Twelfth Annual

Fertilizer Research & Education Program Conference

Proceedings November 9, 2004

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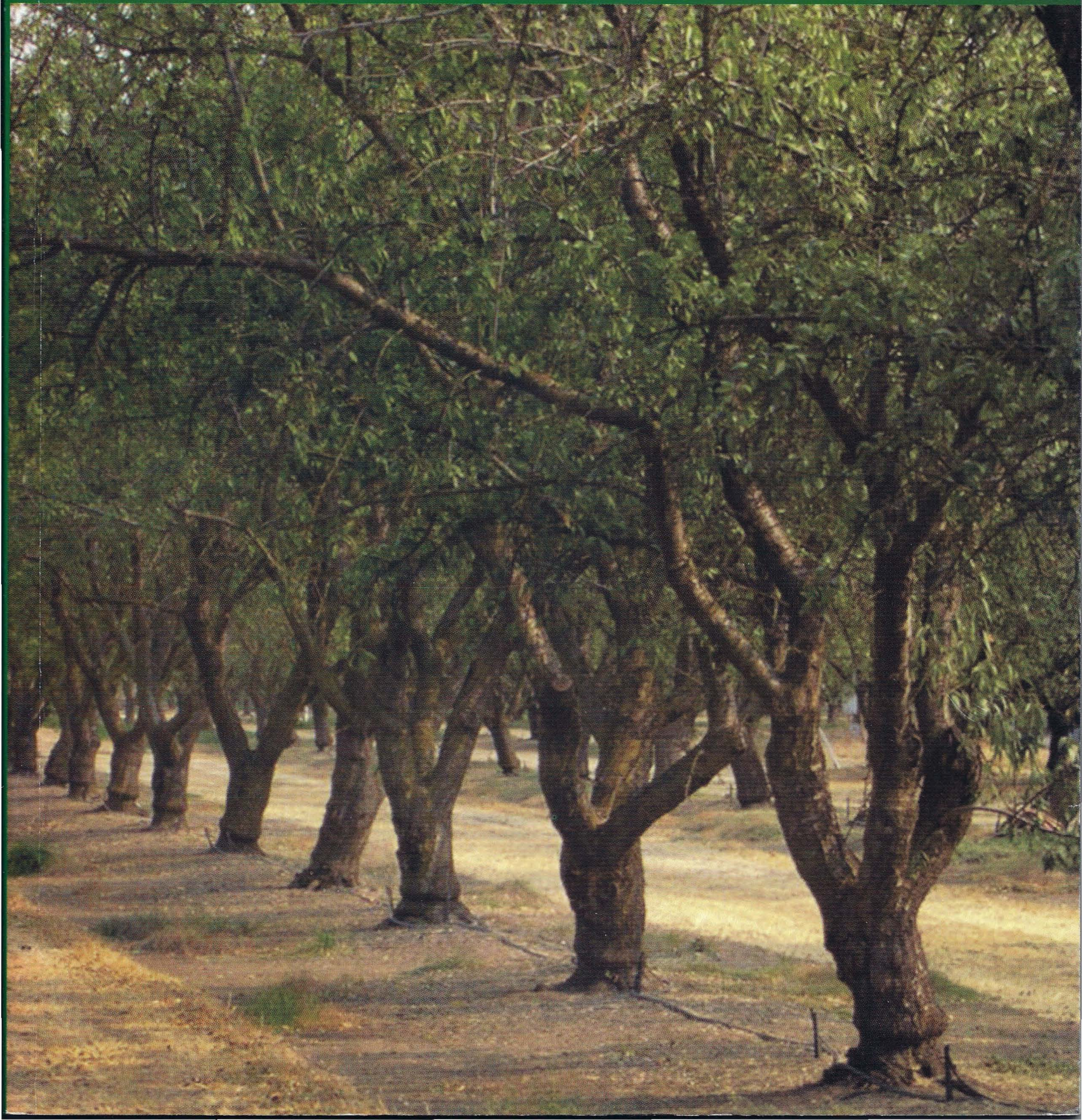
CALIFORNIA DEPARTMENT OF FOOD & AGRICULTURE



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Blaine Hanson UC Davis, Department of Land, Air, and Water Resources

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Donald J. Merhaut, UC Riverside, Department of Botany and Plant Sciences

CCA & PCA Credits

8 hours of CCA and 1 hour of PCA professional credits are available for this conference.

FERTILIZER RESEARCH & EDUCATION PROGRAM

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Since 1990, the California Department of Food and Agriculture's Fertilizer Research and Education Program (FREP) has advanced its mission to promote the environmentally safe and the agronomical sound use and handling of commercial fertilizers. To improve the use efficiency of commercial fertilizing materials to benefit crop production and quality while minimizing nitrogen losses to the environment is the primary objective of FREP.

FREP strives for excellence by supporting high quality research and education endeavors that have gone through a rigorous statewide competitive process, including independent peer review. From 1990-2003, FREP has supported well over 100 research and education projects for a total of nearly $6 million in funding. FREP activities are funded entirely from a mill tax on the sale of commercial fertilizers in the State of California, which currently generates close to $1 million per year for project funding and program support.

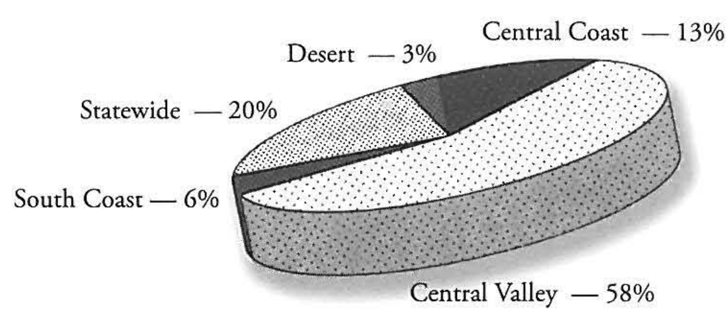
CURRENT FREP FUNDING PRIORITIES INCLUDE:

- Research on crop nutrient uptake, including the amounts, timing and partitioning of nutrients removed from the soil, and the role of balanced nutrition in improving crop production and reducing the amount of nutrients available for surface runoff or leaching from the root zone.
- Development of fertilization practices and application methodologies to improve crop production, fertilizer use efficiency or environmental sustainability.
- Irrigation management as related to fertilizer use efficiency and the reduction of nutrient losses to ground and surface water.
- Site-specific crop and fertilizer management technologies and best management practices related to precision agriculture.
- Development, testing, and demonstration of the use and benefits of practical field monitoring tools.
- Nutrient interactions with growth regulators, plant pests, and disease.
- The integrated use of commercial fertilizers with cover crops or agricultural composts to improve crop yield or quality and to minimize nutrient losses in ground or surface water.
- Development and distribution of educational products and public information.

PROJECT FUNDING ANALYSIS

This publication includes summaries and results to date, of most of the projects that are currently receiving funding from FREP. Section III lists completed projects. See Section IV of these proceedings for a list of articles published in peer-reviewed journals. Figures 1-3 show where the cumulative program resources have been distributed in terms of geographic location, discipline and agricultural commodity for FREP funded projects. Figure 1 shows that 58 percent of the funding to date has been conducted in, or has primary relevance to, the Central Valley. This is in line with current agricultural production for the state. The Central Coast has also received a significant portion of research funds. These have mostly been focused on fertility management of cool-season vegetables in Monterey County

Figure 1. CDFA FREP Projects by Location: 1990-2003



and points south. A substantial number of projects have had statewide relevance, while smaller portions have been directed at the desert and south coast areas.

As detailed above, FREP has numerous funding priority areas, which have remained relatively consistent over the life of the program. Because the nature of the nitrate program is complex, different research approaches are necessary. Figure 2 shows the distribution of funded projects by discipline. 41 percent of the FREP projects have been related to developing, testing and demonstrating various nutrient tissue and/or soil testing procedures. The program has favored growers using standard laboratory testing for nutrient assessment. Research efforts have also been directed at developing pre-sidedress testing for cool-season vegetables where growers can test their nutrient soil levels themselves to guide in-season nutrient applications.

Work in improving irrigation management and fertigation practices to optimize both water and nutrient delivery has also been an important focus of the program (19%). In-season water applications have a marked effect of transporting nitrogen beyond the root zone.

Studies regarding the use of new precision agriculture technologies for nutrient management, such as using GIS, GPS, remote sensing, and yield monitors have also received funding attention. Other areas under consideration include the relationship between pests and diseases with fertility management, composts and cover crops, heavy metals, and air quality issues.

Figure 3 shows that research has been conducted in roughly equal proportions among the general crop types; one third field crops, one third vegetable crops, and one third fruit, nut and vine crops. Turf and nursery related projects are also receiving FREP support.

We have also continued our efforts in the area of agricultural literacy advancement. The California Plant Health Association (CPHA) has produced and distributed videos and companion materials that guide the viewer on developing, planning and installing gardens on school sites. To receive a copy of the video, contact CPHA at (916) 446-3316.

FREP continues to support the California Certified Crop Adviser Program. Now headquartered in Sacramento, this program is raising the level of professional knowledge of crop advisers in the state through a voluntary certification program. Visit their web site at www.cacca.org to learn more about their activities and upcoming test dates.

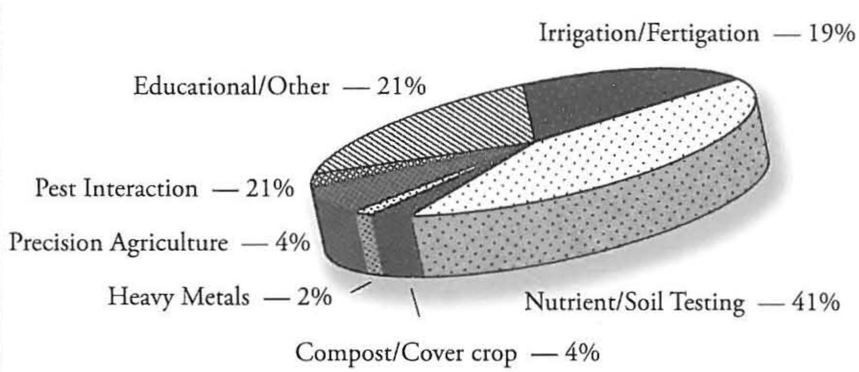
EDUCATION AND OUTREACH

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 (21%) 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 California Plant Health Association
- California Chapter of the American Society of Agronomy
- California Certified Crop Adviser Program
- California Agricultural Production Consultants Association
- Monterey County Water Resources Agency
- University of California, Sustainable Agriculture Research and Education Program
- State Water Resources Control Board, Interagency

Figure 2. CDFA FREP Projects by Discipline: 1990-2003



Coordinating Committee

- University of California Cooperative Extension Program

ACKNOWLEDGMENTS

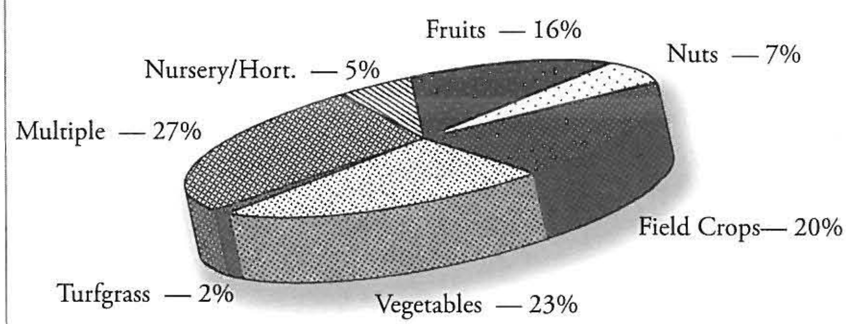
We would like to acknowledge the support of the fertilizer industry in providing funds for the program. Their foresight in creating FREP and their long-term commitment and dedication has been instrumental in the program's success.

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, Eric McGee, 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 California 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 Stephen Mauch, Director of the Division of Inspection Services and Kent Kitade, Program Supervisor of the Agricultural Commodities and Regulatory Services Branch. Katherine Gray and JoAnn Jaschke are recognized for their invaluable role in the publication of the Proceedings and the success of the FREP Conference. Additional support from the Branch's clerical staff is also appreciated.

Figure 3. CDFA FREP Projects by Commodity: 1990-2003



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. Experimentally determined leaf nutrient standards and replacement fertilization data related to yield and fruit size are generally lacking for the 'Hass' avocado in California. Lovatt (2001) tested the hypothesis: Applying N to the soil at key stages of tree phenology will improve yield parameters. A four-year study (Lovatt, 2001) 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 four-year average yield and the four-year cumulative yield, and increased by 70% yield of commercially valuable large size fruit. In addition, the April application significantly reduced the alternate bearing index for the four years of the study.

In our similar, recently completed CDFA/FREP-funded project on optimal timing of N fertilization, treatments producing the three numerically, but not statistically, greater cumulative yields for 2001 plus 2002, were the soil application of 3x N in April > the control > application of 2x N in November. In this study, each of the optimal times for applying N was incorporated into the control as a single dose of N (1x N, 25 lbs. N/acre). The optimal times were: 1) April – anthesis, fruit set and initiation of the spring vegetative flush; 2) July – rapid increase in fruit size; 3) August – transition from vegetative to reproductive development, i.e., inflorescence initiation; and 4) November – end of the fall vegetative flush and beginning of flower initiation. No treatment significantly affected potential nitrate pollution of groundwater, but the control treatment did reduce its potential by a large numerical value.

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 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.

OBJECTIVES

The objectives of the 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) disseminate the results of the research to the avocado growers of California. Treatments will continue for three years in order to obtain the year two harvests.

DESCRIPTION

To meet the first objective 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 (BMP for N, control). 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/year, half in July and half in August according to the grower's standard practice. Treatments B and C 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./acre/year, except treatment A. The N treatments had been in effect for four 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, respectively, with trees receiving a double dose of P and K (7.5 and 45 lbs./acre, respectively) with the double dose of N only (treatment A) or the remaining P and K with the remaining N (treatments b and C). Trees in BMP for NPK treatment received 3.75 lbs. P and 22.5 lbs. K in July, August, November, and April. The orchard is located in Somis, Calif. The trees are 24-year-old 'Hass' on Duke 7.

Harvest data include total kg fruit/tree. The weight of 100 randomly selected individual fruit/tree was used to calculate packout (fruit size distribution)/tree and total number of fruit/tree. 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 quality parameters were visually determined using a scale from zero (none) to four (extensive, present in all four quarters of the fruit). All data were statistically analyzed using the General Linear Model procedures of SAS. ANOVA was used to test for treatment effects on yield, fruit size, and fruit quality parameters. Means were separated using Duncan's multiple range test at $P \leq 0.05$ and at $P \leq 0.10$. In year 3 when the second set of harvest data will be obtained, treatment effects on cumulative yield and on alternate bearing index [ABI = (year 1 yield – year 2 yield) ÷ (year 1 yield + year 2 yield)] will be determined by ANOVA. Treatment effects across years will be determined by repeated measures analysis with year as the repeated measures factor. A cost/benefit analysis for each treatment will be calculated.

RESULTS AND CONCLUSIONS

Trees receiving 1x NPK (25, 3.75 and 22.5 lbs. NPK/acre, respectively) in July, and again in August, yielded significantly more large size fruit (packing carton sizes 60+48+40, i.e., fruit weighing 178-325 g, and packing carton sizes ≥ 60, i.e., fruit weighing ≥ 173) per tree ($P \leq 0.10$) and had numerically, but not significantly, more total yield per tree compared to trees receiving only 1x N in July and August, trees in the BMP for NPK treatment, and trees receiving a double dose of NPK (2x NPK) in November (Table 1). Supplying P and K with N in the other treatments had no significant effect on total yield or yield of large size fruit at the end of the first year of the experiment.

Table 1 Effect of N, P and K fertilization strategies on the yield of 'Hass' avocado harvested after one year.

	Yield (kg/tree)	
Treatment	Total	⊠60+48+40 (178-325 g)
1x NPK in July + Aug.	71.7	47.1 az
BMP N (Control) (1x N in July, Aug., Nov. + April	61.5	40.3 ab
2x N in April	51.6	32.3 ab
2x NPK in April	45.0	31.7 ab
2x N in November	41.5	31.4 ab
1x N in July + Aug.	43.4	29.6 b
BMP NPK (1x NPK in July, Aug., Nov. + April	40.3	28.5 b
2x NPK in November	41.6	26.3 b
P-value	0.1134	0.0944

Values in a vertical column followed by different letters are significantly different at the specified P level by Duncan's Multiple Range Test.

Fertilization treatments had no effect on the length of time it took for fruit to ripen after harvest, peel color at maturity, seed size, seed germination at maturity, or vascularization or discoloration of the mature fruit flesh. The trees receiving a double dose of NPK in November had significantly more internal flesh decay, especially at the stem end, than all other treatments except fruit from trees in the BMP NPK treatment ($P \leq 0.10$).

Alternate bearing is a characteristic of the 'Hass' avocado. Thus, additional years of yield data are required before any conclusions can be made.

POTASSIUM FERTILITY MANAGEMENT FOR OPTIMUM TOMATO YIELD AND FRUIT COLOR

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INTRODUCTION

Fruit color and color uniformity are major quality parameters for California's processing tomato industry. Blended color is important for paste production, and color uniformity is the key for high-quality peeled and diced products. Research conducted in the mid-1990s documented a strong link between soil K status and fruit color. Fields with low soil exchangeable K and/or high soil Mg tend to have significant fruit color problems, particularly the disorder called yellow shoulder (YS), in which the tissue around the stem scar remains yellow after ripening. Fields with these problematic soil characteristics are common in the Sacramento and northern San Joaquin Valleys. Conventional preplant or sidedress K application has been only marginally effective in improving fruit color. The cost effectiveness of conventional K fertilization is questionable, because no yield response is typically seen in soil > 130 PPM exchangeable K, and very high fertilizer rates may be required to attain substantial improvement in fruit color.

One potential method of improving crop response to K fertilization is to deliver K at frequent intervals in drip irrigation. In a 2002 pilot project in a drip-irrigated field at UC Davis, the effectiveness of continuous K injection (at 100 PPPM) throughout the season, or a series of 5 weekly K injections begun either at first bloom or full bloom, was evaluated. Despite high initial soil K (330 PPM), significant yield increase was observed, YS incidence reduced, and other fruit color parameters improved. That trial was repeated at UC Davis in 2003; fruit color was again significantly improved and YS reduced by K fertigation, but yield was unaffected. This project was undertaken to study K fertigation strategies in larger-scale commercial field trials, evaluating the effects of continuous and periodic K fertigation on processing tomato yield and fruit quality.

OBJECTIVE

Compare continuous and periodic K fertigation strategies for increasing yield and fruit quality of drip-irrigated processing tomatoes under representative commercial field conditions in the Sacramento Valley.

METHODS

Two field trials were conducted in 2004 in commercial drip-irrigated processing tomato fields, one near Winters and one near Woodland. The soil at both sites was a Capay silty clay, with intermediate K supply and high exchangeable Mg (190 and 270 PPM K, 15.7 and 14.0 meq 100g-1 Ca, 10.6 and 13.7 100g-1 Mg at Winters and Woodland, respectively). Both sites had a history of YS occurrence. At Winters, plants (cv. Heinz 2601) were transplanted 18 March; at Woodland, plants (cv. Heinz 9780) were transplanted 16 April. At each site two K fertigation treatments were compared:

1. Continuous K fertigation at 100 PPM K
2. Weekly fertigation of 40 lb/acre K

Neither grower applied any in-season K. The continuous fertigation treatment began on May 13 and May 26 at the Winters and Woodland sites, respectively. Crop growth stage was early fruit set at Woodland; at Winters the grower had continued to irrigate with sprinklers through early fruit set, so K fertigation did not begin until the early fruit were approximately three cm diameter. Continuous fertigation was discontinued after a seasonal total of 200 lb K acre-1 had been applied. This occurred on 30 June at Winters, with the crop at about 20% red fruit; K fertigation was terminated at Woodland on 28 June, at which time the first fruits were ripening. In the weekly fertigation treatment, K was applied in one irrigation per week for five consecutive weeks, for a seasonal application of 200 lb K acre-1. Weekly fertigation began on 21 May at the Winters site and June 3 at Woodland. A commercial liquid potassium chloride solution (0-0-12) was used for both fertigation treatments at both sites. For each fertigation treatment a pump operated by a pressure-sensitive switch (which turned on when the irrigation system was pressurized) pumped the KCl into the irrigation stream of individual drip lines; in this manner all plots received the same amount of water and N fertilizer applied by the grower; the only variable was the addition of KCl in selected plots. A randomized complete block experimental design with 6 replications was used at both sites, comparing the K fertigation treatments with a control treatment receiving no K fertigation. Individual plots were one row wide by either 300 ft (Woodland) or 1,300 ft long (Winters).

Leaf samples were collected just prior to the initiation of K fertigation, and twice thereafter, roughly corresponding to three growth stages: early fruit set, full bloom, and early red fruit. Samples of both whole leaves and petioles were oven-dried, ground and analyzed for K. At commercial maturity a 100 ft section of each plot was machine-harvested. Fruit samples were analyzed for soluble solids concentration (SSC) and blended color. Fifty red fruit per plot were evaluated visually for YS. On 25 red fruit per plot the skin was removed from the shoulder region and the subskin color evaluated by a Minolta colorimeter. Two measurements per fruit were taken, with L*, chroma and hue o recorded. These measurements rank the shade and intensity of the fruit color; for all these parameters lower values are more desirable.

Results

K application consistently increased leaf and petiole K concentration, with the two fertigation methods about equally effective (Table 1). Tissue K response was much greater at the Woodland site, where late-season petiole K was more than doubled by K fertigation. At full bloom, whole leaf and petiole K were marginal at both sites, based on currently recognized tissue sufficiency levels. At Winters, neither K treatment significantly increased fruit yield, SSC or brix yield (Table 2), although there was a trend toward higher SSC and brix yield (orthogonal contrast of the SSC of the combined K treatments vs. the grower treatment was significant at $p < 0.10$). Although YS incidence was low across treatments, there was a trend toward reduced YS with K fertigation (orthogonal contrast of combined K treatments vs. the grower treatment was significant at $p < 0.10$). K fertigation improved L* and hue o; the fertigation methods were equally effective in that regard. At Woodland, K fertigation by either method resulted in a significant increase in fruit yield, and brix yield. YS was common in this field, and was not reduced by K fertigation; this result was considered an anomaly, in light of the significant improvement in other color parameters at this site, and the consistent record of YS reduction found in previous K trials.

When viewed together with the UC Davis trials of 2002 and 2003, these results suggest that K fertigation through buried drip irrigation systems can be a beneficial practice, even in fields with reasonably high soil exchangeable K; not only is color quality enhanced, but significant yield improvement may be achieved. In this regard, drip fertigation appears to be more efficient than conventional K application (pre-plant or sidedressing soil application, or injection into furrow irrigation water); in a series of 12 field trials we conducted from 1994-1998 evaluating conventional K fertilization

Table 1. Effect of K fertigation on tissue K concentration, 2004 commercial field trials.

	Leaf K (%)			Petiole K (%)		
K treatment	Pre-treatment	Full bloom	Early red fruit	Pre-treatment	Full bloom	Early red fruit
Winters						
Grower	2.3	1.4 b	0.7 b	3.8	3.1 b	0.5 b
Weekly		1.6 a	0.8 a		3.9 a	0.9 a
Continuous		1.4 b	0.8 a		3.4 ab	0.8 a
Woodland						
Grower	1.8	1.7 b	1.1 b	3.4	2.5 b	1.3 b
Weekly		2.4 a	1.9 a		3.5 a	3.1 a
Continuous		2.3 a	1.9 a		3.5 a	3.4 a

a-b mean separation by Duncan's multiple range test at $p < 0.05$

techniques, no yield response was observed in any field with exchangeable K > 140 PPM.

The issue of yield improvement is critical. Currently, growers generally do not receive premiums for good fruit color characteristics, so improved yield is required to justify the cost of K fertilization. As applied in these trials, 200 lb K (one ton of liquid 0-0-12 solution) would cost approximately $100 per acre, the equivalent of roughly 2 tons of fruit per acre. Additional research is needed to evaluate optimal timing and rate of K fertigation. For this project we chose to fertigate throughout the fruit setting period, on the assumption that yield improvement would most likely come from increased fruit set rather than increased mean fruit weight. That proved to be the case in both the 2002 UC Davis trial as well as the 2004 Woodland trial. Also, prior research from the Midwest suggested that tomato fruit color disorders resulted from low tissue K during early fruit development; our success in improving fruit color with K fertigation during early fruit development supports that conclusion.

Predicting which fields may show yield improvement with K fertigation remains problematic. In addition to soil exchangeable K level, a number of factors can affect crop K uptake: soil K fixation potential, water distribution patterns, wetting and drying cycles, and rooting density (which can be affected by variety and soil conditions). We are currently conducting greenhouse and laboratory experiments to examine the issues of K fixation and diffusion in representative Central Valley soils.

Table 2. Effect of K fertigation on fruit yield, soluble solids concentration, and color quality, 2004 commercial field trials.

	Fruit yield (Mg ha-1)		Soluble solids	Brix yield	Color parameters				
K treatment	Total	Mkt.	(obrix)	(Mg ha-1)	Blended color	% YS	L*	Chroma	Hue
Winters									
Grower	92	87	4.58	4.21	25.5	4	45.2 a	20.8	55.3 a
Weekly	97	92	4.72	4.57	25.2	2	43.5 b	20.3	51.1 b
Continuous	92	90	4.78	4.44	25.0	2	43.5 b	20.5	50.9 b
	ns	ns	ns	ns	ns	ns		ns	
Woodland									
Grower	117 b	109 b	4.42	4.81 b	27.7 a	11	45.9 a	21.7 a	49.8 a
Weekly	127 a	120 a	4.50	5.42 a	26.5 b	15	44.8 b	20.2 b	47.5 ab
Continuous	132 a	125 a	4.55	5.67 a	26.0 b	16	43.8 c	20.7 b	46.3 b
			ns			ns			

ns, a-c non-significant, or mean separation by Duncan's multiple range test at $p < 0.05$

REEVALUATING TISSUE ANALYSIS AS A MANAGEMENT TOOL FOR LETTUCE AND CAULIFLOWER

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INTRODUCTION

Plant tissue analysis is an established practice in the commercial vegetable industry. Both petiole analysis for unassimilated nutrients (NO3-N, PO4-P, and K) and whole leaf analysis for total nutrient concentration are common. Tissue testing has been widely advocated as a fertilizer 'best management practice' by many universities and industry groups. However, in recent years a number of studies (some of them funded by CDFA/FREP) have cast doubt about the accuracy of commonly suggested nutrient 'sufficiency' levels, or even whether tissue testing is a useful management practice. Collectively, these studies found poor correlation between tissue nutrient concentration and nutrient availability in concurrently collected soil samples (particularly for N), a high degree of variability in tissue nutrient concentration in adequately fertilized crops from different fields, and unrealistically high nutrient 'sufficiency' standards for several crops. These findings call into question the practical value of tissue analysis and interpretation as currently performed. Commercial use of a flawed technique could result in excessive fertilization in some fields, and possibly yield loss in others.

This project proposed a comprehensive review of tissue analysis for two important cool-season vegetables (lettuce and cauliflower) to revise currently suggested sufficiency levels, quantify the effects of potentially confounding environmental factors, and reevaluate sampling and handling techniques. This will be accomplished through a large-scale survey of commercial fields in the Salinas and Santa Maria production areas.

OBJECTIVES

1. Develop broadly applicable optimum tissue macro- and micronutrient concentration ranges for lettuce and cauliflower.
2. Quantify the sources of variability in tissue sampling and handling to standardize practices and improve interpretation of results.
3. Document the correlation (or lack thereof) between soil nutrient availability and tissue nutrient level.

METHODS

A survey of 100 commercial fields will be conducted from spring 2004 through fall 2005. These fields will be approximately evenly divided between head lettuce, romaine lettuce, and cauliflower. Fields will be chosen to cover the production season from early spring through fall, with fields scattered from near the coast (low ETo environment) to higher ETo environments farther inland. Fields will be sampled at three growth stages: 1) early vegetative growth (the time of first sidedressing); 2) midseason (early heading stage for lettuce, early button formation for cauliflower); and 3) within a week of harvest. In each field and at each growth stage, one composite sample of soil, of whole leaves, and of petioles will be collected. Table 1 describes the analyses to be performed. Time of day will be noted for each field sampling.

Participating growers will provide the following information: variety, planting and harvesting dates, seasonal fertilizer rates applied, and the commercial yield of the field. Growers will also note any field in which the yield did not reflect the productivity of the crop (poor market conditions, serious disease or insect damage, etc.) so those fields can be dropped from the data set; furthermore, where the information is available to them, the growers will identify any field for which significant post-harvest product quality problems were encountered.

We will use the Diagnosis and Recommendation Integrated System (DRIS) to evaluate this data set. DRIS is a mathematical framework to compare nutrient concentration differences between high- and low-yield crops. In the DRIS approach, differences in tissue nutrient concentrations and nutrient ratios between low- and high-yield fields are used to estimate the degree to which various nutrients may limit yield, either due to deficiency or excess. For each nutrient, a DRIS-derived, growth stage-specific optimum tissue nutrient concentration range will be developed. These optimum ranges should be more widely applicable than current tissue concentration guidelines, which in most cases were empirically derived from just a few fertilizer trials. They will also be the first systematically developed micronutrient guidelines available for these crops in California; given the similarities among vegetable crops in micronutrient sufficiency standards developed elsewhere, these optimum ranges should be applicable to vegetable crops other than lettuce and cauliflower. Furthermore, information on potentially toxic levels of micronutrients, and Na and chloride, will be developed; current toxicity standards are based mainly on sand culture studies that may not be representative of field conditions.

The comprehensive information gathered from survey fields will also be useful in determining the predictive power of soil tests to predict crop P, K, and micronutrient sufficiency. The correlation between tissue N status and concurrently measured soil N availability will show conclusively whether tissue analysis can provide any guidance on future N fertilizer requirement, or on seasonal N fertilization efficiency. Additional sampling will focus on quantifying the confounding effects of variety, environment, and sample collection and handling techniques on tissue nutrient concentration.

RESULTS

Soil and tissue sampling has been initiated in approximately 50 fields to date, spanning the entire production year; analysis of those samples is underway. The remaining 50 fields will be sampled in 2005. Until the complete data set is gathered the DRIS-derived optimum tissue nutrient concentration ranges cannot be developed.

Table 1. Soil and plant sampling protocol.

Sample type	Growth stage	Analyses
soil	early	texture; pH; organic matter; Olsen P; mineral N; exchangeable K, Ca, Mg, Na; DTPA extractable Zn, Mn, Fe, Cu; saturated paste B
	mid	mineral N
	preharvest	mineral N
whole leaves	all	total N, P, K, Ca, Mg, S, Zn, Mn, Mo, Cu, Fe, B, Na, Cl
midribs	all	NO-3N, PO4-P, K

EVALUATION OF POLYACRYLAMIDE (PAM) FOR REDUCING SEDIMENT AND NUTRIENT CONCENTRATION IN TAILWATER FROM CENTRAL COAST VEGETABLE FIELDS

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INTRODUCTION

The Central Coast Regional Water Quality Control Board (RWQCB) identified tailwater from furrow and sprinkler systems as a source of nutrients and sediments into the Salinas and Pajaro River watersheds. Treatment of soils with polyacrylamide (PAM), a large polymer chain molecule (10-15 Mg/mole), may reduce sediments and phosphorus lost from furrow and sprinkler irrigated vegetable fields by maintaining infiltration and stabilizing soil aggregates. Despite documented benefits of PAM for erosion control in other areas of the country, it is not widely used in the central coast region. This project evaluates the effects of PAM on sediment and nutrient concentration in tailwater from vegetable fields across a range of soil types found in the Salinas and Pajaro Valleys. The methodology utilizes column and field studies to quantify the effect of PAM on infiltration rate, runoff, and sediment and nutrient (ortho and total P, total N, and NO3) loss from sprinkler and furrow irrigation systems. Because PAM has not been shown to be beneficial on all soil types and under all water qualities, the column studies screen a larger range of soil types and water compositions than can be accomplished with field studies. Field studies evaluated the effect of PAM on infiltration rate using a recirculating infiltrometer. In addition, trials were conducted in cool season vegetable fields to measure the effect of PAM on runoff, sediment and nutrient loss, as well as the effect on yield and quality.

OBJECTIVES

1. Evaluate effects of PAM on infiltration rates of a range of soil types found in the Salinas and Pajaro Valleys under varying water qualities.
2. Quantify the effect of PAM on sediment and nutrient concentration in irrigation runoff from commercial vegetable fields.

SUMMARY OF RESULTS (2003-2004)

Column Studies

Column studies were conducted to evaluate the effects of polyacrylamide (Amber 1200D1 and Soilfoc 100D2) on infiltration rate of ten soils collected from agricultural fields in Monterey, San Benito, and Santa Cruz counties (Table 1). Soil samples were sieved to pass through a 2 mm screen and packed into 5-cm high acrylic columns with a diameter of 7 cm to a bulk density ranging from 1.1 to 1.5 g cc-1. A constant head burette was used to maintain a 2.5-cm head of water above the surface of the soil. Pressure transducers and dataloggers were used to monitor the rate that water was depleted from the burettes.

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formerly Superfloc A-836, Amber Chem. Inc

2 Soilfloc 100D, Hydrosorb, Inc

Table 1. Soil types selected for PAM infiltration trials.

#	Soil Name/Taxon.	Location	Watershed
1	Placentia sandy loam	Gonzales	Salinas Valley
2	Clear Lake clay	South Salinas	Salinas Valley
3	Mocho silt loam	San Ardo	Salinas Valley
4	Salinas clay loam	Aromas	Pajaro Valley
5	Chualar loam	Chualar	Salinas Valley
6	Oceano loamy sand	Elkhorn Slough	Elkhorn
7	Fluvaquentic Haploxerolls	Pajaro	Pajaro Valley
8	Cropley silty clay	Watsonville	Pajaro Valley
9	Sorrento silty clay loam	Hollister	Pajaro Valley
10	Sorrento silt loam	San Juan Bautista	Pajaro Valley

Table 2. The effect of polyacrylamide concentration on the infiltration rate of soils from Monterey, San Benito, and Santa Cruz Counties.

Treatment[1]	n	Placentia sandy loam	Clear Lake clay	Mocho silt loam	Salinas clay loam	Chualar loam	Oceano loamy sand	FHAX complex [2]	Cropley silty clay	Sorrento silty clay loam	Sorrento silt loam
		final infiltration rate (mm/hr)									
Control	6	9.03	1.47	46.46	3.91	39.94	129.05	17.09	2.29	2.94	5.32
Amber 1200 (10 ppm)	6	8.65	1.26	33.96	3.34	27.53	39.35	11.90	2.03	2.24	5.10
Amber 1200 (20 ppm)	6	6.43	1.24	23.83	2.95	18.88	20.64	6.77	1.54	1.78	3.09
SoilFloc (10 ppm)	6	6.64	0.85	21.40	2.57	21.22	23.24	7.49	1.45	1.75	2.47
SoilFloc (20 ppm)	6	3.71	0.52	12.25	0.96	10.16	14.33	3.92	0.64	0.85	1.01
Average		6.90	1.07	27.58	2.75	23.54	45.32	9.43	0.18	1.91	3.40
$LSD_{0.05}$		1.95	0.21	1.85	0.50	3.46	21.81	1.40	1.59	0.13	0.72
P > F[3]		< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001
CV (%)		10.9	16.4	5.5	14.9	12.0	39.3	12.2	9.2	5.7	17.4

[1] water quality: EC = 1 dS/m, SAR = 2, pH = 6.2

[2] Fluvaquentic Haploxerolls-Aquic Xerofluvents complex (loam).

[3] probability of obtaining (by chance alone) an F statistic greater than the computed F value.

EFFECT OF PAM ON INFILTRATION

PAM applied continuously in the infiltration water decreased the final infiltration rate of all soils tested (Table 2), though the surface of the soil columns remained visibly more aggregated with PAM then without PAM. The greatest decrease in infiltration occurred in the Oceano loamy sand. For all soils, SoilFloc decreased the final infiltration rate more than Amber 1200 and the high concentration of PAM (20 ppm) decreased infiltration more than the low concentration (10 ppm).

INTERACTION BETWEEN WATER QUALITY AND PAM ON INFILTRATION

The effect of PAM on infiltration was dependent on the EC and the SAR of the applied water. In four soil types tested, increasing the EC of water treated with a 10-ppm concentration of Amber 1200 PAM, increased infiltration (Figure 1). Increasing the SAR of water treated with a 10-ppm concentration of PAM, decreased infiltration (Table 3). This result suggests that the ratio of sodium to calcium and magnesium in the water affects the chemical and/or physical properties of polyacrylamide.

EFFECT OF PAM ON WATER VISCOSITY

Relative viscosity measurements, conducted using columns packed with a standard sand media, demonstrated that the viscosity of the applied water increased as the concentration of PAM increased (Table 4). Also, the Soilfloc PAM

Figure 1. Effect of electrical conductivity of water treated with PAM on final infiltration rate of central coast soils

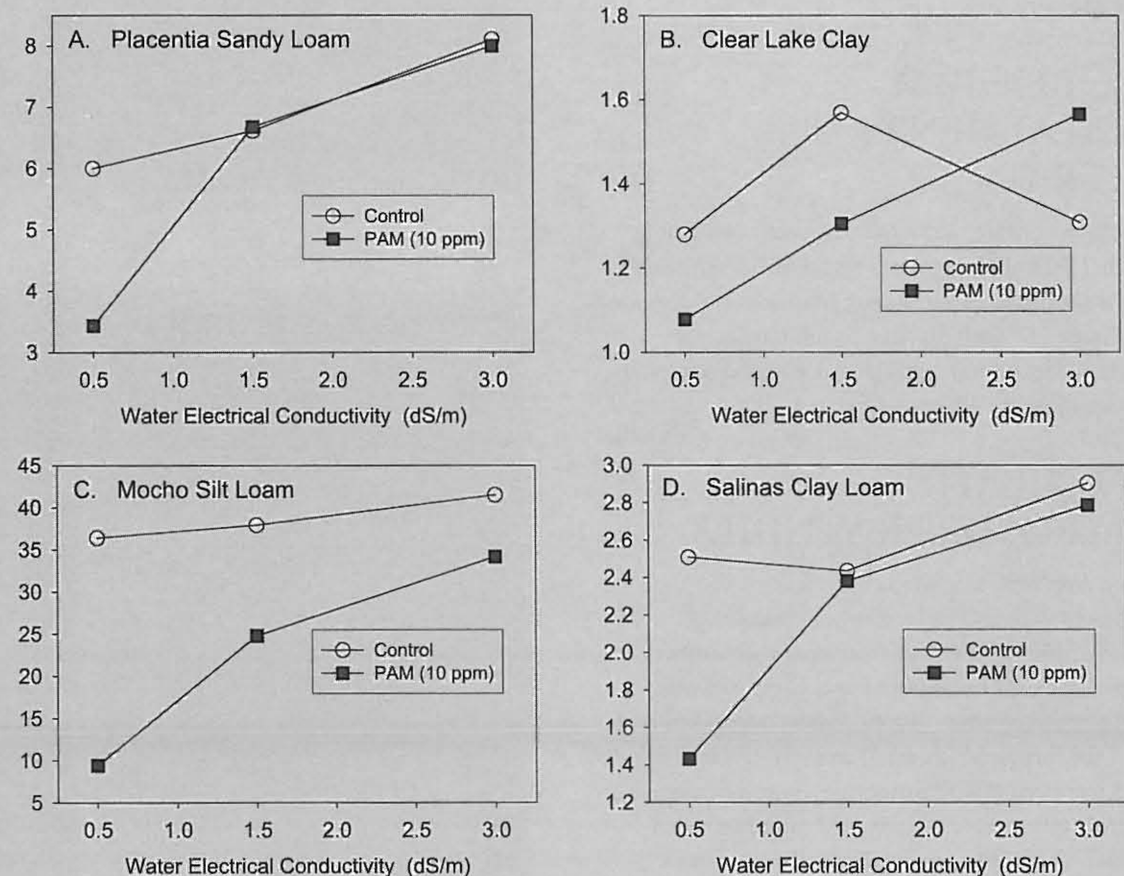


Table 3. Effect of SAR (sodium adsorption ratio) on infiltration rate in soils from Monterey Counties using water treated with polyacrylamide.

PAM	SAR[1]	n	Placentia sandy loam	Clear Lake clay	Mocho silt loam
			---- Infiltration Rate (mm/hr) ----		
control (0 ppm)	0.9	6	6.98	1.56	40.20
control (0 ppm)	4.7	6	6.37	1.84	40.44
control (0 ppm)	9	6	6.73	1.53	37.14
Amber 1200D (10 ppm)	0.9	6	4.71	1.32	22.59
Amber 1200D (10 ppm)	4.7	6	1.79	1.33	7.87
Amber 1200D (10 ppm)	9	6	1.57	1.10	4.58
Soilfloc 100D (10 ppm)	0.9	6	3.77	0.64	12.49
Soilfloc 100D (10 ppm)	9	6	1.30	0.58	6.15
$LSD_{0.05}$			0.66	0.33	2.17
$p > F$[2]			<.0001	<.0001	<.0001
CV (%)[3]			13.3	22.0	8.42

1.water quality: EC = 0.6 dS/m

2. probability of obtaining (by chance alone) an F statistic greater than the computed F value

3. coefficient of variance

had a higher viscosity than the Amber PAM at similar concentrations. The effect of PAM on viscosity may offset the ability of PAM to increase infiltration though improved aggregate structure.

Table 4. Relative viscosity of Amber and Soilfloc polyacrylamide.

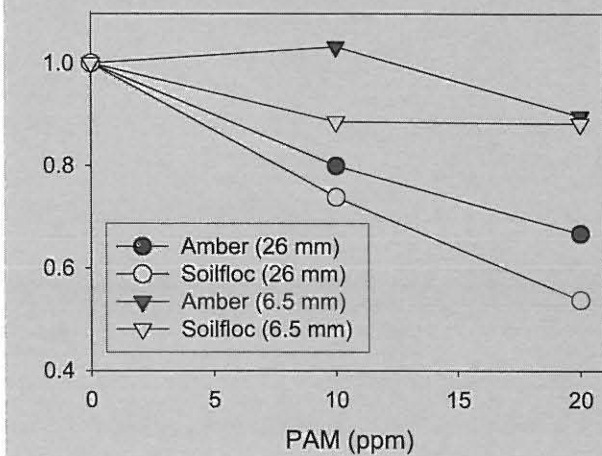
Concentration	n	Relative Viscosity[1] Amber 1200D	Soilfloc 100D
10 ppm	3	2.65	3.09
20 ppm	3	4.44	5.95

1. relative to deionized water

EFFECT OF PAM PRETREATMENT ON INFILTRATION

Pre-treating the surface of the soil with water containing PAM, rather than applying water with PAM continuously, maximized the final infiltration rate relative to the untreated control (Figure 2). The reduction in infiltration was minimized as the pretreatment volume was decreased and the concentration of PAM was decreased.

Figure 2. Effect of PAM pretreatment on infiltration rate in a Salinas-Clay relative to the control (0 ppm PAM).



RECIRCULATING INFILTROMETER STUDIES

Infiltration rates were measured in the furrows of six commercial vegetable fields using a recirculating infiltrometer. Infiltration of water treated with Amber 1200D at a 10-ppm concentration was compared with untreated water at all sites. Water samples were taken at the tail end of the furrow for chemical analyses. Table 5 shows that PAM increased infiltration at one site and decreased infiltration at two sites. Turbidity, and total suspended solids, which are mainly composed of sediments, were significantly reduced in the PAM treated water. Overall, the PAM treatment reduced suspended solids by 85% compared to the untreated control. Additionally, total P, soluble P,

Table 5. Effect of polyacrylamide (PAM) on infiltration and quality of tailwater runoff measured in six commercial vegetable fields.

Treatment	pH	EC	SAR	TKN	NO_3-N	P (Total)	P (Soluble)	Total Soluble Solids	Total Suspended	Turbidity	Final Infiltration Rate
		dS/m		mg/L						NTU	mm/hr
				Mocho silt loam (site 1							
PAM[1]	7.75	0.73	1.0	2.38	1.30	0.85	0.35	478	244	55	7.50
Untreated Control	7.60	0.74	1.0	6.38	1.95	5.30	0.78	503	2024	1977	3.54
				Metz complex (site 2)							
PAM	7.95	1.70	1.5	1.43	23.13	0.35	0.09	1238	156	18	7.91
Untreated Control	7.98	1.68	1.8	2.25	23.33	1.33	0.16	1220	669	473	7.29
				Rincon clay loam (site 3)							
PAM	8.00	1.31	2.0	1.75	22.38	0.68	0.31	840	412	51	2.58
Untreated Control	7.95	1.31	2.0	3.08	22.58	1.88	0.44	823	1715	1013	4.04
				Salinas clay loam (site 4)							
PAM	7.53	0.59	1.0	1.38	0.71	0.80	0.36	343	240	59	5.25
Untreated Control	7.50	0.60	1.0	6.95	1.23	5.40	0.64	213	2759	2437	5.00
				Chualar loam (site 5)							
PAM	7.80	0.67	2.0	2.20	2.03	0.58	0.28	400	306	129	5.77
Untreated Control	7.75	0.68	2.8	8.45	2.09	3.23	0.46	463	2580	2992	4.22
				Chualar sandy loam (site 6)							
PAM	7.95	0.51	3.0	0.43	1.52	0.13	0.09	333	39	24	159.03
Untreated Control	7.98	0.52	3.0	0.73	1.46	0.30	0.12	343	175	183	197.32

1. 10 ppm concentration of Amber 1200D

Table 6. Effect of polyacrylamide (PAM) on the quality of tailwater runoff collected from a sprinkler irrigated romaine lettuce field (Chualar Loam).

Treatments	PAM Application	Applied Water	TKN	NO_3-N	P (soluble)	P (total)	Total Disolved Solids	Total Suspended Solids	Turbidity	Runoff		Sediment
	lb ai/acre	inches	mg/L						NTU	gal/acre	(%)	lb/acre
1st Irrigation 7/9/04												
PAM	0.73	0.78	2.83	6.03	0.41	0.55	905	72.0	66	1389.0	6.6	0.8
Untreated	0.00	0.86	5.20	3.56	0.61	2.83	885	900.3	2647	1138.1	4.9	8.5
F-test		NS	0.005	0.001	0.033	0.001	NS	0.053	0.0001	NS		NS
2nd Irrigation 7/14/04												
PAM	0.58	0.81	2.35	1.97	0.22	0.38	1073	32.25	39	1931.9	8.8	0.5
Untreated	0.00	0.84	5.13	1.51	0.39	2.05	905	785.5	1691	1947.4	8.5	12.8
F-test		NS	0.028	NS	NS	0.0043	NS	0.003	0.0028	NS		0.001
3rd Irrigation 7/19/04												
PAM	0.54	0.82	1.73	10.5	0.33	0.33	1102.5	20.3	16	976.2	4.4	0.2
Untreated	0.00	0.71	4.00	10.1	0.47	2.23	800	1205.0	3031	1506.8	7.9	15.1
F-test		NS	0.024	0.030	0.037	0.003	NS	0.003	0.0017	0.019		0.002
Average/Total												
PAM	1.85	2.41	2.30	6.2	0.32	0.42	1027	41.5	40	1432.4	6.6	1.5
Untreated	0.00	2.41	4.78	5.1	0.49	2.37	863	963.6	2456	1530.8	7.0	36.4
F-test		NS	0.003	NS	NS	0.0002	NS	0.004	0.0003	NS		0.001

Figure 3. Tailwater runoff from sprinkler irrigated lettuce with (left) and without (right) injection of polyacrylamide at a 5 ppm concentration.

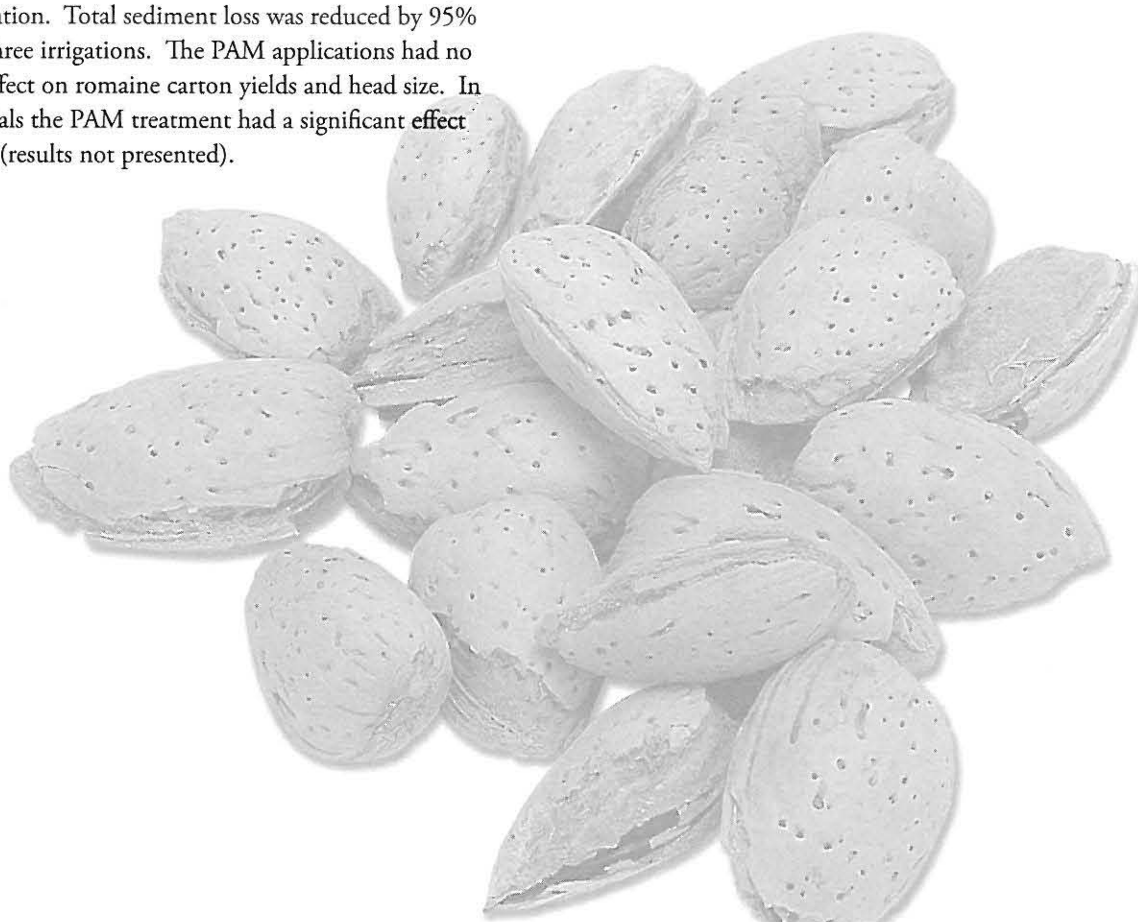
and total nitrogen were reduced in the PAM treated water. However, PAM had no significant effect on nitrate or salt levels in the water.

FIELD TRIALS

PAM was applied in replicated trials, conducted in commercial fields planted with romaine lettuce, iceberg head lettuce or broccoli. Polyacrylamide (Amber 1200D) was injected into the irrigation water at a 5-ppm concentration for sprinkler irrigated trials and at a 10-ppm concentration for the furrow irrigated trial. Runoff measurements and water samples were collected during two to three irrigations per trial. Results of one of the completed trials are presented in Table 6. Water samples from other trials are currently being analyzed. PAM applied through the sprinkler system was able to significantly reduce the turbidity and the suspended solids in the runoff (Figure 3). Similar to the results obtained with the recirculation infiltrometer trials, PAM reduced total P and N in the runoff, but had no significant effect on soluble P and NO3-N. PAM had no significant effect on the amount of runoff during the first two irrigations, but did significantly reduce runoff during the 3rd irrigation. Total sediment loss was reduced by 95% during the three irrigations. The PAM applications had no significant effect on romaine carton yields and head size. In two other trials the PAM treatment had a significant effect on head size (results not presented).

CONCLUSIONS

The results of the column studies showed that polyacrylamide can potentially reduce infiltration rates of Central Coast soils when applied continuously at concentrations of 10-ppm. This reduction in infiltration may be due to the ability of PAM to increase the relative viscosity of water, and the interaction of PAM with the salts contained in the irrigation water. However, field infiltrometer experiments demonstrated that initially applying PAM and then using untreated water, generally maintains or improves infiltration and greatly improves the quality of the tailwater by flocculating out suspended sediments and reducing the load of total P and N nutrients transported in the tailwater. Also, injecting PAM into sprinkler water at a 5-ppm concentration was found to improve the quality of tailwater runoff without significantly increasing runoff. The addition of PAM to the irrigation water had no detrimental effects on lettuce yield and quality. The results of this project demonstrated that polyacrylamide may be an important tool for improving farm water quality on the Central Coast.



RESIDUAL SOIL NITROGEN AND N MANAGEMENT FOR ACALA COTTON

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INTRODUCTION

The drive for greater efficiency in fertilization practices in cotton requires improved evaluations of: a) soil fertility level on a field-by-field basis; b) a means to evaluate and deal with field-by-field variation in crop growth and nutrient status conditions (some measure of plant N status, plant vigor and fruit retention that is adjusted for stage of growth); and c) an understanding of the required timing for split fertilizer applications in meeting critical plant needs. In this type of system, adjustments in nutrient applications are made depending on levels of residual soil N, irrigation water N, and crop condition, which has been referred to as a "feedback" approach to fertilizer N management. This is in contrast to a "scheduled" approach where fertilizer N is applied more on a routine basis determined by stage of growth or month. The "feedback" approach" should have improved potential to reduce losses, improve nutrient use efficiencies, and provide more specific guidelines for use in making N management decisions.

OBJECTIVES

A field-based research and demonstration project was initiated to provide further evaluation of the concepts developed in recent University of CA nitrogen management studies in cotton and to begin evaluations of the potential to integrate laboratory tests for better estimates of mineralizable N. Goals are to demonstrate an integrated N management system based upon soil and plant N status measurements, but incorporating: 1) estimates of crop growth and yield potential; 2) lower initial N applications to reduce potential for leaching losses; and 3) use of split soil N applications and/or foliar applications to supplement supplies when plant sampling indicates high enough yield potential to warrant additional N supply.

DESCRIPTION

Fields were planted with Acala cotton (Gossypium hirsutum L.) varieties at four locations each year for the studies, but only three locations were followed to completion in 2002. Sites represent a range of initial soil residual nitrogen levels and soil types, and were located in the central and southern San Joaquin Valley. The following N application treatments were utilized:

1. Treatment 1: one-time (early vegetative growth) baseline application of fertilizer N (between 100 and 125 lbs applied N/acre depending upon application equipment and levels of residual N in upper two feet)
2. Treatment 2: one-time treatment receiving a full 150-180 lb N/acre application, minus an amount adjusted based upon residual soil nitrate-N in upper two feet of the soil profile;
3. Treatment 3: initial 100 to 125 lbs N/acre application at the timing of first within-season irrigation of the growing season (adjusted to account for residual soil nitrate-N in the upper two feet), plus subsequent l N applications (by water run or side-dress) assessed based on plant mapping of fruit load, and in consideration of early and mid-bloom petiole nitrate-nitrogen. If data called for supplemental N application, it was made between 1 ½

and 3 weeks after first bloom.

4. Treatment 4: as in Treatment 3, but with the Treatment 2 initial application rate (where cooperators allowed).

Sites had a treatment added in which no supplemental N was added (Treatment 5), in order to allow for yield and petiole nitrate-N analyses where only residual soil N supplies could be utilized, although in many cases zero N plot sizes were smaller, with fewer reps (noted in yield table). Sites selected differ in soil texture and in estimated effective rooting depth, but were selected to represent the difficult management range of "low" to "intermediate" in soil residual N in the upper two feet versus four feet of profile, where the ability of soil nitrate tests to accurately predict plant-available N carries more risk to potential yields. Pre-season soil samples to a depth of four feet were collected for analysis of residual soil NO3--N levels, PO4-P, exchangeable-K, and Zn.

Samples were collected at all sites within two weeks after planting to a depth of four feet for initial NO3-N and mineralizable N tests to allow for the comparison of residual N made in the upper four feet, upper four feet and upper four feet of the profile. The reason for this is that two-foot sampling depths are commonplace among advisors and agronomists, while recommendations for pre-season or early-season soil sampling to three or four feet depths would require some convincing evidence that it significantly improves estimates. In addition, in both the spring (early post-plant) and again near harvest in the fall, soil samples were collected to a depth of eight feet in one-foot increments and analyzed for soil NO3-N, Cl-, exchangeable K and PO4-P. The soil NO3-N and Cl- data will be used in combination with irrigation water NO3-N and Cl to estimate leaching loss potential at any sites where irrigation water Cl- levels are high enough to allow these calculations. Irrigation water samples were taken and analyzed for NO3-N, and the timing and amounts of applied water estimated to allow calculation of irrigation water contributions to applied N.

SOIL MINERALIZABLE NITROGEN EVALUATIONS

One of the primary problems with soil N tests is the general uncertainty many agronomists, soil scientists and consultants express in assessing the accuracy and adequacy of soil nitrate tests to explain the likely dynamics of plant-available N. Since NO3-N is just part of the soil N pool, and ammonium-N tests are highly variable and of limited value in many of our western soils, there remains interest in other tests that might be better-correlated with plant-available N.

One primary mineralizable N analysis method was evaluated as part of this experiment, strictly for comparison with the amounts of residual nitrate-N determined with our current sampling methods. Gianello and Bremner (1982) developed a "hot KCl" method to assess potentially available organic N in the soil. The procedure involves air-dried soil samples that are heated with 2N KCl to 100C for a 4-hour period, followed by cooling and determination of ammonium-N. An alternative method developed by Franzluebbers et al (1996) was evaluated on a more limited number of samples for comparison, with potential N mineralization estimates made using a 24-hour incubation of soil samples placed in airtight tubes and a 24-hour incubation done at 25 C. After this period, the amount of CO2 evolved is determined by titration.

RESULTS AND CONCLUSIONS

Field Nitrogen Management Studies – 2001, 2002, 2003

In the field test sites, residual soil nitrate-N analyses done on soil samples collected within three to six weeks following planting yielded (Table 1) average quantities in the surface two, third and fourth foot depths of the soil profile (0-60 cm, 60-90 cm, 90-120 cm, respectively). Based upon our prior five-year nitrogen fertilizer rate study (1996-2000), recommendations for nitrogen fertilization for this study (based upon spring soil nitrate data in the upper two feet of the soil profile) would be:

- if less than 55 lbs N as NO3-N/acre, then fertilizer application recommended at 125-175 lbs N/acre unless low yields predicted due to late planting or field history
- if between 55 and 100 lbs N as NO3-N/acre, then reduce fertilizer application recommendation to 100 to 125 lbs N/acre, use plant mapping and petiole nitrate analyses to assess yield, plant N status
- if over 100 lbs N as NO3-N/acre in the upper two feet of soil profile, lower fertilizer recommendation to 75 lbs N/acre or less, use plant mapping and petiole nitrate analyses

The data shown in Table 1 indicates the dilemma in use of soil test data for the upper two feet of soil profile. For the four sites shown in 2001 and the three sites in 2003, the percent of total soil nitrate-N in the upper four feet accounted for if sampling was restricted to the top two feet ranged from about 40 to slightly over 60 percent. For the 2002 sampling year, the percent in the upper four feet accounted for if sampling was restricted to the top two feet ranged from about 45 percent to over 70 percent, depending upon location.

Table 1. Site average soil nitrate-N in upper 60, 90 or 120 inches of soil at planting as function of location.

Depth of soil sampled (inches)	2001 Field Study Sites Average Soil Nitrate-N (lbs N/acre as NO3-N on soil dry wt basis)							
	Site A (Kern)		Site B (Shafter)		Site C (Fresno)		Site D (WSREC)	
	Avg. 1	S.E.	Avg.	S.E.	Avg.	S.E.	Avg.	S.E.
0-60	69	7	41	3	113	17	58	9
60-90	15	4	20	2	15	5	14	3
90-120	32 10 25 4 48 11 25 6							
	2002 Field Study Sites							
	Site A (Fresno)		Site B (Shafter)		Site C (WSREC)			
0-60	44	10	92	16	60	12		
60-90	16	3	24	2	17	4		
90-120	19 4 8 3 9 3							
	2003 Field Study Sites							
	Site A (Kern)		Site B (Shafter)		Site C (WSREC)		Site D (Tulare)	
0-60	41	8	58	10	45	6	69	13
60-90	30	10	19	4	31	7	27	5
90-120	12	3	12	2	26	6	36	7

1 Avg. = average; S.E. = standard error across samples

If a crop (such as cotton) is expected to have roots active in water and nutrient uptake below two feet, there is an advantage in collecting deeper soil samples in order to attempt to account for deeper, potentially available N. An additional advantage to early post-plant information on deeper (to three or four feet) soil nitrate-N would be that it provides some incentive to avoid application of large amounts of early-season irrigation that could leach soil nutrients. Based upon these results, it would significantly improve nutrient management information to collect soil samples to a depth of three or four feet, instead of only two feet. It is important to note, however, that since soil nitrate losses can occur and since there are other potential sources of N represented in the soil N pool, identification of potential soil nitrate-N reserves will still not fully represent plant-available N for making fertilization decisions. This is where

Table 2. Petiole nitrate-N as a function of growth stage in 2003 sites for treatment 3 (late supplemental N)

Date of petiole sampling (by growth stage)	***2003 Field Study Sites*** Petiole Nitrate-N (mg/kg x1000 as NO3-N on dry wt basis) * data from treatment # 3 only (lower initial N / supplemental N treatment)							
	Site A (Kern)		Site B (Shafter)		Site C (WSREC)		Site D (Tulare)	
	Mg/kg x 1000		Mg/kg x 1000		Mg/kg x 1000		Mg/kg x 1000	
	Low [1]	High	Low	Low	Low	High	Low	High
Early bloom (1st bloom+/-5 days)	13.1	16.5	12.7	15.0	13.4	13.9	12.0	15.6.
15-20 days after first bloom	10.2	11.6	9.3	12.1	9.6	10.8	9.1	10.4
28 to 35 days after first bloom	6.6	8.9	6.8	10.4	8.7	9.4	5.8	7.3

1 Data shows range of values for averages within reps of treatment; low = low average; high = high rep

estimates of crop yield potential (from plant mapping) and plant nutrient status (from petiole nitrate analyses) can play an important role. Based on prior plant N uptake studies, assumptions in this study were that each additional bale of lint yield per acre would require an additional supply of 55 lbs N/acre from some source such as supplemental fertilizer. Therefore, if total N supply in the upper 4 feet of soil equaled about 165 lbs, this would be assumed adequate for a 3 bale/acre yield. If plant map data suggested a 4 bale/acre yield was possible, an additional 55 pounds of N/acre would need to be supplied from some source. Plant mapping data was used to help interpret the petiole data for use in recommendations for supplemental nitrogen. Yield potential estimates at the different sites based upon within-season plant mapping data indicated relative yield potentials and timing of the crop. The petiole data and yield potential estimates were used to assess the need for a supplemental fertilizer application, resulting in a late side-dress fertilizer applications in Treatment 3 and Treatment 4 at multiple sites during each year of the experiment.

Yield responses to the applied N treatments indicated significantly higher yields with all N application treatments when compared with no supplemental N in three of the four locations in 2001, and all locations in 2002 and 2003. This yield response data comparing the no N to other treatments indicates that at the initial residual N levels shown in Table 1 in the upper two, three, or four feet, additional N fertilizer was needed to achieve moderately high yields (Table 3). At the Fresno County site in 2001, high initial residual nitrate-N across all treatments resulted in no difference in yield between no N and moderate applied N treatments (Treatments 1, and 3), but resulted in a yield decrease due to excessive vegetative growth in the high N application treatment (Treatment 2). Similarly, at the West Side REC site in 2003, split fertilizer applications (Treatment 3 and Treatment 4) resulted in more vegetative growth and lower net yields than in treatments with one-time applications (Treatment 1 and Treatment 2). At three of four sites in 2001, two of three sites in 2002, and two of four sites in 2003, use of the feedback management approach (Treatment 3) resulted in apparent yield improvements over the high N treatment, although it can be noted differences were significant only at some sites as shown in Table 3. Use of the feedback approach (Treatment 3) significantly improved yields over the low N application treatment (Treatment 1) at five sites out of the 11 sites: year combinations in these trials, generally at sites with high yields (over 1600 lbs lint/acre).

Impacts of specific treatments on soil nitrate-N accumulation patterns at depths from four to eight feet deep in the soil profile have been analyzed across years and sites. These analyses are too complicated to be reproduced in detail in this report. At the more permeable soil sites in this study, with higher soil infiltration rates early and mid-season, patterns consistently show that split applications (such as those with Treatments 3 and 4) reduced soil nitrate-N levels in the fall measurements made at the four to eight foot depth when compared with the one time higher application rates used in Treatment 2 (data not shown). Split N applications were somewhat more inconsistent in producing any crop growth benefits over one-time applications, at least growth that resulted in increased fruit retention or growth and eventual lint and seed yield. Since yields were not generally reduced with timely split nitrogen

Table 3. Lint yield as a function of site and treatment in 2001, 2002 and 2003 sites.

	2001 Field Study Sites							
Site / location	Lint Yield (lbs lint per acre)							
	Trt 1	Trt 2	Trt 3	Trt 4	No N			
Kern Co.	1517a	1542a	1615a	1608 a	984 b			
Shafter	1291a	1292a	1227ab	1210 b	678 c*			
Fresno Co.	1435 b	1689 a	1734a	1504 b	1665 a			
West Side REC	1807b 1815ab 1896a 1767 c 1331 c							
	2002 Field Study Sites							
Shafter	1740 a	1791 a	1784 a	1814 a	1287 b			
Fresno Co.	1293 c	1912ab	2045 a	1877 b	880 d			
West Side REC	1686 b 2005 a 2001 a 1995 a 976 c*							
	2003 Field Study Sites							
Kern	1154 c	1359 b	1487 a	1415 ab	1088 c			
Shafter	1521 bc	1615 a	1563 ab	1577 ab	1444 c			
West Side REC	1871 a	1836 ab	1770 c	1787 bc	1791 bc			
Tulare	1256 b	1387 a	1408 a	1302 ab	1153 c*			

* only 2 replications; ** yields followed by a different letter were significantly different at 5% level by LSD method.

applications in this trial, however, indications of potential to reduce downward movement of soil nitrate-N through use of split applications may provide enough incentive to promote split applications as a better practice to limit nitrate N losses below the active root zone.

MINERALIZABLE NITROGEN ANALYSES

Analysis of results completed to date show positive correlations and fairly good agreement ($r2$ = 0.79- 2001; 0.68 – 2002) between mineralizable N estimates using the hot KCl and incubation methods. In analyses of 2001 and

2002 samples for the upper two feet of soil, mineralizable N estimates average 137 percent of soil nitrate-N values in post-planting analyses, but only 112 percent of soil nitrate-N values in samples collected after harvest but before fall tillage operations. It must be acknowledged that these analyses have been on low organic matter soils with sandy loam and clay loam textures and with one exception, at sites where land application of dairy waste or large amounts of crop residue were not part of the management.

IMPROVING THE DIAGNOSTIC CAPABILITIES FOR DETECTING MOLYBDENUM DEFICIENCY IN ALFALFA AND AVOIDING TOXIC CONCENTRATIONS FOR ANIMALS.

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OBJECTIVES

1. To characterize the relationship between plant tissue molybdenum, boron, and copper concentrations and alfalfa yield and quality response where molybdenum is applied at several rates.
2. To develop a broader ranged diagnostic capability by assessing plant tissue molybdenum concentrations at different stages of alfalfa growth where several rates of molybdenum have been applied.
3. To provide standard forage samples for distribution to analytical laboratories by collecting large quantities (10-25 lbs) of two alfalfa samples having molybdenum concentrations in the range of 0.1-0.3 ppm and 0.5-0.7 ppm. Also, it is intended that a small quantity of a low molybdenum (0.1-0.3 ppm)-boron (9-11 ppm) bulk sample will be made available.

RESULTS AND DISCUSSION

Two sites were established, one in Shasta County several miles north of Burney, CA (Site or experiment #1), and a second in Siskiyou County several miles northwest of Fort Jones, CA, in Scott Valley (Site or Experiment #2). The Shasta County site was initiated on March 31, 2000 when the treatments listed in Table 1 were applied. Individual plots were 10 ft by 25 ft in size and the field trial design was a randomized complete block with three blocks or replications. Several alfalfa fields on the ranch were sampled in August 1999 and indicated top 1/3 of plant concentrations of molybdenum were in the 0.1 – 0.3 ppm range. Plant tissue samples also indicated that phosphorus (midstem PO4-P), potassium (midstem K), sulfate-sulfur (midstem leaf SO4-S) and boron were in the adequate range.

Yield results from Site 1 (Experiment #1) for the four-year period 2000-2003 are given in Table 1. Even though there were no significant yield responses to molybdenum or lime treatments, slight trends did exist during 2000 (Probability=13.8%), 2002 (Probability=11.9%), and for the four year total yields (Probability=21.3%). One individual harvest in 2000 and one in 2002 had highly significant yield responses to molybdenum. Note that the lime alone treatment resulted in equally as high a yield as the molybdenum treatments in the second, third and fourth years, but not in the first year. This is often the case since raising the soil pH increases the availability of molybdenum to plants, but some period of time is necessary to effect yields if no incorporation of the lime occurs. Maximum yield was often achieved with as little as 0.2 lbs Mo/A up to the higher rates of 0.8 lbs Mo/A. However, rates greater than 0.6 – 0.8 lbs Mo/A often increase molybdenum concentrations in the forage to undesirable levels the first year or two after application considering the needs of animals, particularly if copper concentrations are below the 8 – 10 ppm range (See Figure 4). Phosphorus (midstem PO4-P), potassium (midstem K), and sulfate-sulfur (midstem leaf SO4-S) and boron were all maintained in the adequate range.

Plant growth stage samples were taken at six inches height, 12 inches height, prebud (only a small ball was formed to indicate the new bud), and at harvest (early bud to 1/10 bloom) for three harvests in 2001 and one each in 2000, 2002 and 2003. All of the plant material of the samples collected at the six-inch growth stage and only the top six inches of the 12-inch high or older plants were analyzed for molybdenum, boron, and copper concentrations to develop the relationships between growth stage and molybdenum, boron, and copper concentrations.

To evaluate the effect of molybdenum and lime treatments on alfalfa forage quality, chemical analyses for crude protein and acid detergent fiber (ADF) to determine total digestible nutrients (TDN) were conducted on four harvests in 2001 and three harvests in 2002 and 2003. There were no statistically significant differences in crude protein as a result of the treatments. There did seem to be a rather consistent trend for the crude protein to be slightly higher for most of the molybdenum and lime treatments, however. Acid detergent fiber (ADF) analysis on whole plant samples to determine total digestible nutrient (TDN) levels also showed no statistically significant differences in total digestible nutrient (TDN) levels as a result of the molybdenum or lime treatments.

The Siskiyou County site (Experiment #2) was initiated when the treatments given in Table 2 were applied, lime on March 9, 2001 and boron and molybdenum on March 10, 2001. Individual plots were 10 ft by 25 ft in size and the field trial design was a randomized complete block with three blocks or replications. The alfalfa field proposed for a trial was sampled on June 21, 2000, and found to have low concentrations of molybdenum (0.2 – 0.3 ppm) and boron (6 ppm). Plant tissue samples also indicated that phosphorus (midstem PO4-P), potassium (midstem K), and sulfate-sulfur (midstem leaf SO4-S) were in the above adequate range.

Yield results of the three years from Site 2 (Experiment #2) for the period 2001-2003 are given in Table 2. Selected treatments of molybdenum and boron resulted in significantly higher yields over the control during 2002 and for the three-year totals. Three individual harvests, two in 2002 and one in 2003, showed significant yield responses to molybdenum plus boron treatments. It can be noted that neither molybdenum, boron nor lime alone resulted in as consistently high yields as when at least molybdenum and boron were applied. As was observed in Experiment 1, near maximum yield was often achieved with as little as 0.2 lbs Mo/A. Visual observations of the trial just prior to most harvests indicated the control plots as well as those receiving molybdenum alone had slightly chlorotic tops of the plants because of boron deficiency. This slightly chlorotic appearance of the tops of the plants caused by boron deficiency generally does not result in large vegetative yield decreases but could reduce seed yields by 25 to 50% or more.

Table 1. Alfalfa yields (100% dry matter basis) during the four-year period 2000-2003, as influenced by molybdenum and lime treatments applied on March 31, 2000. Four harvests were made in 2000 and 2001 while three harvests were made in 2002 and 2003.

Treatment	Mo (lbs/A)	Lime (tons/A)	2000 Yield (tons DM/A)	2001 Yield (tons DM/A)	2002 Yield (tons DM/A)	2003 Yield (tons DM/A)	Total Yield (tons DM/A)
1. Control	0	0	6.74	5.39	4.81	5.17	22.10
2. Mo	0.2	0	7.01	5.60	5.04	5.25	22.90
3. Mo	0.3	0	7.15	5.79	5.08	5.38	23.41
4. Mo	0.4	0	7.16	5.42	4.93	5.12	22.63
5. Mo	0.6	0	7.45	5.68	5.02	5.72	23.87
6. Mo	0.8	0	7.42	5.73	5.41	5.60	24.15
7. Mo	1.2	0	7.25	5.38	4.83	5.35	22.81
8. Lime	0	2	6.72	6.06	5.41	5.58	23.77
Probability			0.138	0.400	0.119	0.633	0.213

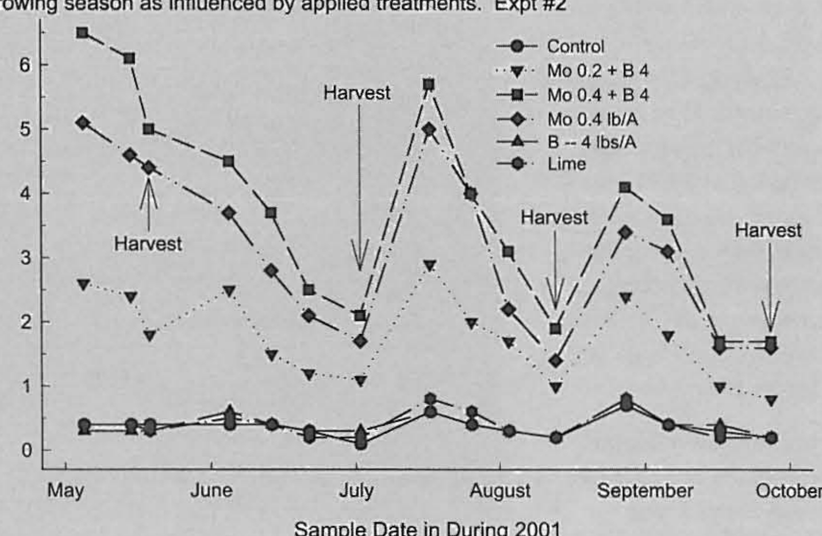
Table 2. Alfalfa yield (100% dry matter basis) during the three-year period 2001-2003 as influenced by molybdenum, boron and lime treatments applied on March 9-10, 2001.

Treatment	Mo (lbs/A)	B (lbs/A)	Lime (tons/A)	2001 Yield (tons DM/A)	2002 Yield (tons DM/A	2003 Yield (tons DM/A	Total Yield (tons DM/A
1. Control	0		0	7.24	6.89 d	4.08	18.21 e
2. Mo plus B	0.2	4	0	7.89	8.05a ‘	4.54	20.47a ‘
3. Mo plus B	0.3	4	0	7.76	7.98a ‘	4.42	20.15abc ‘
4. Mo plus B	0.4	4	0	7.71	7.90a ‘	4.66	20.27ab ‘
5. Mo plus B	0.6	4	0	7.95	7.99a ‘	4.53	20.48a ‘
6. Mo plus B	0.8	4	0	7.71	7.67ab ‘	4.40	19.78abcde
7. Mo plus B	1.2	4	0	7.87	7.92a ‘	4.42	20.21abc ‘
8. Mo	0.4	0	0	7.52	7.02 cd	3.89	18.43 de
9. Mo	0.8	0	0	7.51	7.19 bcd	3.88	18.58 cde
10. B	0	2	0	7.47	7.45abcd	3.72	18.64 bcde
11. B	0	4	0	7.64	7.67ab ‘	4.33	19.64abcde
12. Lime	0		2	7.34	7.17 bcd	3.93	18.45 de
13. Mo+B+Lime	0.2	4	2	7.58	7.65ab ‘	4.35	19.58abcde
14. Mo+B+Lime	0.4	4	2	7.73	7.62abc ‘	4.69	20.04abcd ‘
Probability				0.592	0.006	0.052	0.037

Plant growth stage samples were taken at six inches height, 12 inches height, prebud, and at harvest (early bud to 1/10th bloom) prior to four harvests in 2001, and the first and third harvests in 2002 and 2003. To produce higher quality alfalfa hay, growers harvest prior to 1/10 bloom growth stage so samples taken at harvest will be characterized as to stage of growth. All of the plant material of the samples collected at the six-inch growth stage and only the top six inches of the 12-inch high or older plants were analyzed for molybdenum, boron, and copper concentrations to develop the relationships between growth stage and molybdenum or other nutrient concentrations.

Figure 1 gives the molybdenum concentration in the top 1/3 of the plant samples taken two times prior to the first harvest and three times prior to the second, third, and fourth harvests, as well as at each harvest. These data indicate that molybdenum concentrations in the top 1/3 of the plant, when they are in the deficient range (<0.9 ppm), remain fairly constant during the early growth stage through the harvest growth period for each of the four harvests during the year. This becomes particularly desirable for diagnostic purposes if plant samples can be taken anytime during the growth of the crop, not just at a defined stage of growth such as 1/10 bloom stage. Of particular interest is the fact that if the molybdenum concentration is in the adequate range, that is above 1 ppm, it generally decreased as the alfalfa matures and is harvested.

Figure 1. Alfalfa-top 1/3 of plant-molybdenum concentrations during the 2001 growing season as influenced by applied treatments. Expt #2



Note as well, that the 0.2 lb/A rate of molybdenum plus the 4 lbs/A rate of boron had approximately one-half the concentration of molybdenum as did the 0.4 lb/A rate of molybdenum plus the 4 lbs/A rate of boron. Also note that the 0.4 lb/A rate of molybdenum plus the 4 lbs/A rate of boron had a higher molybdenum concentration than did the 0.4 lb/A rate of molybdenum alone for much of the first year after application. The control, boron alone at the 4 lbs/A rate and the lime alone treatments had nearly the same low molybdenum concentration of 0.2 to 0.9 ppm throughout the year. A single application of the 0.4 lb/A rate of molybdenum is expected to last approximately 10 years based on a number of fields that have been sampled over time. Fields having a history of molybdenum concentrations less than 1 ppm should be resampled at least every three years at the early bud to 1/10 bloom growth stage to monitor the molybdenum status for maintaining high alfalfa yields.

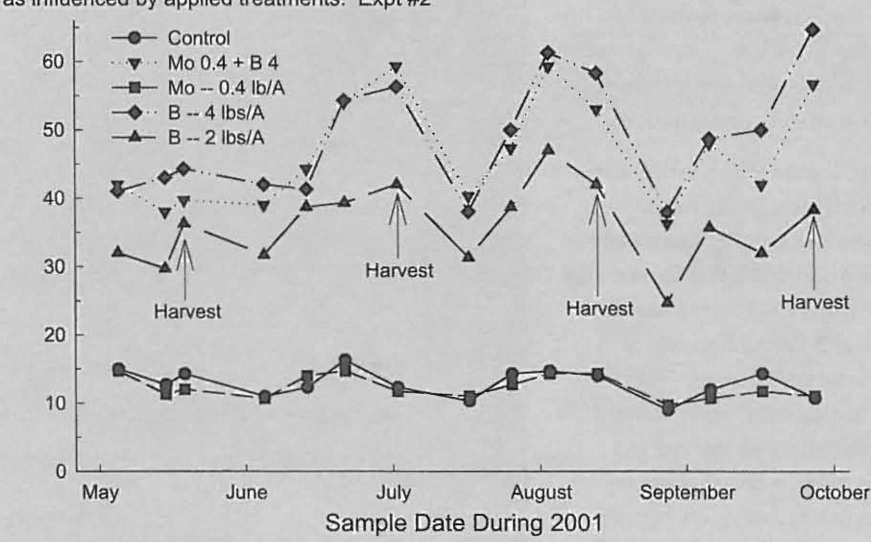
The boron concentration in the top 1/3 of the alfalfa plant for several treatments during the 2001 growing season is given in Figure 2. They are fairly consistent when no boron is applied (control and molybdenum alone treatment) but vary considerably when boron is applied at either the two or four pound per acre rates. The two-pound rate of boron had only slightly lower boron concentration in the top 1/3 of the plant than the 4-pound rate. The top 1/3 of the plant samples from the second and third harvests in 2003 have approximately half the boron concentrations for the two and four-pound rates as compared to the 2001 results. This would suggest that the 2-pound rate of boron should be applied every other year and the 4-pound rate should be applied every four years. Fields having a history of boron concentrations less than 15 ppm should be resampled at least every two years to monitor the boron status for maintaining high alfalfa yields. Fields used for alfalfa seed production should be maintained at a somewhat higher boron concentration of 20-25 ppm and sampled annually to adjust the rate of boron application to maintain the >25 ppm concentration in the top 1/3 of plant samples at the early bud to 1/10 bloom growth stage.

The same samples collected during 2001 for molybdenum and boron analyses were also analyzed for copper concentrations. Figure 3 illustrates the copper concentrations for the same treatments that are given in Figure 1 for molybdenum treatments. The copper concentrations decrease to nearly one-half from the early growth to the harvest time sampling. This is nearly the same pattern exhibited for the molybdenum concentrations. Since the harvest concentrations of copper are only slightly above 5 ppm, to maintain the desired ratio of 2:1 for copper: molybdenum, the molybdenum concentration should not exceed 2.5 ppm. Figure 1 indicates that the first harvest molybdenum concentration at approximately 5 ppm is well in excess of the desired 2.5 ppm but the second, third and fourth harvests are in the desired range of 2-2.5 ppm. This would certainly suggest that when molybdenum is applied it should not be applied in excess of the 0.4 lb/A rate of molybdenum or 1 lb/A rate of sodium molybdate.

Figure 4 gives a comparison between the whole plant (harvested hay) molybdenum concentrations and the top 1/3 of the alfalfa plant concentrations for four harvests in 2001 and 2002. It can be observed that even though these two plant parts are much different, they have the same molybdenum concentrations and can therefore be used equally well for diagnosing molybdenum deficiencies. Since this procedure has not been tested on very many locations and production seasons, use of the top 1/3 of the alfalfa plant concentrations would still be the preferred sampling and monitoring approach.

Alfalfa forage quality was evaluated by conducting chemical analyses for crude protein and acid detergent fiber (ADF) on whole plant samples to determine total digestible nutrients (TDN). These analyses were conducted on all samples,

Figure 2. Alfalfa-top 1/3 of plant-boron concentrations during the 2001 growing season as influenced by applied treatments. Expt #2



from four harvests in 2001 and 2002, as well as the three harvests in 2003. There were no statistically significant differences in crude protein as a result of the molybdenum, boron and lime treatments. There appeared to be a trend for crude protein to be slightly higher in several harvests as a result of combinations of molybdenum and boron treatments. No statistically significant differences in total digestible nutrient (TDN) levels were observed in any of the harvests as a result of the molybdenum, boron or lime treatments.

All of the plant material collected for analysis was being saved for the preparation of several large bulk samples of known molybdenum and boron concentrations. This was resulting in only small quantities of alfalfa bulk samples and a fire on the outside of our steel storage unit destroyed most of this plant material. During the last harvest of 2003 and the first harvest of 2004, the top 1/3 of plants from the entire individual plot of the three replications was harvested from several treatments at each site to acquire larger amounts of material for the bulk samples. The analyses of these samples has been completed and another set of the combined materials are being prepared for analyses to achieve the two bulk samples having similar molybdenum concentrations in the range of 0.1-0.3 ppm and 0.5-0.7 ppm. Also, it is intended that a small quantity of a low molybdenum (0.1-0.3 ppm)—low boron (9-11 ppm) bulk sample can be made available. These three standard forage samples will then be prepared for distribution to analytical laboratories.

Figure 3. Alfalfa-top 1/3 of plant-copper concentrations during the 2001 growing season as influenced by applied treatments. Expt #2

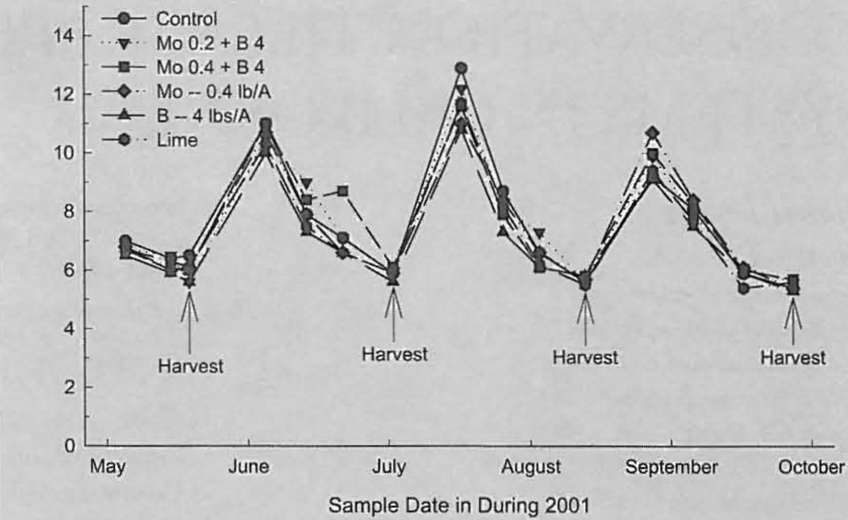
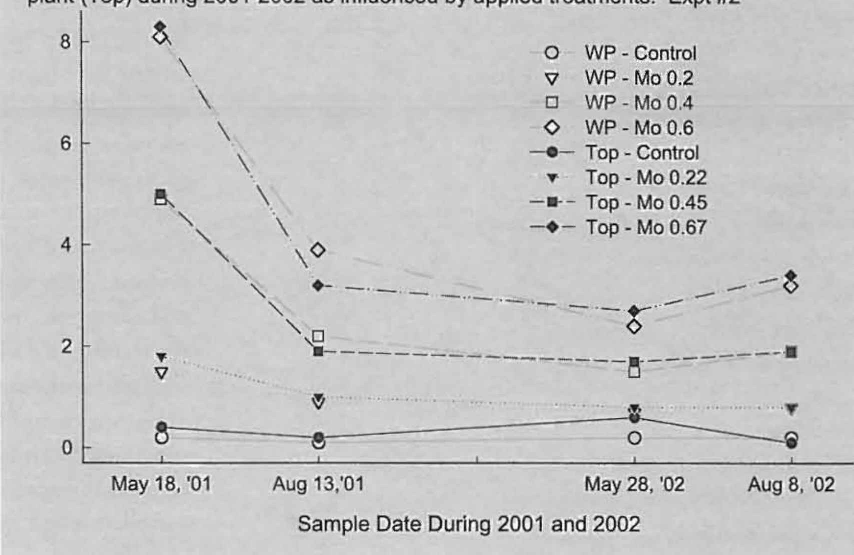


Figure 4. Alfalfa molybdenum concentrations, whole plant (WP) versus top 1/3 of plant (Top) during 2001-2002 as influenced by applied treatments. Expt #2



FERTILIZATION TECHNOLOGIES FOR CONSERVATION TILLAGE PRODUCTION SYSTEMS IN CALIFORNIA

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INTRODUCTION

Conservation tillage production in row crop systems has a number of potential advantages that may be desirable to California producers including reduced production costs, maintenance of soil organic matter, and water conservation. Evaluation of this potential has been an increasingly important focus of the University of California Division of Agriculture and Natural Resources Conservation Tillage Workgroup in recent years. To date, however, no systematic studies have been conducted in California to evaluate and understand the basis for optimal fertilization management strategies for these reduced tillage systems. The selection of fertilizer rates, materials and application methods will likely require management decisions in conservation tillage systems that differ from those used in conventionally tilled systems. This project addresses two of FREP's key research and education priorities by developing new information on the fertilizer use efficiency of conservation tillage systems with and without cover crops compared to standard tillage systems with and without winter cover crops, and by providing this information in educational functions, such as field demonstrations, that are readily accessible to producers, consultants and resource managers.

Despite a 300% increase in conservation tillage (CT) production systems in the Midwest during the past decade, less than 0.3% of the acreage in California's Central Valley (CV) is currently farmed using CT practices. Preplant tillage operations typically account for 18 – 24% of overall production costs for annual crops grown in this region. An average of nine to 11 tillage-related passes are routinely done during the fall-spring period to prepare the soil for summer cropping. These passes represent not only considerable energy, equipment and labor costs, but recent research indicates that tillage reduces soil organic matter (SOM) and emits considerable respirable dust as well. Because SOM is widely regarded as an important attribute of good soil quality and long-term productivity, interest has been growing over the last several years, in developing alternative production systems that reduce costs, while at the same time improve the soil resource through greater carbon sequestration.

Tillage in most annual cropping systems in California's Central Valley is typically done in a "broadcast" manner through a field, without deliberate regard to preserving dedicated crop growth or traffic zones. Studies by Carter over the last several decades, however, have confirmed the benefits of CT practices. CT production systems have the potential to eliminate deep tillage, decrease the number of soil preparation operations by as much as 60%, reduce unit production costs, lower soil impedance, maintain productivity in a number of CV cropping contexts. In addition, using reduced precision or zone tillage practices limits traffic to permanent paths throughout a field, reducing soil compaction and preserving an optimum soil volume for root exploration and growth. No systematic studies have been conducted in California, however, that evaluate optimal fertilization strategies for these reduced tillage systems. Horwath et al. have shown that changes in fertilizer use efficiency occur when soils are managed for C sequestration in California. Additional work in other regions of the US has shown that the selection of nitrogen fertilizer rates, source, and application methods requires management decisions in CT systems that differ from those used in conventionally tilled systems. Factors such as the type or quality of surface residue, residual soil fertility levels, soil temperatures, planting dates, crop variety, and soil moisture determine optimal fertilization programs in CT systems. Soils in conservation tillage tend to be cooler, wetter, more firm, and higher in organic matter near the surface than in conventional tillage. The likelihood of obtaining a yield response to starter fertilizer increased rapidly as tillage operations decrease.

In this project, we are adapting fertilization equipment that is currently used in CT systems in the midwest and southeast US, and determining the fertilizer use efficiency using CT practices that we develop for San Joaquin and Sacramento Valley row crop systems. The hypothesis that we are testing is that CT practices will promote an increase in soil organic matter (SOM), which in turn will lead to a greater nutrient cycling potential in the soil. This increased potential may then result in a lower fertilizer use efficiency, but a correspondingly lower rate of required fertilization.

OBJECTIVES

1. to evaluate the effectiveness of various fertilization practices in conservation tillage tomato, corn, and cotton production systems
2. to determine the fertilizer use efficiency in conservation tillage production systems transitioning to CT, and
3. to extend information developed by the project widely to Central Valley row crop producers via field days, equipment demonstrations and written project outcome summaries

DESCRIPTION

This project is being conducted in a five-acre field at the Vegetable Crops and Weed Science Field Headquarters on the UC Davis campus where a corn/tomato/corn/tomato rotation is being pursued.

Four experimental treatments (standard tillage no cover crop, STNO, standard tillage with incorporated cover crop, STCC, conservation tillage no cover crop, CTNO, and conservation tillage with cover crop, CTCC) were established in the fall of 2000 in nine-bed (60"each) field plots that are replicated four times in a randomized complete block design. In 2001, a uniform field corn crop was produced across the entire field. Following corn harvest in September 2001, common vetch cover crops were seeded in each of the CC plots. Forty 15N microplots (4.57m wide band 3m long) were then established during the 2001 – 2002 winter as indicated below.

STNO	STCC	CTNO	CTCC
Zero N	Zero N	Zero N	Zero N
Labeled fertilizer	Labeled fertilizer + vetch	Labeled fertilizer	Labeled fertilizer + vetch
	Labeled vetch + fertilizer		Labeled vetch + fertilizer

These microplots are being used to track the amount of 15N-labeled fertilizer and vetch cover crop that is taken up by each of the main summer crops during the course of the study.

RESULTS AND SUMMARY

CROP YIELD

In general, crop yields in the ST systems were higher than in CT systems in each year of this study. ST Tomato yields averaged as much as 33% higher than CT yields for tomato and about 8 – 10% higher for corn (Figure 1). These yield trends were roughly similar in both the hand-harvested microplot-derived yields and in machine-harvested full plot yield determinations (Figure 1 and Table 1).

15N-LABELED UPTAKE BY CROPS

The relative amounts of 15N-label that was taken up by crops from 2002 – 2004 is shown in Figure 2. Compared to ST, less fertilizer N was taken up by the first tomato crop under CT. In both ST and CT, uptake of fertilizer in the cover cropped systems tended to be less than in the non-cover cropped systems.

SOIL RESIDUAL 15N

By the end of the second season, more of the original input 15N, whether fertilizer or vetch, was found in the soil under CT management. This is likely related to greater crop uptake and removal of input-N during the first season under ST management.

SUMMARY AND OUTLOOK

The primary objective of this ongoing study is to determine the relative uptake characteristics of labeled fertilizer and vetch cover crop material under ST and CT management in a tomato-corn-tomato-corn rotation so as to begin to identify management strategies for optimizing CT production. A dominant outcome of this work to date is that both tomato and corn yields have been consistently higher in ST relative to CT. Lower yields in the ST systems most likely influenced our finding of higher soil residual 15N-label in the CT systems; lower yields meant less overall N removed under CT and more N residual in the soil.

Based on these very initial observations, it appears, particularly for tomato, that N fertility management is a critical factor for more successful CT production systems. By definition, CT systems "disturb" or "stir" the soil less and thus there may have been less movement or mixing of the originally-applied N throughout the crops' developing root zone. While care was taken to simulate actual labeled fertilizer and vetch application techniques in our CT microplots relative to those used in the ST systems, there was considerably less soil disturbance done in the CT systems than in the ST systems and this, in conjunction perhaps with denser, CT soils that may have developed, may have contributed to the relative growth and yield differences that were determined between the tillage systems.

Possible remedies to these initial observations may include N application closer to the plant, better "at planting" N application techniques and somehow providing for more efficient crop N acquisition, particularly early in the season.

Table 1. Crop yields in 2002, 2003 and 2004. Tillage system mean + standard error. Tomato yields are ton/acre. Corn yields are lbs/plot.

	2002 Tomato	2003 Corn	2004 Tomato
STNO	51.8 + 2.2	2158 + 130	37.3 + 2.3
STCC	51.8 + 2.7	2351 + 126	38.6 + 2.3
CTNO	38.5 + 1.6	1536 + 66	25.1 + 2.8
CTCC	50.3 + 3.2	1782 + 67	22.0 + 2.7

Figure 1. Recovery in subsequent crops of original labeled (*) input-N applied in spring 2002

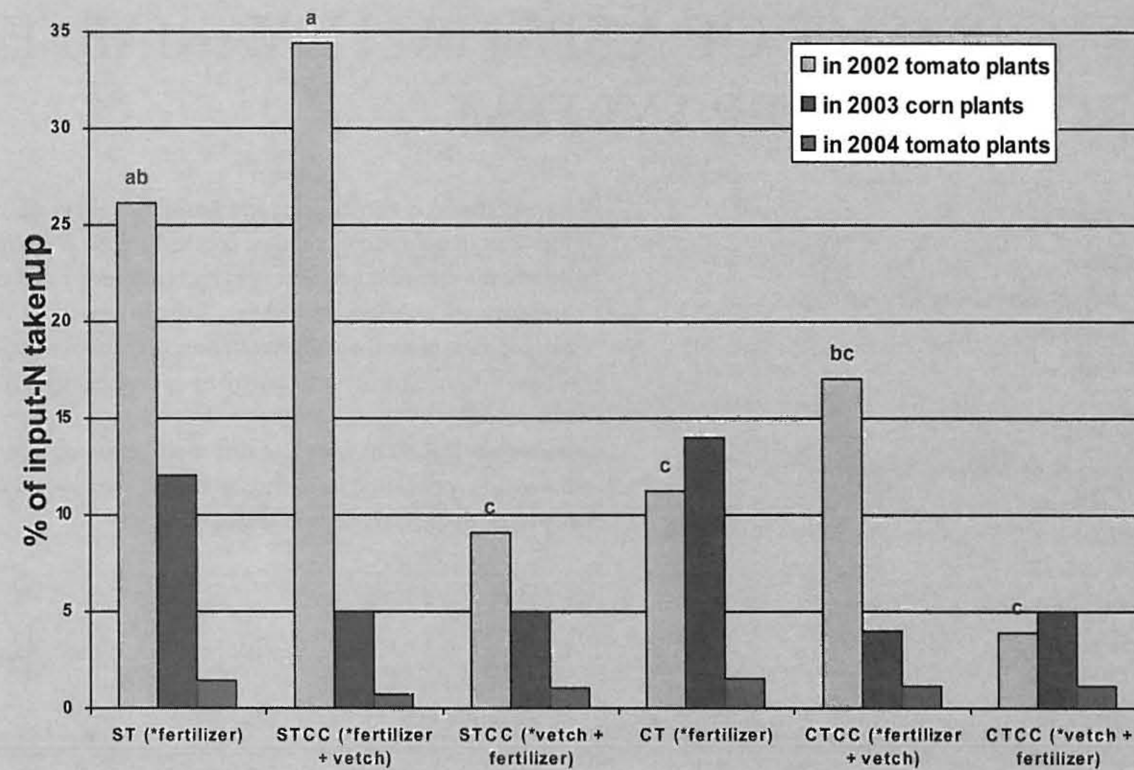
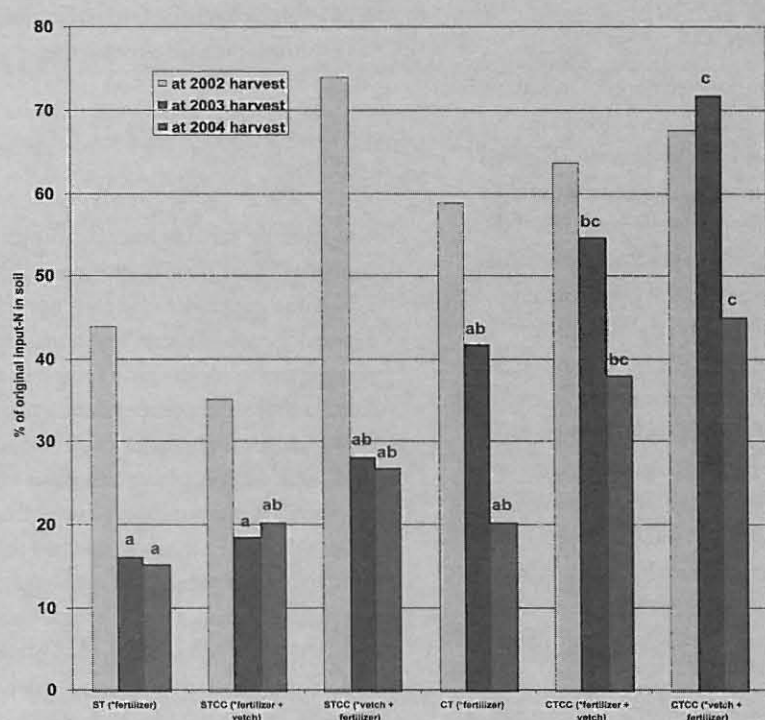


Figure 2. Percent remaining in soil (0-30 cm) of the original labeled input-N applied in spring 2002



PRECISION FERTIGATION IN ORCHARDS: DEVELOPMENT OF A SPATIALLY VARIABLE MICROSPRINKLER SYSTEM

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INTRODUCTION

Previous research in almond and pistachio orchards shows that a significant variation in yield occurs among sites within an orchard and between individual trees. Figure 1 is an example of yield variation within a pistachio orchard. Typical pistachio yields in California vary from 1,000 lb to 6,000 lb per acre (dry in-shell splits). Remote sensing, soil sampling, and yield monitoring have provided simple and effective quantification of yield spatial variability and possible causes of this variability such as soil nutrient concentration, water availability, disease and pests, and tree genetics. Spatially variable delivery of water (irrigation) and water-dissolved chemical fertilizers (chemigation or fertigation) is of great interest. Studies have shown that optimized irrigation using spatially variable systems increases yield over that of uniform distribution. Spatially variable management can minimize water usage and runoff, as well as mitigate excess fertilizer application that is wasteful and can leach into groundwater.

Most of the developments in spatially variable irrigation have occurred in center pivot and linear move systems. However, these systems are used for field crops. In orchards, significant variation between trees indicates individual tree management may be worthwhile. A single pistachio tree can produce more than $5,000 in nuts over its lifetime. Growers have significant incentive to optimize productivity and profit by bringing each tree to its maximum yield potential. Precision control of drip emitters would also have wide application in the containerized nursery industry, landscape management, and greenhouses.

OBJECTIVES

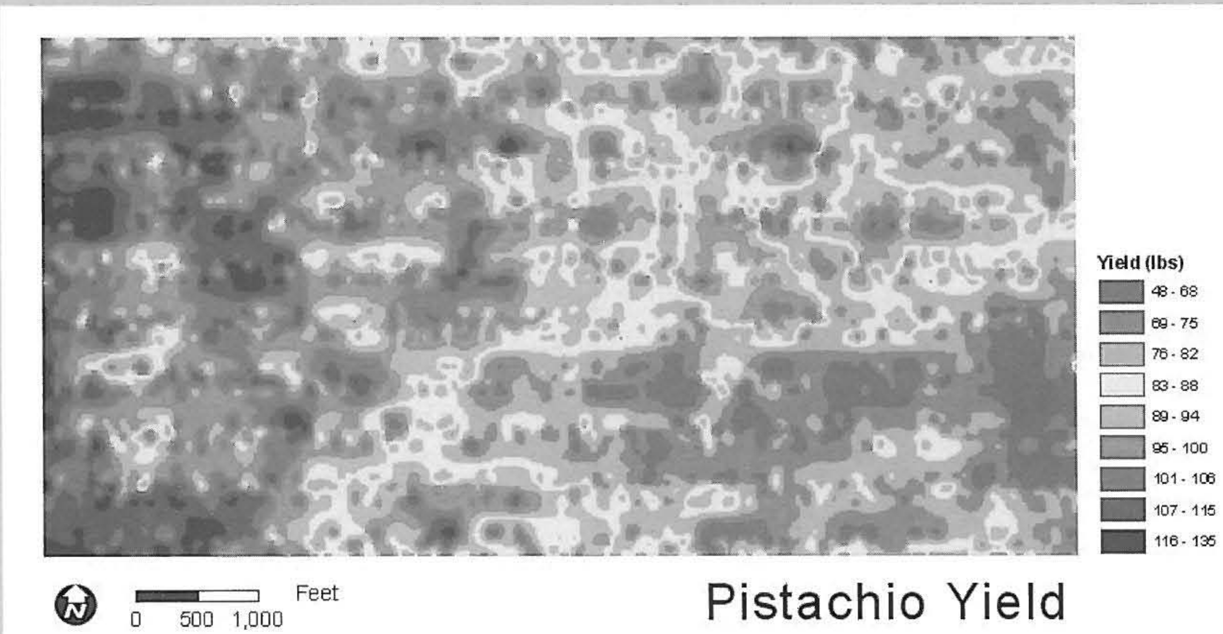
1. Design and develop electronic hardware for individually controllable microsprinklers along a drip tubing irrigation line.
2. Develop the communication network and software for control of the microsprinkler network by a master computer.
3. Experimentally evaluate the system performance and potential problems caused by operation in the field.
4. Develop potential fertigation control strategies to optimize orchard production.

DESCRIPTION

SYSTEM OVERVIEW

The spatially variable microsprinkler system (Figure 2) consists of four basic components: microsprinkler nodes, a drip line controller, the communication and power network between them, and a master computer. Each microsprinkler node has a valve and an electronic circuit to control that valve independently of all others in the field. Using identical emitters, the amount of water and fertilizer applied at different locations in an orchard can be adjusted by changing the duration of time that each microsprinkler valve is open. Each node also has the capability to interface with electronic sensors for measuring drip line pressure and soil moisture level. The drip line controller stores irrigation and fertigation schedules and controls the microsprinkler nodes. The master computer is a laptop computer that provides an interface for the user to store schedules, monitor

Figure 1. Contour yield map of Pistachio Orchard, Lost Hills, CA, with yield expressed as lbs in-hull green weight per tree. (A 100-lb per tree yield is equivalent to 33 lb in-shell splits per tree and 4,900 lb/acre.)



system status, retrieve sensor data, and manually control the network.

NETWORK

A prototype system with 50 microsprinkler nodes is under development in a nectarine orchard at UC Davis. Three 14-gauge wires (power, ground, signal) provide power to the microsprinkler nodes and allow communication between devices. It is envisioned that the conductors would be embedded in the drip tube to provide a more efficient means of installation. Wireless communication is also a possibility. A 12 V battery provides power for the drip line controller, microsprinkler nodes, and valves. A solar panel charges the battery during daylight hours.

MICROSPRINKLER NODE

A simple 8-bit microcontroller is included in each node circuit. Each node has its own valve and microsprinkler. The microcontroller can communicate with the drip line controller, open or close the valve, and measure analog signals from external sensors (e.g., soil moisture, water pressure). The data collected from pressure sensors can be used to estimate flow rates and detect damage to the drip line. Each node circuit board is mounted in a weather resistant box.

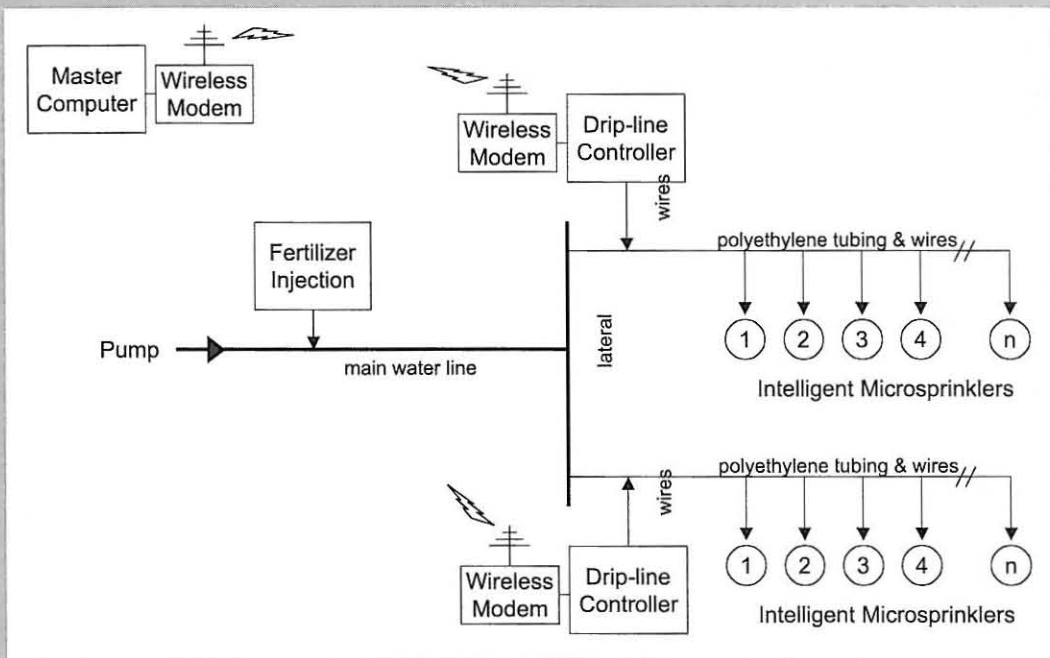
DRIP LINE CONTROLLER

The drip line controller consists of an embedded controller, signal buffer, power sources and wireless modem. An LCD and keypad provide visual feedback during testing and allow manual control of the system. The embedded controller stores and executes irrigation and fertigation schedules and retrieves sensor data from microsprinkler node sensors. A 900 MHz wireless modem allows the drip line controller to be accessed remotely from the master computer. The 14-gauge wires are connected to the drip line controller to allow communication with the microsprinkler nodes. A 12 V switching power supply or lead-acid battery with solar-powered charger provides power. Once a schedule is stored, the drip line controller operates in Auto mode. During periods of inactivity, the controller 'sleeps' to conserve energy. The user can suspend Auto mode in order to execute a number of other operations, including 1) store a new schedule; 2) read the existing schedule; 3) set a new clock time; 4) read the existing clock time; 5) manually send commands to a specific valve; 6) take pressure readings; 7) read the error log, and (8) return drip line controller to Auto mode. Additional functions will be added to both modes for soil moisture readings and fault detection routines.

MASTER COMPUTER

The master computer is a laptop that provides a user interface for storing irrigation and fertigation schedules, retrieving sensor data and issuing other commands to the drip line controller. The user uses a terminal program to interact with a text-based menu from the drip line controller.

Figure 2. System layout for a spatially variable microsprinkler system with 'intelligent' microsprinkler nodes, drip line controllers, and master computer



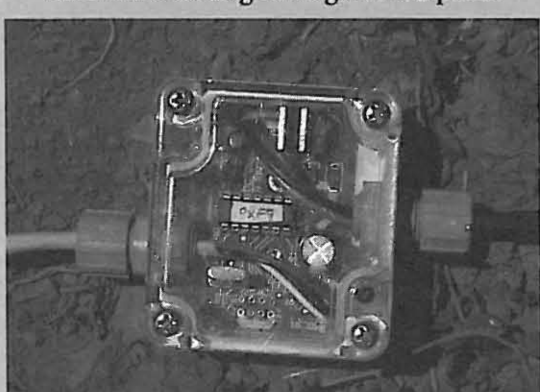
A graphical interface will be created in the future.

RESULTS AND CONCLUSIONS

SYSTEM DESIGN AND DEMONSTRATION SYSTEM

Figures 3 through 6 show the spatially variable microsprinkler system components and the system in operation.

Figure 3. Circuit board and enclosure of a microsprinkler node with power/signal wires and valve wires exiting through sealed ports.



PRELIMINARY FIELD TESTS

Four tests were conducted on a prototype system with four microsprinkler nodes: 1) volume output test; 2) simulated line break test; 3) valve reliability test; and 4) wireless modem range test. Table 1 shows data from a volume measurement trial. The valve, sprinkler, and position columns indicate the location of each valve and sprinkler

Figure 4. Drip line controller with embedded controller (center), wireless modem (left), signal buffer (top), and power sources (bottom). Wires to connect with the power/signal bus exit the enclosure through sealed ports on the right.

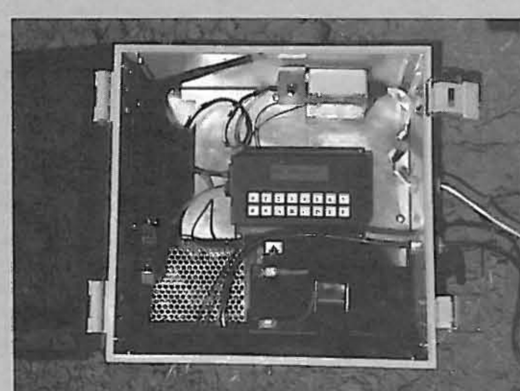


Figure 5. Microsprinkler node showing circuit, valve, and microsprinkler connected to power/ signal bus and drip line.

Figure 6. Three microsprinkler nodes turned on. Drip line controller and spool of wire visible in distance.

Table 1. Microsprinkler Emitter Rates

Valve	Position	Sprinkler	Volume (gal)	Time (min)	Rate (gal/h)
1	3	3	0.7	5	8.4
2	4	4	2.7	15	10.8
4	2	2	4.2	20	12.6
3	1	1	2.5	10	14.7

along the drip line. The next two columns show the volume of water collected from each microsprinkler node and the time duration it was turned on. As required, each node output a different volume of water. However, the data shows that the rate of water output was not uniform for the four-microsprinkler nodes. It was determined that the microsprinklers were the main source of variability, and this will be corrected in the 50-unit field trial.

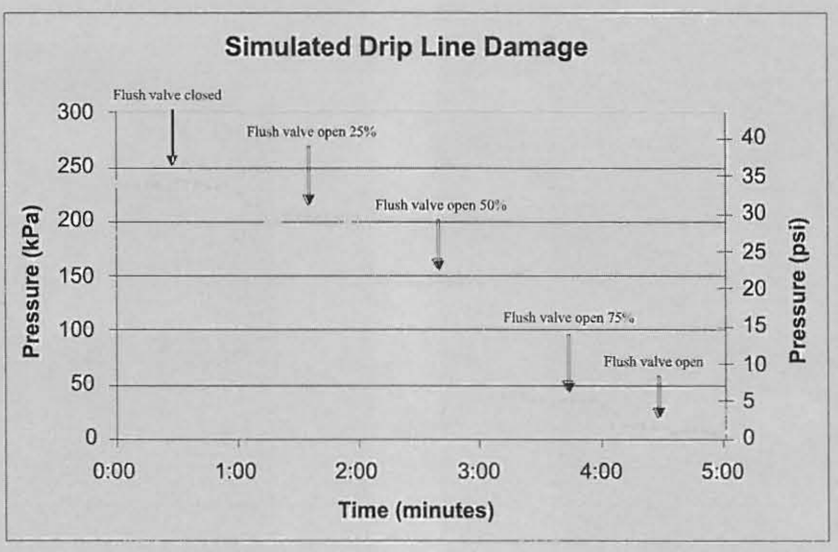
Figure 7 shows a plot of the drip line pressure over time for a simulated line break. Pressure was recorded from a microsprinkler node containing a pressure sensor. Each level part of the curve represents a different amount of water being released from the drip line. It is evident that a sufficiently large pressure drop could be evidence of a broken drip line. A scheme will be developed in which the line pressure is monitored for drip line damage.

During a two-hour reliability test, each microsprinkler valve was opened and closed 720 times without error. Future reliability tests will focus on the risk of valve clogging and extended operation times.

A visual line-of-sight test yielded a maximum wireless modem range of about 800 ft between master computer and drip line controller. The maximum range through an orchard was approximately 300 ft. Improved antenna position could increase the maximum range. Also, the wireless modems can be configured to make multiple transmission attempts when data are not correctly received by the other modem. These and other range enhancing options will be explored.

The development of a spatially variable microsprinkler system has resulted in a 50-node demonstration system that will be tested this fall. Each microsprinkler node is comprised of a simple microcontroller and electronic circuitry. Latching solenoid valves provide a way to individually control water flow at each microsprinkler. A pressure sensor monitors drip line pressure. A drip line controller provides adequate memory to store fertigation schedules and sensor data, and a master computer is used to transmit these schedules and access the sensor data. Preliminary results show that spatially variable management is possible. Further tests are ongoing.

Figure 7. Line pressure at various levels of simulated drip line damage.



IMPROVING THE PROCEDURE FOR NUTRIENT SAMPLING IN STONE FRUIT TREES

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INTRODUCTION

Midsummer is the recommended period of sampling leaves for nutrient analysis in fruit trees. This practice was first developed in the 1940s and was widely applied to orchards during the 1950s. In 1971, 39 peach studies were compiled from seven countries and Leece, the researcher, concluded, "With few exceptions, good agreement existed amongst the studies for any particular nutrient." Thus, the practice became very widespread and is the standard to this date. The timing of about 100 to 140 days after bloom has been established because the concentration of most nutrients remains fairly stable during this time. This corresponds to the period from early June through late July in the central valleys of California.

We see at least two problems with this timing, especially in light of our modern era of environmental concerns and an emphasis on good sustainable fertilization practices. First, the timing of mid summer for sampling does not fit well into a sustainable fertilizer program since many fertility decisions need to be made early in the spring. Growers are generally most interested in fertility management as they watch their trees flower, leaf out and set a crop in the spring. By summer their interest has waned. Second, this timing also does not make sense from a tree physiological perspective. Many critical processes such as flowering, fruit set, initial fruit growth, and shoot growth are all happening in the early spring and should be dependent on tree nutrient status at that time. A dormant or early spring sample should give a good indication of stored nutrients and whether any are limiting.

This study will evaluate the nutritional status of several different plant parts in hopes of finding a reliable and consistent sampling procedure to help guide fertilization practices in the spring.

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.

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, a Grand Pearl nectarine (white flesh), and a 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 2004, there were clear signs of N, P, B and Zn deficiencies in individual peach and nectarine trees (Table 1). Several other nutrients also showed some indication of deficiency but will not be included in this project until more convincing symptoms are obtained.

Shoot samples were taken from all 180 trees in January of both 2003 and 2004. Root samples were taken at the same time in 2004. Flowers were sampled at full bloom in March of both years. All samples were dried, ground, 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 each tissue. This report will include results from only the peach and nectarine trees.

RESULTS

Nutrient concentrations in dormant roots, dormant shoots, and flowers were all compared. A preliminary evaluation of newly emerging leaves was also made. Of these four tissues, dormant shoots appeared to be best for several reasons. First, it was a simple and easy sample to take. Roots took a lot more effort and flowers had to be sampled within a short period of time. Second, the timing was early enough to allow for correction before growth started. By the time of flowering and early leaf emergence, it was too late to affect processes such as fruit set and early fruit growth. Finally, nutrient concentrations in shoots correlated better with midsummer leaf levels and tended to be better than the

Table 1. Sand tank nutrient deficiencies 2004. Summary of deficiency symptoms and effects.

		July Leaf Sample			
Nutrient	Evidence of Deficiency	Published Deficiency Threshold (Peach)	Lowest Level in Sand Tank Trees	Reduced Fruit Size	Other Symptoms and Comments
N	**	2.3%	1.61%	*	Greatly reduced shoot growth, good fruit quality
P	**	–	.06%	*	Fruit drop, nectarine cracking, early defoliation
K	–	1.0%	.82%	–	No clear deficiency effects yet
S	*	-	830 ppm	*	Reduced shoot growth, often closely correlated with N
Ca	*	–	.79%	–	A few fruit quality problems, some leaf symptoms in 2003, not 2004
Mg	?	.25%	.20%	–	Some leaf symptoms in 2003, not 2004
B	**	18 ppm	14 ppm	*	Reduced fruit set and shoot growth
Zn	**	15 ppm	5 ppm	*	Definite leaf symptoms, fruit quality problems
Mn	–	20 ppm	26 ppm	–	No deficiency yet, some plums as low as 23 ppm
Fe	*	60 ppm	39 ppm	*	Minor effects
Cu	*	–	3.1 ppm	*	Minor effects
Mo	?	-	<.05	–	Very low in plums

other tissues at reflecting the wide range of added fertilizers. Some nutrients in the roots were consistently low no matter how much fertilizer had been added. Flowers, on the other hand, had just the opposite situation. Often, their nutrient concentrations were very high, even in trees showing evidence of deficiency. Therefore, shoot samples will be the focus of this report, even though ongoing evaluations will continue with root and flower samples.

Figure 1. The relationship between dormant shoot B and percent fruit set of Zee Lady peaches in 2003.

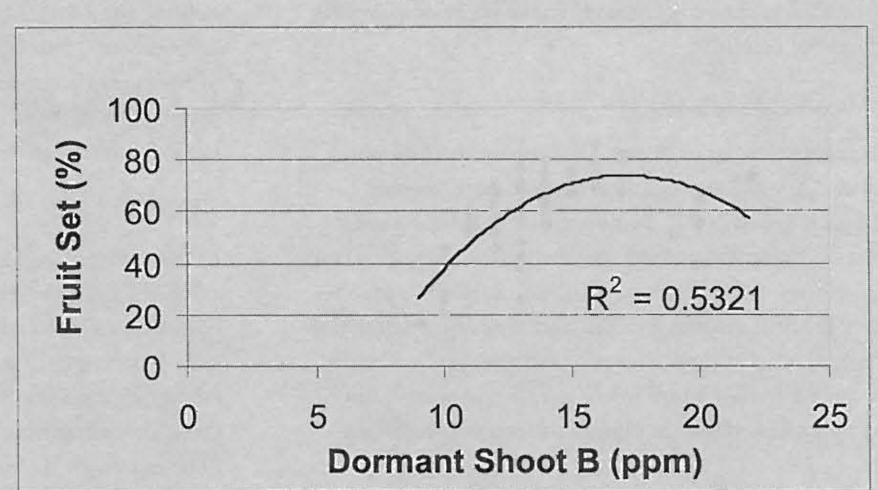
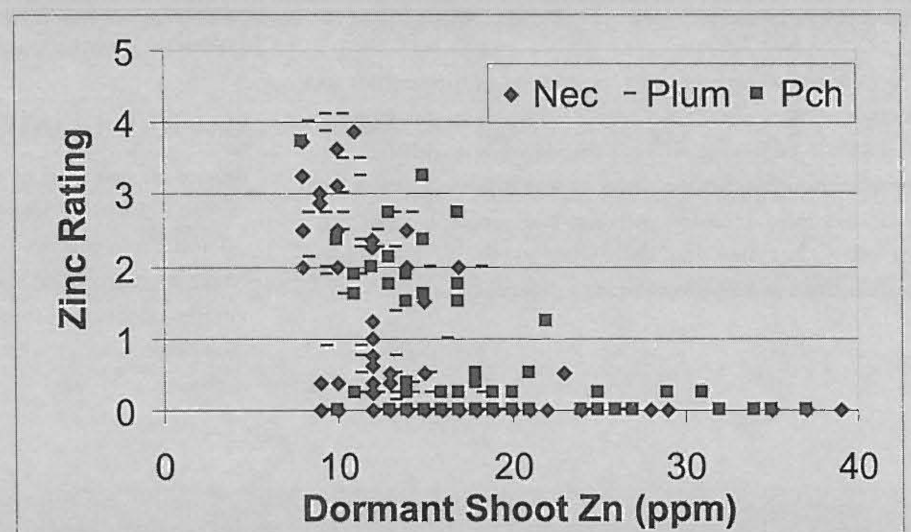


Figure 2. The relationship between dormant shoot Zn and spring Zn deficiency symptoms of peaches, plums and nectarines in 2004. Zinc rating is the average of 4 experts and is based on a 0 (none) to 5 (severe symptoms) scale.



In order to determine a deficiency threshold it is necessary to correlate nutrient concentrations to some sort of "problem" in the tree such as the occurrence of leaf symptoms or the inhibition of a physiological process. The only nutrient with distinct and unique deficiency leaf symptoms was zinc. Deficiencies of the other nutrients often caused a general slowing of shoot and fruit growth without any distinguishing leaf marks. In these cases, total vegetative growth, as measured by growth in a trunk cross-sectional area, and final fruit size was useful in establishing deficiency thresholds. In addition, other processes such as fruit set, fruit drop and fruit cracking, were clearly affected by individual nutrients (Table 1). All of this information was used in establishing N, P, B and Zn deficiency thresholds for dormant shoots of peaches and nectarines.

NITROGEN (N)

Nitrogen deficiency was easy to impose on these trees growing in sand culture. Typical symptoms of reduced shoot growth, yellow leaves, reddish stems, smaller fruit size, more highly colored fruit, earlier ripening fruit, and more smooth fruit finish were all observed. Midsummer leaf samples as low as 1.6% N were obtained, indicating extreme deficiency. At the other extreme, N levels over 4.0% were measured, creating a wide range of values with corresponding large differences in tree vigor.

Despite these substantial differences, the result of the dormant shoot sampling was disappointing. Values ranged from .91 to 1.88%, but often the low N trees were no different than high N trees. It is still unclear why these results were obtained. Perhaps it is somehow related to the sand culture system or the fertilization practices employed there. Other nitrogen experiments conducted by the authors and other scientists suggest dormant wood is a good indicator of the N status of fruit trees. Based on these various studies, a tentative deficiency threshold of 1.5% will be used as the project moves to the phase of surveying commercial orchards.

PHOSPHORUS (P)

Phosphorus deficiency started showing up in a few peach trees in 2003 and was clearly evident in both peaches and nectarines in 2004. Symptoms included substantial reduction in both vegetative and fruit growth, fruit cracking in nectarines, more flattened fruit (side to side) in peaches, preharvest fruit drop in peaches, and premature defoliation in both peaches and nectarines. As these leaves senesced, they tended to have more red or purple coloration rather than the typical yellow or orange color of well-fertilized trees.

Concentrations of P in dormant shoots varied from .06 to .18 %, which is a little lower than the values found in midsummer leaf samples. Typical summer leaf values in the sand tank trees varied from .10 to .24 %. Most deficiency symptoms were particularly severe below shoot values of about .11 to .12 % P for both peach and nectarine.

BORON (B)

Over the past couple of years, percent set in the peaches and nectarines has varied considerably from tree to tree (from 5 to 86%). Generally, this has correlated best with tree B status, although other nutrients appear to have played a secondary role. Trees low in B also had smaller fruit size at harvest. Other than that, there were no other leaf symptoms or reductions in vigor to indicate a deficiency.

Midsummer leaf concentrations ranged from 12 to 36 ppm B in the sand tank trees. Dormant shoot samples were considerably lower, but showed about the same variability, ranging from 8 to 22 ppm. Generally, when values dropped below about 13 to 14 ppm, there was a substantial decrease in fruit set or fruit size. Figure 1 is an example of the relationship between dormant shoot B and fruit set in Zee Lady peach for 2003.

ZINC (ZN)

In the spring of 2004, about half the sand tank trees exhibited some degree of Zn deficiency symptoms. Four pomology experts independently rated the trees on a scale from 0 to 5, with 5 indicating severe symptoms. The average of these four scores was graphed against dormant shoot Zn concentration for that tree (Figure 2). Although some trees with Zn values as low as 9 and 10 ppm showed no detectable deficiency symptoms, the majority of trees with these levels exhibited extreme deficiency. At concentrations above 20 ppm, there were no indications of deficiency in any trees.

Several other yield components were also affected by Zn deficiency. Fruit size tended to be smaller and nectarine cracking was increased. A deficiency threshold of 20 ppm in dormant shoots applied to these parameters as well.

CONCLUSION

Based on two years of data, dormant shoots appear to be a reliable tissue for determining the nutrient status of N, P, B and Zn in peaches and nectarines. Deficiency thresholds have been proposed for these nutrients (Table 2) and will be used to evaluate commercial orchards in the next phase of the project.

Table 2. Proposed deficiency thresholds of N, P, B and Zn in dormant shoots of peaches and nectarines.

Nutrient	Proposed Deficiency Thresholds
Nitrogen	1.5%
Phosphorus	.12%
Boron	14 ppm
Zinc	20 ppm

CROP NITRATE AVAILABILITY AND NITRATE LEACHING UNDER MICRO-IRRIGATION FOR DIFFERENT FERTIGATION STRATEGIES

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INTRODUCTION

Fertigation is the process of applying fertilizers through the irrigation water. For micro-irrigation systems, a recommendation frequently used for fertigation is to inject during the middle one-third or the middle one-half of the irrigation set time to insure a field-wide uniformity of applied fertilizer equal to that of the irrigation water and a relatively uniform chemical distribution in the root zone. However, a common practice is to fertigate for a short period of time, i.e. one or two hours is common. The primary motivation for this practice is convenience. Short-term fertigation events could result in relatively nonuniform distributions of fertilizer in the root zone and an increased potential for fertilizer leaching depending on the fertigation strategy.

OBJECTIVES

1. To determine the effect of different fertigation strategies for micro-irrigation systems on water and nutrient use efficiencies and on nitrate leaching using state-of-the-art modeling tools.
2. To develop jointly a publication and slide show for our target audience, highlighting the recommendations using color graphics of two-dimensional simulation results to illustrate the effect of proposed fertigation strategies on the movement of nitrate for various microirrigation systems.

DESCRIPTION

The computer simulation model HYDRUS-2D was used to assess the effect of various fertigation strategies on water and nitrate distribution in the root zone and on nitrate leaching. Outputs of the model include distributions of nitrate and soil water and a mass balance of nitrate in different parts of the root zone.

Fertigation scenarios evaluated by the model are:

— Micro-irrigation systems were 1) SPR - microsprinkler (citrus) using a sprinkler discharge rate of 2.6 l/h (SPR); 2) DRIP - surface drip irrigation (grapes) using 3.7 l/h emitters; 3) SURTAPE - surface drip irrigation (strawberries) using drip tape with a tape discharge rate of 334 l/h-100m; and 4) SUBTAPE - subsurface drip irrigation (tomatoes) using drip tape buried at 0.2 m with a tape discharge rate of 164 l/h-100m.

— Soil types: sandy loam (SL), loam (L), silt clay (SC), anisotropic silt clay (AC) with a ratio of horizontal hydraulic conductivity to vertical conductivity equal to five.

— Fertigation strategies include 1) B – inject for two hours starting one hour after start of irrigation; (2) M - inject for 2 hours in the middle of the irrigation set; 3) E - inject for two hours starting three hours before cutoff of irrigation water; 4) M50 - during the middle 50% of the irrigation set time (M50); and 5) C - inject continuously during the irrigation set starting one hour after start of irrigation and ending one hour before irrigation cutoff.

Assumptions used for the modeling include 1) maximum evapotranspiration conditions and an irrigation efficiency of 85%; 2) an irrigation set time sufficiently long to apply the desired amount of water; 3) no nitrate in the soil profile at

Figure 1. Patterns of nitrate around the drip line for SUBTAPE - sandy loam at the end of the irrigation for A) fertigation for 2 hr at the beginning of the irrigation starting 1 h after start of irrigation; B) fertigation for 2 h ending 1h before the end of the irrigation; C) fertigation during the middle 50 percent of the irrigation set; and D) continuous fertigation starting 1 h after start of irrigation and ending 1 h before irrigation cutoff. Duration of irrigation was 27 h. The black dot shows the location of the drip line. Concentrations are relative to the nitrate concentration of the irrigation water for the 2-h fertigation strategies.

Nitrate distribution for DRIP - loam showed a leached zone in the immediate vicinity of the drip line for the B strategy (Fig. 2A). Nitrate was distributed in the vicinity of the drip line for the E strategy with concentrations much higher compared to the B strategy (Fig. 2B). The M50 and C strategies resulted in a more uniform nitrate distribution compared to the other strategies (Fig. 2C and 2D). Similar patterns were found for the sandy loam.

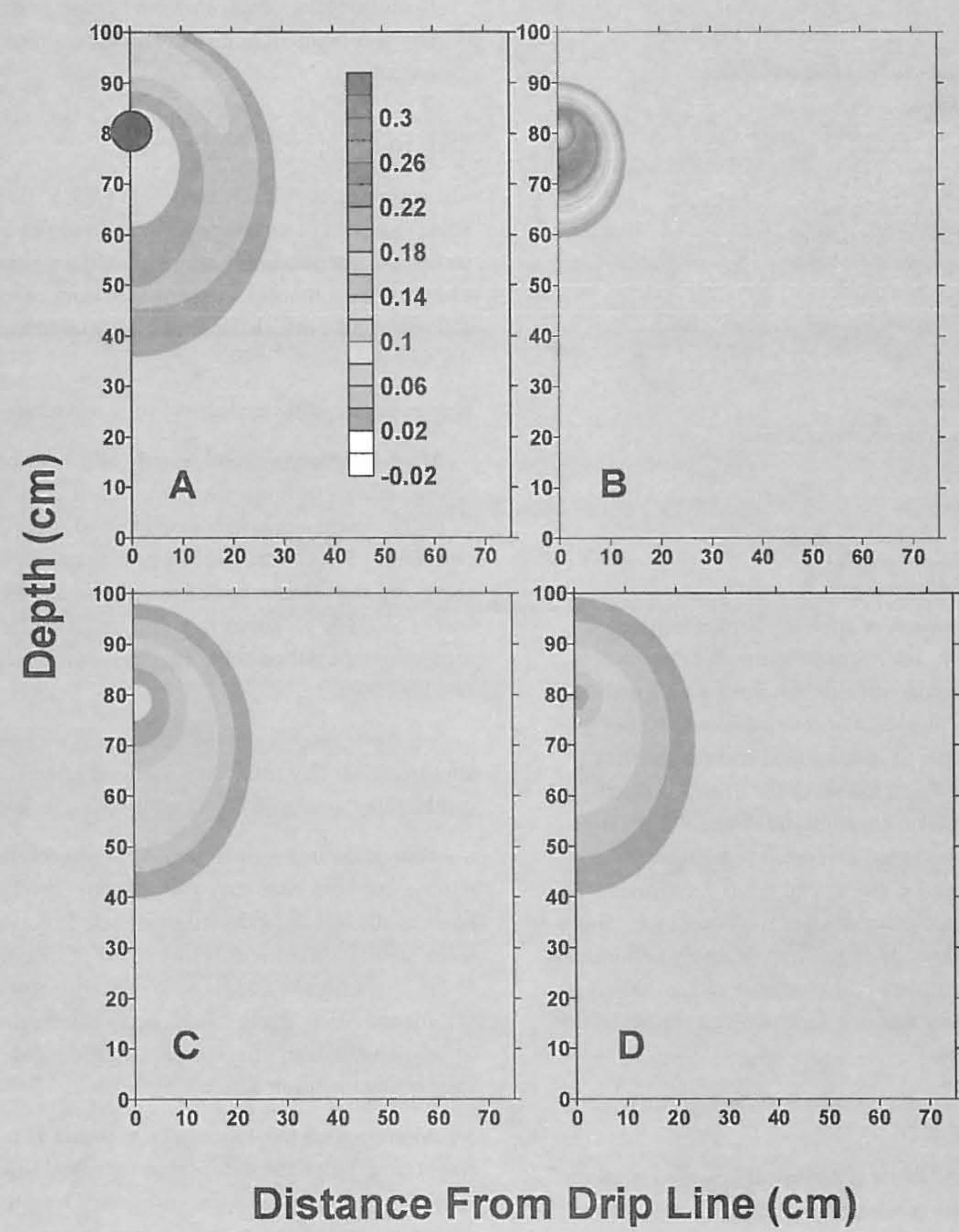

Figure 2. Patterns of nitrate around the drip line DRIP - loam at the end of the irrigation for A) fertigation for 2 hr at the beginning of the irrigation starting 1 h after start of irrigation; B) fertigation for 2 h ending 1h before the end of the irrigation; C) fertigation during the middle 50 percent of the irrigation set; and D) continuous fertigation starting 1 h after start of irrigation and ending 1 h before irrigation cutoff. Duration of irrigation was 36 h. The black dot shows the location of the drip line. Concentrations are relative to the nitrate concentration of the irrigation water for the 2-h fertigation strategies.

Nitrate distributions for DRIP - silt clay (Fig. 3) differed from those of the loam and sandy loam (not shown). Water ponded on the soil surface, which caused downward water flow instead of the radial flow found in sandy loam and loam soil. The downward flowing water resulted in a horizontal band of nitrate for the B strategy (Fig. 3A). The E strategy resulted in a narrow zone of nitrate near the surface (Fig. 3B). Nitrate was dispersed more uniformly in the upper part of the soil profile for strategies M50 and C (Fig. 3C and 3D).

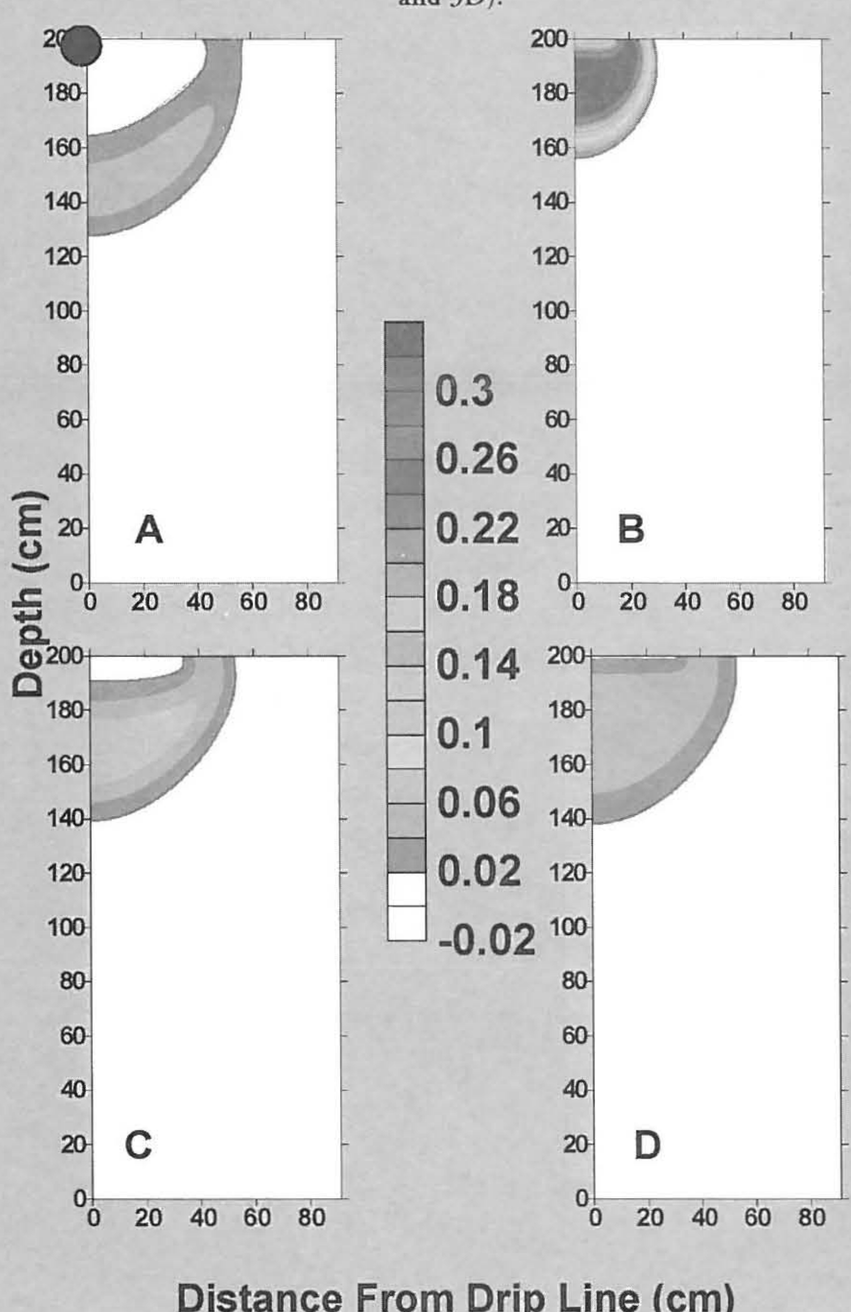

Figure 3. Patterns of nitrate around the drip line for DRIP - silt clay at the end of the irrigation for A) fertigation for 2 hr at the beginning of the irrigation starting 1 h after start of irrigation; B) fertigation for 2 h ending 1h before the end of the irrigation; C) fertigation during the middle 50 percent of the irrigation set; and D) continuous fertigation starting 1 h after start of irrigation and ending 1 h before irrigation cutoff. Duration of irrigation was 36 h. The black dot shows the location of the drip line. Concentrations are relative to the nitrate concentration of the irrigation water for the 2-h fertigation strategies.

Nitrate distributions of the microsprinkler reflected the water application pattern of the microsprinkler. Most of the water applied by this sprinkler occurred within about 1.2 m from the sprinkler (data not shown). Injecting near the beginning of the irrigation for a short time period leached most of the nitrate down in the soil profile (Fig. 4A), whereas injecting near the end of the irrigation left most of the nitrate near the soil surface (Fig. 4B).

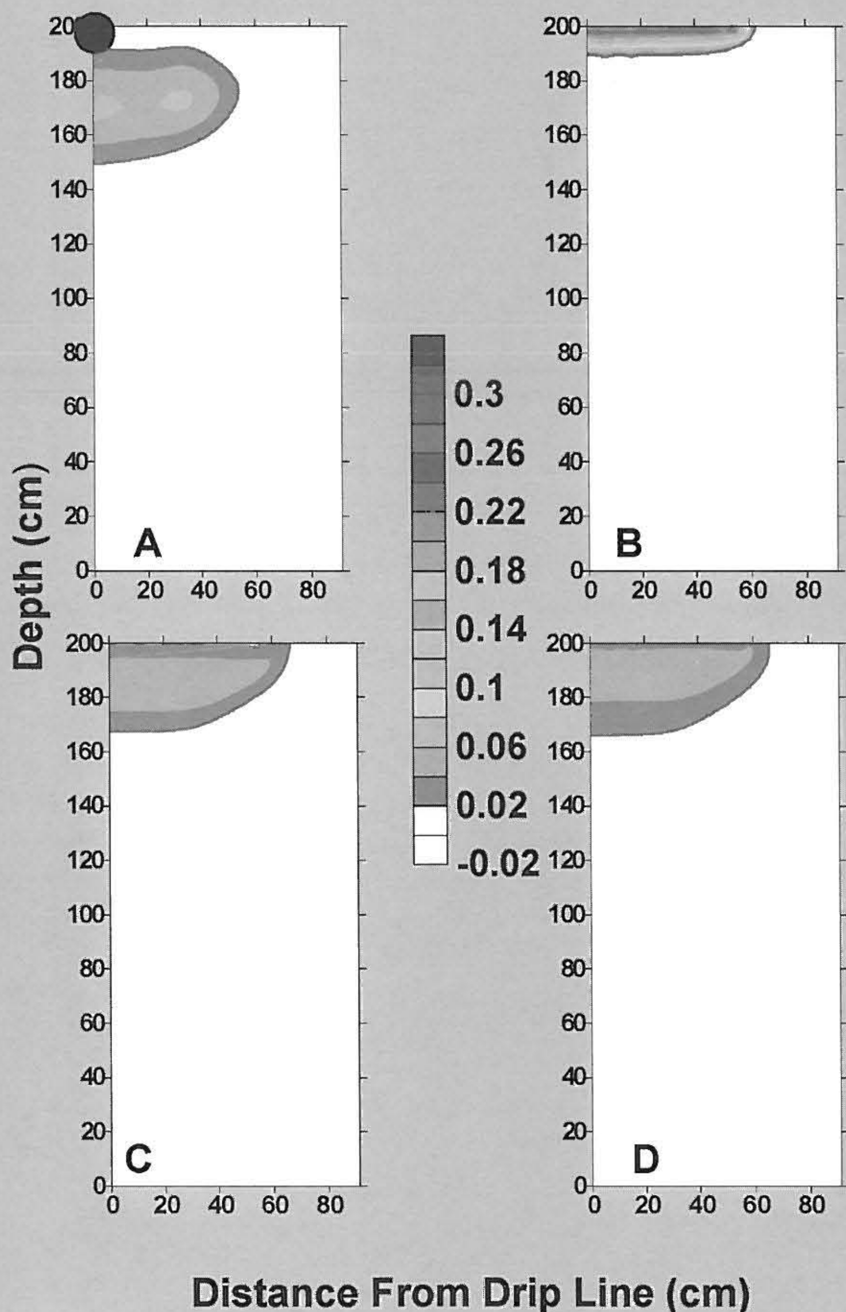

Figure 4. Patterns of nitrate around the drip line for SPR - sandy loam at the end of the irrigation for A) fertigation for 2 hr at the beginning of the irrigation starting 1 h after start of irrigation; B) fertigation for 2 h ending 1h before the end of the irrigation; and C) fertigation during the middle 50 percent of the irrigation set. The black dot shows the location of the drip line. Concentrations are relative to the nitrate concentration of the irrigation water for the 2-h fertigation strategies.

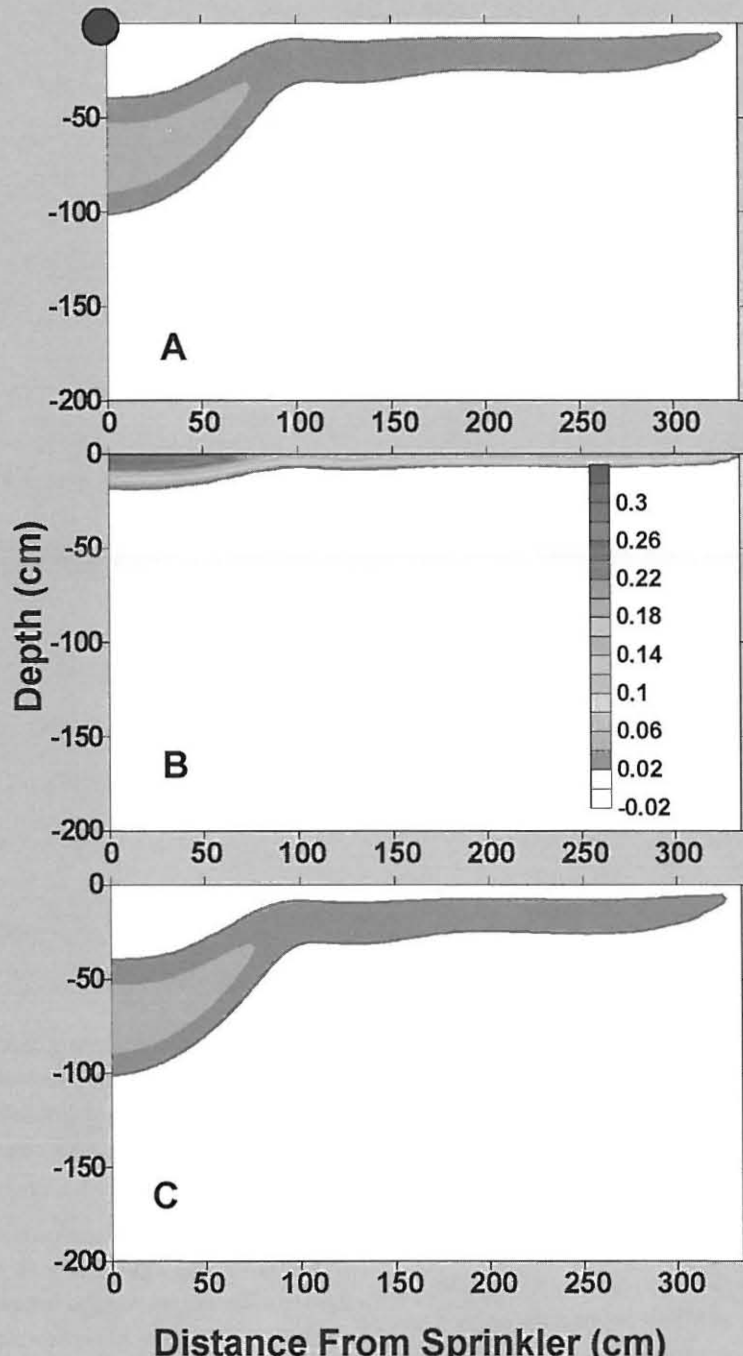

Table 1. Percentage of N leached, as a fraction of the total N added.

Soil Type	Fertigation Strategy	% N leached of total N added			
		SPR	DRIP	SURTAPE	SUBTAPE
SL	B	12.98	22.57	23.12	6.65
	M	10.30	33.15	23.12	8.65
	E	7.60	13.42	22.68	6.59
	C	10.34	28.52	22.69	7.90
	M50	10.32	32.05	23.32	8.43
	Average	10.30	25.94	22.98	***7.64***
	STD (CV,%)	1.90 (18)	8.13 (31)	0.29 (1.3)	***0.98 (13)***
L	**B**	7.64	9.20	13.02	0.19
	M	5.87	7.20	12.28	0.19
	E	4.22	2.78	11.37	0.14
	C	5.89	6.69	12.13	0.18
	M50	5.88	7.00	12.38	0.19
	Average	5.90	6.57	12.24	***0.18***
	STD (CV,%)	1.21 (20)	2.33 (35)	0.59 (5)	***0.024(13)***
SC	**B**	1.64	1.96	3.60	0.02
	M	0.90	0.45	8.14	0.02
	E	0.43	0.78	13.85	0.01
	C	0.95	0.91	10.45	0.01
	M50	0.91	0.82	6.58	0.02
	Average	0.97	0.99	8.52	***0.01***
	STD (CV,%)	0.43 (43)	0.57 (58)	3.88 (46)	***0.003 (21)***
AC	**B**	0.204	0.037	4.302	0.000013
	M	0.100	0.015	8.649	0.000008
	E	0.042	0.007	14.232	0.000003
	C	0.109	0.019	10.626	0.000008
	M50	0.103	0.016	7.615	0.000008
	Average	0.112	0.019	9.085	***0.000***
	STD (CV,%)	0.059 (55)	0.011(57)	3.677(40)	***0.00 (0)***

the start of simulation; 4) quasi-equilibrium soil moisture content patterns at the start of the fertigation scenarios; and (5) and the same amount of nitrogen injected for each scenario.

RESULTS AND CONCLUSIONS

Nitrate distributions for SUBTAPE - sandy loam showed a zone of leached soil in the immediate vicinity of the drip line for the B strategy with a zone of nitrate beyond the leached soil due to the relatively long irrigation time after fertigation (Fig. 1A). For the E strategy, however, relatively high nitrate concentrations occurred in the immediate vicinity of the drip line (Fig. 1B). Upward movement of nitrate was much higher for the B strategy due to the relatively dry soil above the drip line at the beginning of fertigation compare to the E strategy. Nitrate distributions of the M50 and C strategies showed a more uniform distribution over more of the soil profile compared to the 2-h fertigation strategies (Fig. 1C and 1D).

Similar nitrate distributions occurred for SURTAPE for all fertigation strategies except for the E strategy (data not shown). The reason for this behavior was the relatively small irrigation times of this scenario. Thus, for the short fertigation events, which were 0.5 h, irrigation times following fertigation were relatively small.

Nitrate moved more in the horizontal direction than in the vertical for the anisotropic silt clay scenarios (data not shown).

In general, fewer nitrates were leached from the root zone for the E strategy compared to the other strategies (Table 1). A more continuous fertigation results in a more uniform distribution of nitrate in the soil. However, more nitrate leaching occurred for SURTAPE compared to the other micro-irrigation methods, reflecting the shallow root depth, about 0.3 m, of the crop (strawberries) used for this scenario. Leaching was the highest for sandy loam compared to the other soil types.

TILLAGE AND CROPPING SYSTEM EFFECTS ON RUNOFF AND WATER QUALITY FROM IRRIGATED AGRICULTURE IN CALIFORNIA

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INTRODUCTION

Agricultural activities are potential non-point sources of pollution of California's surface water. Beginning in January 2005, new regulations will hold California growers accountable for known pollutants draining off of their land. Minimum tillage (MT) and winter cover cropping (CC) are two practices for reducing runoff and minimizing nutrient and sediment losses. The plant canopy and residue cover in MT and CC systems can lead to improved water quality through enhanced infiltration.

To demonstrate this effect on irrigated agriculture in California, this project has established a network of automated water samplers at the long-term UC Davis Sustainable Agricultural Farming Systems (SAFS) research plots and in grower fields in the surrounding Central Valley. The automated samplers provide year-round monitoring of surface runoff to assess the effectiveness of MT and CC in reducing runoff quantity and improving runoff quality. Runoff volume and water quality parameters including turbidity, suspended sediment, total dissolved nitrogen and phosphorous, phosphate, inorganic nitrogen, dissolved organic carbon, and herbicides are being determined. Relationships of surface runoff from rainfall/irrigation and management practices will be used to develop monitoring tools for different land uses and management practices such as minimum tillage and cover cropping to minimize the export of water constituents of concern.

OBJECTIVES

1. To quantify the amount of runoff from plots and fields

farmed using conventional, low-input, and organic practices including comparisons of conservation versus standard tillage. (Conventional fertility management relies on commercial fertilizer alone; low-input integrates cover cropping and commercial fertilizer, while organic fertility management combines manures and cover cropping).

2. To quantify the concentrations of water constituents such as suspended sediment, total dissolved nitrogen and phosphorous, inorganic nitrogen and phosphate, herbicides, and dissolved organic carbon.
3. To develop monitoring tools for different land uses and management practices such as minimum tillage and cover cropping. These tools will be useful to growers, policymakers, and the general public by providing a straightforward method that can identify sources of TMDL violations and to minimize the export of water constituents of concern.

DESCRIPTION

This project is a three-year effort to quantify relationships between tillage, fertility management, runoff, and nutrient losses from soils farmed using several different management strategies. Measurements necessary to quantify these relationships are being made in grower fields in the surrounding Central Valley, as well as at the Sustainable Agriculture Farming Systems (SAFS) research site, now located at the Long-Term Research in Agricultural Systems (LTRAS) experiment at UC Davis' Russell Ranch. SAFS is an effort created in 1988 by a multidisciplinary team of researchers, growers, and farm advisors to perform long-term comparisons of conventional, low-input, and organic farming systems. All three management systems include a comparison of conservation vs. standard tillage. The experiment will also take advantage of growers' interest in examining relationships between tillage, cover cropping, and nutrient runoff.

At the research site, plots of one-half acre in size (to allow use of full-scale farm equipment) are being treated with a tillage x farming system factorial design for conventional, organic, and low-input systems. The cropping system is a 2-year tomato-corn rotation. All farming-system treatments are using "best grower management practices," which are determined by consensus of the research team, which includes growers and farm advisors. The SAFS project is unique in that growers participate in every stage of the research process, including planning and design, execution, and interpretation and dissemination of results.

The conventional systems are being managed with practices typical of the surrounding area, which include the use of synthetic fertilizers and pesticides. In the low-input systems, fertilizer and pesticide inputs are being reduced, primarily by using legume cover crops to improve soil fertility, and predominantly mechanical cultivation for weed management. The organic system is managed according to the regulations of California Certified Organic Farmers (CCOF, 1995), with no use of synthetic chemical pesticides or fertilizers. Instead, management includes the use of cover crops, composted animal manure, mechanical cultivation, and limited use of CCOF-approved products. The project group, prior to planting and after harvesting, decides upon the tillage practices. The well-developed SAFS outreach structure will be used to extend models and results generated from the study to growers, farm advisors, policymakers, and the general public.

MEASUREMENTS

Runoff from each of the SAFS plots is channeled through a trapezoidal flume draining into a ditch at the end of each plot. In grower's fields, runoff is channeled through a drainage ditch and measured with an area-velocity (AV) sensor placed at the bottom of the ditch. Both setups use an ISCO 6712 portable sampler and datalogger (ISCO, Lincoln, NB) to collect data on the quantity of runoff. This system allows readings to be taken several times a minute so that the velocity and volume of runoff can be plotted over time and directly related to rainfall intensity.

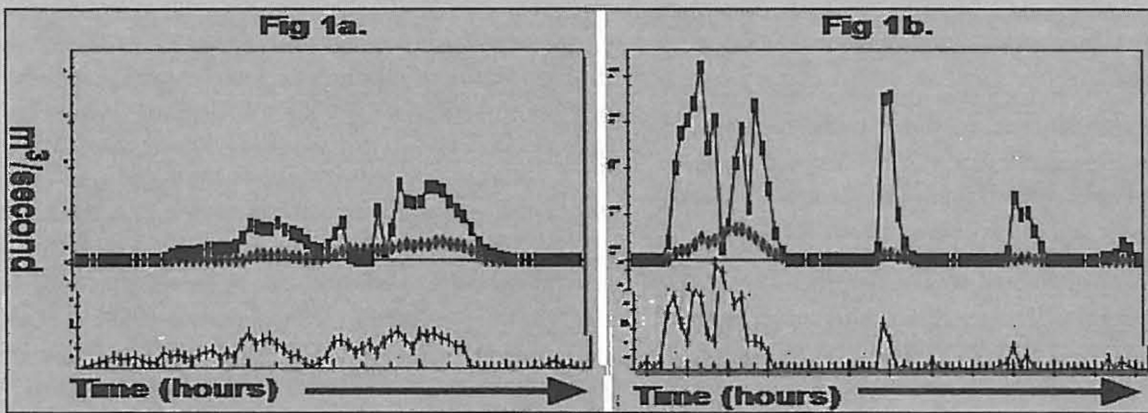
In addition to the runoff volume measurements, water samples are taken at regular intervals by the portable sampler during storm or irrigation events. When overland flow of a specified head and time interval are detected, an internal datalogger signals the auto-sampler to commence a preprogrammed sampling protocol. Individual samples of up to 1000mL are then automatically dispensed into polyethylene bottles, which are collected from the field within 24 hours of sampling. Fresh samples are analyzed for EC, pH, and turbidity, and then filtered for determination of total suspended solids. The filtrate is refrigerated and analyzed for total dissolved nitrogen and phosphorous, inorganic nitrogen, phosphate, dissolved organic carbon, and herbicides.

RESULTS AND CONCLUSIONS

QUANTITY OF RUNOFF

Initial results from the grower's field during the 2003-2004 rain season show a stark contrast in runoff quantity between a field planted in a winter legume/oats cover crop and a field

Figure 1a and b. Runoff (m3/second) from grower's non-cover cropped (NCC) and cover cropped (CC) fields in early storm season (a) and late storm season (b). The highest, darker line represents the NCC field. The lighter, middle line is CC. The bottom line is rainfall.



with no plant cover (Fig. 1a and 1b). Notably, the quantity of runoff discharged from the winter CC field was less than one-tenth the runoff of winter non-cover cropped (NCC) fields, or about 1% of total rainfall. In addition, yields between treatments showed no significant difference. Our findings indicate a difference between the two treatments shortly after winter cover crop emergence, suggesting that even a minimal canopy cover can affect runoff quantity (Fig. 1a).

The results support previous research showing increased infiltration through the use of cover crops. Surface runoff occurs when water inputs, in the form of rainfall or irrigation, exceed the rate of infiltration. Covering the soil in the winter with a cover crop or crop residue performs three functions that minimizes impact energy of raindrops on the soil surface, slows overland flow, and improves soil tilth. These three functions relate to an improvement in water infiltration.

QUALITY OF RUNOFF

AMMONIUM AND NITRATE

For a single two-day rain event measured in the grower's fields on February 25th and 26th of 2004, the NCC runoff contained twice the ammonium concentrations and four times the nitrate concentrations compared to the CC field (Fig. 2). The uptake of ammonium and nitrate in the cover crop no doubt decreased their movement in runoff compared to the NCC field. Additionally, increased water infiltration in the CC field may have led to the movement of nitrate deeper into the soil profile making it less susceptible to move in runoff. Furthermore, the larger or more active microbial biomass most likely increases the immobilization of inorganic N in the CC fields.

Figure 2. Average concentrations (mg/L) of ammonium and nitrate from grower's fields were lower in the CC field compared to the NCC field during late-season two-day storm event.

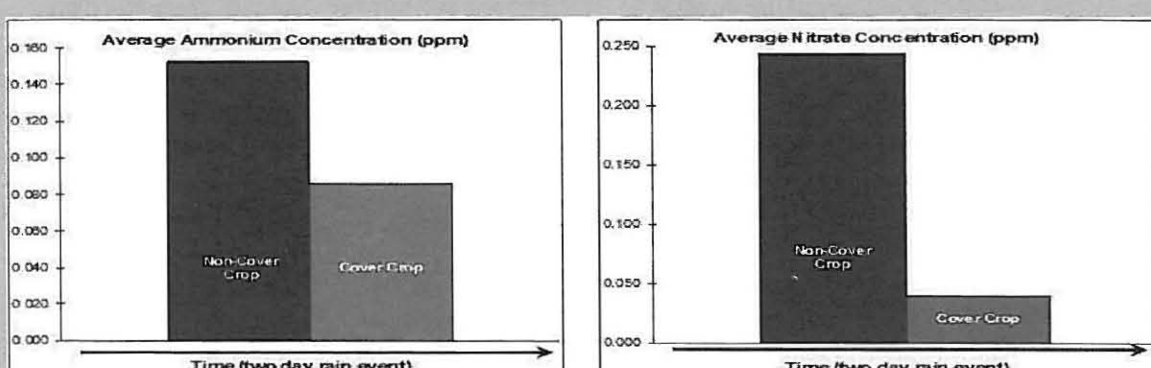
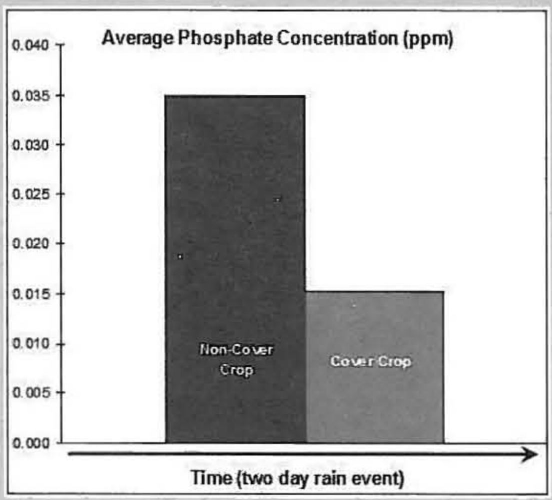


Figure 3. Average concentration (mg/L)of phosphate from grower's field during late-season two day storm event was two fold higher in NCC field compared to CC field.



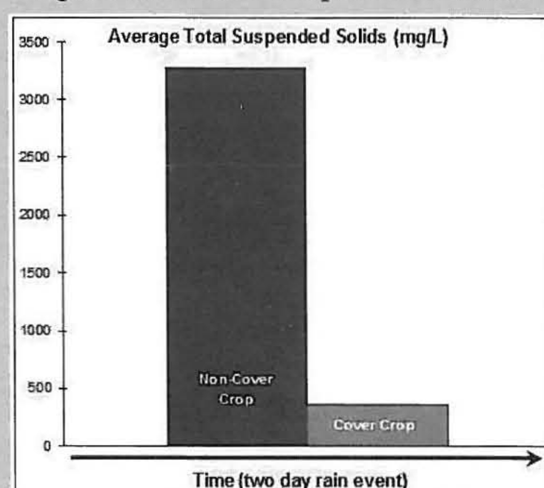
PHOSPHATE AND TOTAL SUSPENDED SOLIDS

Phosphorus (P) transported from most cultivated land occurs in the form of P attached to soil minerals and organic material eroded during runoff events. Consequently, runoff and soil erosion from agricultural lands are major causes of surface water P contamination. In our study, average concentrations of phosphate were twice as high in the grower's NCC field compared to the CC field for the two-day rain event mentioned above (Fig 3). This appears to be related to the higher sediment concentration in the NCC runoff compared to the CC runoff (Fig. 4). The lower sediment concentration in the CC field may be related to the lower flow velocities observed during runoff events. Our findings once again are supported by past research. As mentioned earlier, cover cropping provides vegetative cover during periods when water runoff energy is high, as does minimum tillage residue. The CC system in this experiment appears to be preventing the detachment and rearrangement of soil particles that result in the creation of soil seals. Preventing the development of soil seals can be particularly important in areas such as the Central Valley of California, where soils have low slopes, thus, detachment from rainfall, as opposed to overland flow, is the dominant erosion process. The surface cover of the CC field served to increase infiltration, prevent creation of soil seals, minimize overland flow, and prevent sediment from leaving the field.

OPPORTUNITIES FOR GROWTH

The most reliable data collection of winter runoff was limited to a single two-day event from the grower's fields on February 25th and 26th of 2004 due to several complexities that were presented to our team in the first storm season. The ISCO 6712 portable sampler was chosen for this project because of its ease of use and accuracy in data collection. However, the sampler was not designed for this particular scale of operation and therefore there were unique challenges specific to our project related to direct on-farm monitoring. To begin with, storm event length and intensity are unpredictable. Furrow dimensions and dynamics change after storm events, irrigation, and cultivation. Each field changes throughout the season as aboveground biomass accumulates. Storm events, irrigation, and cultivation change dimensions of furrows and drainage canals. The duration of irrigation events change throughout growing season, influencing velocity and quantity of runoff as well as sediment load. Grower's management practices and timing are different for every crop and field. Finally, overshadowing these dynamics is that each field has different slopes, soils, and grower management practices. The natural variation associated with agroecosystems is an important factor to consider when monitoring for water quality. Lessons learned about data collection methods by the researchers on this project will be shared with coalition groups and regulators when monitoring begins in 2005.

Figure 4. Average concentration (mg/L) of total suspended solids from grower's field during lateseason two-day storm event were 8 times higher in NCC field compared to CC field.



CHOOSING A LANDSCAPE COMPANY: GUIDELINES FOR HOMEOWNERS IN CALIFORNIA

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INTRODUCTION

Homeowners have recently been targeted as contributors to non-point source pollution problems. Materials applied to yards and other landscaped areas, run-off the properties into storm drains, and ultimately into water bodies that have multiple beneficial uses. Many of these water bodies are on the State's 303(d) list of Impaired Water Bodies. Because of its large size, it is almost impossible to regulate the general population, with regard to maintenance of their yard and landscaped areas, and pollution resulting from those activities. However, it has been noted, that large numbers of homeowners or homeowners' associations contract their landscape maintenance to commercial landscape personnel. This provides an opportunity for homeowners to specifically request certain practices from the landscape companies, and also an opportunity for the landscape companies to market environmentally sound practices.

OBJECTIVES

1. To develop educational materials and a corresponding educational outreach effort regarding environmentally sound practices for lawn and garden care.

DESCRIPTION

The primary educational product is a booklet entitled "Choosing a Landscape Company: Guidelines for Homeowners in California," covering best management practices for plant selection, fertilization practices, irrigation practices, pest management, and weed control. A corresponding interview questionnaire for use by homeowners when selecting a landscape company is also under development. The outreach efforts include educational seminars and distribution of materials through landscape trade associations, homeowners' associations, and municipalities and county governments. This is a cooperative project between University of California, Cooperative Extension, San Diego County, and the California Plant Health Association.

EVALUATING THE IMPACT OF NUTRIENT MANAGEMENT ON GROUDWATER QUALITY IN THE PRESENCE OF DEEP UNSATURATED ALLUVIAL SEDIMENT

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INTRODUCTION

Over the last four decades, intensive use of agrochemicals has been recognized as a major source of surface and groundwater deterioration and associated ecological problems worldwide. In the USA, under various state and federal regulatory guidelines, agriculture is now increasingly evaluated for its major contribution to groundwater contamination. Among chemicals used to enhance agricultural productivity, nitrate is of particular interest due to its widespread use, high mobility, and persistence. Agricultural growth particularly in the San Joaquin Valley of California has led to not only increased demand for groundwater but also groundwater pollution by extensive use of nitrate. The occurrence of nitrate in water sources throughout the Valley offers graphic evidence that nitrate is not contained in the root zone.

In the Valley, public awareness in water quality problems caused by agricultural practices is rising; yet, the mechanisms governing the migration of fertilizers, particularly nitrate, below the root zone are poorly understood. The vadose zone, as a critical link between the land surface and groundwater, plays an essential role in the development of nutrient management protocols. Currently, the principal tool for predicting nitrate leaching potential to groundwater is a root zone nutrient mass balance method based on estimating N fluxes in the root zone. If coupled with a water budget analysis, this method can predict the mass of N accumulation below the root zone and annual N mass flux to groundwater. Field scale spatial variability of soil hydraulic properties below the root zone still remains unaccounted for in most of groundwater quality assessment studies. To properly investigate the impact of agricultural practices on groundwater quality, an emerging task is to analyze the physical processes and transport behavior of nitrate in the deep vadose zone, where it exists, instead of the past practices that focused on the top soil horizon (0 – 30 cm) or on the root zone (0 – 180 cm), or exclusively on the saturated zone.

OBJECTIVES

The major objective of our work is to investigate the influence of thick, predominantly alluvial unsaturated sediments on nitrate leaching to groundwater at a long-term research orchard with a stratigraphy typical of many areas on the east side of the San Joaquin Valley. Our specific objectives are:

§ to assemble an intensive database for a detailed geologic, hydraulic, and biochemical characterization of the Kearney Research site, Fresno, located on the Kings River alluvial fans, utilizing the data obtained from a long-term (12-year) nitrate fertilizer experiment conducted at the site

§ to perform advanced statistical and geostatistical analyses to describe the spatial variability of physical and biochemical properties.

§ to determine the soil physical properties of the vadose zone in relation to the major sedimentary facies identified at the site.

§ to develop modeling strategies to investigate the effects of physical and biochemical heterogeneity on nitrate transport in the deep vadose zone to assess the impact of various nitrate fertilizer management practices on groundwater quality.

A comprehensive assessment of nitrate transport in a 15.8-m deep alluvial vadose zone is implemented to better understand the role of a deep vadose zone in evaluating the long-term impact of agricultural practices, in particular in irrigated orchards in the California Central Valley, on groundwater quality. The approach taken in this study combines advanced statistical and geostatistical data analyses to demonstrate the observed spatial variability of water flux and nitrate in the vadose zone beneath a former "Fantasia" nectarine orchard located at the Kearney Agricultural Center in Fresno, California. We here report on our results from three models developed using the database that had been constructed earlier from field and laboratory data as the basis for modeling flow and nitrate transport beneath the orchard.

A long-term numerical experiment was conducted to simulate transient, two-dimensional flow and nitrate transport through the entire vadose zone and to estimate potential for N leaching to groundwater. The simulations are carried out for two alternative N management practices with an annual fertilizer rate of 110 and 365 kg N/ha. The simulations emulate actual, temporally varying site boundary conditions for flow and nitrate transport utilizing data obtained from a 12-year fertilizer experiment (1982-1995) conducted at Kearney Research Site. Three modeling approaches are demonstrated to quantify the impact of vadose zone subsurface heterogeneity on nitrate fate and transport through the deep alluvial vadose zone; to predict nitrate mass storage below the root zone (i.e., in the deep vadose zone); and to predict nitrate travel time and flux to groundwater. Each model demonstrates a different level of risk analysis to predict the loss of nitrate from the root zone, nitrate storage in the deep vadose zone and potential nitrate leaching to groundwater. The three different risk assessment levels represent different representations of the site subsurface. Each level is associated with an increasingly more detailed representation of the site heterogeneity (field, facies, and Darcy's).

A conventional field scale root zone nitrogen mass balance (MB) analysis is used in conjunction with uniform flow conditions through the deep vadose zone to estimate water and N fluxes out of the root zone from precipitation, irrigation, evapotranspiration, fertilization, and plant uptake data. The MB approach provides the first level risk assessment for the amount of nitrate in the deep vadose zone and nitrate travel time to groundwater from the three subplots. The other two models are numerical experiments conducted to simulate a two-dimensional transient flow and nitrate transport through the 15.8 m vadose zone. The horizontal simulation domain of 6.1 m (20 ft) represents the individual subplots of the original field experiment. The models were simulated over 7 years (1990 – 1997) for both the standard subplot (110 kg N/ha/yr) and the high application subplot (365 kg N/ha/yr) using temporally varying realistic site boundary conditions for flow (e.g., precipitation, irrigation, and crop evapotranspiration) and nitrate transport (fertilizer applications). Nitrate moves as a non-reacting solute (tracer) in the deep vadose zone, which is a simplification made based on the analysis of the measured biochemical properties for nitrate concentrations, soluble organic carbon, soil pH, and 15N isotopes.

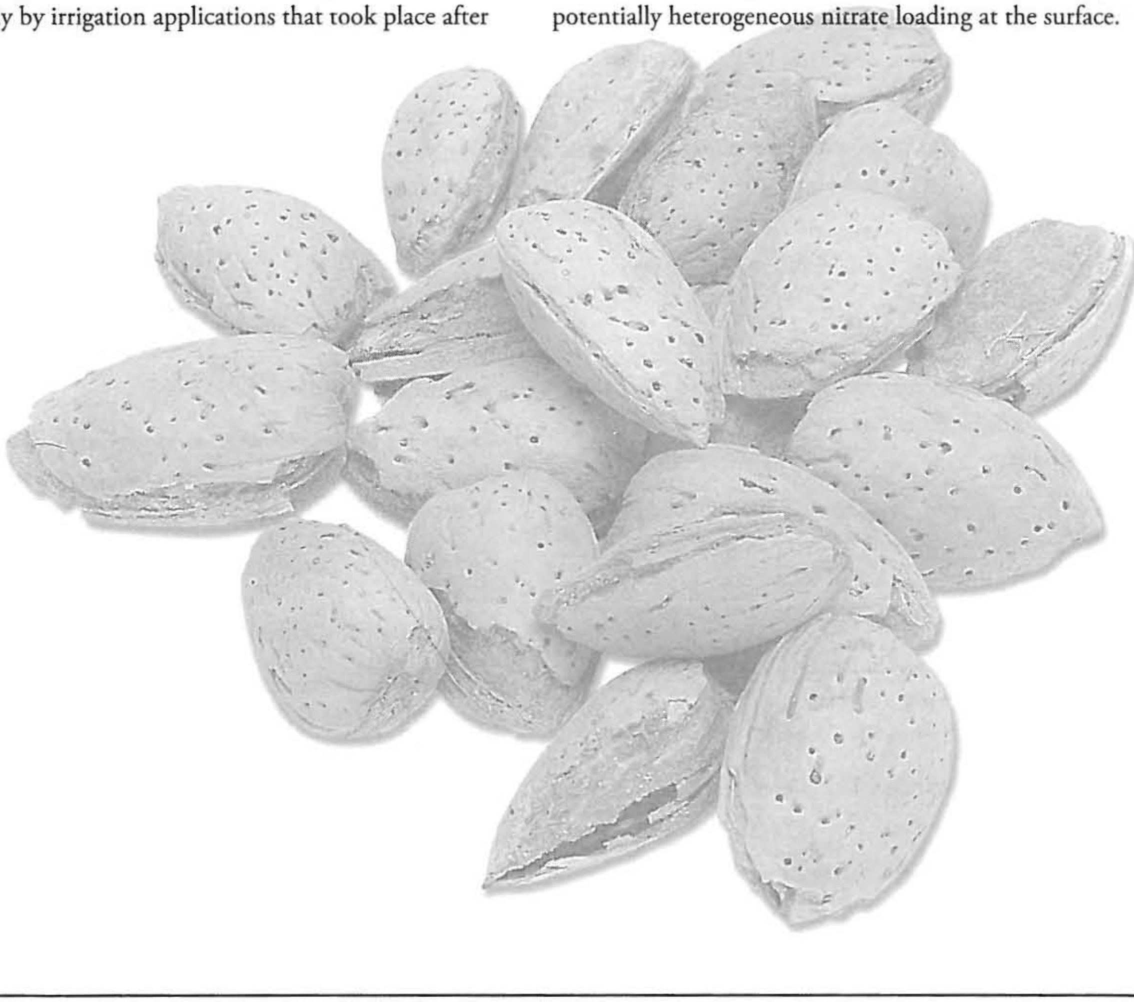
In the first of the two numerical models, the subsurface is composed of eight non-horizontal layers, representing the actual boundaries of major lithofacies that were identified at the field based on a visual inspection of soil cores for color, texture, and cementation. Each facies is conceptualized as a homogenous unit with average soil hydraulic parameters for the van Genuchten hydraulic model. Only the larger scale subsurface heterogeneity between facies is preserved. Soil properties vary between facies. This model is designed to gain familiarity of the subsurface flow system and boundary conditions in a manner that is simple and computationally less time demanding. The results are interpreted as the second level risk assessment of groundwater quality, and also used as the basis for the evaluation of more detailed characterization of the subsurface considered in the final numerical model.

The design of the second two-dimensional numerical flow and nitrate transport model is the same as the first numerical model for both simulation time period (7 yr, from 1990-1997) and spatial domain (610 X 1580 cm2). Herein, the effects of Darcy's scale heterogeneity on nitrate transport is examined by characterizing facies as a heterogeneous flow region as opposed to a homogenous system considered in the first numerical model. This model with a more refined discretization of the spatial heterogeneity represents the maximum, third level risk assessment in quantifying the role of deep vadose zone and in assessing potential nitrate leaching to groundwater.

The three models were used for a thorough quantitative evaluation of the total vadose zone nitrogen mass, which was also estimated directly via kriging measured nitrate and water content at the treatment sites. The measured nitrate from the vadose zone sampling (60 sediment cores drilled to the water table at 16 m) provides a validation framework for the comparison of the three different levels of risk assessments of the deep vadose zone nitrate storage and nitrate leaching to groundwater.

Our field data indicate that vadose zone nitrate is highly variable and that fertilizer treatment had a significant effect on nitrate levels in the vadose zone. However, the actual deep vadose zone nitrogen mass obtained by integrating (via kriging) measured data totaled only one-sixth to one-third of the mass predicted by the standard root zone nitrogen and water flux mass balance approach (1st level risk assessment). The results from the numerical models indicate that there is a profound effect of atmospheric boundary conditions on water flux throughout the vadose zone, despite the presence of a deep vadose zone above groundwater. Temporal changes in the mean pressure head both in the root zone and in the deep vadose zone are primarily controlled by irrigation wetting regimes. The results further suggest that irrigation management practices are not well integrated with the site climate conditions and crop water requirements. Substantial amount of nitrate is carried through the root zone primarily by irrigation applications that took place after the fall fertilizer application and to a lesser extent by winter precipitation. The practice of fall fertilization was established in the early days of dry-farming when growers depended on winter rains to carry applied N into the root zone. Our results suggest that the timing of the fertilizer applications should be reevaluated.

Deep vadose zone nitrate mass estimated from both numerical models, with homogenous or heterogeneous facies, are remarkably similar. But they are significantly different from the mass estimated from kriging (measured nitrate mass). Vadose zone denitrification estimates could not account for this discrepancy. Instead, the discrepancy is attributed to highly heterogeneous flux conditions that are apparently not properly accounted for, even by the 3rd level risk assessment modeling approach. Our results suggest that scaling technique that was implemented to represent the highest spatial heterogeneity of the subsurface maybe oversimplifying the extend of heterogeneity observed at the site, leading to less realistic representation of the subsurface. Future work should investigate the discrepancies between the model results and the measured data by developing a model that highlights, for instance, the impact of the lack of third dimensionality in the current model and the impact of potentially heterogeneous nitrate loading at the surface.



COMPLETED PROJECTS

The following is a list of FREP projects completed prior to October 2003. Summaries of many of these projects appear in the 2002 and 2003 FREP Conference Proceedings. Previous conference proceedings and final project reports are available by calling FREP at (916) 445-0444.

FRUIT/NUT AND VINE CROPS

Fertilizer Use Efficiency and Influence of Rootstocks on Uptake and Nutrient Accumulation in Winegrapes
Larry Williams

Development of Nitrogen Fertilizer Recommendation Model for California Almond Orchards
Patrick Brown and Steven A. Weinbaum

Development of Diagnostic Measures of Tree Nitrogen Status to Optimize Nitrogen Fertilizer Use
Patrick Brown

Citrus Growers Can Reduce Nitrate Ground Water Pollution and Increase Profits by Using Foliar Urea Fertilization
Carol J. Lovatt

Development of Nitrogen Best Management Practices
Carol J. Lovatt

Crop Management for Efficient Potassium Use and Optimum Winegrape Quality
Mark A. Matthews

Potential Nitrate Movement below the Root Zone in Drip Irrigated Almonds
Roland D. Meyer

Field Evaluation of Water and Nitrate Flux through the Root Zone in a Drip/Trickle Irrigated Vineyard
Donald W. Grimes

Influence of Irrigation Management on Nitrogen Use Efficiency, Nitrate Movement, and Ground Water Quality in a Peach Orchard
R. Scott Johnson

Using High Rates of Foliar Urea to Replace Soil-Applied Fertilizers in Early Maturing Peaches
R. Scott Johnson and Richard Rosecrance

Nitrogen Efficiency in Drip Irrigated Almonds
Robert J. Zasoski

Effects of Four Levels of Applied Nitrogen on Three Fungal Diseases of Almond Trees
Beth Teviotdale

Nitrogen Fertilizer Management to Reduce Groundwater Degradation
Steve Weinbaum

Avocado Growers can Reduce Soil Nitrate Groundwater Pollution and Increase Yield and Profit
Carol Lovatt

Relationship Between Nitrogen Fertilization and Bacterial Canker Disease in French Prune
Steven Southwick, Bruce Kirkpatrick, and Becky Westerdahl

Relationship between Fertilization and Pistachio Diseases
Themis J. Michailides

The Effect of Nutrient Deficiencies on Stone Fruit Production and Quality
R. Scott Johnson

Development of Nitrogen Fertilizer Recommendation Model for California Almond Orchard
Steve Weinbaum

Long-term Nitrate Leaching Below the Root Zone in California Tree Fruit Orchards
Thomas Harter

Development of Nitrogen Best Management Practices for the "Hass" Avocado
Carol Lovatt

VEGETABLE CROPS

Soil Testing to Optimize Nitrogen Management for Processing Tomatoes
Jeffrey Mitchell/ Don May

Water and Fertilizer Management for Garlic: Productivity, Nutrient and Water Use Efficiency and Postharvest Quality
Marita Cantwell/Ron Voss/Blaine Hansen

Soil Testing to Optimize Nitrogen Management for Processing Tomatoes
Jeffrey Mitchell/Don May/Henry Krusekopf

Determining Nitrogen Best Management Practices for Broccoli Production in the San Joaquain Valley
Michelle LeStrange, Jeffrey Mitchell and Louise Jackson

Effects of Irrigation Non-Uniformity on Nitrogen and Water Use Efficiencies in Shallow-Rooted Vegetable Cropping Systems
Blake Sanden/Jeffrey Mitchell/Laosheng Wu

Demonstration of Pre-sidedress Soil Nitrate Testing as an Nitrogen Management Tool
Timothy K. Hartz

Drip Irrigation and Fertigation Scheduling for Celery Production
Timothy K. Hartz

Diagnostic Tools for Efficient Nitrogen management of Vegetables Produced in the Low Desert
Charles Sanchez

Evaluation of Controlled Release Fertilizers and fertigation in Strawberries and Vegetables
Warren Bendixen

Optimizing Drip Irrigation Management for Improved Water and Nitrogen Use Efficiency
Timothy K. Hartz

Improvement of Nitrogen Management in Vegetable Cropping Systems in the Salinas Valley and Adjacent Areas
Stuart Pettygrove

Nitrogen Management through Intensive On-Farm Monitoring
Timothy K. Hartz

Development and Promotion of Nitrogen Quick Tests for Determining Nitrogen Fertilizer Needs of Vegetables
Kurt Schulbach and Richard Smith

On-Farm Demonstration and Education to Improve Fertilizer Management
Danyal Kasapligil, Eric Overeem and Dale Handley

Evaluating and Demonstrating the Effectiveness of In-Field Nitrate Testing in Drip and Sprinkler Irrigated Vegetables
Marc Buchanan

Winter Cover Crops Before Late-Season Processing Tomatoes for Soil Quality and Production Benefits
Gene Miyao and Paul Robins

Efficient Irrigation for Reduced Non-Point Source Pollution from Low Desert Vegetables
Charles Sanchez, Dawit Zerrihun and Khaled Bali

Evaluation of Controlled Release Fertilizers for Cool Season Vegetable Production in the Salinas Valley
Richard Smith

Effect of Different Rates of N and K on Drip Irrigated Beauregard Sweetpotatoes
Bill Weir

Use of Ion Exchange Resin Bags to Monitor Soil Nitrate in Tomato Cropping Systems
Robert Miller

Site-Specific Farming Information Systems in a Tomato-Based Rotation in the Sacramento Valley
Stuart Pettygrove

FIELD CROPS

Developing Site-Specific Farming Information for Cropping Systems in California
G. Stuart Pettygrove, et.al.

Development and Testing of Application Systems for Precision Variable Rate Fertilization
Ken Giles

Management of Nitrogen Fertilization in Sudangrass for Optimum Production, Forage Quality and Environmental Protection
Dan Putnam

Impact of Microbial Processes on Crop Use of Fertilizers from Organic and Mineral Sources
Kate M. Scow

Effects of Various Phosphorus Placements on No-Till Barley Production
Michael J. Smith

Establishing Updated Guidelines for Cotton Nutrition
Bill Weir and Robert Travis

Nitrogen Budget in California Cotton Cropping Systems
William Rains, Robert Travis and Robert Hutmacher

Nitrogen Fertilization and Grain Protein Content in California Wheat
Lee Jackson

Interaction of Nitrogen Fertility Practices and Cotton Aphid Population Dynamics in California Cotton
Larry Godfrey and Robert Hutmacher

Development and Demonstration of Nitrogen Best Management Practices for Sweet Corn in the Low-Desert
Jose L. Aguiar, Keith Mayberry, Marita Cantwell-de-trejo and Charles Sanchez

Potassium Responses in California Rice Fields as Affected by Straw Management Practices
Chris van Kessel, William Horwath, John K. Williams, Eric Byous and Grace Jones

Long Term Rice Straw Incorporation: Does it Impact Maximum Yield?
Chris van Kessel and William Horwath

Location of Potassium-Fixing Soils in the San Joaquin Valley and a New, Practical Soil K Test Procedure
Stuart Pettygrove

Development of Irrigation and Nitrogen-Fertilization Programs for Turfgrass
Robert Green

HORTICULTURE CROPS

Development of Fertilization and Irrigation Practices for Commercial Nurseries
Richard Evans

Precision Horticulture: Technology Development and Research and Management Applications
Patrick Brown

Minimizing Nitrogen Runoff and Improving Nitrogen Use Efficiency in Containerized Woody Ornamentals Through Management of Nitrate and Ammonium-Nitrogen
Donald J. Merhaut

IRRIGATION AND FERTIGATION

Uniformity of Chemigation in Micro-Irrigated Permanent Crops
Larry Schwankl/Terry Prichard

Development of Irrigation and Nitrogen Fertilization Programs on Tall Fescue to Facilitate Irrigation Water Savings and Fertilizer-Use Efficiency
Robert Green and Victor Gibeault

Agricultural Baseline Monitoring and BMP Implementation: Steps towards Meeting TMDL Compliance Deadlines within the Newport Bay/ San Diego Creek Watershed
Laosheg Wu and John Kabshima

EDUCATIONAL/ MISCELLANEOUS

Improving the Fertilization Practices of Southeast Asians in Fresno and Tulare Counties
Richard Molinar and Manuel Jimenez

Western States Agricultural Laboratory Proficiency Testing Program
Janice Kotuby-Amacher and Robert O. Miller

Agriculture and Fertilizer Education for K-12
Pamela Emery and Richard Engel

Use of Ion Exchange Resin Bags to Monitor Soil Nitrate in Tomato Cropping Systems
Robert O. Miller and Diana Friedman

Education through Radio
Patrick Cavanaugh

Integrating Agriculture and Fertilizer Education into California's Science Framework Curriculum
Mark Linder and Pamela Emery

The Use of Composts to Increase Nutrient Utilization Efficiency in Agricultural Systems and Reduce Pollution from Agricultural Activities
Mark van Horn

Nitrogen Management for Improved Wheat Yields, Grain Protein and the Reduction of Excess Nitrogen
Bonnie Fernandez

Determination of Soil Nitrogen Content In-Situ
Shrini K. Updahyaya

Extending Information on Fertilizer Best Management Practices and Recent Research Findings for Crops in Tulare County
Carol Frate

Educating California's Small and Ethnic Minority Farmers: Ways to Improve Fertilizer Use Efficiency Through the Use of Best Management Practices (BMPs)
Ronald Voss

Survey of Changes in Irrigation Methods and Fertilizer Management Practices in California
John Letey, Jr.

Air Quality and Fertilization Practices: An Inventory of Fertilizer Application Practices for Agriculture in the San Joaquin Valley
Jack King, Jr.

Practical Irrigation Management and Equipment Maintenance Workshops
Danyal Kasapligil, Charles Burt and Eric Zilbert

Irrigation and Nutrient Management Conference and Trade Fair
Danyal Kasapligil

On-Farm Monitoring and Management Practice Tracking for Central Coast Watershed Working Groups
Kelly Huff

From the Ground Up: A Step-by-Step Guide to Growing a School Garden
Jennifer Lombardi

Development of an Educational Handbook on Fertigation for Grape Growers
Glenn T. McGourty

California State Fair Farm Upgrade Project
Michael Bradley, Joe Brengle and Teresa Winovitch

California Certified Crop Advisor Management Project
Hank Giclas

Teach the Teachers: Garden-Based Education about Fertility and Fertilizers
Peggy S. McLaughlin

Nitrogen Mineralization Rate of Biosolids and Biosolids Compost
Tim Hartz

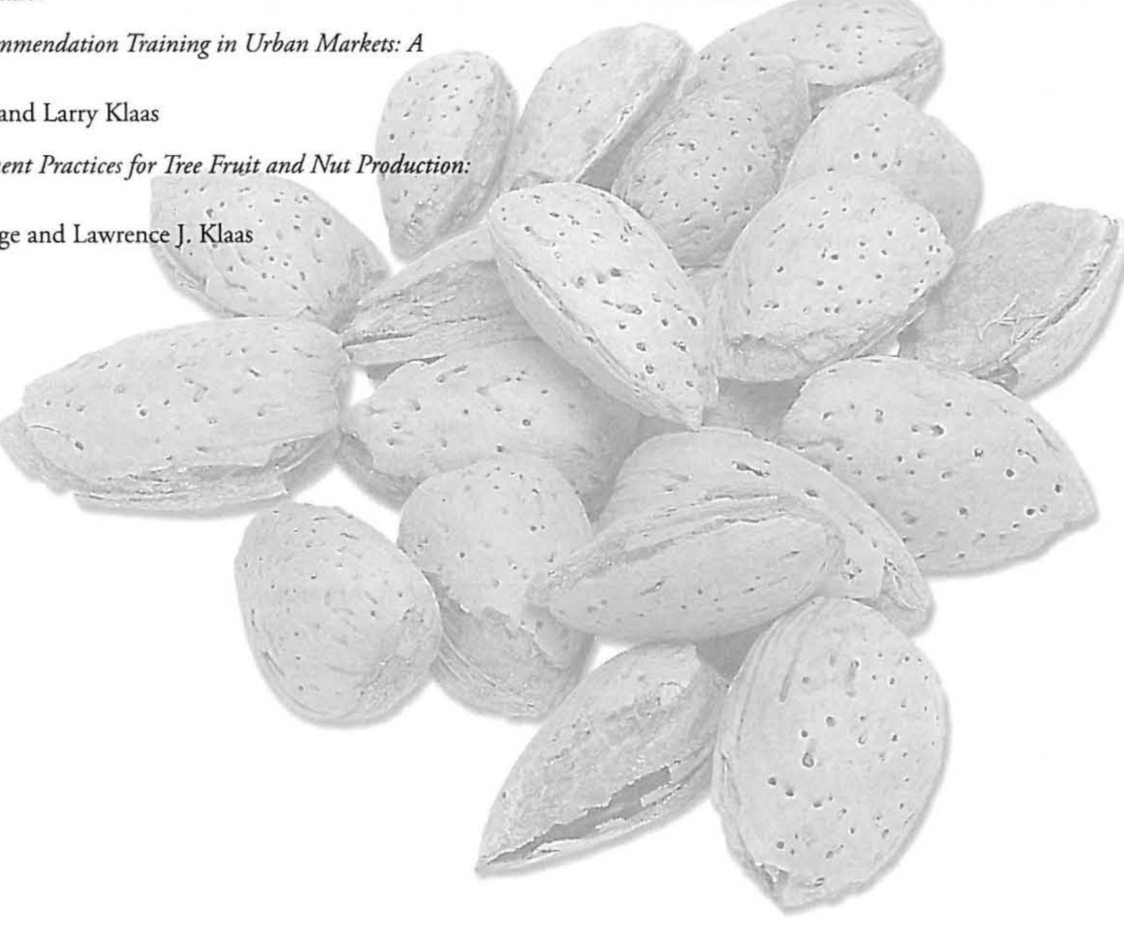
EDUCATIONAL VIDEOS

Best Management Practices for Nitrogen and Water Use in Irrigated Agriculture: A Video
Larry Klaas and Thomas Doerge

Drip Irrigation and Nitrogen Fertigation Management for California Vegetable Growers Videotape
Timothy K. Hartz

Nutrient Recommendation Training in Urban Markets: A Video
Wendy Jenks and Larry Klaas

Best Management Practices for Tree Fruit and Nut Production: A Video
Thomas Doerge and Lawrence J. Klaas



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