate
Aptenia cordifolia	Heartleaf Ice Plant	3.49	21.88	26.76
Armeria maritima	Sea Pink	1.00	12.67	11.36
Berberis thunbergii 'Crimson Pygmy'	Japanese Barberry	1.60	15.32	16.04
Buxus microphylla 'Winter Gem'	Boxwood	3.52	16.86	18.02
Euonymus fortunei 'Green and Gold'	Wintercreeper Euonymus	3.78	15.99	16.99
Gazania 'Majestic Yellow'	Gazania	1.44	18.60	19.77
Hemerocallis 'Stella de Oro'	Daylily	8.60	45.56	53.67
Hypericum calycinum	St. John's Wort	1.49	32.92	36.61
Ilex aquifolium 'San Gabriel'	English Holly	6.30	25.90	25.06
Imperata cylindrica 'Red Baron'	Japanese Blood Grass	0.92	22.62	20.62
Lagerstroemia indica 'Petite Orchid'	Crape Myrtle	2.42	24.58	28.37
Ligustrum japonicum 'Texanum'	Privet	4.36	28.57	25.69
Miscanthus sinensis 'Purpurescens'	Flame Grass	2.74	25.99	20.84
Pachysandra terminalis	Japanese Spurge	5.84	27.60	29.13
Parthenocissus quinquefolia	Virginia Creeper	4.27	26.53	23.95
Phalaris arundinacea 'Strawberries and Cream'	Ribbon Grass	1.87	26.82	29.79
Prunus laurocerasus 'Zabeliana'	English Laurel	0.78	18.70	23.60
Pyracantha coccinea 'Low Boy'	Firethorn	2.28	16.68	19.56
Pyracantha koidzumii 'Walderi Prostrata'	Firethorn	4.64	35.64	37.14
Rhaphiolepis indica 'Pink Lady'	Indian hawthorn	2.75	35.18	29.02
Rosa 'The Fairy'	Rose, polyantha	2.93	25.41	24.00
Rosmarinus officinalis 'Prostratus'	Rosemary	0.84	31.71	31.45
Spiraea japonica 'Neon Flash'	Spiraea	2.18	16.66	15.82
Thuja 'Green Giant'	Arborvitae	4.93	15.27	20.88

Table 9. Whole shoot nutrient concentrations (% dry weight) of finished plants in Year 3 experiment.

Scientific name/cultivar	Low fertilizer rate N (%)	Low fertilizer rate P (%)	Low fertilizer rate K (%)	High fertilizer rate N (%)	High fertilizer rate P (%)	High fertilizer rate K (%)
Aptenia cordifolia	2.45	1.21	6.74	3.25	1.10	7.75
Armeria maritima	2.04	0.50	3.31	2.19	0.43	4.38
Berberis thunbergii 'Crimson Pygmy'	1.37	0.20	1.36	1.70	0.25	1.82
Buxus microphylla 'Winter Gem'	1.97	0.17	1.30	2.28	0.20	1.74
Euonymus fortunei 'Green and Gold'	1.85	0.23	1.64	2.49	0.30	1.99
Gazania 'Majestic Yellow'	2.47	0.51	4.88	3.62	0.57	6.32
Hemerocallis 'Stella de Oro'	2.58	0.44	3.52	3.05	0.47	3.94
Hypericum calycinum	1.71	0.30	2.03	1.87	0.34	2.11
Ilex aquifolium 'San Gabriel'	1.35	0.15	1.70	1.73	0.21	2.18
Imperata cylindrica 'Red Baron'	1.12	0.31	2.17	1.20	0.34	2.26
Lagerstroemia indica 'Petite Orchid'	2.40	0.64	2.27	3.08	0.70	2.84
Ligustrum japonicum 'Texanum'	1.49	0.17	1.50	1.81	0.19	1.57
Miscanthus sinensis 'Purpurescens'	1.15	0.25	1.51	1.73	0.27	1.72
Pachysandra terminalis	1.58	0.21	1.89	2.13	0.25	2.41
Parthenocissus quinquefolia	2.00	0.49	1.66	2.69	0.98	2.14
Phalaris arundinacea 'Strawberries and Cream'	3.08	0.81	4.46	4.03	0.82	5.14
Prunus laurocerasus 'Zabeliana'	2.18	0.43	1.98	2.68	0.44	1.82
Pyracantha coccinea 'Low Boy'	2.28	0.30	1.60	2.77	0.32	1.77
Pyracantha koidzumii 'Walderi Prostrata'	1.63	0.27	1.31	2.05	0.33	1.51
Rhaphiolepis indica 'Pink Lady'	1.42	0.26	1.61	1.66	0.29	1.83
Rosa 'The Fairy'	2.04	0.36	1.59	2.33	0.42	1.74
Rosmarinus officinalis 'Prostratus'	2.14	0.41	3.07	2.58	0.52	3.64
Spiraea japonica 'Neon Flash'	2.32	0.51	2.34	2.57	0.48	2.34
Thuja 'Green Giant'	1.30	0.24	1.58	1.61	0.28	1.64

Table 10. Whole plant nutrient uptake of finished plants in Year 3 experiment.

Scientific name/cultivar	Low fertilizer rate N (mg)	Low fertilizer rate P (mg)	Low fertilizer rate K (mg)	High fertilizer rate N (mg)	High fertilizer rate P (mg)	High fertilizer rate K (mg)
Aptenia cordifolia	439	225	1232	772	256	1805
Armeria maritima	257	67	404	249	53	470
Berberis thunbergii 'Crimson Pygmy'	219	17	210	293	39	277
Buxus microphylla 'Winter Gem'	295	30	191	390	38	274
Euonymus fortunei 'Green and Gold'	237	32	202	370	52	280
Gazania 'Majestic Yellow'	400	91	797	662	107	1146
Hemerocallis 'Stella de Oro'	740	148	975	1253	210	1334
Hypericum calycinum	539	105	637	693	131	750
Ilex aquifolium 'San Gabriel'	279	53	374	362	57	458
Imperata cylindrica 'Red Baron'	246	73	491	254	73	462
Lagerstroemia indica 'Petite Orchid'	462	126	456	729	165	669
Ligustrum japonicum 'Texanum'	339	46	376	381	51	354
Miscanthus sinensis 'Purpurescens'	213	53	349	296	51	312
Pachysandra terminalis	286	46	392	480	83	586
Parthenocissus quinquefolia	408	113	404	518	200	476
Phalaris arundinacea 'Strawberries and Cream'	637	179	943	981	214	1285
Prunus laurocerasus 'Zabeliana'	352	72	344	594	120	417
Pyracantha coccinea 'Low Boy'	317	10	239	479	37	337
Pyracantha koidzumii 'Walderi Prostrata'	487	49	419	676	67	502
Rhaphiolepis indica 'Pink Lady'	410	51	509	408	49	466
Rosa 'The Fairy'	437	32	364	496	43	381
Rosmarinus officinalis 'Prostratus'	643	128	927	779	165	1105
Spiraea japonica 'Neon Flash'	326	77	327	348	70	311
Thuja 'Green Giant'	123	32	200	260	61	303

Table 11. Cumulative water uptake and calculated minimum liquid feed NPK concentrations (based on ratio of total NPK uptake and total water uptake) in Year 3 experiment.

Scientific name/cultivar	Low fertilizer rate Water Use (L)	Low fertilizer rate N (mg/l)	Low fertilizer rate P (mg/l)	Low fertilizer rate K (mg/l)	High fertilizer rate Water Use (L)	High fertilizer rate N (mg/l)	High fertilizer rate P (mg/l)	High fertilizer rate K (mg/l)
Aptenia cordifolia	10.4	42	22	118	11.3	68	23	160
Armeria maritima	9.4	27	7	43	8.6	29	6	55
Berberis thunbergii 'Crimson Pygmy'	7.9	28	2	27	7.8	38	5	36
Buxus microphylla 'Winter Gem'	11.6	25	3	16	12.1	32	3	23
Euonymus fortunei 'Green and Gold'	11.4	21	3	18	12.6	29	4	22
Gazania 'Majestic Yellow'	8.9	45	10	90	10.1	66	11	114
Hemerocallis 'Stella de Oro'	9.3	80	16	105	8.9	140	24	149
Hypericum calycinum	16.3	33	6	39	16.6	42	8	45
Ilex aquifolium 'San Gabriel'	13.8	20	4	27	14.1	26	4	33
Imperata cylindrica 'Red Baron'	9.4	26	8	52	9.0	28	8	52
Lagerstroemia indica 'Petite Orchid'	10.6	44	12	43	11.3	65	15	59
Ligustrum japonicum 'Texanum'	7.4	46	6	51	7.4	51	7	48
Miscanthus sinensis 'Purpurescens'	10.3	21	5	34	9.9	30	5	31
Pachysandra terminalis	6.9	41	7	57	7.7	62	11	76
Parthenocissus quinquefolia	7.6	54	15	53	8.0	65	25	59
Phalaris 'Strawberries and Cream'	15.5	41	12	61	15.9	62	13	81
Prunus laurocerasus 'Zabeliana'	13.4	26	5	26	15.0	40	8	28
Pyracantha coccinea 'Low Boy'	7.7	41	1	31	8.0	60	5	42
P. koidzumii 'Walderi Prostrata'	14.6	33	3	29	15.2	45	4	33
Rhaphiolepis indica 'Pink Lady'	14.4	28	4	35	13.0	31	4	36
Rosa 'The Fairy'	10.0	44	3	36	8.6	58	5	44
Rosmarinus officinalis 'Prostratus'	16.1	40	8	58	15.9	49	10	69
Spiraea japonica 'Neon Flash'	7.2	45	11	45	6.3	55	11	49
Thuja 'Green Giant'	8.0	15	4	25	8.1	32	7	37

CONCLUSIONS

Nursery crops vary widely in both nutrient and water consumption, hence it is difficult to establish a fertilizer recommendation that satisfies all common nursery crops. In most cases, however, woody species should receive adequate nutrition from a liquid feed containing 50 mg N/l, 20 mg P/l, and 50 mg K/l. Most herbaceous species require about 100-150 mg N/l, 20 mg P/l, and 120-150 mg K/l. Water use in one-gallon or smaller containers rarely exceeds 250 ml/day (about one-half pint), but it is not well correlated with ET_o. It is unlikely that reliable crop coefficients can be established for most of these crops.

Groundwater Quality Issues related to Using Dairy Manure as Fertilizer

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Abstract

Environmentally sustainable land application of dairy (and other animal) manure is a significant concern for animal feeding operations (AFOs) and for agencies regulating those facilities. But for many growers, the use of liquid manure, solid manure, or composted manure as fertilizer or soil amendment is also a financially attractive alternative to commercial products.

With respect to groundwater quality, prevention of excessive levels of groundwater nitrate and, in semi-arid and arid basins, prevention of long-term salinization are central issues associated with the land application of manure. Key challenges to sustainable nutrient management are irrigation efficiency, the large amounts of organic nitrogen contained in manure, and the high nitrogen demand of some key forage crops. In many manure land application areas, irrigation efficiencies remain low due to the use of flood irrigation. Even where irrigation efficiencies have improved, irrigation uniformity and uniformity of manure applications are challenges. Corn-winter grain double-cropped forage systems have short and intense periods of nutrient uptake around July and March. In contrast, organic nitrogen acts like a slow-release fertilizer that is emitting nitrate continuously throughout the year, although at much lower rates during the cooler winter months. The mismatch between nitrate release and crop nitrate uptake is difficult to manage without significant leaching losses of nitrate to groundwater.

A variety of other groundwater quality issues have also been associated with manure applications. Groundwater phosphorus levels are of concern, where very shallow groundwater discharges to nearby surface waters. The fate of emerging contaminants, particularly pharmaceuticals, has become a recent concern as laboratory methods have improved the detection of pharmaceuticals to levels of one-thousandth of 1 microgram per liter. Large amounts of pharmaceuticals are administered on AFOs, particularly antibiotics, mostly in the swine, poultry, and beef industry. Remaining largely unabsorbed by the animal body, significant levels of antibiotics are found in manure applied to forage land or in storage lagoons.

Antibiotic levels in groundwater have not confirmed an immediate risk of groundwater degradation, even in relatively vulnerable groundwater aquifers. However, a couple of studies suggest antibiotic-resistant bacteria may travel into groundwater. Synthetic hormones are used to improve production, but only some will be excreted and little is known about their potential fate in soils. More importantly, endogenous natural steroid hormones occur at significant concentrations in manure and can be detected in groundwater at the ng/l level. As with antibiotics, groundwater impacts due to hormones have rarely been observed, are sporadic, and found at concentrations that give little concern for drinking water consumption. Yet, soil storage and degradation pathways are still poorly understood. Other chemicals used on AFOs are those being collected with the animal waste, but not excreted by the animal, including iodine and other disinfectants used in milk barns, and $CuSO_4$ or $ZnSO_4$ which are used for foot baths. Monitoring of groundwater impacts from land applications of manure in AFOs or neighboring farms is difficult due to the multitude and temporal as well as spatial variability of source loading, but also due to typically complex groundwater heterogeneity.

Bio

Thomas Harter, Ph.D., received a B.S. in hydrology from the University of Freiburg, Germany and a M.S. in hydrology from the University of Stuttgart, Germany. He received his Ph.D. in hydrology (with emphasis on subsurface hydrology) at the University of Arizona, where he became the 1991 Harshbarger fellow for outstanding research in subsurface flow and transport modeling. In 1995, he joined the faculty at the Department of Land, Air, and Water Resources, University of California, Davis. His research focuses on nonpoint-source pollution of groundwater, groundwater resources evaluation under uncertainty, groundwater modeling, and contaminant transport. Dr. Harter has done extensive modeling of heterogeneous aquifer/vadose zone systems.

Detecting and Correcting Soil Calcium Limitations

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Introduction

The issue of calcium (Ca) availability and activity in alkaline, mineral soils has long been a matter of contention. Based on the commonly used 'exchangeable cations' test (ammonium acetate extraction), most California soils are well supplied with Ca. However, in alkaline soils, a substantial percentage of 'exchangeable' calcium identified by this test can be in chemical forms not in soil solution nor readily available to plants. Calcium-related physiological disorders such as blossom-end rot of fruiting crops and tipburn on lettuce are commonly encountered in commercial fields. In an attempt to combat these disorders, to improve postharvest quality, and to improve soil structure and water infiltration, California vegetable growers use significant quantities of calcium-based fertilizers and amendments. There are a number of competing Ca-containing products in the marketplace, and a variety of claims have been made regarding their comparative performance. This project conducted a comprehensive evaluation of both the measurement of soil calcium status, and the effect of calcium fertilizers on vegetable crop nutrition.

Objectives

a) Evaluate the relative accuracy of common soil test methods in estimating soil Ca status.
b) Compare the efficacy of common soil-applied calcium fertilizers on vegetable crop productivity, postharvest quality, and Ca content.

Project Description

A set of 22 representative agricultural soils was collected from fields in vegetable rotations in the Sacramento, Salinas, San Joaquin, and Santa Maria Valleys. These soils were chosen to represent a range of texture (sandy loam to clay), pH (6.7 - 7.8), and calcium status. Air-dried samples (top foot of soil) were analyzed for cation content (Ca, Mg, K, and Na) by the standard ammonium acetate extraction and saturated paste extraction methods. To measure the cation composition of actual soil solution, each soil was wetted to field capacity moisture content with deionized water, allowed to equilibrate overnight, and then spun in a centrifuge to extract the soil solution. That solution was analyzed for cation content.

To compare the relationship between the various measures of soil Ca status and plant Ca uptake, a greenhouse assay was performed. Sixteen of the soils from the extraction methods comparison were used. These soils were packed into 5-inch wide trays placed over reservoirs of a N/P/K nutrient solution. The soils were in contact with capillary matting, which extended into the reservoirs; the matting was used to wick solution from the reservoirs to the soil. A set height differential between the solution level and the bottom of the soil was maintained to keep soil moisture level near field capacity.

Seed of 'Green Towers' romaine lettuce were germinated in rock wool cubes, then placed in 4 x 4-inch pots in which the bottoms had been replaced with a layer of thin, 400-mesh nylon fabric. The pots were placed on the wetted soil. The pores of the nylon fabric were sufficiently small to prevent roots from penetrating into the soil, while allowing the penetration of root hairs, effectively creating a two-dimensional root interface. This approach was used to minimize the effects of differences in soil texture and structure that could affect rooting density and, subsequently, cation uptake. There were 4 replicate trays of each field soil, and one plant per tray. Lettuce plants were harvested after 6 weeks of growth. The plants (excluding roots) were oven-dried and analyzed for cation concentration.

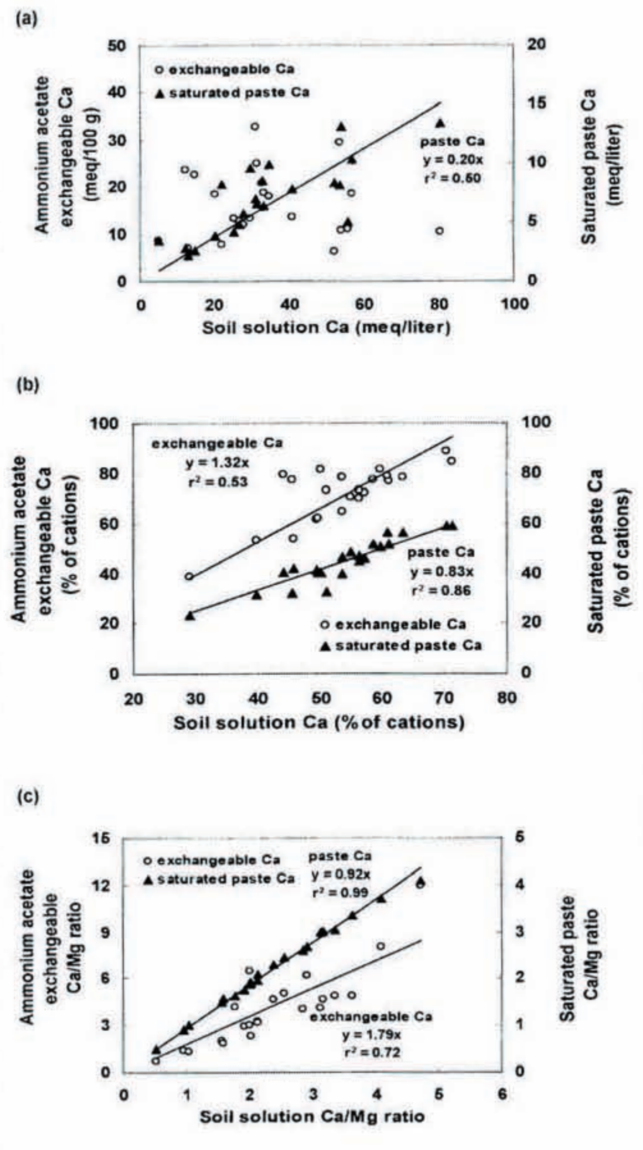
Four field trials were conducted to evaluate the effects of Ca fertilizers applied through drip irrigation on vegetable crop yield and product quality. Two trials were performed on melons, a 2005 trial on honeydew conducted in Yolo County, and a 2006 trial on cantaloupe conducted in Fresno County. In the 2005 trial, three Ca fertilizers [calcium nitrate (CN-9), calcium thiosulfate (CATS) and calcium chloride ($CaCl_2$)] were applied during fruit development in three weekly applications of 10 lb Ca/acre, for a seasonal total of 30 lb Ca/acre. In 2006 two applications of 15 lb Ca/acre from CATS or $CaCl_2$ were made. These fertigation rates were based on manufacturer's recommendations. Experimental design was randomized complete block, with 5 (2005) or 4 (2006) replications. At commercial harvest stage fruit yield, soluble solids concentration (SSC, °brix) and flesh firmness (by a mechanical firmness tester) were compared among the Ca fertilizers and a control treatment receiving no fertigated Ca. Additional fruit were evaluated for firmness after refrigerated storage of 14 days (2005) or 7 days (2006). Fruit flesh samples were oven-dried and analyzed for Ca concentration.

Two trials were conducted on romaine lettuce in the Salinas Valley in 2005 to evaluate the effects of fertigated Ca on crop yield and the severity of tipburn, a calcium-related disorder. The three Ca fertilizers were compared with a control treatment not receiving Ca fertigation. Two drip fertigations of 15 lb Ca/acre each were made approximately 14 and 7 days before harvest. At commercial maturity plant biomass, tipburn severity, and Ca concentration of inner leaves (those most susceptible to tipburn) were measured.

Results and Conclusions

Using soil solution Ca obtained by centrifugation as the standard of accuracy for predicting cation availability, saturated paste Ca was a much more accurate estimation of soil Ca status than was ammonium acetate extraction. On the basis of the amount of Ca extracted, there was no significant correlation between soil solution Ca and ammonium acetate exchangeable Ca (Fig. 1a); there was a modest correlation between saturated paste Ca and soil solution Ca ($r^2 = 0.50$). In general, it takes approximately twice the gravimetric water content at field capacity to prepare a saturated paste extract; therefore, if the techniques were removing equivalent amounts of Ca, the Ca concentration in a saturated paste extraction should be approximately half that in soil solution. In fact, on average the saturated paste extract had only 20% of the Ca concentration in soil solution (the regression slope = 0.20). The discrepancy is due to the attraction of cations to soil cation exchange sites. Water closer to soil particles has higher Ca concentration than water further away; due to the greater force applied, soil water recovered by centrifugation was in closer proximity to soil particles than water recovered

Fig. 1. Comparison of ammonium acetate and saturated paste extraction methods with soil solution extraction by centrifugation for estimating soil Ca status. Comparisons made on the basis of meq extracted (a), % of cations extracted (b), and Ca/Mg ratio (c).



from a saturated paste. This effect was only significant for divalent cations (Ca and Mg). For the monovalent cations (K and Na), the concentration in saturated paste extracts was close to that in soil solution, after adjusting for the water volume used.

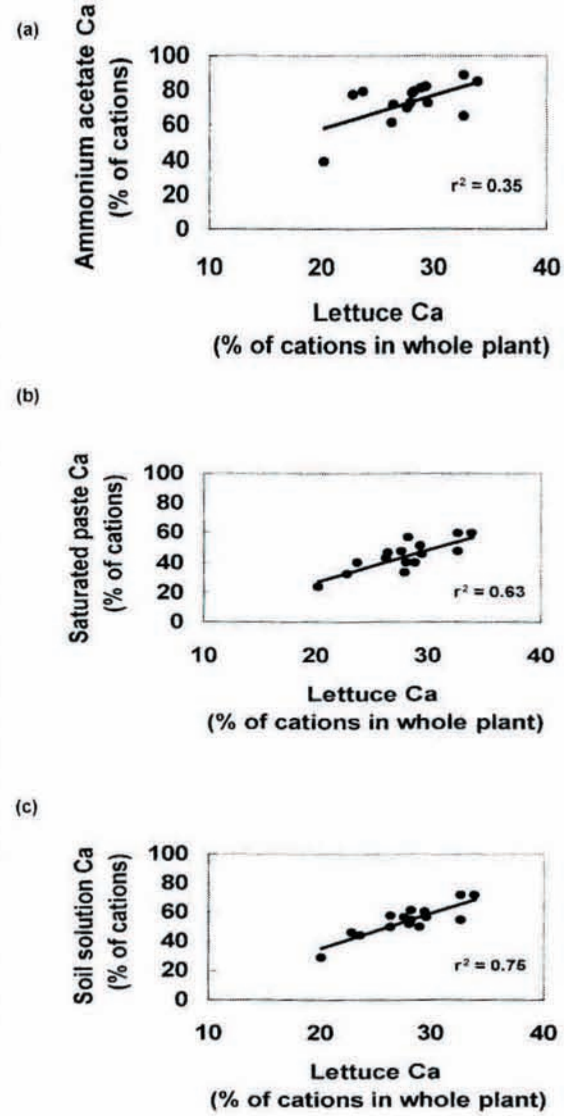
When expressed as a percentage of cations in the extract (on a meq basis), Ca removed by both extraction techniques was correlated to soil solution Ca, with the saturated paste correlation much stronger (Fig. 1b). Ammonium acetate extraction overestimated soil solution Ca (regression slope = 1.32), while saturated paste extraction marginally underestimated it (regression slope = 0.83). There was a nearly perfect relationship between the Ca/Mg ratio in soil solution and that in saturated paste extraction (Fig. 1c). While the overall correlation in Ca/Mg ratio between ammonium acetate and soil solution was significant, within the range of the majority of soils tested (Ca/Mg ratio between 2 and 4) these techniques were not correlated.

Results of the greenhouse lettuce bioassay confirmed that soil Ca availability was best predicted by soil solution Ca, followed by saturated paste Ca; ammonium acetate exchangeable Ca was a poor measure of soil Ca availability (Fig. 2). When whole plant Ca concentration was expressed as a % of all cations in the plant tissue (on a meq basis), the correlation with soil solution Ca and saturated paste Ca was strong (r^2 = 0.75 and 0.63, respectively).

In neither melon experiment did fertigated Ca significantly increase fruit yield, SSC or flesh firmness (Table 1). Furthermore, melon flesh Ca concentration was unaffected by Ca fertigation. The much lower soil Ca status of the 2005 site (Ca representing only 29% of cations, compared to 54% at the 2006 site) was reflected in the much lower fruit Ca concentrations observed (0.041 % Ca in the control treatment in 2005 vs. 0.70 % Ca in 2006). Similarly, applying calcium fertilizers through surface drip irrigation had no measurable effects on romaine yield or Ca concentration in the inner leaves of the head (Table 2). No tipburn was observed in any treatment in the first trial; a low level of tipburn was detected in the second trial, but Ca fertigation did not reduce it.

To understand the lack of benefit from Ca fertigation observed in the melon and romaine trials, it is instructive to consider the amount of Ca typically present in soil solution, and the dynamics of Ca movement in plants. Soil solution Ca in the soils utilized in the extraction methods

Fig. 2. Relationship between lettuce Ca content (expressed as % of cations in dry biomass, meq basis) and soil calcium status as determined by ammonium acetate extraction (a), saturated paste extraction (b) or soil solution extraction by centrifugation (c).



comparison ranged from 5 - 80 meq/liter. Each meq Ca/liter is equivalent to 20 PPM; therefore, soil solution Ca varied from 100 - 1,600 PPM Ca. Multiplying soil solution Ca concentration by the gravimetric water content at field capacity gives an estimate of the mass of Ca in soil solution. Using the standard estimate of 4,000,000 lb dry soil/acre in the top foot, and the gravimetric water content of each soil at field capacity, these test soils ranged from approximately 50 - 1,500 lb Ca/acre in soil solution. In the Ca fertigation

Table 1. Effect of calcium fertigation on melon fruit yield, soluble solids, flesh firmness and calcium concentration.

Trial	Ca in soil solution meq/liter	Ca in soil solution % of cations	Ca treatment	Fruit yield (cartons/acre)	Soluble solids (obrix)	Flesh firmness (lbs) At harvest	Flesh firmness (lbs) After storage	Fruit Ca (% dry wt)
2005 honeydew	13	29	control	1,362	11.5	9.2	6.6	.041
			CN-9	1,279	12.0	8.5	7.3	.043
			CATS	1,234	11.8	8.7	6.3	.040
			$CaCl_2$	1,355	11.8	8.4	6.1	.040
				ns	ns	ns	ns	ns
2006 cantaloupe	12	54	control	1,252	11.2	4.1	2.0	.070
			CATS	1,344	11.0	4.1	2.0	.075
			$CaCl_2$	1,139	10.3	3.8	2.0	.093
				ns	ns	ns	ns	ns

ns treatment differences not statistically significant

Table 2. Effect of calcium fertigation on romaine lettuce yield, tipburn severity and leaf Ca concentration.

Trial	Ca in soil solution meq/liter	Ca in soil solution % of cations	Ca treatment	Mean plant wt. (lb)	Marketable plants (%)	Tipburn rating[z]	% leaf Ca
1	19	62	control	1.68	97	0	0.43
			CN-9	1.74	98	0	0.47
			CATS	1.74	97	0	0.46
			CaCl2	1.76	98	0	0.44
				ns	ns	ns	ns
2	35	55	control	1.85	98	0.3	0.37
			CN-9	1.87	98	0.4	0.41
			CATS	1.83	97	0.2	0.39
			CaCl2	1.83	98	0.2	0.39
				ns	ns	ns	ns

ns treatment differences not statistically significant
z number of inner leaves per plant showing tipburn

trial fields, the estimated mass of Ca in soil solution ranged from 250 – 420 lb Ca/acre. The application of 10-15 lb Ca/acre in a single irrigation, or 30 lb Ca/acre seasonally, represented only a minimal increase in soluble Ca. That amount of Ca would represent a substantial increase in bioavailable Ca only in very coarse textured, low cation exchange capacity soils.

The other limitation to effectively enhancing crop Ca nutrition with Ca fertilizers is the close connection of Ca uptake with plant transpiration. Ca moves in a plant mostly in the transpirational flow, which results in the majority of Ca moving into the most actively transpiring tissue – fully exposed leaves. Melon fruit, and fruits in general, have very limited transpiration. Similarly, the inner leaves of romaine, protected within the head, transpire much less than older, more exposed leaves. Therefore, even if one is successful in substantially increasing plant Ca uptake, little of that additional Ca is likely to move into these Ca-sensitive, but minimally-transpiring plant parts.

In summary, for typical mineral soils of neutral to alkaline pH, saturated paste extraction provides a reliable relative estimate of soil Ca status; the actual Ca concentration in soil solution will typically be 4-5 times higher than in a saturated paste extract. Ammonium acetate extraction may provide a misleading estimate of soil Ca status. Given the relatively high Ca concentration present in most California soils, calcium-related disorders are more likely to be induced by environmental conditions than by soil Ca limitations. At the application rates commonly used in drip-irrigated culture, Ca fertilizers only marginally increase soil Ca availability. Ca fertigation is likely to significantly affect crop Ca status, or confer quality benefits on vegetable crops, only in coarse-textured soils of low Ca status.

Practical Soil Test Methods for Predicting N Mineralization

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Introduction

Many productive mineral soils contain several thousand kilograms of N per hectare, most of which is unavailable for plants in the form of organic matter. Predicting the release of soil N has proven to be elusive. The mineralization of only a small part of the organic N during the cropping season can provide a significant proportion of the N needed by crops. The application of N fertilizer without taking into account the soil mineralization potential can therefore lead to inefficient use of N and an increased risk of groundwater pollution with nitrate. Therefore, it is essential to predict soil N mineralization to increase the efficient use of both soil and fertilizer N.

There have been many attempts to find an accurate chemical or biological index of soil N availability that could be used to improve N fertilizer recommendations. None of these tests has found widespread acceptance for row crops or other systems. For this reason, farmers rely mainly on their experience from preceding years to estimate crop N demand.

The objective of the present study was to evaluate the correlation between the most promising soil tests described in the peer reviewed scientific literature, including the direct diffusion method for amino sugars. The evaluation of the methods was done in two steps: First, the soil tests were compared with the results of an aerobic incubation that is generally recognized as an accurate measure of the mineralization potential of a soil. However, the complexities of the aerobic incubation method preclude its use as an N test in soil testing labs. Second, the different tests were compared with the N uptake of corn and corn response to N fertilization in the field. This two-step approach was chosen because many factors, such as weather pattern and crop management, affect crop development in the field.

Objectives

1. Develop one or more commercially practical soil analytical procedures for measuring available soil N during the growing season of low-organic matter-irrigated soils in various rotations and crops, and on both manured and non-manured sites. The primary candidates for analytical methods are the recently developed soil amino sugar method.
2. Compare the soil amino sugar method with other soil N availability assays (extractable N, aerobic incubation, pre-sidedress nitrate test (PSNT), anaerobic incubation, soil amino sugar, hot KCl, CO_2 evolution, and field fertilization trials).

Methods

A description of methods, soil sampling, sites, and soil characteristics can be found in previous interim reports. Briefly, soil samples were taken from 19 different sites planted to corn in spring from the top 20 cm when the corn had between 2 and 7 leaves (stage V2 to V7). A composite sample of at least five cores was taken from each plot. The soil samples were dried at 40° C and crushed to pass a 2 mm sieve. The sites represent a range of soil texture, soil C, and fertility management.

Results and Discussion

Aerobic N mineralization and N mineralization indices

The nitrogen mineralized during the 70-day aerobic incubation ranged from 25.0 to 168.4 mg N/kg dry soil (data not shown). Total soil N and N mineralized were significantly correlated (p-value < 0.0001), but the correlation was only moderate (R^2 = 0.476). Between 2.1% and 9.5% of the total soil N was mineralized. This percentage was higher for soils with a high net N mineralization, which may be due to the fact that net N mineralization was highest in fields with a history of animal manure application or high organic residue input (cover crop, use as pasture). The proportion of N mineralized decreased significantly with increasing clay content (p-value = 0.0024).

All the N availability indices were positively and highly significantly correlated with the N mineralized during ten weeks of aerobic incubation. Nevertheless, the variability of the data was large, resulting in moderate agreement between the different indices and the N mineralized. The R^2 values, which are a measure of the proportion of the total variability explained by the linear regression, ranged from 0.20 to 0.65. The index most closely related to net N mineralization was the three-day CO_2 flush. This result clearly shows how closely the cycles of carbon and nitrogen are linked in soils, but it is surprising to see such a close correlation between a short term CO_2 flush, highly related to the effects of sieving and drying the soil samples, and the N mineralized during ten weeks. The other methods were no better or even less well related to N mineralization than the soil total C and N content.

Relationship between soil amino sugar and other N mineralization indices

The soil amino sugar method was well related to the total soil N (R^2 = 0.86). No other method, including total C, was closer related with total N than soil amino sugar. The correlations between soil amino sugar and total carbon (R^2 = 0.83), aerobic incubation (R^2 = 0.48), anaerobic incubation (R^2 = 0.33), hot KCl method (R^2 = 0.35), and CO_2 flush (R^2 = 0.36) were lower, but still highly significant (p-values < 0.001). A very weak but still statistically significant correlation was observed between the amino sugar content and the PSNT and C/N-ratio of the soil organic matter. All these correlations were positive, which means that an increase in soil amino sugar was associated with an increase in the other variable.

Corn growth in the field and N mineralization indices

The corn yield in the unfertilized plots varied widely between sites, while the yield obtained in the fertilized plots covered a much smaller range, which may indicate that the yield in the fertilized plots was close to its maximum yield potential. In general, N fertilization increased plant N concentrations. Therefore, the response to N fertilization was more pronounced when aboveground N uptake rather than yield was compared. The corrected N uptake in unfertilized plots (N uptake – starter-N*0.75), a measure for the N mineralization potential of a site, ranged from 45 to 319 kg N/ha.

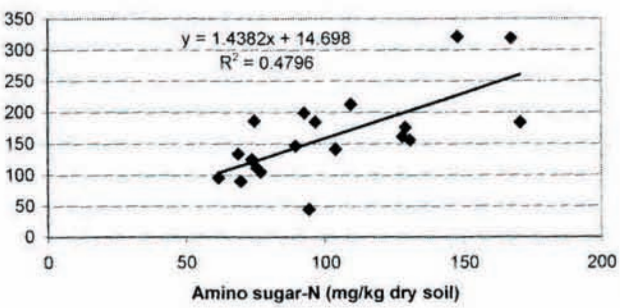
As mentioned above, the validity of the comparison between soil N mineralization and N uptake relies on the assumption that the unfertilized crop did not receive any additional N. The calculation of the fertilizer response depends on this assumption as well, but also requires that the fertilized plants reached their growth maximum. N containing irrigation water or the use of pre-plant N may have compromised this assumption.

A total of 17 fields were included in the comparison between soil tests and crop response to N fertilization, and 19 fields were included in the comparison between soil tests and N uptake in unfertilized plots. The excluded fields contained significant N in their irrigation water.

The 70-day aerobic incubation was moderately well correlated with the corrected N uptake in unfertilized plots (R^2 = 0.41; p-value = 0.0033). The calculated N mineralization potential (N_0) was not significantly related to the corn N uptake. This may be at least partly due to the fact that the cumulative N mineralization from some soils could not be expressed with the exponential equation.

The other tests were significantly but only moderately well correlated with N uptake, except for the anaerobic incubation and the CO_2 flush, which had no significant correlation with N uptake. The amino sugar method was among a group of tests with a similar performance (Figure 1).

Figure 1: Relationship between soil amino sugar and N uptake in unfertilized plots.



The correlation between N uptake and the different N mineralization indices could be improved when the initial mineral N was added to the N mineralized. This procedure makes sense, as both the mineral N present in spring and the N mineralized during the cropping season contribute to plant nutrition. With this adjustment, the best tests, the amino sugar method, reached R^2 values of 0.65.

Only half of the N mineralization indices were significantly related to the fertilizer response. As the distribution of the fertilizer response more closely followed a logarithmic scale than a normal scale, transforming the data improved the agreement between the N mineralization indices and the fertilizer response (Fig. 2 and 3).

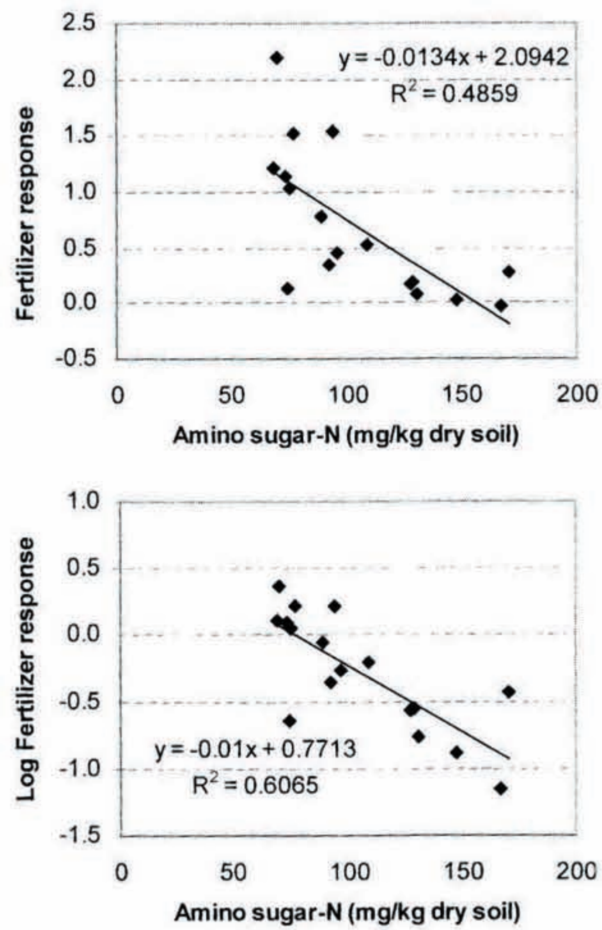
The N mineralization index best related to the transformed fertilizer response was the soil amino sugar content (R^2 = 0.61; Fig. 3). Adding mineral N to the result of the soil tests increased the correlations only slightly. The total soil N was as good a predictor for the crop performance as the other N mineralization indices.

Summary and Conclusions

All the soil tests were positively correlated with the N mineralized during the 10-week aerobic incubation. The correlation coefficients for most of the methods were within a relatively small range. Even though the proportion of the total N mineralized varied from 2.1% to 9.5%, the total N was as well correlated with N mineralization as the other soil tests.

The amino sugar content above which corn does not respond to further fertilization was lower in this study than that reported in Illinois where the method was developed. This may be due to lower soil N content California compared to Illinois.

Figures 2 and 3: Relationship between soil amino sugar and response of corn to N fertilization.



The total soil N and the amino sugar method were good predictors of yield, they have not been widely adopted as soil tests to predict response to fertilization. As mentioned above, factors affecting the mineralization of N range from climatic to management. Therefore, combining the amino sugar test with total soil N may provide flexibility in interpreting N mineralization potential, since the amino sugar test expresses the biological component of mineralization while total soil N represents the size or potential to mineralize N.

IMPROVING THE PROCEDURE FOR NUTRIENT SAMPLING IN STONE FRUIT TREES

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Introduction

This is the last year of a 3-year project to investigate the possibilities of using a dormant sampling technique to complement the widely used mid-summer leaf sampling for nutrient analysis. The argument was made that this approach might fit better into a grower's typical fertility management program and be more timely for correcting most deficiencies. We have now collected 4 years of data on 60 Zee Lady peach and 60 Grand Pearl nectarine trees growing in sand culture. By varying fertilization rates we have been able to obtain a wide range of nutrient levels among the trees and have observed distinct deficiency symptoms for several nutrients. Each year we collected dormant shoot samples from the trees in January and analyzed them for 12 essential elements. Based on tree performance and deficiency symptoms we have established thresholds for some nutrients that have stayed consistent over all 4 years for both the peach and the nectarine. During 2006, our emphasis was on refining these relationships. We also made an extra effort to induce certain deficiencies that have been difficult to obtain.

Objectives

1. To test the feasibility of measuring boron, zinc, and nitrogen (and other nutrients if possible) in stone fruit trees during the dormant season or early spring and relate those nutrient levels to the various components of yield and fruit quality.
2. To develop deficiency threshold values for these nutrients that can be used to guide fertilization decisions early in the season.
3. To test the usefulness of these threshold values in commercial orchards.

Project Description

Sixty large plastic tanks measuring 11'x 8' and 4' deep were obtained in 1999 and placed in trenches in the field. In 2000, each tank was filled with sand and planted with a Zee Lady peach, Grand Pearl nectarine (white flesh), and Fortune plum tree. Fifteen different fertilizer treatments have been imposed since 2001 (see 2000 through 2003 FREP reports for details). The main objective was to obtain trees deficient in each essential nutrient. By 2005, there were clear signs of N, P, B, and Zn deficiencies in multiple peach, plum, and nectarine trees. There were also individual trees exhibiting K and Mn deficiency symptoms and other trees showing indications of other deficiencies as well.

Shoot samples were taken from all 180 trees in January of 2003, 2004, 2005, and 2006 and analyzed for N, P, K, S, Ca, Mg, B, Zn, Mn, Fe, and Cu. Measurements were made of yield and fruit quality components including flowering, fruit set, early fruit growth, early shoot growth, fruit drop, final fruit size, fruit defects, fruit quality, and total vegetative growth. These parameters were then correlated with nutrient levels in the dormant shoots. Using this approach, deficiency thresholds were proposed for N, P, B, and Zn (see 2004 FREP report).

The emphasis in 2005 was on applying these deficiency thresholds to commercial orchards. This part of the project was not very successful as deficiencies in the field were difficult to find (see 2005 FREP report). Both P and B deficiencies appear to be rare in peach orchards in the San Joaquin Valley, and N and Zn fertilizers are routinely applied to almost all orchards to prevent these deficiencies.

Results

2006 was the last year of this project. In order to wrap up loose ends there were a number of questions to be answered with each nutrient. Thus, we conducted various experiments with the sand tank trees or in selected commercial orchards surveyed in 2005. The results are discussed under each nutrient listed below.

Nitrogen (N)

After 4 years of analysis, we have concluded that total N in dormant shoots is not a very sensitive indicator of the N status of peach trees. Instead, we have been pursuing another test for N that has shown promise in the scientific literature. Specific amino acids such as arginine have been shown to be very indicative of the N status of fruit trees. Arginine is the main storage amino acid in dormant peach trees. In 2006 we analyzed some stored shoot samples for all major amino acids including arginine. The initial results were disappointing as there were no differences between N-deficient trees and fully fertilized controls. We are continuing to pursue the approach using different methods of sample preparation. Final results will be presented in our 2006 annual report.

Phosphorus (P)

Since 2004, we have had trees in the sand tanks showing obvious symptoms of P deficiency including reduced shoot growth, smaller fruit size, fruit cracking, and early defoliation. Dormant shoot samples have had P values consistently below the threshold we initially established (0.12%). Even though we have been unable to find P deficiency in the field, we are confident this threshold will apply to commercial orchards as well.

Boron (B)

Based on trees in the sand tanks, we established a threshold in dormant shoots of 14 ppm B. Deficient trees have consistently tested below this threshold with some as low as 8 ppm. Several commercial orchards had B levels as low as 13 ppm but no benefit from B fertilizers could be demonstrated in 2005 or 2006. Thus, the threshold we have suggested may be a little high.

Zinc (Zn)

Since the spring of 2003, we have observed a range of Zn deficiency symptoms in the sand tank trees that correlated well with dormant shoot Zn levels. However, there have always been some trees with very low Zn levels that showed no symptoms and grew vigorously. This prompted us to take a closer look at the variability of Zn levels throughout the tree. In 2006, we did several experiments where we sampled extensively in different locations. Preliminary results suggest substantial differences in Zn between the top and bottom of the tree. Once we have analyzed all the samples we should be able to improve the sampling protocol for Zn. These results will be presented in our final report.

Manganese (Mn)

We have never achieved severe Mn deficiency in the sand tank trees. However, in our 2005 survey of commercial orchards, several had dormant shoot levels of 8 or 9 ppm Mn and exhibited minor Mn deficiency symptoms in the spring. None of the orchards showed any ill effects from these symptoms in terms of fruit size, productivity or vigor in 2005 or 2006. Therefore, we have concluded that this threshold of 8 ppm Mn is not significant and the threshold of concern is probably lower than this for Mn deficiency severe enough to cause problems with tree performance.

Potassium (K), Magnesium (Mg), and Calcium (Ca)

Since we have not been able to induce K, Mg or Ca deficiency in the sand tank trees, we decided to take drastic measures in 2006. Our main source of irrigation water for the tanks has significant levels of all 3 of these cations. Therefore, our first step was to install a water softening system for the Minus Mg and Minus Ca treatments. The company that supplied the ion exchange tanks was willing to recharge them with K instead of Na (typical of most domestic water softeners) so we did not need to worry about salt problems. After a full season of treatment, we still see no symptoms of Mg or Ca deficiency, but leaf and soil samples have been taken to see what changes have occurred. For the Minus K treatment, we used a source of deionized water for irrigation. There is a Reverse Osmosis (RO) unit at the greenhouse complex at KAC. Water from the RO unit was trucked over to the sand tanks and stored in a 5,000-gallon storage container. Several of the trees in this treatment showed symptoms resembling K deficiency. Leaf and soil samples have been taken in this treatment as well. We plan to continue both these treatments for at least another year.

Conclusion

Over the 3 years of this project, we have been able to establish deficiency thresholds in dormant shoots for several nutrients and have made good progress with several others. Specifically, we have reliable thresholds for P, B, and Zn (with a possibly revised protocol) and still have hope for N. In addition, once we induce deficiencies of Mn, K, Mg, and Ca we should be able to develop thresholds for these nutrients as well. Even though the project is officially over in 2006, work will continue on the original objectives for at least one more year.

Increasing Yield of the 'Hass' Avocado by Adding P and K to Properly Timed Soil N Applications

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Introduction

'Hass' avocado yields in California have averaged only 5,700 lbs./acre for the last 25 years (Arpaia, 1998). Experimentally determined leaf nutrient standards and replacement fertilization data related to yield and fruit size are generally lacking for the 'Hass' avocado in California. In a prior study, Lovatt tested the following hypothesis: applying N to the soil at key stages of tree phenology will improve yield parameters. The 4-year study identified key stages in the phenology of the 'Hass' avocado that benefited from a double dose (2x) N (50 lbs./acre). The optimal application times for extra N corresponded to the following phenological events: (1) April – anthesis, fruit set and initiation of the spring vegetative flush and (2) November – end of the fall vegetative flush and beginning of flower initiation. At these phenological stages, soil-applied 2x N significantly increased the 4-year average yield and the 4-year cumulative yield, and increased the yield of commercially valuable large size fruit by 70%. In addition, the April application significantly reduced the alternate bearing index for the 4 years of the study. In our recently completed CDFA FREP-funded project, which was undertaken to test the hypothesis that trees receiving their total annual N (125 lbs./acre per year) applied in equal 1x N doses each at a key stage in 'Hass' avocado phenology (multiple 1x N treatment; 25 lbs./acre x 5 key stages) will yield as well as trees receiving 2x N (50 lbs./acre) or 3x N (75 lbs./acre) at only one or two key stages. Averaged over the 4 years of the experiment, trees that received 2x N in April, 0.8x N in July and August (only 40 lbs./acre per year), and multiple 1x N had significantly more total yield in kilograms fruit per tree than trees receiving 2x N in both November and April or 3x foliar N in April ($P = 0.0178$). N treatment had no significant effect in leaf N concentration for trees in all N treatments or on the amount of N leaching past the root zone for all trees receiving N at 12 lbs./acre per year. The multiple 1x N treatment proved to be equally effective as strategies supplying 2x N in April or 2x in November, but application of 0.8x N (40 lbs./acre per year) in July and August achieved an equally high total yield and yield of large size fruit for the 4 years of the study with 85 lbs./acre per year (68%) less N than all other treatments. This N strategy is more cost-effective and has an inherently lower potential to contribute to nitrate pollution of groundwater than the other N strategies tested. These two research projects were conducted in orchards with optimal nutrition based on standard leaf analysis. Moreover, the orchards were located in two climatically and edaphically different avocado growing areas of California to develop a strategy that works across avocado-producing areas of California. With the identification of the proper time to apply N, the next logical question is whether a greater response to N soil applications would be obtained if P and K were supplied simultaneously. Due to its immobility, P is commonly limiting. K runs a close second due to its high mobility and loss by leaching. In addition, avocado trees have a high demand for K because avocado fruit are rich in K, having more K/g fresh wt. edible fruit than bananas! This project tests the following hypothesis: low available soil P or K at key stages in tree phenology will diminish the tree's response to properly timed soil-applied N.

Project Objectives

The objectives of the proposed research are: (1) to quantify the effects of properly timed soil-applied N vs. N supplemented with P and K on yield, fruit size, and alternate bearing index in a commercial 'Hass' orchard with optimal nutrition based on leaf analysis, and (2) to disseminate the results of the research to the avocado growers of California. Treatments will continue for 3 years in order to obtain the year 2 harvest.

Project Description

To meet objective (1), two fertilizer treatments (N or NPK) were applied at the following times: (A) July and August; (B) November; (C) April; and (D) July, August, November, and April [best management practice for N (BMP N)]. These application times correspond to the following key stages of 'Hass' avocado tree phenology: July – period of rapid cell division and significant increase in fruit size; August – inflorescence initiation; November – end of the fall vegetative flush and beginning of flower initiation; and April – anthesis, fruit set and initiation of the spring vegetative flush. The treatments were replicated on 20 individual trees in a randomized complete block design. N was applied as ammonium nitrate to all treatments as follows: in treatment A, trees received only 50 lbs. N/acre per year, half in July and half in August. Treatments B and C each received 50 lbs. N/acre in November and April, respectively, with the remaining 50 lbs. N/acre applied equally in April, July and August or July, August and November, respectively. Treatment D received 25 lbs. N/acre in July, August, November, and April. Thus, all treatments received 100 lbs. N/acre per year, except treatment A. The N treatments had been in effect for 4 years prior to the addition of P and K to half of the trees in each treatment (20 trees per treatment) in year 1 of this project. The rates of P and K were 15 and 90 lbs./acre per year, respectively, with trees receiving a double dose of P and K (7.5 and 45 lbs./acre, respectively) with the double dose of N (treatments B and C) and as a split application in July and August (treatment A). Treatments B and C, but not A, received the remaining P and K with the remaining N. Trees in BMP for NPK treatment received 3.75 lbs. P and 22.5 lbs. K in July, August, November, and April. The treatments are summarized in Table 1. The orchard is located in Somis, Calif. The trees are 24-year-old 'Hass' on clonal Duke 7 rootstock.

Harvest data included total kg fruit/tree. The weight of 100 randomly selected individual fruit/tree was used to calculate the total number of fruit per tree and the packout (fruit size distribution) per tree as kg and number of fruit of packing carton sizes 84 (99-134 g/fruit), 70 (135-177 g/fruit), 60 (178-212 g/fruit), 48 (213-269 g/fruit), 40 (270-325 g/fruit), 36 (326-354 g/fruit) and 32 (355-397 g/fruit). Two fruit per tree were evaluated for the length of time to ripen, peel color at maturity, and internal fruit quality (seed germination, vascularization, discoloration, decay). Fruit

Table 1. N, P and K fertilization strategies.

	Month of application														
	April			July			August			November			Total		
Treatment	N[z]	P	K	N	P	K	N	P	K	N	P	K	N	P	K
	lbs./acre														
1x N in July +August	–	–	–	25	–	–	25	–	–	–	–	–	50	–	–
1x NPK in July + August	–	–	–	25	3.75	22.5	25	3.75	22.5	–	–	–	50	7.5	45
2x N in November	16.7	–	–	16.7	–	–	16.7	–	–	50	–	–	100	–	–
2x NPK in November	16.7	2.5	15	16.7	2.5	15	16.7	2.5	15	50	7.5	45	100	15	90
2x N in April	50	–	–	16.7	–	–	16.7	–	–	16.7	–	–	100	–	–
2x NPK in April	50	7.5	45	16.7	2.5	15	16.7	2.5	15	16.7	2.5	15	100	15	90
BMP N (Control) (1x N in July, Aug., Nov. + Apr.)	25	–	–	25	–	–	25	–	–	25	–	–	100	–	–
BMP NPK (1x NPK in July, Aug., Nov. + Apr.)	25	3.75	22.5	25	3.75	22.5	25	3.75	22.5	25	3.75	22.5	100	15	90

z *Nitrogen applied as ammonium nitrate.*

Table 2. Effect of soil-applied N or NPK fertilizer on leaf total N, P and K (expressed as % dry wt.) of the 'Hass' avocado. Data for 2006 are not available, yet.

	2004			2005		
Treatment	N	P	K	N	P	K
1x N in July +August	2.31 b[z]	0.15 bc	1.23	2.13 ab	0.16 b	1.21 c
1x NPK in July + August	2.28 b	0.16 a	1.31	2.17 ab	0.16 ab	1.32 ab
2x N in November	2.37 ab	0.16 abc	1.29	2.22 a	0.18 a	1.35 a
2x NPK in November	2.35 ab	0.15 bc	1.19	2.03 b	0.16 ab	1.22 c
2x N in April	2.34 ab	0.15 bc	1.22	2.20 a	0.17 ab	1.24 bc
2x NPK in April	2.45 a	0.15 abc	1.24	2.25 a	0.17 ab	1.22 c
BMP N (Control) (1x N in July, Aug., Nov. + Apr.)	2.38 ab	0.16 ab	1.26	2.25 a	0.17 ab	1.24 bc
BMP NPK (1x NPK in July, Aug., Nov. + Apr.)	2.33 b	0.14 c	1.26	2.17 ab	0.16 ab	1.20 c
P-value	0.0417	0.0339	0.4861	0.0282	0.1078	0.0107

z Means in a vertical column followed by a different letter are different at P = 0.05 by Duncan's Multiple Range Test.

quality parameters are visually determined using a scale from 0 (none) to 4 (extensive, present in all four quarters of the fruit).

The severity of alternate bearing is expressed as the alternate bearing index (ABI). ABI was calculated for each sequential 2-year period using the equation: ABI = (year 1 yield minus year 2 yield) / (sum of year 1 yield plus year 2 yield), where yield is in kilograms fruit per tree. When ABI = 1.0, there is complete alternate bearing, i.e., crop one year with no crop the second year. An ABI of zero means alternate bearing is absent.

The experimental design, with 20 individual tree replications per treatment, was a randomized complete block design. Repeated measures analysis was used to test for treatment effects on yield parameters with year as the repeated measures factor. This analysis was performed using the General Linear Model procedures of the SAS statistical program (SAS Inst., Inc., Cary, N.C.). ANOVA was used to test for treatment effects on leaf nutrient concentrations, yield, cumulative yield, fruit size, and fruit quality parameters. Means were separated using Duncan's multiple range test at $P = 0.05$.

RESULTS

Leaf N concentration

When leaves were collected for analysis in Sept. 2004, the trees had only been under treatment for half a year, so trees had not received their total annual N or NPK, except trees receiving 1x N or NPK in July and August only. In 2004, September leaf N concentrations were higher than the 2.1% recommended by the California Avocado Commission for the 'Hass' avocado. By Sept. 2004, trees receiving 2x NPK in April had the highest leaf N concentration, which was significantly greater than leaves from trees receiving 0.8x N or NPK in July and August and the BMP NPK treatment, but not significantly different from leaves of trees receiving 2x N in April, BMP N or 2x N or NPK in November, which had intermediate leaf N concentrations (Table 2). In 2005, leaf N concentrations for trees in all treatments were lower and closer to the recommended 2.1% N. Trees receiving 2x NPK in April again had the highest leaf N concentration obtained, but it was not significantly different from that of trees receiving BMP N, 2x N in April, or 2x N in November, all of which had leaf N concentrations significantly greater than trees receiving 2x NPK in November. Trees receiving 1x N or NPK in July and August or BMP NPK had intermediate concentrations of leaf N that were not significantly different from leaf N concentrations for all other treatments (Table 2).

Leaf P concentration

Leaf P in 2004 tended to be lower than in 2005, but within the preferred range presently in use. In addition, the 2004 leaf P concentrations exhibited more variation than in 2005 (Table 2), but keep in mind that only trees receiving 1x N or NPK in July and August had received their total annual N or NPK treatment. In 2004, trees receiving 0.8x NPK in July and August had greater leaf P concentrations than trees receiving 1x N in July and August, 2x NPK in November, 2x N in April and BMP NPK. Trees in the BMP N treatment had leaf P concentrations that were intermediate but still significantly greater than trees in the BMP NPK treatment. Trees receiving 2x N in November and 2x NPK in April had leaf P concentrations that were intermediate and not significantly different from any other treatment. In 2005, September leaf P concentrations were optimal for all treatments. Trees receiving 2x N in November had the highest leaf P concentration, which was significantly greater than trees receiving 1x N in July and August but only at P = 0.1078 (Table 2). Leaf P concentrations for all other treatments were intermediate and not significantly different from all other treatments.

Leaf K concentration

In 2004, there were no significant treatment effects on leaf K concentration (Table 2). Values ranged from 1.19% to 1.33%, which were within the current optimal range. By 2005, leaf K concentration was significantly affected by the fertilizer treatments (Table 2). Trees receiving 2x N in November had the highest leaf K concentration and it was significantly greater than leaf K for trees in all other treatments except trees receiving 0.8x NPK in July and August. Trees receiving 1x NPK in July and August had greater leaf K concentrations than trees receiving 1x N in July and August, but also trees in all other NPK treatments, i.e., 2x NPK in November, 2x NPK in April and BMP NPK. Leaf K was well within the current optimal range for trees in all treatments.

Relationships between leaf nutrient concentrations and yield parameters

Leaf N was not related to total yield or fruit size in either year of the study. This is consistent with results obtained in all other N fertilization studies with the 'Hass' avocado (Lovatt, C.J. and G. Witney. 2001. AvoResearch 1(3):1-4, 11). Leaf P concentration in Sept. 2004 was positively and significantly (P < 0.0001) related to the yield of large size fruit (packing carton sizes 60+48+40) in the harvest of 2004, the on-crop year. Leaf P concentration explained 22% of the variation in the yield of large size fruit. Sept. 2005 leaf P concentrations were not significantly related to any yield parameter. Leaf K concentration in Sept. 2004 and 2005 was not related to any yield parameter.

Leaf nutrient analyses for 2006

Leaves were collected during the second week of September but the results of the analyses are unknown at this time.

Yield 2006

Fertilizer treatment had a statistically significant effect on total yield as both kilograms (P = 0.0146) and number of fruit (P = 0.0345) per tree (Tables 3 and 4). The best treatment was 1x NPK in July and August only. It was significantly better than all other treatments except 1x N in July and August only and BMP N (control), which were intermediate to and not significantly different from any other treatment. Fertilizer strategies also significantly affected the yield of large size fruit of packing carton sizes 60 (P = 0.0028), 48 (P = 0.0044) and 40 (P = 0.0996) and the yield of fruit in the combined pool of fruit of packing

Table 3. Effect of N versus N, P and K fertilization strategies on the yield and fruit size of 'Hass' avocado harvested in 2006.

		Yield of small and large fruit based on packing carton sizes[z]						
Treatment	Total yield	84	70	Σ84-70	60	48	40	Σ60-40
	kg fruit/tree							
1x N in July +August	36.47 ab[y]	3.55	13.97	17.52	10.01 bc	7.32 b	1.51 ab	18.84 b
1x NPK in July + August	57.21 a	4.52	20.14	24.65	18.70 a	12.14 a	1.60 a	32.44 a
2x N in November	29.44 b	1.77	11.46	13.23	10.15 bc	5.74 b	0.30 b	16.20 b
2x NPK in November	25.25 b	3.40	10.17	13.57	6.59 c	3.90 b	1.11 ab	11.61 b
2x N in April	29.25 b	2.40	9.68	12.08	8.62 bc	6.92 b	1.50 ab	17.04 b
2x NPK in April	30.63 b	3.85	12.23	16.08	9.33 bc	4.45 b	0.74 ab	14.51 b
BMP N (Control) (1x N in July, Aug., Nov. + Apr.)	42.55 ab	3.42	17.73	21.15	14.22 ab	6.86 b	0.32 b	21.40 b
BMP NPK (1x NPK in July, Aug., Nov. + Apr.)	20.95 b	2.69	8.11	10.80	5.52 c	4.03 b	0.58 ab	10.13 b
P-value	0.0146	0.8340	0.1432	0.2839	0.0028	0.0044	0.0996	0.0015

z Packing carton fruit sizes include 84 (94-134 g), 70 (135-177 g), 60 (178-212 g), 48 (213-269 g) and 40 (270-325 g).
y Means in a vertical column followed by a different letter are different at P = 0.05 by Duncan's Multiple Range Test.

Table 4. Effect of N versus N, P and K fertilization strategies on the yield and fruit size of 'Hass' avocado harvested in 2006.

		Yield of small and large fruit based on packing carton sizes[z]						
Treatment	Total yield	84	70	Σ84-70	60	48	40	Σ60-40
	No. fruit/tree							
1x N in July +August	207 ab[y]	31	90	120	51 bc	30 b	5.1 ab	87 b
1x NPK in July + August	320 a	39	129	168	96 a	50 a	5.4 a	152 a
2x N in November	166 b	15	73	89	52 bc	24 b	1.0 b	77 b
2x NPK in November	148 b	29	65	94	34 c	16 b	3.7 ab	54 b
2x N in April	161 b	21	62	83	44 bc	29 b	5.0 ab	78 b
2x NPK in April	180 b	33	78	111	48 bc	18 b	2.5 ab	69 b
BMP N (Control) (1x N in July, Aug., Nov. + Apr.)	245 ab	29	114	143	73 ab	28 b	1.1 b	102 ab
BMP NPK (1x NPK in July, Aug., Nov. + Apr.)	122 b	23	52	75	28 c	17 b	2.0 ab	47 b
P-value	0.0345	0.8340	0.1432	0.3307	0.0028	0.0044	0.0996	0.0014

z Packing carton fruit sizes include 84 (94-134 g), 70 (135-177 g), 60 (178-212 g), 48 (213-269 g) and 40 (270-325 g).
y Means in a vertical column followed by a different letter are different at P = 0.05 by Duncan's Multiple Range Test.

carton sizes 60, 48 and 40 (P = 0.0015) as kilograms fruit per tree (Table 3). In all cases, the best treatment was 1x NPK in July and August only. The same was true when yield was determined in number of fruit per tree (Table 4). Thus, 1x NPK applied in July and August not only increased fruit retention, but also increased fruit growth. Comparison of the BMP N treatment with the BMP NPK treatment in Tables 3 and 4 provides clear evidence that supplying P and K this frequently at the rate used in this study has a negative effect on yield. There were no fertilizer treatment effects on the number of days required for fruit to ripen after harvest, fruit length, fruit width or seed size, but treatments influenced the width of the flesh (edible portion of the fruit) (P = 0.0046) (Table 5). Trees treated with BMP NPK produced fruit with significantly wider flesh than fruit from trees treated with 1x N in July and August, 2x N in April and BMP N (control) (Table 5). Fruit from all other treatments had flesh that was intermediate in width and not significantly different from any other treatment. Fertilizer strategies had no significant effect on peel color, flesh quality, or seed germination.

Three-year average yield

When averaged across the 3 years of the study, fertilizer strategies had significant effects on total yield as kilograms (P = 0.0020) and number of fruit (P = 0.0060) per tree (Tables 6 and 7). Trees treated with 1x NPK in July and August had a significantly greater 3-year average total yield in kilograms per tree than trees treated with 2x N in November, 2x NPK in November, 2x NPK in April and BMP NPK. Trees receiving other treatments had 3-year average total yields that were intermediate and not significantly different from any other treatment (Table 6). The BMP N (control) treatment resulted in a 3-year average yield of small fruit of packing carton size 70 that was significantly greater as both kilograms and number of fruit per tree than trees receiving 2x N in November, 2x NPK in November, 2x NPK in April or BMP NPK (P = 0.0221) (Tables 6 and 7). Trees receiving 1x NPK in July and August or BMP N (control) had a significantly greater 3-year average yield of large size fruit of packing carton size 60 as both kilograms (P = 0.0133) and number of fruit (P = 0.0133) per tree compared to trees receiving 2x NPK in November and BMP NPK (Tables 6 and 7). Trees receiving 1x NPK in July and August or 2x N in April had the highest 3-year average yields of fruit in the combined pool of fruit of packing carton sizes 60, 48 and 40 as both kilograms (P = 0.0223) and number of fruit (P = 0.0170) per tree (Tables 6 and 7). All other treatments produced yields that were intermediate and not significantly different from any other treatment. Year had a statistically significant effect on every yield parameter except the kilograms and number of fruit of packing carton size 60 (Tables 6 and 7). Year 1 was an on-crop year followed by two off-crop years. Note that the first off-crop was characterized by the production of large size fruit at the expense of small size fruit. In contrast, the subsequent off-crop was comprised predominantly of small size fruit with few large size fruit (Tables 6 and 7). Treatment by year interactions affected the yield (as both kilograms and number of fruit per tree) of fruit of packing carton sizes 60 (P = 0.0385) and 48 (P = 0.0143) and yield

Table 5. Effect of N versus N, P and K fertilization strategies on fruit quality of the 'Hass' avocado harvested in 2006.

Treatment	Days to ripen	Fruit length	Fruit width	Seed diameter	Flesh width	Peel color	Seed germination	Flesh quality[z] Vascularization	Discoloration	Decay
1x N in July +August	11.1	89.29	62.98	34.40	28.82 bc[y]	3.7	0.4	0.6	0.8	0.3
1x NPK in July + August	10.4	89.79	63.41	34.38	29.03 abc	3.6	0.5	0.4	0.4	0.2
2x N in November	10.4	92.49	64.98	35.19	29.55 abc	3.6	0.2	0.8	0.9	0.6
2x NPK in November	10.0	91.15	64.06	34.83	29.11 abc	3.6	0.2	0.5	0.7	0.2
2x N in April	10.7	90.95	64.27	35.90	27.85 c	3.7	0.4	0.8	0.6	0.3
2x NPK in April	9.6	89.79	64.71	34.30	30.53 ab	3.5	0.3	0.4	0.4	0.3
BMP N (Control) (1x N in July, Aug., Nov. + Apr.)	10.8	89.58	62.92	34.23	28.56 c	3.7	0.3	0.5	0.7	0.2
BMP NPK (1x NPK in July, Aug., Nov. + Apr.)	9.8	93.78	65.44	34.78	30.66 a	3.6	0.2	0.4	0.5	0.2
P-value	0.1082	0.1081	0.2326	0.8166	0.0046	0.6754	0.7276	0.1554	0.5717	0.3153

z When ripe, internal fruit quality was evaluated for abnormalities and discoloration. Vascularization (presence of vascular bundles and associated fibers) of the flesh was also determined. The internal fruit quality parameters were visually rated on a scale from 0 (normal) to 4 (high incidence of abnormalities, discoloration, or vascularization).

y Means in a vertical column followed by a different letter are different at $P = 0.05$ by Duncan's Multiple Range Test.

Table 6. Effect of N versus N, P and K fertilization strategies on the 3-year average yield and fruit size of 'Hass' avocado harvested in 2004, 2005 and 2006.

	Total yield	Yield of small and large fruit based on packing carton sizes[z] 84	70	Σ84-70	60	48	40	Σ60-40
	kg fruit/tree							
Treatment								
1x N in July +August	39.11 abc[y]	2.48	9.32 abc	11.79 ab	10.16 abc	12.44	4.28	26.87 ab
1x NPK in July + August	46.23 a	2.77	12.31 ab	15.08 ab	12.58 a	12.27	4.36	29.22 a
2x N in November	36.24 bc	1.08	7.43 bc	8.51 b	10.72 abc	11.82	4.13	26.67 ab
2x NPK in November	33.00 c	1.89	7.23 c	9.12 b	8.87 bc	10.25	2.99	22.11 b
2x N in April	42.57 ab	2.87	8.87 abc	11.74 ab	12.27 ab	13.62	4.17	30.06 a
2x NPK in April	36.74 bc	2.34	8.16 bc	10.50 ab	10.21 abc	11.75	3.72	25.67 ab
BMP N (Control) (1x N in July, Aug., Nov. + Apr.)	45.07 ab	2.52	13.52 a	16.04 a	13.60 a	11.30	3.15	28.06 ab
BMP NPK (1x NPK in July, Aug., Nov. + Apr.)	32.28 c	1.72	8.44 bc	10.17 ab	8.50 c	10.10	3.01	21.62 b
Year								
2004	49.58 a	3.06 a	10.72 a	13.77 a	11.91	14.70 a	6.70 a	33.31 a
2005	33.29 b	0.40 b	4.61 b	5.01 b	10.35	14.04 a	3.55 b	27.95 a
2006	33.97 b	3.21 a	12.94 a	16.14 a	10.38	6.41 b	0.96 c	17.76 b
P-value								
Treatment (T)	0.0020	0.6343	0.0221	0.0866	0.0133	0.3228	0.3972	0.0223
Year (Y)	0.0005	<0.0001	<0.0001	<0.0001	0.5946	<0.0001	<0.0001	<0.0001
T x Y	0.0624	0.8580	0.5486	0.6964	0.0385	0.0143	0.6663	0.0143

z Packing carton fruit sizes include 84 (94-134 g), 70 (135-177 g), 60 (178-212 g), 48 (213-269 g) and 40 (270-325 g).

y Means in a vertical column followed by a different letter are different at $P = 0.05$ by Duncan's Multiple Range Test.

Table 7. Effect of N versus N, P and K fertilization strategies on the 3-year average yield and fruit size of 'Hass' avocado harvested in 2004, 2005 and 2006.

	Total yield	84	70	Σ84-70	60	48	40	Σ60-40
		Yield of small and large fruit based on packing carton sizes[z]						
	No. fruit/tree							
Treatment								
1x N in July +August	200 ab[y]	21	60 abc	81	52 abc	52	14	118 abc
1x NPK in July + August	235 a	24	79 ab	103	65 a	51	15	130 a
2x N in November	178 b	9	48 bc	57	55 abc	49	14	118 abc
2x NPK in November	163 b	16	46 c	63	45 bc	43	10	98 bc
2x N in April	217 ab	25	57 abc	82	63 ab	57	14	133 a
2x NPK in April	188 ab	20	52 bc	72	52 abc	49	13	114 abc
BMP N (Control) (1x N in July, Aug., Nov. + Apr.)	238 a	22	87 a	108	70 a	47	11	127 ab
BMP NPK (1x NPK in July, Aug., Nov. + Apr.)	166 b	15	54 bc	69	44 c	42	10	96 c
Year								
2004	245 a	26 a	69 a	95 a	61	61 a	23 a	145 a
2005	157 b	3 b	30 b	33 b	53	58 a	12 b	123 a
2006	194 ab	28 a	83 a	110 a	53	27 b	3 c	83 b
P-value								
Treatment (T)	0.0060	0.6343	0.0221	0.1172	0.0133	0.3228	0.3972	0.0170
Year (Y)	0.0041	<0.0001	<0.0001	<0.0001	0.5946	<0.0001	<0.0001	<0.0001
T x Y	0.1513	0.8580	0.5486	0.7269	0.0385	0.0143	0.6663	0.0137

z Packing carton fruit sizes include 84 (94-134 g), 70 (135-177 g), 60 (178-212 g), 48 (213-269 g) and 40 (270-325 g)

y Means in a vertical column followed by a different letter are different at P = 0.05 by Duncan's Multiple Range Test.

of fruit in the combined pool of packing carton sizes 60, 48 and 40 (P = 0.0143) (Tables 6 and 7).

Three-year cumulative yield

The fertilizer strategies significantly affected 3-year cumulative total yield as both kilograms (P = 0.0035) and number of fruit (P = 0.0111) per tree (Tables 8 and 9). Trees receiving 1x NPK in July and August produced a significantly greater 3-year cumulative total yield (in kilograms and number of fruit per tree) than trees receiving 2x N in November, 2x NPK in November, 2x NPK in April and BMP NPK. All other treatments resulted in intermediate 3-year cumulative total yields that were not significantly different from any other treatment (Tables 8 and 9). Trees receiving 1x NPK in July and August or BMP N (control) had marginally greater 3-year cumulative yields of fruit of packing carton size 60 (as kilograms and number of fruit per tree) than trees receiving BMP NPK, but not any other treatment (P = 0.0661) (Tables 8 and 9). Trees receiving 1x NPK in July and August and 2x N in April had significantly higher yields of fruit in the combined pool of packing carton sizes 60, 48 and 40 as both kilograms (P = 0.0109) and number of fruit (P = 0.0105) per tree than trees receiving 2x NPK in November and BMP NPK (Tables 8 and 9). Yields for all other treatments were intermediate and not significantly different from any other treatment.

Three-year average fruit quality

Averaged over the 3 years of the experiment, fertilizer treatment had a significant effect only on vascularization, the presence of vascular bundles, and associated fibers in the flesh (P = 0.0405) (Table 10). The lowest amount of vascularization was in fruit from trees receiving 1x NPK in July and August and 2x NPK in April. Year was a significant factor influencing the number of days required for fruit to ripen, vascularization, flesh discoloration, and decay. There was, however, no significant treatment by year interactions (Table 10).

Alternate bearing

The alternate bearing index (ABI) for 2004-2005 ranged from 0.54 to 0.66 (Table 11). For 2005-2006, alternate

Table 8. Effect of N versus N, P and K fertilization strategies on the 3-year cumulative yield and fruit size of 'Hass' avocado harvested in 2004, 2005 and 2006.

Treatment	Total yield	Yield of small and large fruit based on packing carton sizes[z]						
		84	70	Σ84-70	60	48	40	Σ60-40
	kg fruit/tree							
1x N in July +August	115.78 abc[y]	7.02	26.57 ab	33.60	28.81 ab	37.20	14.33	80.33 abc
1x NPK in July + August	138.58 a	7.86	35.14 a	43.00	37.83 a	39.26	15.60	92.68 a
2x N in November	108.61 bc	3.21	20.56 b	23.77	29.65 ab	36.46	14.78	80.88 abc
2x NPK in November	99.10 c	4.84	21.28 b	26.12	27.26 ab	32.21	10.58	70.05 bc
2x N in April	127.55 ab	7.96	25.68 ab	33.64	34.32 ab	41.67	15.09	91.08 a
2x NPK in April	110.16 bc	6.52	22.81 ab	29.33	29.55 ab	36.20	13.19	78.93 abc
BMP N (Control) (1x N in July, Aug., Nov. + Apr.)	133.26 ab	6.18	33.31 ab	39.48	37.50 a	37.87	14.09	89.47 ab
BMP NPK (1x NPK in July, Aug., Nov. + Apr.)	96.68 c	5.11	24.65 ab	29.76	25.66 b	30.11	9.63	65.40 c
P-value	0.0035	0.5359	0.0969	0.1854	0.0661	0.1586	0.3758	0.0109

z Packing carton fruit sizes include 84 (94-134 g), 70 (135-177 g), 60 (178-212 g), 48 (213-269 g) and 40 (270-325 g).

y Means in a vertical column followed by a different letter are different at P = 0.05 by Duncan's Multiple Range Test.

Table 9. Effect of N versus N, P and K fertilization strategies on the 3-year cumulative yield and fruit size of 'Hass' avocado harvested in 2004, 2005 and 2006.

Treatment	Total yield	Yield of small and large fruit based on packing carton sizes[z]						
		84	70	Σ84-70	60	48	40	Σ60-40
	No. fruit/tree							
1x N in July +August	586 abc[y]	60	170 ab	231	148 ab	154	48	350 ab
1x NPK in July + August	710 a	67	225 a	293	194 a	163	52	409 a
2x N in November	524 bc	28	132 b	159	152 ab	151	50	353 ab
2x NPK in November	493 c	42	136 b	178	140 ab	134	36	309 b
2x N in April	641 abc	68	165 ab	233	176 ab	173	51	400 a
2x NPK in April	554 abc	56	146 ab	202	152 ab	150	44	346 ab
BMP N (Control) (1x N in July, Aug., Nov. + Apr.)	676 ab	53	214 ab	267	192 a	157	47	397 a
BMP NPK (1x NPK in July, Aug., Nov. + Apr.)	495 c	44	158 ab	202	132 b	125	32	289 b
P-value	0.0111	0.5359	0.0969	0.2142	0.0661	0.1586	0.3758	0.0105

z Packing carton fruit sizes include 84 (94-134 g), 70 (135-177 g), 60 (178-212 g), 48 (213-269 g) and 40 (270-325 g).

y Means in a vertical column followed by a different letter are different at P = 0.05 by Duncan's Multiple Range Test.

Table 10. Effect of N versus N, P and K fertilization strategies on 3-year average fruit quality of the 'Hass' avocado harvested in 2004, 2005 and 2006.

	Days to ripen	Flesh quality[z]		
		Vascularization	Discoloration	Decay
Treatment				
1x N in July +August	10.4	0.4 ab[y]	0.60	0.30
1x NPK in July + August	9.8	0.3 b	0.60	0.30
2x N in November	10.0	0.5 a	0.70	0.40
2x NPK in November	10.2	0.3 ab	0.70	0.30
2x N in April	10.2	0.4 ab	0.50	0.30
2x NPK in April	9.4	0.3 b	0.50	0.20
BMP N (Control) (1x N in July, Aug., Nov. + Apr.)	10.2	0.4 ab	0.60	0.20
BMP NPK (1x NPK in July, Aug., Nov. + Apr.)	10.0	0.3 ab	0.50	0.30
Year				
2004	9.3 b	0.2 c	0.3 c	0.1 c
2005	10.4 a	0.3 b	0.9 a	0.5 a
2006	10.3 a	0.5 a	0.6 b	0.3 b
P-value				
Treatment (T)	0.2949	0.0405	0.5376	0.5915
Year (Y)	<0.0001	<0.0001	<0.0001	<0.0001
T x Y	0.3373	0.2257	0.7116	0.5253

z When ripe, internal fruit quality was evaluated for abnormalities and discoloration. Vascularization (presence of vascular bundles and associated fibers) of the flesh was also determined. The internal fruit quality parameters were visually rated on a scale from 0 (normal) to 4 (high incidence of abnormalities, discoloration, or vascularization).

y Means in a vertical column followed by a different letter are different at P = 0.05 by Duncan's Multiple Range Test.

bearing was more severe, i.e., ABIs ranged from 0.62 to 0.70 (Table 11). The fertilizer treatments had no significant effect on alternate bearing (Table 11).

Conclusions

Supplementing the 1x N in July and August with P and K had a consistent beneficial, though not significant, effect on total yield and yield of commercially valuable large size fruit (packing carton sizes 60, 48 and 40; fruit weighing 178-325 g/fruit) compared to trees receiving only 1x N in July and August. Trees treated with 1x NPK in July and August produced total yields and yields of large size fruit (178-325 g/fruit) equal to or better than trees receiving all other treatments, including the BMP N (control) or BMP NPK treatments. Note that trees receiving 1x NPK in July and August received 50% less N, P, and K than trees in all other treatments. Yield results obtained in two separate CDFA FREP-funded projects identified the fertilizer application time of July and August, combined with a significantly reduced rate of fertilizer, as equal to or better than other strategies requiring more frequent applications and a higher total annual rate of fertilizer (N or NPK). July and August correspond to the following phenological and physiological events: July – period of "June" drop for the current crop (Garner, 2004), rapid N and K uptake by mature fruit from the previous spring bloom (Rosecrance and Lovatt, personal communication), and development of the summer vegetative flush (Salazar-García et al., 1998) and August – period of exponential increase in fruit size for the current crop and abscission of mature fruit (Garner, 2004), and inflorescence initiation for next year's crop (Salazar-García et al., 1998).

Table 11. Effect of N versus N, P and K fertilization strategies on the alternate bearing index of 'Hass' avocado harvested in 2004, 2005 and 2006.

	Alternate bearing index		
Treatment	2004-2005	2005-2006	2-year average
1x N in July +August	0.60	0.63	0.61
1x NPK in July + August	0.66	0.66	0.66
2x N in November	0.58	0.70	0.64
2x NPK in November	0.61	0.64	0.60
2x N in April	0.59	0.70	0.65
2x NPK in April	0.55	0.68	0.61
BMP N (Control) (1x N in July, Aug., Nov. + Apr.)	0.59	0.66	0.63
BMP NPK (1x NPK in July, Aug., Nov. + Apr.)	0.54	0.62	0.60
P-value	0.9286	0.9927	0.9922

Acknowledgement

I would like to express my sincere appreciation to Mr. John Grether. Without special individuals like Mr. Grether, who make their orchards available for the type of research reported herein, FREP-funded projects would not be possible. This is Mr. Grether's second such project with me and I am extremely grateful.

Minimizing Nitrogen Runoff and Improving Nitrogen Use Efficiency in Containerized Woody Ornamentals through Management of Nitrate and Ammonium-Nitrogen

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Introduction

Cultural practices to mitigate nitrate (NO_3) runoff from agricultural facilities are being developed as a result of state regulations developed from guidelines established in the federally directed Clean Water Act. Of the chemicals listed in these guidelines, nitrogen (N) has the greatest risk for contaminating runoff, since N usage by the container nursery industry is relatively high (536 $lb{\cdot}A^{-1}$ each year) compared to other chemicals used on horticultural crops, and various cultural practices of the industry are highly conducive to NO_3^- leaching. In order for the nursery industry to comply with these regulations, it is imperative that more efficient fertilization and irrigation guidelines are developed and more effective fertilizers are designed so that nutrient use efficiency (NUE) is optimized and nutrient leaching is minimized.

Controlled-release fertilizers (CRFs) are used extensively for the production of containerized woody ornamental plants. Most of the research related to nutrient release characteristics from CRFs has been undertaken using atypical substrates such as 100% sand under controlled laboratory conditions or by means of field studies, none of which reflect conditions experienced in container-production facilities. In addition, the duration of many experiments has been limited to six months or less, which is insufficient for measuring nutrient release from 12-month-release fertilizer formulations. The following experiments quantified the nutrient release patterns of four types of CRFs, when blended into an acid substrate during an 11-month period in an unheated greenhouse environment, a production scenario often used for crops such as azaleas and rhododendrons.

Objectives

1. Determine the fate of nitrogen and phosphorus from controlled-release fertilizers (CRF) in containerized woody ornamentals growing in acid (5.0) pH media during an 11-month period.

2. Develop fertilization and irrigation guidelines for woody ornamental crop production that will minimize nutrient runoff and improve nutrient-use efficiency.

3. Disseminate guidelines to growers, fertilizer producers, consultants, farm advisors, educators, and extension specialists involved in woody ornamental crop production.

Description

Research plots were located at the Agricultural Experiment Station at the University of California at Riverside.

Fertilizer Treatments

Treatments consisted of four different types of 365-day release CRFs: Osmocote 24-4-9, Nutricote 18-6-8, Multicote 17-5-11, and Apex 17-5-11. Since the percentage of nutrients varied for the different fertilizers, the amount of fertilizer added was calculated so that all treatments contained 33 g N/ ft^3.

Irrigation Protocol

To minimize channeling of water, containers were drip irrigated with circular drip rings, which had drip holes equally spaced every two cm. Irrigation frequency was every day for the first 10 weeks, and every other day thereafter.

Leachate collection

Leachate was collected twice per week and combined for one week. Samples were acidified to pH 2.0 to stabilize nitrogen forms.

Leachate Analyses

Electrical conductivity was measured after the first irrigation of the week. Total leachate volume was measured at the end of the week. A 70 ml aliquot was then taken and frozen until analyses. Solutions were analyzed for nitrate and total phosphorus.

Table 1. List of fertilizer treatments. Nitrate = NO_3 and ammonium = NH_4.

Treatment	Fertilizer Rate	Fertilizer Type
1	3.0 lb N/yd³	Osmocote CRF
2	3.0 lb N/yd³	Polyon CRF
3	3.0 lb N/yd³	Nutricote CRF
4	3.0 lb N/yd³	Multicote CRF

RESULTS AND DISCUSSION

1. Greenhouse temperatures reflected seasonal changes in temperature (Figure 1).
2. Electrical conductivity was elevated during the first 15 weeks, gradually dropping and leveling off during the last 2/3 of the experiment (Figure 2).
3. Concentrations of ammonium were low, then increased during weeks seven through ten (Figure 3). Ammonium concentrations decreased thereafter, with few differences between treatments.

Fig. 1. Daily average (solid line), minimum (lower dotted line) and maximum (upper dotted line) greenhouse air temperatures over a 47-week period (1 Aug 2001 to 27 June 2002), with gray horizontal lines indicating media temperatures for 12-month fertilizer release as specified by the respective manufacturers of Osmocote (OS), Polyon (PO), Multicote (MU), and Nutricote (NU).

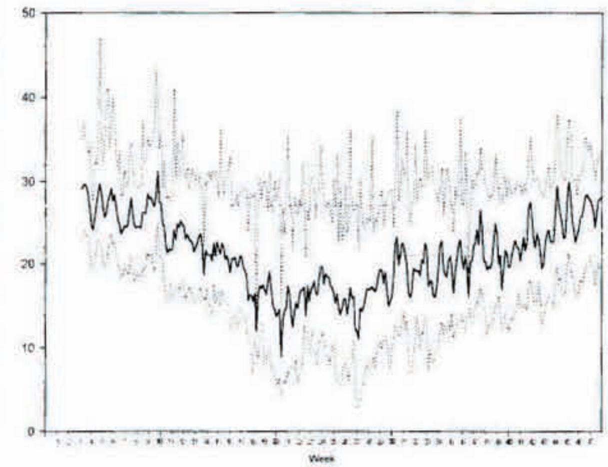


Fig. 2. Electrical conductivity (EC) of irrigation leachate collected weekly over a 47-week period (1 Aug 2001 to 27 June 2002) from a pinebark/peat-based substrate prepared with four controlled-release fertilizers at equal rates of total N. One-gallon containers of substrate were located in a controlled-environment greenhouse during the experiment and irrigated with drip emitters using municipal tap water (EC 0.5 mS·cm⁻¹). Significant differences in least squares means for pairs of treatments for each week (bottom) is indicated with the first treatment listed in each pair being greater than (+), less than (–) or not different from (·) the second treatment listed in each pair according to Tukey's Test (P ≤ 0.10).

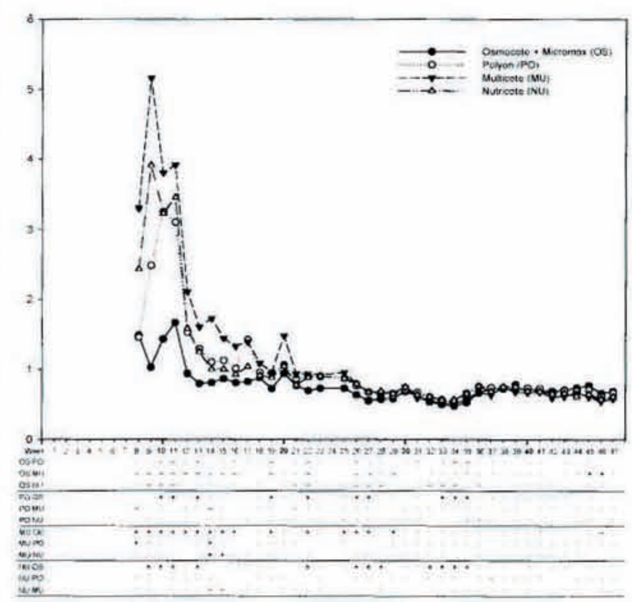


Fig. 3. Concentration of NH_4-N (mg·L⁻¹) in irrigation leachate collected weekly over a 47-week period (1 Aug 2001 to 27 June 2002) from a pinebark/peat-based substrate prepared with four controlled-release fertilizers at equal rates of total N. Significant differences in least squares means for pairs of treatments for each week (bottom) is indicated with the first treatment listed in each pair being greater than (+), less than (–) or not different from (·) the second treatment listed in each pair according to Tukey's Test ($P \leq 0.10$). One-gallon containers containing substrate were located in a controlled-environment greenhouse during the experiment and irrigated with drip emitters using municipal tap water.

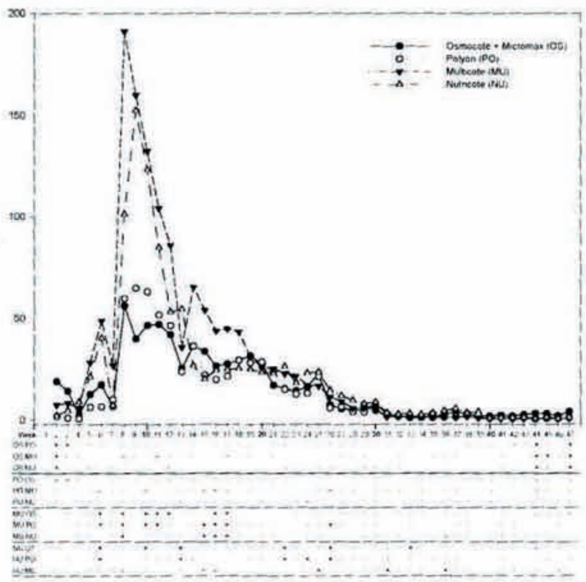
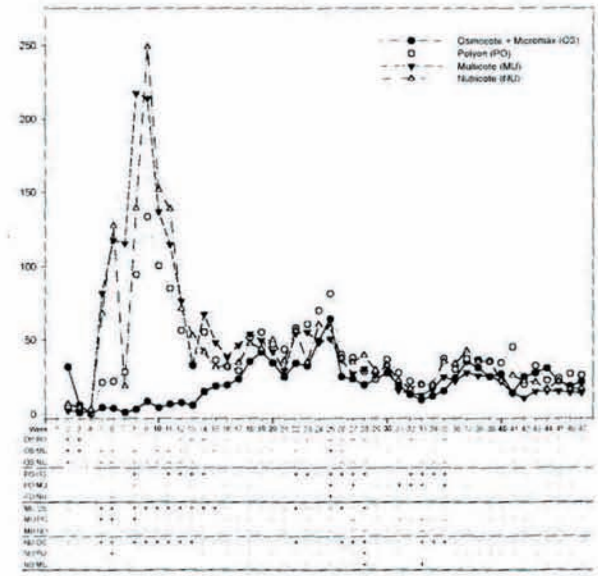


Fig. 4. Concentration of NO_3-N (mg·L⁻¹) in irrigation leachate collected weekly over a 47-week period (1 Aug 2001 to 27 June 2002) from a pinebark/peat-based substrate prepared with four controlled-release fertilizers at equal rates of total N. Significant differences in least squares means for pairs of treatments for each week (bottom) is indicated with the first treatment listed in each pair being greater than (+), less than (–) or not different from (·) the second treatment listed in each pair according to Tukey's Test ($P \leq 0.10$). One-gallon containers containing substrate were located in a controlled-environment greenhouse during the experiment and irrigated with drip emitters using municipal tap water.



4. Concentrations of nitrate for all treatments except Osmocote increased rapidly during the first ten weeks, and then decreased (Figure 4). Of all treatments, concentrations of nitrate were often lower for Osmocote than the other fertilizer types.
5. Concentrations of total inorganic nitrogen (ammonium + nitrate) increased during the first ten weeks of the study, and then slowly decreased during the remainder of the experiment for all treatments. However, total inorganic nitrogen of leachates from Osmocote appeared to be more stable than leachates derived from the other fertilizers studied.
6. Total phosphorus in leachates was relatively high during the first 15 weeks of the experiment, and then decreased during the remainder of the study for all fertilizer types. Leachate concentrations of total phosphorus were often higher for Multicote than other fertilizer types.

Under unheated greenhouse conditions, the release characteristics of ammonium, nitrate, and P from all CRFs tested were elevated during the first half of the study, followed by lower release during the later half of the 11-month period. The nutrient release rates do not appear to be associated with ambient temperature, as high temperatures were moderated with evaporative cooling pads and fans, and there was a general increase in temperature during the spring. Based on the results of this study and data from other long term studies, it appears that nutrient release from all the CRFs tested may be in excess of plant requirements during the first half of the production period, but may be insufficient during later stages of production, depending on the nutrient demands of the crop being grown and the temperature profiles during production. Leachate EC is probably associated with both nutrient release from CRF and soluble salts leached out of the substrate during the first few weeks of the study.

Differences were noted among fertilizer types, with Multicote often exhibiting a higher nutrient release than the other CRFs tested during the first 20 weeks of the study. However, during the last half of the study, nutrient concentrations in Multicote leachates were sometimes less than the nutrient concentrations recovered from the other fertilizer treatments, suggesting that the high release rates measured for Multicote during the first half of the

Fig. 5. Concentration of inorganic N (NH_4-N + NO_3-N) ($mg \cdot L^{-1}$) in irrigation leachate collected weekly over a 47-week period (1 Aug 2001 to 27 June 2002) from a pinebark/peat-based substrate prepared with four controlled-release fertilizers at equal rates of total N. Significant differences in least squares means for pairs of treatments for each week (bottom) is indicated with the first treatment listed in each pair being greater than (+), less than (–) or not different from (·) the second treatment listed in each pair according to Tukey's Test ($P \leq 0.10$). One-gallon containers containing substrate were located in a controlled-environment greenhouse during the experiment and irrigated with drip emitters using municipal tap water.

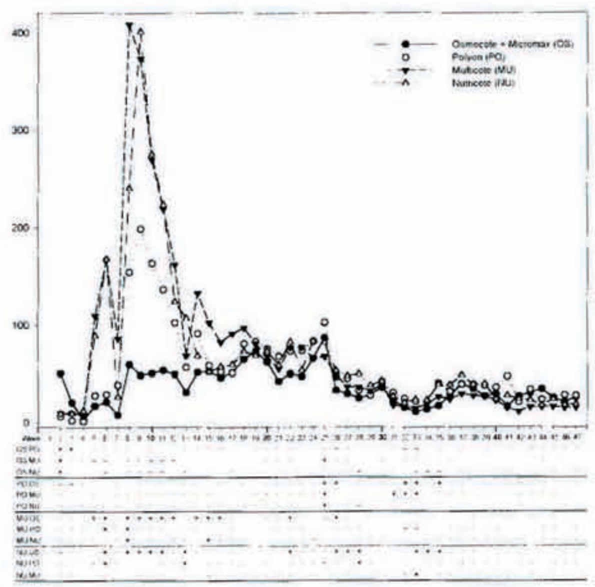
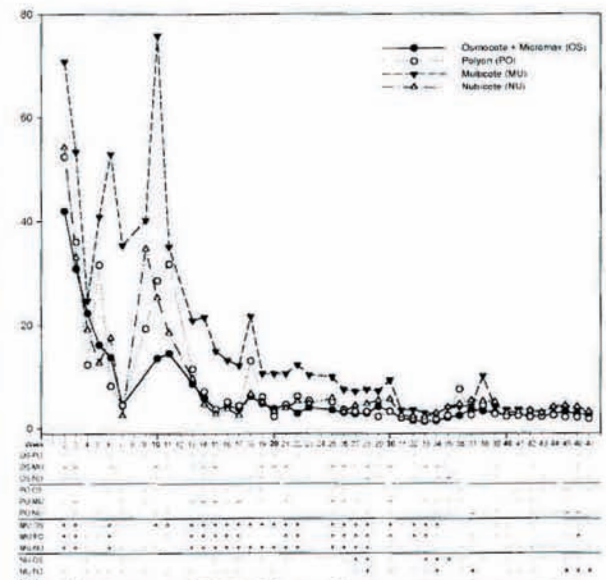


Fig. 6. Concentration of total P ($mg \cdot L^{-1}$) in irrigation leachate collected weekly over a 47-week period (1 Aug 2001 to 27 June 2002) from a pinebark/peat-based substrate prepared with four controlled-release fertilizers at equal rates of total N. Significant differences in least squares means for pairs of treatments for each week (bottom) is indicated with the first treatment listed in each pair being greater than (+), less than (–) or not different from (·) the second treatment listed in each pair according to Tukey's Test ($P \leq 0.10$). One-gallon containers containing substrate were located in a controlled-environment greenhouse during the experiment and irrigated with drip emitters using municipal tap water.



experiment resulted in a noticeably smaller pool of nutrients available for release during the last half of the study.

From an environmental perspective, risk of water impairment when using the CRFs employed in the present study would be greatest during the first 20 weeks of crop production when EC, NH_4-N, NO_3-N, and total P were elevated.

Improving Water-Run Nitrogen Fertilizer Practices in Furrow- and Border Check-Irrigated Crops

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INTRODUCTION

Injection of fertilizers in irrigation water (fertigation) is a common practice in the Western U.S. The main limitation of fertigation is the potential for non-uniform nutrient application, possibly leading to deficiencies in some parts of the field and – with N fertilizers – excess N and nitrate leaching losses in other parts of the field. Two factors can contribute to this non-uniformity: (1) Non-uniform irrigation water application; and (2) loss of N by ammonia volatilization where the source is anhydrous or aqua ammonia.

Management practices for improving water distribution uniformity (DU) in furrow and border check irrigation systems are well known and include cutting fields in half and compacting furrow bottoms with heavy weights (torpedoes). Such practices may be beneficial only in certain situations and can be costly or difficult to carry out. A method for improving fertilizer application uniformity that does not depend on improved water DU is to delay fertilizer injection until the water has advanced some distance across the field. This avoids fertilizer application on the upper end of the field early in the irrigation during the time of the most rapid infiltration.

OBJECTIVES

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

PROJECT DESCRIPTION

We conducted on-farm trials in corn fields at five sites in 2005 and three in 2006. The experiments were conducted when corn plants were small to facilitate visual monitoring of the water advance rate. At most sites, data was collected from a single furrow during three irrigation sets on consecutive days. At one site, data was collected in a border check-irrigated field. Field length ranged from 1100 to 2000 ft. Fertilizer retailers provided commercial tanks of N fertilizer – anhydrous ammonia at seven sites and urea-ammonium nitrate solution (UAN-32) at one site.

To carry out the two delayed fertilizer injection treatments, the fertilizer valve was not turned on until water had advanced to about 50% or 75% of the distance across the field. In order to provide the same total amount of N per acre in the shorter time of injection in the delayed treatments, a higher N flow rate was used.

During each irrigation set, flow rate in a single furrow was monitored with a flume placed near the head of the field, and advance times for the water were recorded at 100-ft intervals. In the border check site, the grower cooperated by irrigating only a single check at a time, and a flow meter was used to monitor the irrigation pump output. At regular time intervals (20-60 minutes), water samples were collected simultaneously from points along the furrow or border check and stored in ice chests for later analysis.

RESULTS

Measurements in 2005 show that at some sites, the delayed application strategy resulted in a higher distribution uniformity (DU) for N than for irrigation water (Table 1). DU is defined as the amount of water or N applied in the quarter of the area receiving the lowest amount as a percent of the average amount applied over the entire area. (For additional results see the 2005 Fertilizer Research & Education Conference and the 2006 California Plant & Soil Conference proceedings. Analysis of 2006 data is only partially completed.)

In both years, at all sites where anhydrous ammonia was used, concentrations in irrigation water collected at or near the tail end of fields were 10 to 40% lower than at the head of the field. An example from one of the 2006 sites is shown in Fig. 1. At some locations, the reductions in ammonium

Table 1. Irrigation water applied and distribution uniformity in anhydrous ammonia fertigation experiment at three sites in 2005.

Site/Treatment	Irrig set time	Irrigation water Applied	Irrigation water DU	NH_3 fertilizer Applied	NH_3 fertilizer DU
	hours	inches	%	lb N/acre	%
T1-sandy loam					
Continuous	6	2.1	73	21.4	60
Delay 50%	6	2.9	67	23.5	74
Delay 75%	5	2.5	86	4.1	66
T2-sandy loam*					
Delay 75%	8	6.2	49	35.7	74
SJ1-clay					
Continuous	9	4.8	89	30.0	80
Delay 50%	9	6.5	52	44.2	72
Delay 75%	9	6.1	55	35.9	84
SJ2-sandy loam					
Continuous	7	4.0	87	22.4	64
Delay 50%	7	5.9	63	53.1	61
Delay 75%	7	4.4	80	47.8	89

** At site T2, there were problems with the anhydrous fertilizer injection into the head ditch, and therefore N concentration data from the continuous and "delay-50%" treatments are not included in this report.*

Fig. 1. Decrease in ammonium concentration in furrow irrigation with delayed injection of anhydrous ammonia. At 10:40 a.m. the fertilizer had advanced only to 500 ft. By 11:30 a.m., fertilizer has reached 1100 ft, but even 30 minutes later, the concentration shows a linear decrease with increasing distance from the head of the field. (Site T3_06, 6/20/06)

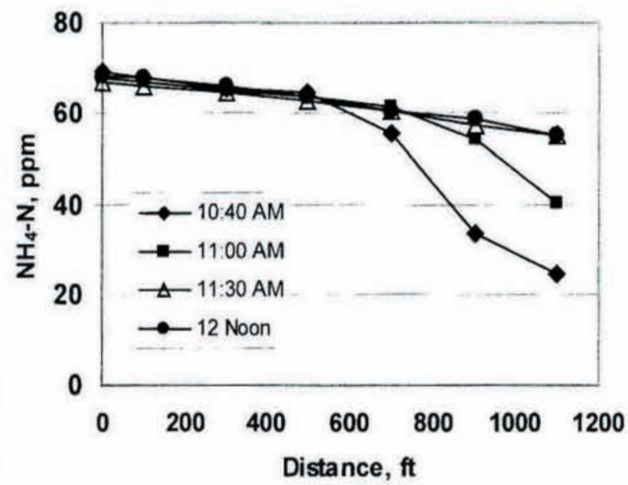
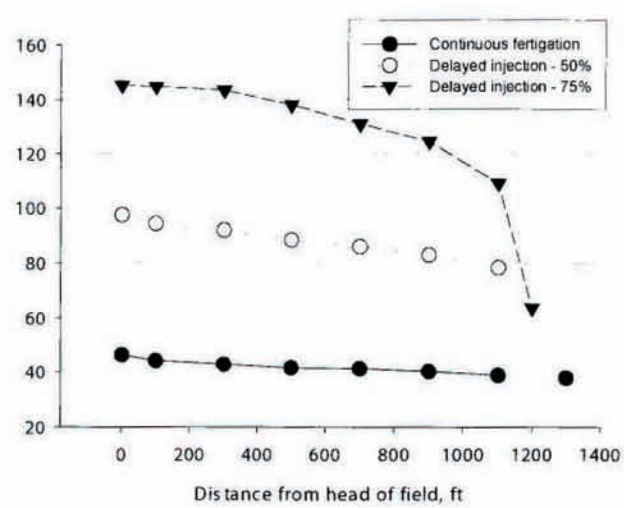


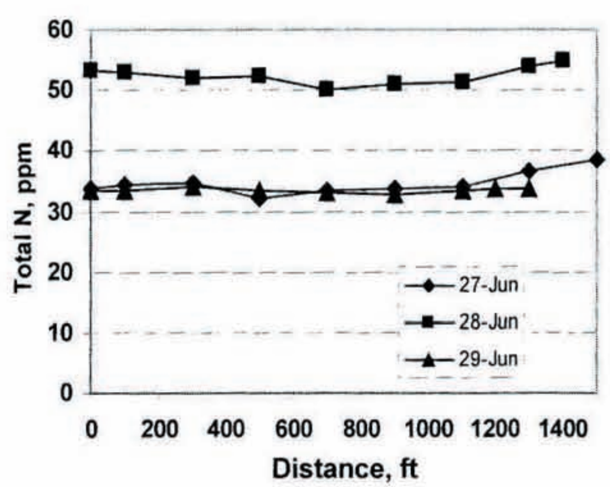
Fig. 2. Decrease in ammonium concentration in irrigation water under three different injection timing strategies. (Site T1_06)



N concentration were greater at the higher concentrations required for the delayed injection strategy (example shown in Fig. 2).

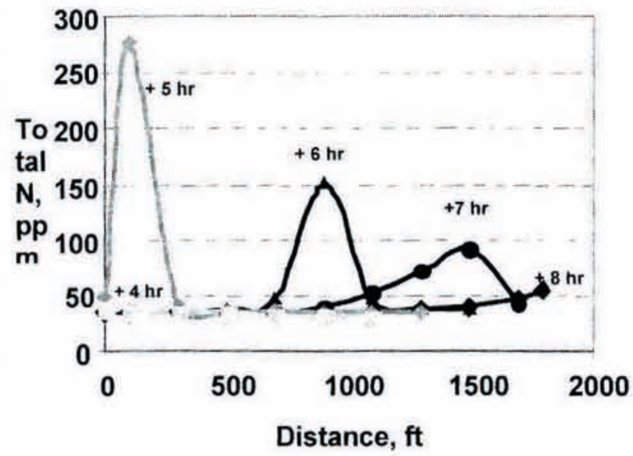
Although no attempt was made to directly measure ammonia volatilization, this was almost certainly the cause of the observed decrease in concentration. We observed large increases in irrigation water pH from ~7 to 9.5-10.3 at all sites immediately following injection of anhydrous ammonia. Such a high pH would greatly increase the proportion of N present as dissolved gaseous ammonia and would lead to greater NH_3 volatilization. Also, we observed significant water temperature increases down the length of fields during irrigation events, which would explain the linear decreases in NH_4 concentration observed down the entire length of the field. In one case when air temperature ranged from 98 to 106° F, water entering the field at 85° F had warmed to 102° F at a distance of 1700 ft from the irrigation valve. Finally, in support of the ammonia volatilization hypothesis, at the site at which UAN-32 was used instead of anhydrous ammonia, no N concentration decrease was observed (Fig. 3).

Fig. 3. Nitrogen concentration in irrigation water did not decrease down the length of the field when the source of N was urea-ammonium nitrate solution (UAN-32) instead of anhydrous ammonia. (Site T2_06)



Our measurements also clearly show that fertilizer injected after water has advanced halfway or more across a field quickly catches up to the advancing water. At the UAN-continuously fertigated site, an accidental release of a pulse of UAN illustrates this, as shown in Fig. 4. The pulse of N was detected at 100 ft from the head of the field when the advancing water was at 1300 ft. Two hours later, the pulse of N had reached 1500 ft, during which time the water had advanced only an additional 400 ft.

Fig. 4. Advance of pulse of UAN fertilizer during border check irrigation. Times refer to hours after beginning of irrigation. (Site T2_06, 6/27/06)



Additional measurements are planned for 2007.

ACKNOWLEDGEMENTS

Jiayou Deng, Staff Research Associate, UC Davis, collected and organized much of the data shown in this report. Assistance was also provided by field technicians from the Tulare, San Joaquin, and Yolo Co. Cooperative Extension offices. Fertilizer solution analyses shown in Figs. 3 and 4 were performed by the UC DANR Analytical Laboratory. We are grateful to several growers and their employees and fertilizer retailers in Tulare and San Joaquin Counties for their assistance and for allowing us access to fields.

Developing Starter Fertilizer Recommendations for California Rice Growers

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Introduction

In 1991, the California Rice Straw Burning Reduction Act (AB1378) attempted to mitigate the negative impact of rice straw burning on air quality by requiring rice farmers to adopt alternative methods of straw disposal for the more than 500,000 acres of rice grown in the Sacramento Valley. Despite initial uncertainty over the impact of straw incorporation on rice growth and yield, in-field residue incorporation has transitioned from a burning "alternative" to the primary means of residue management. As a result, the amount of organic matter in the soil has increased and nutrient availability has been altered. From long-term experiments, it is clear that available soil N is increased after 3 years of residue incorporation and winter flooding (Eagle et al., 2000); however, the impact on soil fertility in growers' fields, where management options are frequently rotated to reduce pest and weed pressure, is uncertain.

Survey results indicate that 29% of growers reported reducing fertilizer applications in fields where they regularly incorporated residues, while 9% of growers increased fertilizer rates, and 52% reported no change following legislated reductions in burning.[1] Given the reported lack of a clear consensus on the impact of straw management on soil fertility and fertilizer practices, it is not surprising that there is a perceived need among growers for improved fertility management guidelines. In an effort to address that need, we began a comprehensive evaluation of the impact of rice straw incorporation on nutrient cycling and fertility management by rice growers throughout the Sacramento Valley in 2003. The research included fertility trials conducted with 15 growers in 38 fields, self-reporting, extensive soil and plant sampling and monitoring of three different N rates across a variety of soils, under different management practices.[2] When three-year field histories provided by the growers were used to group the data for analysis, a comparison of relative yields within fields indicated that those fields with a history of residue incorporation had significantly greater yields under the reduced fertilizer treatment than those where residue was consistently burnt or baled ($P=0.03$), reaffirming that changes in straw management have altered nutrient availability. Furthermore, greater than 50% of those fields studied in 2003 were P-deficient according to current soil fertility guidelines, though less than 5% exhibited leaf tissue concentrations below the critical level at maximum tillering (<1000ppm), suggesting that either the soil or tissue guidelines should be reevaluated.

With the assistance of CDFA/FREP, we are continuing trials in grower-managed fields and expanding the scope of the trials to include sites where more complete fertilizer timing, material, and rate response trials will occur. The specific objectives are: 1) To evaluate current starter fertilizer recommendations for flooded rice soils; 2) To improve critical N, P, and K guidelines for mid-season tissue.

[1] A summary of the results is available on the UCCE Rice web page: http://agronomy.ucdavis.edu/uccerice

[2] All rate manipulations were made to pre-plant fertilizer applications. The N rates were based upon grower standard practice for a given field, and included a 25% or 25 lb N ac^{-1} decrease in pre-plant N, standard practice, and a 25 % or 25 lb N ac^{-1} increase in pre-plant N.

OBJECTIVES (TASKS)

1. To evaluate current starter fertilizer recommendations for flooded rice soils.
2. To improve critical N, P, and K guidelines for mid-season tissue.

METHODS

In 2005, replicated experiments were set up in 5 growers' fields representing soil and management practices common to California rice production (Table 1). At all sites a medium grain Japonica-type rice was grown.

Eight treatments were used to evaluate crop response to and efficiency of N, P, and K starter fertilizers (Table 2). Treatments (Table 2) were set up in a randomized complete block design at each site with each site having 5 replications. Efforts were made to have each replication in different checks; however, at two locations (both in Butte county) all replications had to be in a single check to facilitate farmer field operations. The two growers in Butte county applied starter fertilizer by air, requiring us to have all five blocks in a single check.

Plot size varied by site to account for differences in equipment width (fertilizer applicators and harvesters). Plot length ranged from 125 ft to 200 ft. A single replication showing the layout of the eight treatments is shown in Figure 1. Treatment details are shown in Table 2. The rationale for the treatments are as follows:

- TRT 5-8 is a simple nutrient omission trial to identify what nutrients are limiting. Nutrient limitations will be determined on the basis of plant biomass and yield.
- TRT 1 is a control and gives us the indigenous N supply. From this we can measure the benefit (and efficiency) of fertilizer N of the other treatments.
- TRT 2 is a control. We can use this to measure fertilizer use efficiency of starter fertilizer (by mass balance).
- When the growth and N uptake curves of 1 and 2 and of 4 and 5 diverge, this will determine when the crop under starter and no starter has reached the aqua-N.
- Treatment 5 with the ^{15}N will enable us to determine the contribution of the starter to the total N uptake, as well as determine N use efficiency. Comparison of this with the ^{15}N in treatment 3 will indicate if P and K improve N use efficiency.

Table 1. Site location and details for each field in the study.

Town	Previous years straw mgmt	Aqua-N rate (kgN/ha)	Starter N* (kg N/ha)	Topdress N (kg N/ha)	Total N applied (kg N/ha)	Early season water mgmt.
Arbuckle	Straw incorp past 2 yr. Tomato before	112	30	0	142	Leathers method
Sheridan	Straw incorp/roll since 1996	148	30	24	202	Drained May 24- re-flooded June 13
Princeton	Straw incorporated for past 3 yr	159	30	0	189	Perm. flood
Gridley	Straw incorporated for past 10 yr	107	30	0	137	Perm. flood
Richvale	Straw incorporated for past 15 yr	118	30	0	148	Perm flood

** Starter N was a treatment variable and either 0 or 30 kg N/ha was applied.*

Table 2. Treatments and design

Treatment #	Basal Aqua N	Starter Fertilizer	Plot type	^{15}N plot included as part of main trt
1	0	-PK	Main	
2	Yes	---	Main	
3	Yes	N--	Inside #2	Yes
4	0	NPK	Inside #1	
5	Yes	NPK	Main	Yes
6	Yes	-PK	Main	
7	Yes	N-K	Main	
8	Yes	NP-	Main	

Starter fertilizer rates will be: N (30), P_2O_5 (50), K_2O (50). Aqua-N will be as per grower.
Sources: N (ammonium sulfate), P (TSP) and K (Potassium sulfate)

Every effort was made to apply the starter fertilizer as the farmer would. In all cases it was surface applied. Soils were sampled from each replication after the fields were planed. These were dried and processed in preparation for analysis. At 3 and 4 weeks after sowing, whole plant samples were taken from treatments 1, 2, 4, 5, and 6. These plants were analyzed for above-ground biomass and nutrient content. Data from these samples will be used for the determination of starter N fertilizer uptake efficiency. Five weeks after sowing (mid-tillering), (1) plant samples were taken for above-ground biomass from all treatments, (2) soil and plant samples were taken from the ^{15}N plots, and (3) the most recently expanded leaf from 20 plants in each plot was taken for tissue analysis. At harvest, crop cuts were taken from each treatment to determine biomass. From the ^{15}N plots, soils and plant samples were taken to determine N use efficiency.

Results

Early season

Results on early season biomass production measured at 3, 4, and 5 (mid-tillering) weeks after planting (Table 3) indicate that:

1. At all sites there was a benefit to applying a complete starter (N, P, and K) application. Early season above-ground biomass was significantly higher when there was an NPK starter application than when no starter fertilizer was applied.
2. At all sites there were benefits to the application of starter N. Where starter N was applied, biomass was higher at all sites and sample times. This is despite a wide range of early season water management practices for seed establishment (water drained for seed establishment-Leathers method) and weed control (one site dried down soil for "Clincher" application and three sites had soils permanently flooded).
3. The early season biomass data indicate that the crop begins taking up aqua-N some time before three weeks after planting, despite aqua-N being injected 4 inches deep. However, even though young rice seedlings are able to take up aqua-N very early, there was still a positive benefit of applying starter N near the surface.

Harvest

Results based on data taken at harvest indicate that:

1. At no sites was there a P or K deficiency as indicated by a significant yield response to P and K fertilizer (data not shown).

Table 3. Above-ground biomass measured at approximately 3, 4, and 5 weeks after sowing (DAS) at each farmer site.

Colusa-Arbuckle

#	Treatment: Basal Aqua N	Treatment: Starter Fertilizer	Above-ground biomass (kg ha $^{-1}$) T1 (22 DAS)	T2 (30 DAS)	T3 (37 DAS)
1	0	-PK	30 b	95 c	212 d
2	Yes	---	30 b	112 bc	306 c
3	Yes	N--			453 a
4	0	NPK	36 a	156 a	379 b
5	Yes	NPK	35 a	172 a	442 a
6	Yes	-PK	33 ab	124 b	368 bc
7	Yes	N-K			412 ab
8	Yes	NP-			456 a
	ANOVA (P)		0.0508	0.0000	0.0000

Yuba-Sheridan

#	Treatment: Basal Aqua N	Treatment: Starter Fertilizer	Above-ground biomass (kg ha $^{-1}$) T1 (26 DAS)	T2 (31 DAS)	T3 (38 DAS)
1	0	-PK	190 c	418 c	546 f
2	Yes	---	212 bc	499 b	703 de
3	Yes	N--			901 ab
4	0	NPK	249 a	530 ab	675 e
5	Yes	NPK	249 a	580 a	959 a
6	Yes	-PK	226 a	475 b	709 cde
7	Yes	N-K			819 bc
8	Yes	NP-			759 bcd
	ANOVA (P)		0.0037	0.0002	0.0000

Colusa-Princeton

#	Treatment: Basal Aqua N	Treatment: Starter Fertilizer	Above-ground biomass (kg ha $^{-1}$) T1 (22 DAS)	T2 (29 DAS)	T3 (35 DAS)
1	0	-PK	119 c	233 d	578 e
2	Yes	---	144 b	315 c	879 cd
3	Yes	N--			1036 ab
4	0	NPK	190 a	382 b	841 d
5	Yes	NPK	207 a	460 a	1163 a
6	Yes	-PK	164 b	353 bc	1003 bc
7	Yes	N-K			1006 bc
8	Yes	NP-			1116 ab
	ANOVA (P)		0.0000	0.0000	0.0000

Butte-Gridley

#	Treatment: Basal Aqua N	Treatment: Starter Fertilizer	Above-ground biomass (kg ha $^{-1}$) T1 (21 DAS)	T2 (27 DAS)	T3 (35 DAS)
1	0	-PK	136 b	306 c	726 d
2	Yes	---	145 b	287 c	681 d
3	Yes	N--			741 d
4	0	NPK	159 ab	368 b	960 c
5	Yes	NPK	187 a	412 a	1312 ab
6	Yes	-PK	182 a	410 a	1249 b
7	Yes	N-K			760 d
8	Yes	NP-			1424 a
ANOVA (P)			0.0071	0.0000	0.0000

Butte-Richvale

#	Treatment: Basal Aqua N	Treatment: Starter Fertilizer	Above-ground biomass (kg ha $^{-1}$) T1 (20 DAS)	T2 (26 DAS)	T3 (33 DAS)
1	0	-PK	69 c	215 c	578 e
2	Yes	---	75 bc	293 b	915 cd
3	Yes	N--			988 bcd
4	0	NPK	82 ab	306 b	871 d
5	Yes	NPK	87 a	345 a	1148 ab
6	Yes	-PK	76 bc	289 b	916 cd
7	Yes	N-K			1098 abc
8	Yes	NP-			1206 a
ANOVA (P)			0.0093	0.0000	0.0001

2. Applying starter N increased grain yields at only two of the five sites (Figure 1). A significant response to starter N was observed at sites with lower aqua-N rates (except Gridley).
3. The N-use efficiency (NUE) of the deep aqua-N was similar across sites and averaged 56% (Figure 2).
4. The NUE of starter fertilizer varied from 0 to 99% (Figure 2). The NUE of surface applied N was higher at locations that received lower aqua-N, suggesting that N rates may have been high where starter NUE was low.
5. Using ^{15}N-labeled starter fertilizer, it was clear that the starter fertilizer, which was not taken up by the crop or lost to the atmosphere, remained at the soil surface (top 0-7.5 cm) where it was applied (Figure 3).

Conclusions

1. The rice crop begins to take up aqua-N very early in crop growth.
2. While starter N does increase early season growth, at only two sites was there a yield response to starter N.
3. Grain yield responses to starter N and high NUE were noted at sites where the aqua N rate was low. It is possible that if the aqua-N rate was increased, there would not be a response to starter N.
4. There is no indication that starter N is necessary for good crop growth. It is possible that by increasing the aqua-N rate, there would be no need to apply starter N. Doing this would eliminate a pass across the field. This is the focus of the 2006 field studies.

Figure 1. Grain yield response to starter N fertilizer.

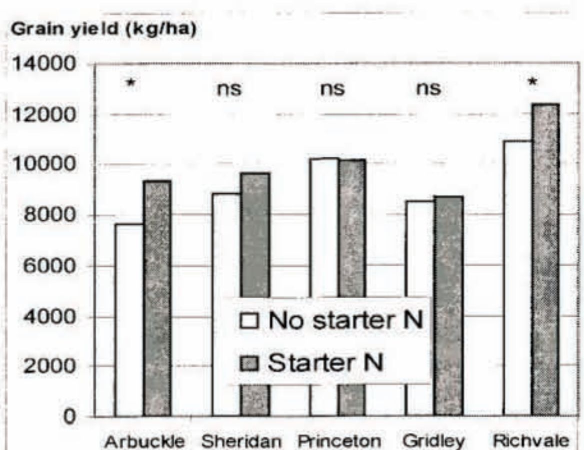


Figure 2. Nitrogen use efficiency of the starter and aqua N fertilizer.

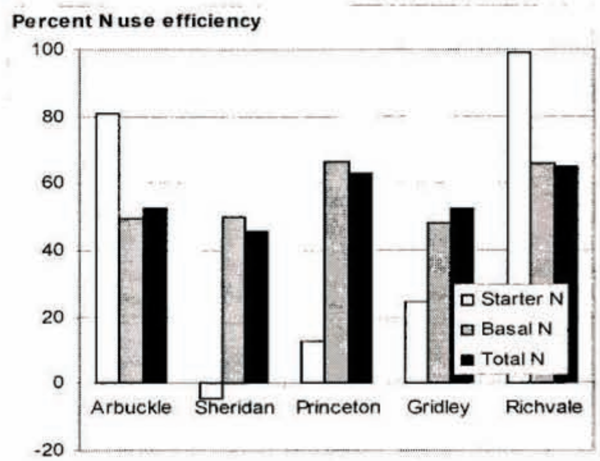
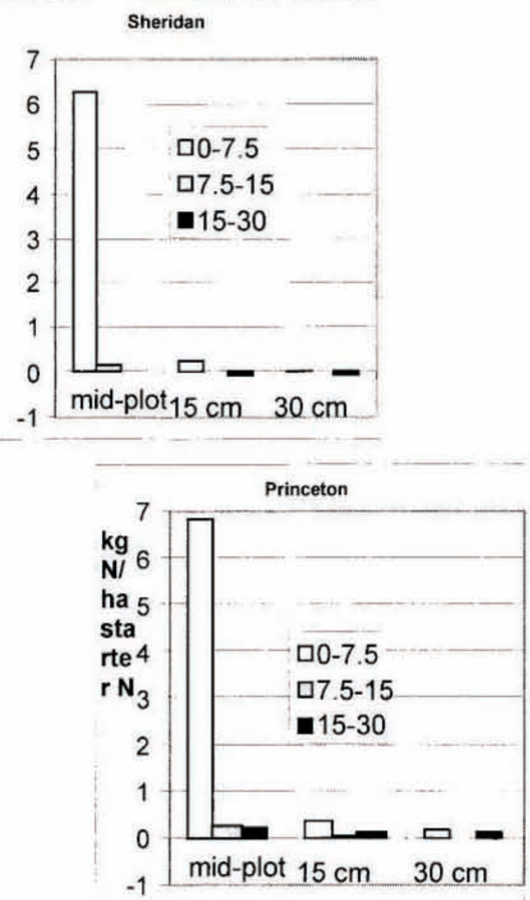


Figure 3. The location of starter N in the soil (depth and distance from application point) at two of the sites. Soils were sampled at 0-7.5 cm, 7.5 to 15 cm, and 15 to 30 cm depths inside the plot, 15 cm outside the plot, and 30 cm outside the plot. Samples were taken at harvest.



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

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INTRODUCTION

Zinc (Zn) is an essential plant micronutrient, and Zn deficiency is widespread, causing economic losses throughout the world. Among fruit crops, pecan, peach, citrus, and avocado seem to be particularly sensitive to this disorder. Zinc is the most widely limiting micronutrient for tree fruit production in California, and deficiencies are worse in sandy and alkaline soils. Inadequate zinc availability in soils and limited responses to soil applications of fertilizer zinc has resulted in the large-scale adoption of foliar applications. Recent studies suggest that foliar-applied zinc remains in or on treated leaves and is not transported to other plant parts. As a result, zinc accumulates in the soil because much of the foliar-applied Zn is carried to the orchard floor in leaf litter following leaf fall.

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

OBJECTIVES

1.) Assess the feasibility of alternative zinc application methodologies to increase the efficiency of zinc recovery by using soil applications to acidify and stimulate root proliferation in a limited portion of the soil volume.
2.) Evaluate the potential of using zinc-efficient cover crops to mobilize soil zinc and make it more available to tree roots.
3.) Evaluate an experimental peach rootstock that appears to have greater capacity for zinc uptake from soil than rootstocks currently in commercial usage.
4.) Compare the efficiency of zinc uptake into the woody tissues of peach trees before, during, and after leaf abscission in the fall.
5.) Evaluate the distribution of zinc throughout young peach trees (especially to the roots) from a fall foliar application.

RESULTS AND DISCUSSION

2006 is the second year of a three-year project. Many individual experiments have been initiated and some preliminary results have been obtained. Most of the experiments will continue for several years. Below is a brief summary of each set of experiments.

Soil Acidification

A technique developed in Germany called CULTAN (Controlled Uptake Long Term Ammonium Nutrition) has been used successfully to treat Fe and Zn deficiencies in crop plants. The idea is to add Fe or Zn, together with ammonium fertilizer (to stimulate root growth), to a small acidified portion of the soil. This increases the uptake of these metals since they are much more available at a lower pH. We tried the technique with some mature peach trees by adding soil sulfur, urea, and varying rates of zinc sulfate to an 18" deep hole near the tree. Leaf samples one year later showed somewhat higher zinc levels with high rates of zinc sulfate (Table 1). Acidification alone was not sufficient to increase Zn but did increase other heavy metals including manganese, iron, and copper. Manganese showed a competitive relationship with the added Zn.

To newly planted peach trees we tried a modification of this approach. Within each planting hole we added a "root bag" containing 100g urea, 100g sulfur and 0, 10 or 50g zinc sulfate. Each bag was wrapped with cheesecloth for easy handling. By mid-summer, leaf Zn levels had been increased but only with the highest rate of zinc sulfate (Table 2). Dormant shoot samples indicated greatly increased Zn levels at both zinc sulfate rates. Other heavy metals were also affected by the treatments but not necessarily in the same way as the mature trees.

Table 1. The effect of CULTAN treatments on leaf nutrients of mature Loadel peach trees. CULTAN treatments consisted of 300 g urea, 15 g sulfur and varying rates of zinc sulfate applied in an 18-inch deep hole by each tree. Treatments were made in July 2004.

Leaf Nutrients 6/30/05	Untreated Control	CULTAN – Treatments with the following Zn sulfate amounts				
		0g	3g	30g	150g	450g
Zn (ppm)	18.4 b[z]	17.8 b	17.9 b	17.6 b	20.1 b	24.3 a
Mn (ppm)	26.2 c	74.9 a	74.3 a	53.8 b	37.3 c	34.2 c
Fe (ppm)	68.8 c	92.4 a	80.9 b	79.0 bc	81.1 b	78.1 bc
Cu (ppm)	5.5 d	6.8 ab	6.5 bc	6.2 c	6.9 a	6.4 bc

[z] *Values in rows followed by the same letter are not significantly different.*

Table 2. The effect of root bags placed on the planting hole of young peach trees on mid-summer leaf nutrients and dormant shoot nutrients. Root bags consisted of 100 g urea, 100 g sulfur, and varying rates of zinc sulfate. Treatments made at planting in March 2005.

	Untreated Control	Root bags with the following Zn sulfate amounts		
		0g	10g	50g
Leaf Nutrients 7/11/05				
Zn (ppm)	15.5 b[z]	16.0 b	12.1 b	21.3 a
Mn (ppm)	27.1 c	94.3 b	95.0 b	127.5 a
Fe (ppm)	87.9 c	98.7 bc	106.2 ab	114.1 a
Cu (ppm)	4.4 a	4.1 a	3.5 b	3.4 b
Shoot Nutrients 1/4/06				
Zn (ppm)	36.0 c	41.5 c	71.7 b	112.4 a
Mn (ppm)	18.5 c	30.6 b	33.1 ab	40.0 a
Fe (ppm)	109.6 a	106.2 a	114.6 a	114.7 a
Cu (ppm)	7.8 a	8.8 a	7.9 a	7.5 a

[z] *Values in rows followed by the same letter are not significantly different.*

In 2006, we made up over 100 root bags and put them in several commercial plantings. Mid-summer leaf samples were taken but have not yet been analyzed. We will continue to monitor all these trials to see how long elevated zinc levels are maintained by a single application.

Companion Crops

Barley and other graminaceous species are very efficient at taking up Zn and Fe under conditions where these metals are low in the soil. They do this by releasing molecules called phytosiderophores that help extract these nutrients from the soil. When another crop is planted with the barley, its Zn and Fe uptake can also be improved if its roots are in close proximity to the barley roots. On our first attempt we planted winter barley in the rows next to some 3-year-old peach trees, but could not measure any increase in leaf Zn. We felt it was probably because the roots of the two species were not close enough together. In the fall of 2005 we planted barley directly under some Springcrest peach trees that were showing minor Zn deficiency symptoms. Spring and summer leaf samples were taken but have not yet been analyzed. We will also rate deficiency symptoms in the fall of 2006.

We have also obtained seed from a barley variety that is reported to be even more zinc efficient than normal varieties. It is not commercially grown in the USA so only a small amount was available. We planted this seed around a single tree in the fall of 2005. Peach leaf samples were taken and seeds were harvested from the barley plants so a larger trial can be conducted in 2007 if the approach shows merit.

Rootstocks

In our 2005 FREP report we presented information on the rootstock Hiawatha, which has considerably more zinc in the leaves and especially in dormant shoots compared to the standard rootstock Nemaguard. We will continue to monitor the Zn status of trees in this rootstock planting, which has never been sprayed with zinc.

^{68}Zn Studies

This area will be a major emphasis in the third and final year of the project. So far we have conducted one ^{68}Zn study that suggested Zn is much more mobile in a peach tree than we originally thought. Thus, most future experiments will include whole trees as Zn is definitely transported to the roots. We have developed a greenhouse system using small peach seedlings that will allow us to ask a number of questions about foliar rates, formulations, and additives. We have already conducted some preliminary experiments to refine the technique and will start some full experiments in the fall of 2006. We have also started some trials with different Zn formulations to test their relative phytotoxicity on different fruit crops, and currently have an experiment on Arabidopsis to test their relative uptake efficiencies. All of this research should guide us to a few critical trials to conduct in 2007 with the overall goal of determining the most efficient timing, rate, and formulation of getting Zn into fruit and nut trees. Most of these trials are working with foliar applications, but we also have one experiment evaluating the efficiency of fertigation as an approach to Zn fertilization.

CONCLUSION

We have explored many different approaches of increasing the efficiency of zinc applications to fruit and nut trees. Over the past two years we have made significant progress in several of these areas. During the third and final year we expect to focus on the most efficient and environmentally sound ways to supply this nutrient to the plant.

DEVELOPMENT OF A LEAF COLOR CHART FOR CALIFORNIA RICE VARIETIES (NO. 01-0510)

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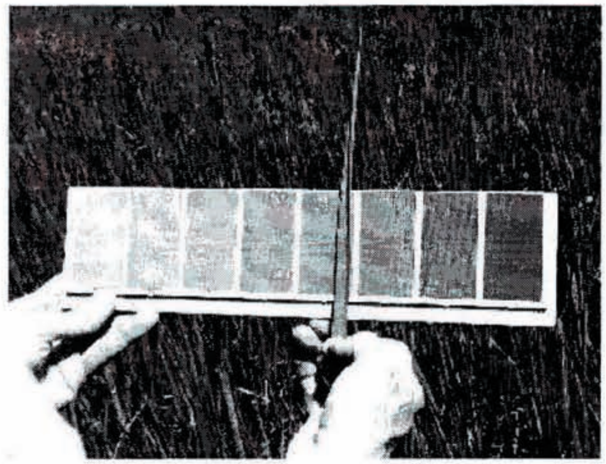
INTRODUCTION

Precise fertility management of large acreage of rice necessitates a reliable real-time measure of leaf nitrogen. Research on rice and other plant species demonstrated that a leaf reflectance spectrum predicts leaf nitrogen concentration. However, the instrumentation used to measure color is not always suitable for on-farm use. Hand held chlorophyll meters, in contrast, can be used to estimate leaf nitrogen. These instruments are costly and require extensive sampling to accurately calibrate before they are useful. To address the need for a real-time nitrogen management tool, a project was initiated in 1998 to develop a leaf color chart (LCC, Figure 1) to estimate leaf nitrogen content in rice based on leaf color. Eight public varieties of rice were grown under a range of preplant applied nitrogen levels. Sample leaves at panicle initiation were harvested from all varieties and total nitrogen content chemically determined. The leaf reflectance

Figure 1. The University of California leaf color chart (LCC) predicts leaf N based on color.



characteristics were measured with a spectrophotometer. Spectral reflectance characteristics of the individual leaves from the controlled experiment were recorded over the visible spectrum (400 to 700 nm) in 10 nm increments. Spectral data were used to fabricate acrylic plates (color cells) representative of leaf color. The spectral characteristics of the color cells were tested repeatedly to ensure that leaf color was accurately described. Quality standards were met by evaluating color and color differences. Finished chips were then reevaluated for color quality, again using a spectrophotometer.

Estimating tissue N status at critical points of the plant's life cycle can greatly improve the economics of rice production. Fertility management decisions must frequently be made for numerous large fields in a short period of time. Quick tests for tissue nitrogen, such as petiole nitrate, are not applicable to rice where nitrogen is taken up as ammonia due to the anaerobic soils conditions. Given that many growers apply mid-season fertilizer to their fields, the LCC enables them to more accurately predict necessary application rates at the sub-field level if desired.

Special Qualities of the LCC

The LCC is constructed of high temperature acrylic plastic capable of withstanding temperatures of 180° F. The pigmentation in color cells is photo-stable. Additionally, the LCC is linear. In that the incremental change in color and the associated tissue nitrogen is uniform between color cells. Thus, a user can effectively extrapolate between cells, should a leaf be darker than one cell and lighter than the adjacent one.

Project Objectives

The overall objective was to introduce and promote the adoption of the LCC, a real-time nitrogen tool for rice. Specific objectives were to:

1.) Refine the chart calibration algorithms for multiple varieties across location;

2.) Improve the use and sampling techniques for single leaf and whole field nitrogen determination;

3.) Promote the adoption and proper use of the LCC through a series of field meetings and workshops training growers and PCA's.

Results and Conclusions

Objective 1

Refine the chart calibration algorithms for multiple varieties across location.

This objective was addressed using a three-phase approach: controlled studies, sampling multiple locations across the rice growing region, and cooperators providing tissue samples with corresponding LCC values. Over 160 growers and PCAs that participated in the study received a free LCC (Figure 2). Sampling instructions, tissue air-drying procedures, and a

Figure 2. Leaf color chart, protective sleeve, and instruction sheet provided to rice growers and pest control advisors free of charge.

Figure 3. Leaf nitrogen (%) as a function of LCC values for rice leaves at panicle initiation for nine varieties collected in the Sacramento Valley in 2003. N = 86.

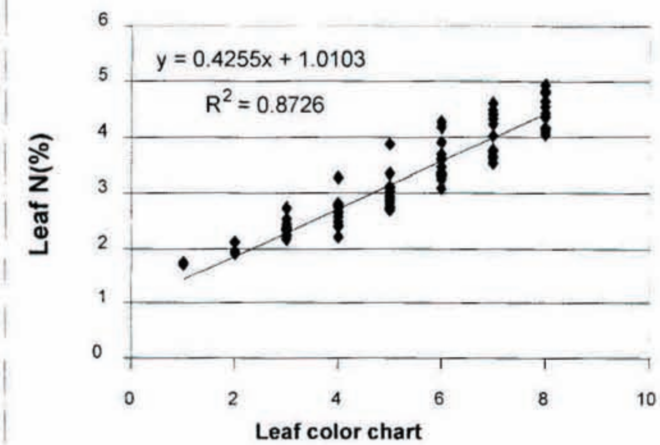


Table 1. Correlation analysis describing the relation between leaf N content predicted by the leaf color chart used by growers and percent leaf N as determined by laboratory analysis for selected varieties of rice. Samples were taken at panicle initiation.

Variety	Regression equation	R2	N
Akitakomachi	Y = 0.432X + 0.891	0.891	2
Arborio	Y = 0.427X + 1.236	0.948	2
M-104	Y = 0.389X + 0.956	0.842	3
M-202	Y = 0.483X + 0.920	0.920	18
M-205	Y = 0.581X + 0.471	0.940	15
M-206	Y = 0.413X + 0.865	0.837	11
M-401	Y = 0.442X + 0.769	0.885	8
All varieties combined	Y = 0.443X + 0.846	0.812	61

representative set of sample bags were provided. Air-dried leaf tissue samples were analyzed for nitrogen content. Leaf samples represented 7 varieties of rice. The LCC predicted leaf N with a high degree of accuracy for all varieties tested by the growers (Table 1). The accuracy of the LCC when used by participating growers compared favorably to results obtained from the controlled experiments.

Valley Wide Multi-location Sampling and Calibration
UC staff collected samples from 86 fields in 8 counties in Sacramento Valley. The LCC predicted leaf N best at panicle initiation (Table 2). Pooling data from location and variety demonstrated a single curve could be used for all varieties

Table 2. Determination of leaf N from single leaf color at mid-tiller and panicle initiation stages for each variety: equations of best fit, applicable range, leaf N (%) calculation.

Variety	Stage	Fitted equation of Leaf Color vs Leaf N(%) Prediction equation	R-Square	LCC Range
M205 M206	MidTlr	N = 0.344 * LCC + 0.925	0.76	1.3 ≤ LCC ≤ 3.7
	PI	N = 0.420* LCC + 1.01	0.91	1.4 ≤ LCC ≤ 4.4
	Both Stages	N = 0.430 * LCC + 0.869	0.66	1.3 ≤ LCC ≤ 4.3
M202 S102	MidTlr	N = 0.377 * LCC + 1.289	0.79	1.7 ≤ LCC ≤ 4.3
	PI	N = 0.376 * LCC + 0.883	0.88	1.3 ≤ LCC ≤ 3.9
	Both Stages	N = 0.380 * LCC + 0.730	0.72	1.1 ≤ LCC ≤ 3.8
M402 M104	MidTlr	N = 0.365 * LCC + 1.045	0.86	1.4 ≤ LCC ≤ 4.0
	PI	N = 0.416 * LCC + 1.11	0.90	1.6 ≤ LCC ≤ 4.4
	Both Stages	N = 0.395 * LCC + 0.933	0.76	1.3 ≤ LCC ≤ 4.1
All Varieties	MidTlr	N = 0.437 * LCC + 0.983	0.70	1.4 ≤ LCC ≤ 4.5
	PI	N = 0.385 * LCC + 1.15	0.86	1.5 ≤ LCC ≤ 4.2
	Both Stages	N = 0.432 * LCC + 1.2079	0.66	1.6 ≤ LCC ≤ 4.7

(Figure 3). Previous work demonstrated that there were slight but statistically insignificant variations in the calibration curves between varieties. Based on this sample population of clientele the LCC is readily adaptable to different varieties across a range of growing conditions.

Objective 2

Improve the use and sampling techniques for single leaf and whole field nitrogen determination.

Whole field (WF) calibration of the LCC required a more extensive sampling protocol. Canopy color in rice is a function of the top two to three leaves. Consequently, the color of the field is actually a function of the human eye integrating the combined color of the upper canopy. Extensive leaf sampling of the canopy was conducted at several growth stages (tillering, panicle initiation, pollen meiosis, and boot) for developing single leaf and whole field calibration of the LCC. For the whole field methods, nitrogen levels in the top three leaves at the various growth stages and their associated color were analyzed to determine the relative contribution of each leaf to the overall color of the field. Regression analysis demonstrated that the WF method was most accurate at PI for all varieties tested (Table 3). Coefficients of determination ranged from 0.63 at mid-tiller for M-202, M-205, M206, and S-102 to 0.81 at PI for M-402 and M-104. In all cases, the regression fit was stronger at PI than at mid-tiller.

Objective 3

Promote the adoption and proper use of the LCC through a series of field meetings and workshops training growers and PCA's.

Specific outreach and education accomplishments are listed below.

1. **Winter Meetings.** Information from this study was presented at 12 different meetings. Total attendance for the 12 meetings was over 1200 people.
2. **Rice Production Workshop.** Five all-day production workshops were conducted over the course of the project. The use of the LCC was fully integrated into the N management section of the workshop. Combined attendance was over 400 people.

Table 3. Determination of leaf nitrogen from whole field color value at mid-tiller (MidTlr) and panicle initiation (PI) stages for each variety: equations of best fit, range of applicability and leaf N (%) calculation.

Variety	Stage	Fitted equation of Leaf Color vs Leaf N(%) Prediction equation	R-Square	LCC Range
M205 M206 S102	MidTlr	N = 0.472 * LCC + 0.796	0.63	1.3 ≤ LCC ≤ 4.6
M202	PI	N = 0.425 * LCC + 0.736	0.79	1.2 ≤ LCC ≤ 4.1
	Both	N = 0.328 * LCC + 0.851	0.66	1.1 ≤ LCC ≤ 3.7
M402 M104	MidTlr	N = 0.347 * LCC + 0.814	0.67	1.1 ≤ LCC ≤ 3.8
	PI	N = 0.519 * LCC + 0.816	0.81	1.3 ≤ LCC ≤ 5.0
	Both	N = 0.542 * LCC + 0.779	0.76	1.3 ≤ LCC ≤ 5.1
All Var.	MidTlr	N = 0.484 * LCC + 1.4328	0.58	1.9 ≤ LCC ≤ 5.3
	PI	N = 0.485 * LCC + 0.754	0.75	1.2 ≤ LCC ≤ 4.6
	Both Stages	N = 0.402 * LCC + 0.832	0.65	1.2 ≤ LCC ≤ 4.0

3. **Summer Field Meetings.** Two field meetings were held in each year. Combined attendance was 120 people.
4. **Annual Rice Field Day.** Informed growers about the LCC at the Rice Experiment Station Annual Field Day; it was attended by over 600 people.
5. **Newsletters.** Periodic newsletters mailed through the local UCCE offices, the California Rice Commission or the California Research Board (RRB) contained articles on the LCC. The combined mailing lists of the three organizations exceeds 2500 recipients.
6. **Web-Based Information.** Information on the LCC is posted on the UC and RRB websites.
7. **On-farm Visits.** Project personnel were available upon request for personnel consultations during the growing season throughout the rice growing region of California. Sixty-four farm calls and numerous telephone consultations were made.
8. **Grower Participation.** 169 growers and PCAs signed up to participate in the on-farm calibration portion of the project. To date, over 400 LCC's have been given to growers and PCAs in the California.

Conclusions

A leaf color chart (LCC) consisting of 8 color cells representing the actual reflectance characteristics of rice leaves across a range of nitrogen levels, and produced using University of California patented technology, was evaluated for use in rice fields. Controlled replicated studies, area-wide sampling, and grower-generated information produced linear LCC calibration functions that predicted leaf N with a high degree of accuracy. One hundred and sixty-nine LCC were mailed to participants free of charge. Project personnel supported the participants through organized training and demonstration events, on-farm consultations, and by telephone. Results from the grower participation indicated that a limited amount of training was needed to allow for the efficient use of the LCC as part of the on-farm fertility management program. Outreach and education was continually pursued throughout the project. Twenty meetings of various sizes addressing aspects of the LCC were held during the contractual period. Project personnel delivered over 60 personalized on-farm consultations. Over 5400 project-related contacts were logged during the project. Feedback from growers and PCA's indicated a fairly high acceptance rate of the LCC as a tool for nitrogen management.

COMPLETED PROJECTS LIST

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