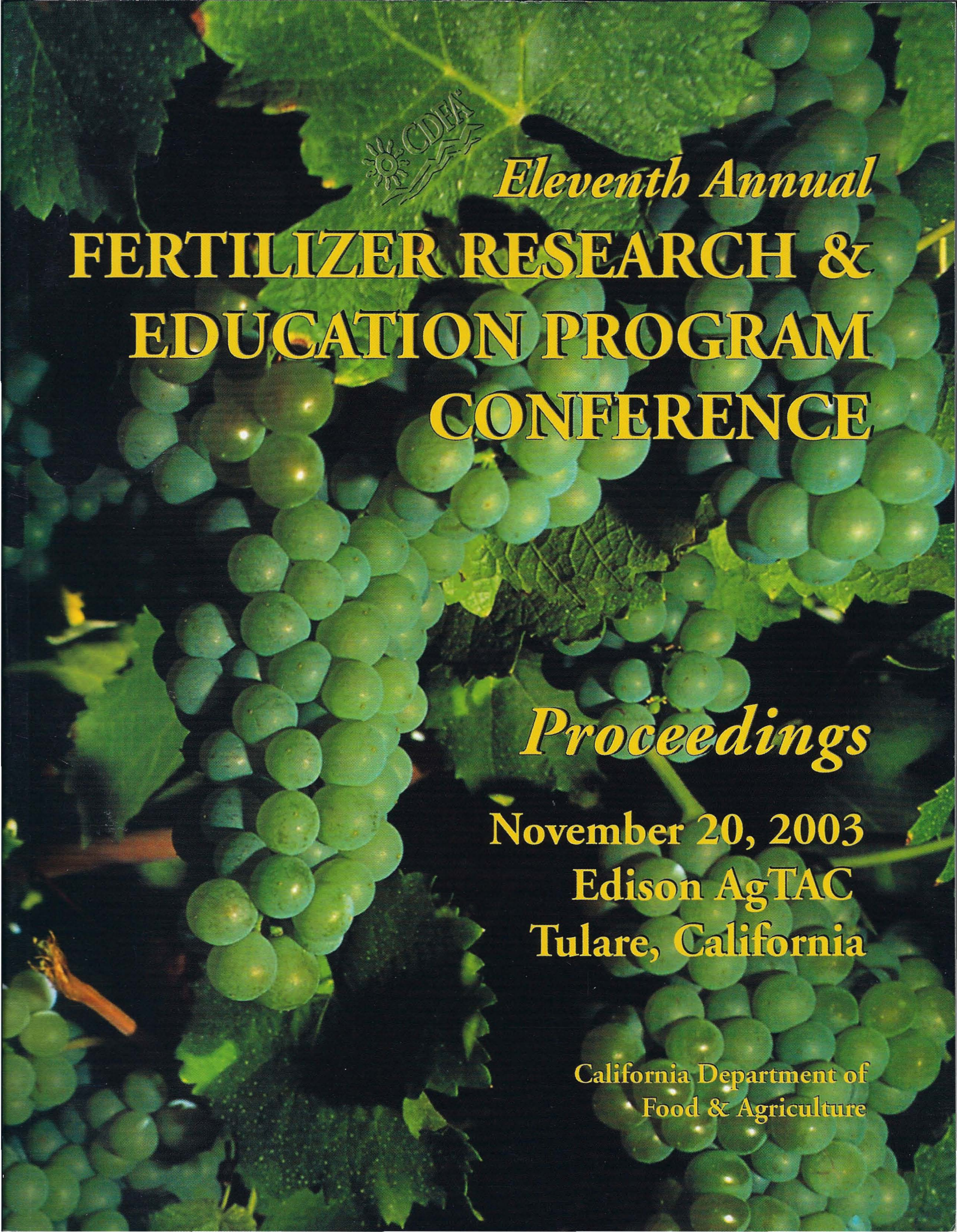

Eleventh Annual

FERTILIZER RESEARCH & EDUCATION PROGRAM CONFERENCE

Proceedings

November 20, 2003
Edison AgTAC
Tulare, California

California Department of
Food & Agriculture

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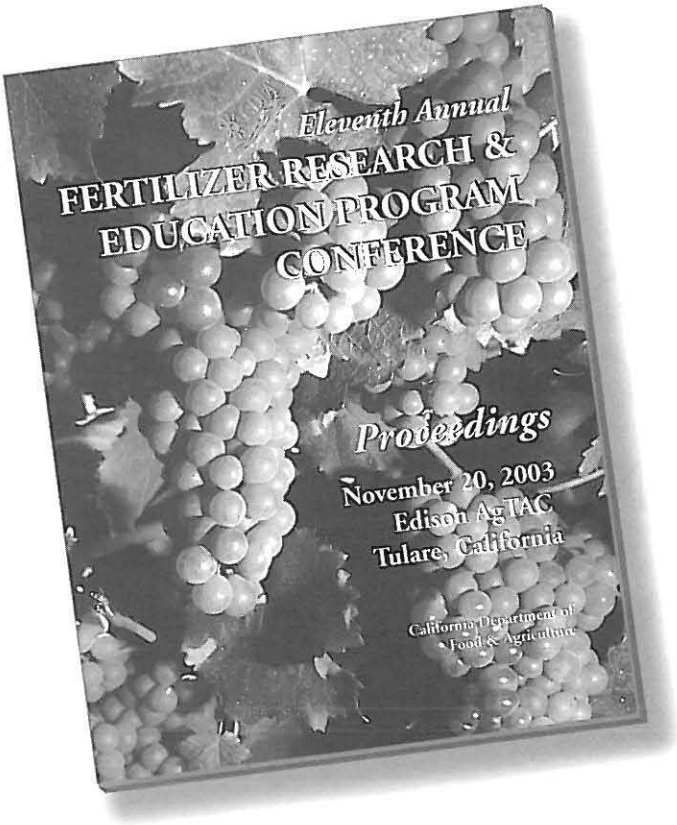
Sponsored by:

California Department of Food and Agriculture
California Plant Health Association
California Certified Crop Adviser Program



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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.

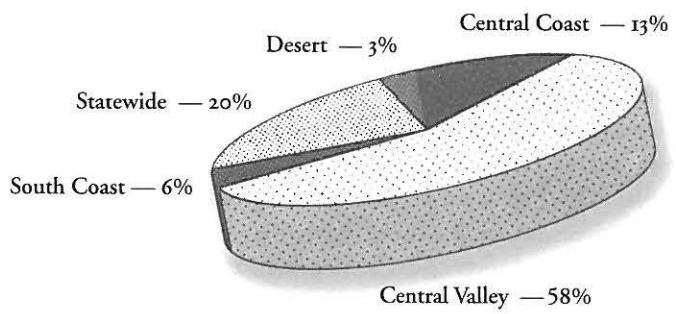
CURRENT FREP FUNDING PRIORITIES INCLUDE:

- 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

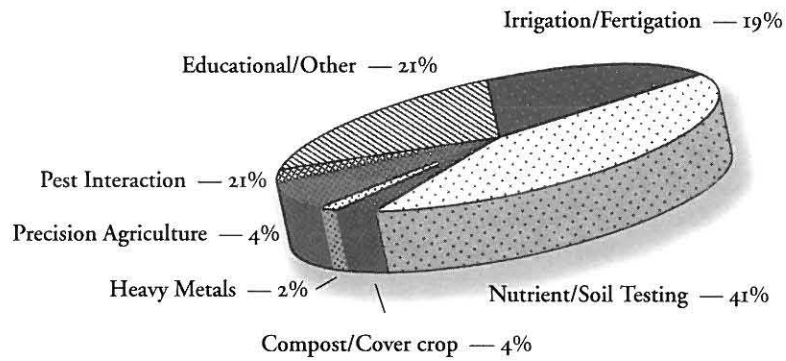
Figure 1. CDFA FREP Projects by Location: 1990-2003



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 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.

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



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.

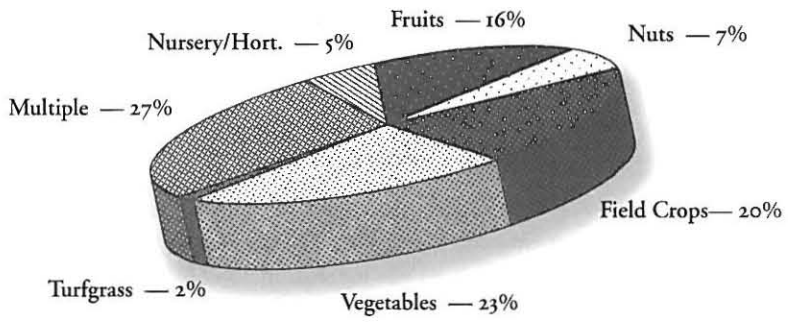
We have also continued our efforts in the area of agricultural literacy advancement. The California Plant Health Association (CPHA) has produced and distributed videos and companion materials that guide the viewer on developing, planning and installing gardens on school sites. To receive a copy of the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

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



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 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 Stephen Beam, Program Supervisor of the Agricultural Commodities and Regulatory Services Branch. Mindy McIntyre is recognized for her 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.

THE EFFECT OF NUTRIENT DEFICIENCIES ON STONE FRUIT PRODUCTION AND QUALITY

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INTRODUCTION

A system has been developed for studying the effect of nutrient deficiencies in mature peach, plum and nectarine trees. The project was initiated in 1999 using sixty large sand-filled tanks in the field. One tree each of Zee Lady peach, Fortune plum and Grand Pearl nectarine (white flesh) was planted in each tank. Differential fertilization treatments have been applied since the summer of 2000 (see previous FREP reports for design and treatment details). By the summer of 2003, very substantial differences among treatments were measured in leaf nutrient levels, shoot growth, tree size, flower production, fruit set, yield, fruit size, fruit defects and fruit quality parameters. We are still in the process of analyzing and interpreting the large amount of data collected. For this brief report, a few highlights will be presented to illustrate major findings. A more complete report will be available in early 2004.

Overall, this project is producing some very interesting and useful findings. Wide ranges of nutrients, from deficient to excess, have been established in the trees so their effect on different plant processes can be quantified. This has allowed us to re-evaluate the published deficiency levels for peaches, plums and nectarines. In some cases the published values appear to be too low, in other cases too high. With some of the nutrients we feel the sampling methodology may need to be changed. In the end we hope to have a revised set of standards which will help growers better interpret leaf analyses from the lab, and thereby optimize yield and fruit quality by proper corrective measures. It should also help reduce environmental contamination by eliminating unnecessary treatments.

OBJECTIVES

1. To induce nutrient deficiencies in full size peach, plum and nectarine trees growing in sand culture in the field and to study the effect of these deficiencies on tree growth, flowering, fruit quality, pest susceptibility and yield.
2. To produce high quality slides and color photos of deficiency symptoms and use these for various educational programs, including a laminated field handbook, our stone fruit manual and many extension meetings.

PROJECT DESCRIPTION

Combinations of fertilizer salts were applied to the different tanks in an effort to achieve the following treatments. Each treatment was replicated in four tanks.

Treatment 1 – All nutrients (Control)

Treatment 2 – No nutrients (-All)

Treatment 3 – No nitrogen (-N)

Treatments 4 & 5 – No phosphorus (-P)

Treatments 6 & 7 – No potassium (-K)

Treatments 8 & 9 – No calcium (-Ca)

Treatment 10 – No sulfur (-S)

Treatments 11 & 12 – No magnesium (-Mg)

Treatments 13, 14 & 15 – No micronutrients - B, Zn, Mn, Fe, Cu (-Micros)

Besides the mixture of salts (based on Hoagland solutions) applied to each treatment, an additional fertilization program was followed in 2002 and 2003 in order to achieve a wide range of nutrients among individual trees and to help depress the specific nutrient for a given treatment (see 2002 FREP report for details).

Leaf samples were collected from all 180 trees in early May and early July 2003. These were sent to the DANR analytical lab for determination of macro and micronutrients. Measurements of flowering and fruit set were taken in the spring, and yield and fruit quality parameters in July.

RESULTS AND CONCLUSIONS

At the time of this report, the July leaf samples were not back from the lab so only data from the May samples will be presented. In addition, the emphasis of the discussion will be on Zee Lady peach. In general, the other two varieties tended to show similar results. Finally, data will only be presented from 9 of the 15 treatments in order to illustrate some of the extreme effects without showing an overwhelming amount of information.

LEAF NUTRIENT LEVELS.

Extremes in leaf nutrients were obtained for just about every nutrient (Table 1). Levels that would be considered deficient were reached for N, P, Ca, Mg, B, Zn and Fe. The other nutrients, K, Mn and Cu were low but not quite deficient. In addition, high (but not toxic) levels were obtained for most of the nutrients. Almost all the nutrients had both higher and lower values in 2003 compared to the year before. Overall, the wide range of values and the low levels measured for each nutrient provide a very useful data set for examining their effects on tree and fruit parameters.

There were surprisingly few leaf deficiency symptoms observed on the trees, considering the very low levels measured in the leaves. Nitrogen deficiency was obvious in the –N and –All treatments, starting right after bloom. Early in the spring, some minor zinc and magnesium deficiency symptoms were apparent, but these tended to disappear as the weather warmed up. One tree in the –P treatment was

Table 1. Nutrient levels for Zee lady peach from leaf samples taken in May 2003. Nine of the 15 treatments are shown.

	Treatment								
Nutrient	Control	-All	-N	-P	-K	-Ca	-Mg1	-Mg2	-Micros
N (%)	3.74	2.87	2.59	3.68	3.66	3.80	3.76	3.56	3.59
P (%)	.25	.17	.17	.18	.16	.18	.24	.15	.24
K (%)	1.53	1.40	1.38	1.23	1.30	2.55	3.19	3.32	1.39
Ca (%)	1.85	2.09	2.24	1.52	1.51	.88	1.42	.94	1.89
Mg (%)	.51	.53	.52	.50	.72	.51	.30	.22	.55
B (ppm)	22.3	21.8	22.0	16.5	18.5	24.5	25.3	15.8	16.8
Zn (ppm)	19.8	13.0	17.0	24.0	22.0	23.5	13.8	17.5	14.8
Mn (ppm)	90	57	52	49	53	48	77	44	60
Fe (ppm)	56	44	35	50	47	47	52	47	46
Ca (ppm)	8.0	4.7	5.1	6.8	6.1	5.6	5.8	4.9	6.5

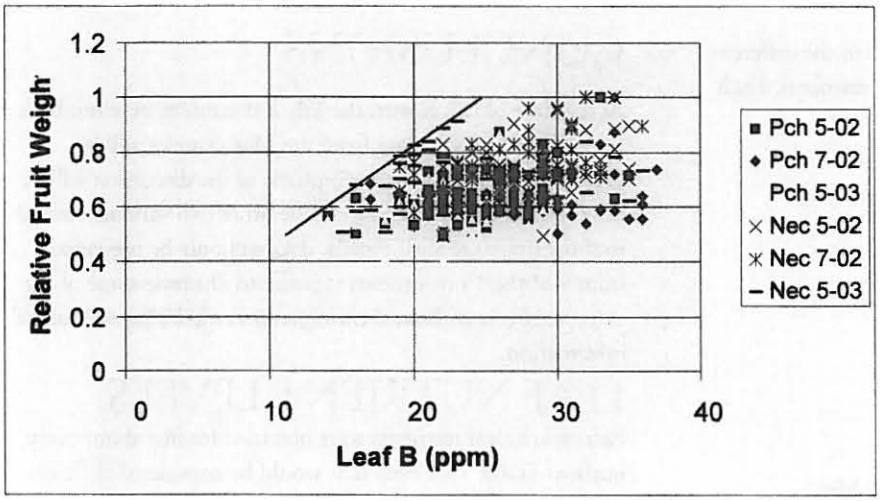

Figure 1. *Plot of relative fruit weight (actual fruit weight/ maximum fruit weight for that variety) vs leaf boron (ppm) collected from Zee Lady peach and Grand Pearl nectarine over 3 sampling dates in 2002 and 2003. The boundary line represents the theoretical maximum fruit weight possible at a given B level.*

weak with purplish leaves – symptoms that have often been associated with phosphorus deficiency. Calcium deficiency symptoms have never been described for peach trees in the field so we weren't sure what to look for. The –Ca treatment had some minor leaf necrosis symptoms in the early spring which disappeared by summer. Otherwise, there was no major dieback, defoliation or severe necrosis in any of the treatments. By midsummer the trees in general looked very healthy and vigorous.

FLOWERING AND FRUIT SET

In 2002, flower density varied considerably among the different treatments. However, in 2003 the treatments were all about the same (Table 2) despite the wide range in leaf nutrients. The difference may be due to tree age. Sometimes it takes a few years for trees to settle into a flowering mode. By 2003, the trees were more mature and it appears nutrition had little effect on flower bud formation. Our experience in the past has suggested peach trees flower fairly consistently under a wide range of conditions. Sometimes they even flower more heavily under stress conditions.

On the other hand, fruit set varied considerably among the treatments (Table 2). Initial fruit set was less than 50% in the –Mg2 treatment and decreased to 23% after "June drop." At the other extreme, the –N treatment retained 78% of its fruit through final set. Therefore, it appears that nitrogen deficiency does not decrease fruit set. Instead, magnesium seems to play a major role. Correlations with leaf nutrients also suggest, boron, calcium and phosphorus have some influence on fruit set. For fresh market stone fruit, where extensive hand thinning is required, a high level of fruit set is not

Table 2. Flowering, fruit set and harvest parameters for Zee Lady peach in sand tank experiment.

	Treatment								
Parameter	Control	-All	-N	-P	-K	-Ca	-Mg1	-Mg2	-Micros
Flower Density (#/cm)	.37	.29	.36	.34	.37	.38	.34	.39	.34
Initial Set (%)	88	75	93	82	74	76	75	48	76
Final Set (%)	76	55	78	64	58	63	61	23	53
Fruit Weight (%)	185	122	112	146	125	126	142	119	141
Cracked Fruit (%)	1.5	3.9	4.4	5.6	5.8	1.5	5.4	32.7	2.6
Yield (kg/tree)	21.7	10.1	9.9	15.8	11.6	10.5	13.7	9.2	12.6

necessary (in fact, it can be a detriment in many situations). Therefore, other than the extreme reduction due to magnesium deficiency, the subtle differences among the other treatments is probably not commercially important.

FRUIT WEIGHT

Fruit size is very important to the profitability of an orchard and appears to be significantly affected by almost every nutrient. The large variation from tree to tree and among treatments was similar to the results from 2002 (Table 2). Every treatment had substantially smaller fruit weight than the control even though many of the trees showed no deficiency symptoms and appeared quite healthy and vigorous. We have made a concerted effort to make sense of and statistically analyze the large database of information we have collected thus far.

Efforts at correlation studies or regression analyses have not been very fruitful. Instead, we have made use of an approach called boundary line analysis. This method has been utilized successfully to determine optimum nutrient levels in field crops. It requires a large database, often obtained from multiple experiments. When the data points are plotted, with a measure of productivity (yield, fruit weight, etc.) on the y-axis and the nutrient of interest on the x-axis, a clear boundary line is often apparent. Figure 1 shows an example of this from our sand tank experiment, with relative fruit weight plotted against leaf B. Three sampling dates were combined for both Zee Lady peach and Grand Pearl nectarine in order to create a large database.

There is a lot of scatter in the data, but notice that no data points exist in the upper left portion of the graph. A boundary line can be drawn along the edge of the data points. Theoretically, this line sets the limits of fruit weight as affected by boron. For example, at a leaf B level of 15 ppm (in either May or July) fruit size will not exceed 70% of maximum fruit size potential. It may be smaller than 70%, probably because of other limiting nutrients or stresses, but will not exceed that boundary. This line can then be used to set deficiency thresholds. For the data in Figure 1, a threshold of about 25 ppm B would be set for peaches and nectarines. Currently, the published threshold is 18 ppm.

Plots similar to Figure 1 have been made for the other nutrients as well. Often, placement of the boundary line is not quite as clear because of a lack of data points in the region of interest on the graph. As more sampling is carried out, the database will be expanded and more definitive boundary lines can be established.

FRUIT QUALITY

At harvest, samples were taken into the lab and evaluated for several parameters of fruit quality. These included firmness, % red color, % soluble solids content and fruit defects. Most of these data are still being summarized and will be presented at a later date. One defect, skin cracking, was very obvious on the trees and varied considerably among treatments (Table 2). Nearly one third of the fruit on the –Mg2 treatment showed this disorder, while the control trees only had 1.5%. Therefore, magnesium deficiency seems to be a major cause of skin cracking, although –Mg2 was also low in P, B and Ca. These other nutrients were probably involved in the disorder as well. It is interesting to note that the –Ca treatment had no more skin cracking than the control.

NITROGEN MANAGEMENT IN CITRUS UNDER LOW VOLUME IRRIGATION

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INTRODUCTIONS

Over the past several seasons, and particularly during 1993-1996, rind quality problems caused serious economic damage to the California navel orange crop. Pioneering work by Embelton, Eaks, Coggins and others during the 1960's and 1970's largely solved rind stain problems by providing leaf analysis fertilization guidelines based in part on fruit quality considerations and also by improving the design of packing lines and postharvest handling of fruit.

Over the past two decades orchard practices have changed. Most irrigation systems installed or renovated in the 1980's and 1990's are micro-irrigation systems with drippers or minisprinklers, rather than furrow, flood or high volume dragline sprinklers that dominated the industry previously. Nitrogen (N) remains relatively inexpensive. Its ability to provide lush foliage growth and good-looking groves has led in recent years to considerable over-use in the industry. Leaf analysis has provided the industry with a tool for monitoring fertilizer needs in citrus orchards, but too often growers are comfortable with nitrogen levels in the high end of the 'optimum' range, or even higher. The common thinking is that high nitrogen in the leaf analysis provides a good degree of safety and no tree in the orchard will suffer nitrogen deficiency. The effect of heavy nitrogen applications (in excess of 2 lb. N/tree), however, could be devastating to postharvest fruit quality.

Many growers have turned to foliar applications of low biuret urea to their trees in January and February to improve fruit set and ultimate yields. Additionally, the threat of nitrate groundwater contamination has changed the way some fertilizer recommendations are made, with several small applications of nitrogen over the season considered less likely to pollute than a single application. It is hoped that this project will assist in developing recommendations that can be made that minimizes nitrate movement into the groundwater while maintaining fruit quality and productivity.

OBJECTIVES

A) to determine the effect of nitrogen applications on navel orange fruit quality and leaching losses of nitrogen;

B) to compare the effects of foliar versus soil applied nitrogen on fruit quality and leaching losses of nitrogen;

C) to evaluate the impact of nitrogen application timing on fruit quality and leaching losses of nitrogen; and

D) to determine the effectiveness of various nitrogen application levels and methods on maintaining optimal nitrogen levels in navel orange trees.

PROJECT DESCRIPTION

Main Project Site

A site for the study in the Exeter - Woodlake area of Tulare County was identified in March 1996. The 15.3 acre experimental site is a mature navel orange grove (Frost Nucellar) on Troyer Citrange rootstock. The tree spacing is 22 x 20 feet. Each experimental plot consists of 12 trees with the central two trees serving as the data trees. The experimental treatments for this site are listed in Table 1. The differential nitrogen treatments were imposed commencing January 1997. The final harvest was completed in Spring 2002.

Leaf samples were collected in September for leaf analysis.

Trunk circumference, tree height, and canopy volume of the data trees were measured in October. Trees were also monitored for the average timing of color break and attainment of minimum maturity. In spring the data trees were harvested. All fruit was taken to UC Lindcove REC, where the fruit was run over the packing line at the Fruit Evaluation Center. We collected both size and grade information from the packing line. A subsample of fruit (from the average peak size) was taken from each data set, waxed and treated with fungicide and subsequently held under simulated storage and transit conditions.

Monitoring of the water and nitrogen status in selected experimental plots within the study site was carried out throughout the year. Soil water content was determined using a neutron probe in access tubes. Soil solution samples were collected from suction lysimeters.

Satellite Sites

The two remaining sites (Sat 1 & Sat 2) are located in commercial groves in Exeter/Woodlake and Orange Cove. The treatments at each site are listed in Table 2. The procedures for site monitoring were the same as outlined for the main site. All sites were harvested upon consultation with the owner and the cooperating packinghouse. All fruit from each site were commercially harvested and treated with standard packinghouse procedures. Yield, fruit size and packout were determined. Three cartons of each of two sizes (determined at the time of harvest) for each treatment were separated at the time of packing and held under simulated storage and transit conditions at the Mitchell Postharvest Lab at the UC-KAC. When sufficient export fruit were available, at least one pallet of fruit from each treatment was included in a Japan export shipment and inspected on arrival for incidence of rind disorders and decay.

RESULTS

Leaf Nitrogen

The differential N applications were applied from 1997 through 2001. The average leaf N contents of each treatment in the first three years of the project are shown in Figure 1. Note that it took multiple years to establish the treatment differentials as reflected by leaf N. Figure 2 reports the same data but for the second three years of the project (1999 – 2001). In these three years there is a clear treatment (amount of N) effect on leaf N, however the effect of the method of application and timing of application is less clear with the possible exception of the foliar only applications.

The mean leaf N contents (1999-2001) for all treatments at the two satellite sites were quite similar to those found at the main site (Figure 3). The data points representing the main site are the means of the data points shown in Figure 2. The data points for the satellite sites, which represent the same time period, are almost indistinguishable from those for the main site. These data demonstrate that the responses in leaf N at the three sites in response to the differential nitrogen application rates were quite similar.

YIELDS

Figure 4 reports the yield data collected in March 2002. The 2002 yield was greatly reduced as compared to previous years (Figure 5). This was in line with overall yield throughout the citrus industry in the San Joaquin Valley due to intense heat during the early stages of fruit set in May 2001, which caused extensive fruit drop. In spite of the reduced yield, we observed similar trends in yield data collected in 2000 and 2001 with yield increasing up to 1.0 to 1.5 lb N per tree regardless of application methodology. The cumulative yields for 2000 – 2002 related to applied N are reported in Figure 6. The data show the same trend of maximum production, under our experimental conditions, being achieved between 1.0 to 1.5 lb N/tree.

Nitrogen below the rootzones

Soil solutions were extracted from the plots almost monthly from 1997 through early 2002. These extracts were analyzed for nitrate-nitrogen (NO3-N) to determine the levels of nitrogen in soil solutions leaching from the root zones and for chloride (Cl) which can be used to account for different fractions of applied water leaving the root zones under the different plots. The soil nitrate data for the main site over the course of the study show an increase in the NO3-N concentrations in the soil leachate with increasing nitrogen application, i.e. higher nitrogen application, higher NO3-N concentrations in leachates leaving the rootzones (Figure 7). While yields did not appear to be affected by method of application, it clearly impacted the NO3-N concentrations in leachates. The highest NO3-N concentrations were found in leachates collected from the plots receiving the soil-only treatments. The foliar-only applications resulted in the lowest concentrations, ones that were not different from the control treatment. The concentrations leaving the combination treatments were intermediate. Within the soil-only treatments, the single application always resulted in higher concentrations of NO3-N in the leachates than the split or continuous applications.

Table 1. *Schedule of experimental treatments for nitrogen management project at the Main site.*

Treatment	Soil Applied (lb/tree/yr)	Timing (times/yr)	Foliar (# applications)	Total N (lb/tree/yr)
1	0	-	-	0.00
2	0	-	1	0.25
3	0	-	2	0.50
4	0	-	4	1.00
5	0.5	1	-	0.50
6	0.5	2	-	0.50
7	0.5	C	-	0.50
8	1.0	1	-	1.00
9	1.0	2	-	1.00
10	1.0	C	-	1.00
11	1.5	1	-	1.50
12	1.5	2	-	1.50
13	1.5	C	-	1.50
14	2.0	1	-	2.00
15	2.0	2	-	2.00
16	2.0	C	-	2.00
17	0.5	C	1	0.75
18	0.5	C	2	1.00
19	0.5	C	4	1.50
20	1.0	C	1	1.25
21	1.0	C	2	1.50
22	1.0	C	4	2.00
23	1.5	C	1	1.75
24	1.5	C	2	2.00
25	2.0	C	1	2.25

Foliar Only

# Applications[z]	Lb N/tree/yr
0	0
1	0.25
2	0.50
4	1.00

Soil Only

Lb N/tree/year	Timing[y]
0.5	1, 2, C
1.0	1, 2, C
1.5	1, 2, C
2.0	1, 2, C

Combination Treatments

Soil Application (lb N/tree/yr)[x]	Foliar Applications (# applications)[z]	Total Lb N/tree/yr
0.5	1, 2, 4	0.75 - 1.50
1.0	1, 2, 4	1.25 - 2.00
1.5	1, 2	1.75 - 2.00
2.0	1	2.25

[z] **Foliar Application:** Low Biuret Urea will be applied to foliage at a rate of 0.25 lb/tree per application. Trees receiving one application will have urea applied in late May. Trees receiving 2 applications will have an additional application in late winter. Trees receiving 4 applications will have additional applications at the pre-bloom stage and 30 days following the late May application.

[y] **Soil Application:** All applications will be made through the irrigation system: 1 = single application per year in late winter; 2 = split application, late winter and early summer; C = Applied with every irrigation from late winter through summer.

[x] **Soil Nitrogen** will be applied as in the "C" treatment described above for the soil applications.

Table 2. *Schedule of experimental treatments for nitrogen management project for satellite experimental sites in Tulare County (Orange Cove, Woodlake/Exeter).*

Treatment	Soil Applied (lb/tree/yr)[z]	Timing (times/yr)	Foliar (# applications)[y]	Total N (lb/tree/yr)
1	1.00	1	-	1.00
2	1.50	1	-	1.50
3	2.00	1	-	2.00
4	1.50	C	-	1.50
5	1.25	1	1	1.50
6	1.00	1	2	1.50

[z] **Soil Application:** All applications will be made through the irrigation system: 1 = single application per year in late winter; 2 = split application, late winter and early summer; C = Applied with every irrigation from late winter through summer.

[y] **Foliar Application:** Low Biuret Urea will be applied to foliage at a rate of 0.25 lb/tree per application. Trees receiving one application will have urea applied in late May. Trees receiving 2 applications will have an additional application in late winter.

The Cl concentrations in extracts were not related to the amounts of nitrogen applied (Figure 8). This is to be expected, as the source of the Cl was the irrigation water and the irrigation system was designed to apply water uniformly across the experimental field. The different Cl concentrations are an indication of different fractions of applied water leaching from the plots, i.e. the higher the concentrations, the lower the proportion of applied water leaching below the rootzone. The different leaching fractions are likely caused by different soil properties (permeability, layering, cementation) in the various plots.

In examining the NO3-N:Cl ratios, the same general trends in nitrogen levels in soil solutions extracted from the plots hold (Figure 9). As applied nitrogen increases, the NO3-N levels relative to Cl increase. These increases are greater for the soil-only treatment, least for the foliar-only treatments and intermediate for the combination treatments. The difference seen in Figure 9 compared to Figure 7 is that the continuous soil application resulted in higher NO3-N to Cl ratios than either the single or split nitrogen application.

The nitrate-nitrogen concentrations in soil solutions leaching beneath the rootzones at the two satellite sites were quite similar to those at the main site (Figure 10). The concentrations at SAT 1 were slightly lower. The concentrations at SAT 2 were slightly higher. But overall they fell within the range of concentrations found at the main site.

Soil samples (6 – 20 ft) were collected during summer 2002 in order to evaluate nitrate leaching below the treated plots by a second method. Comparison of the results obtained by the two methods (soil solutions vs. soil extracts) are shown in Figure 11. Soil applied N is used as the x-axis. The left figure is the same as Figure 7 when adjusted for soil applied N rather than total. The same trends in nitrate-nitrogen concentrations were found by both methods. Overall the average concentrations found by the soil extract method were about 10 mg/l higher at equivalent N soil application rates. The soil solution method measured real time nitrate-nitrogen concentrations leaving the rootzone; whereas, the soil extract method measured nitrate-nitrogen concentrations in soil below the rootzone that has moved there during past years. It likely represents nitrogen leaching during the time of our study and some history before we imposed the differential N treatments. But even in the five years of the study the soil zone from 6 to 20 feet reflects the treatments imposed on the surface. Both methods show that when soil applied N exceeded one pound per tree, the nitrate-nitrogen concentrations increased more rapidly.

FIGURE LEGEND

Figure 1. Average leaf nitrogen content for the Main experimental site for 1996 - 1998. Leaves collected in September of each year.

Figure 2. Average leaf nitrogen content for the Main experimental site for 1999 – 2001. Leaves collected in September of each year.

Figure 3. Average leaf nitrogen content for 1999 – 2001 for the various treatments at the three sites.

Figure 4. Average yields (lbs of fruit per tree) from the Main experimental site. Fruit harvested in March 2002.

Figure 5. Average yields (lbs of fruit per 2-tree plot) at the Main for each year of the study. 1997, 1998 are prior to establishment of differential results in leaf N per tree. 2000 – 2002 are yields from years where there were differential trends in leaf N related to treatment. No yield data was collected in 1999 due to the December 1998 freeze. Fruit harvested in March of each year.

Figure 6. Average cumulative yield (lbs of fruit per tree) from the Main experimental site for 2000 - 2002. Fruit harvested in March of each year.

Figure 7. Mean nitrate N in soil solution extracts collected from 1997 – 2002 from the Main experimental site.

Figure 8. Mean chloride levels in soil solution extracts collected from 1997 – 2002 from the Main experimental site.

Figure 9. Mean nitrate-N:Chloride levels in soil solution extracts collected from 1997 – 2002 for the Main experimental site.

Figure 10. Mean nitrate-N soil solution extracts for all treatments at the three sites for 1997 – 2002. The data points for 1, 1.5, and 2 pounds per tree have been offset slightly to show the data more clearly.

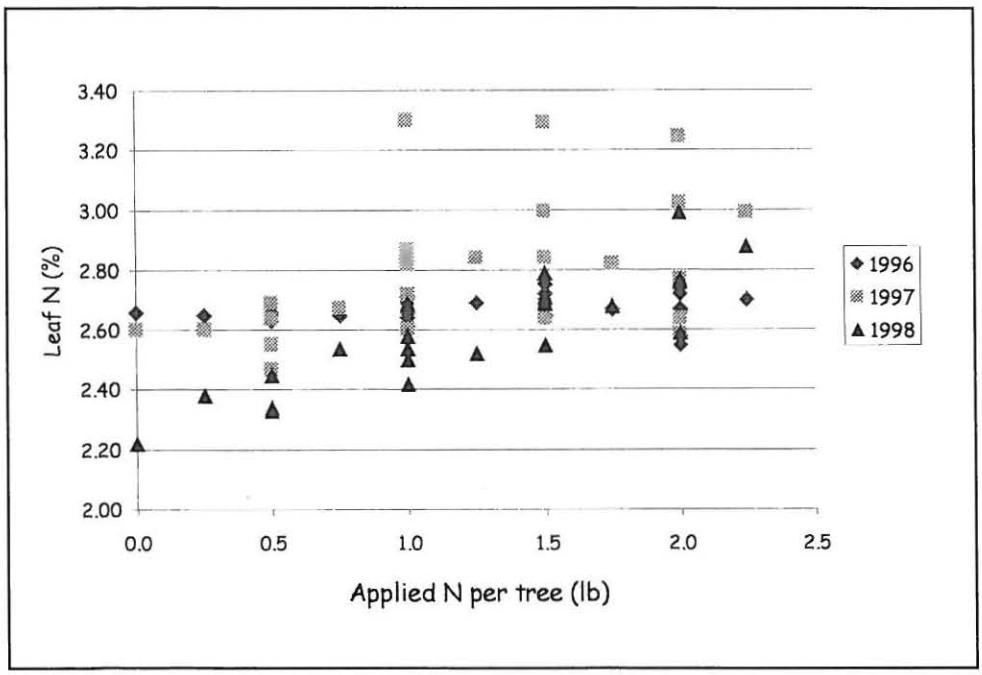


Figure 1. *Average leaf nitrogen content for Main experimental site for 1996 - 1998. Leaves collected in September of each year.*

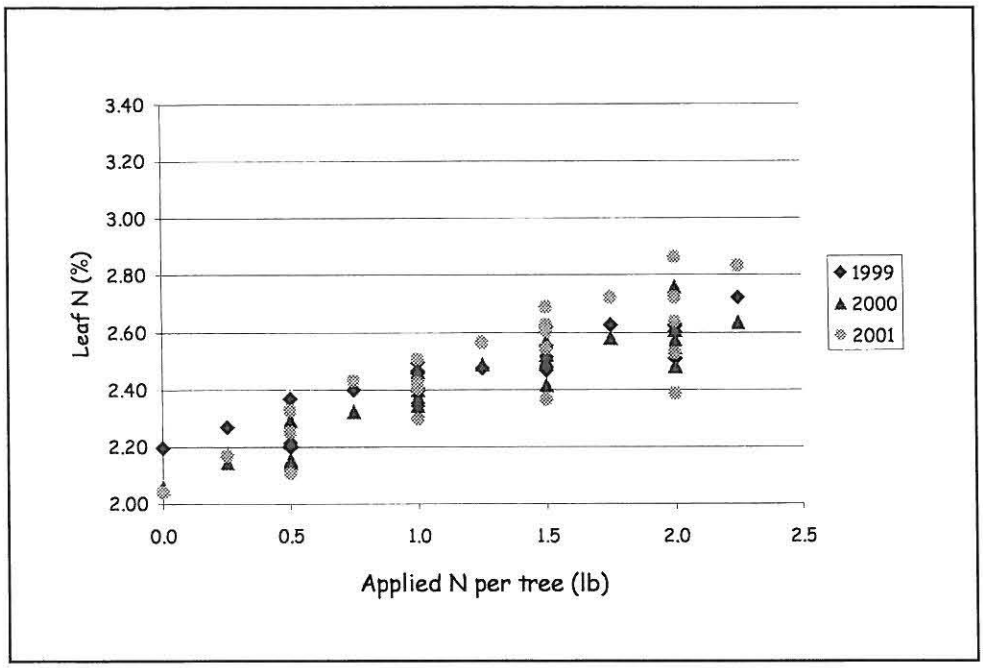


Figure 2. *Average leaf nitrogen content for Main experimental site for 1999 – 2001. Leaves collected in September of each year.*

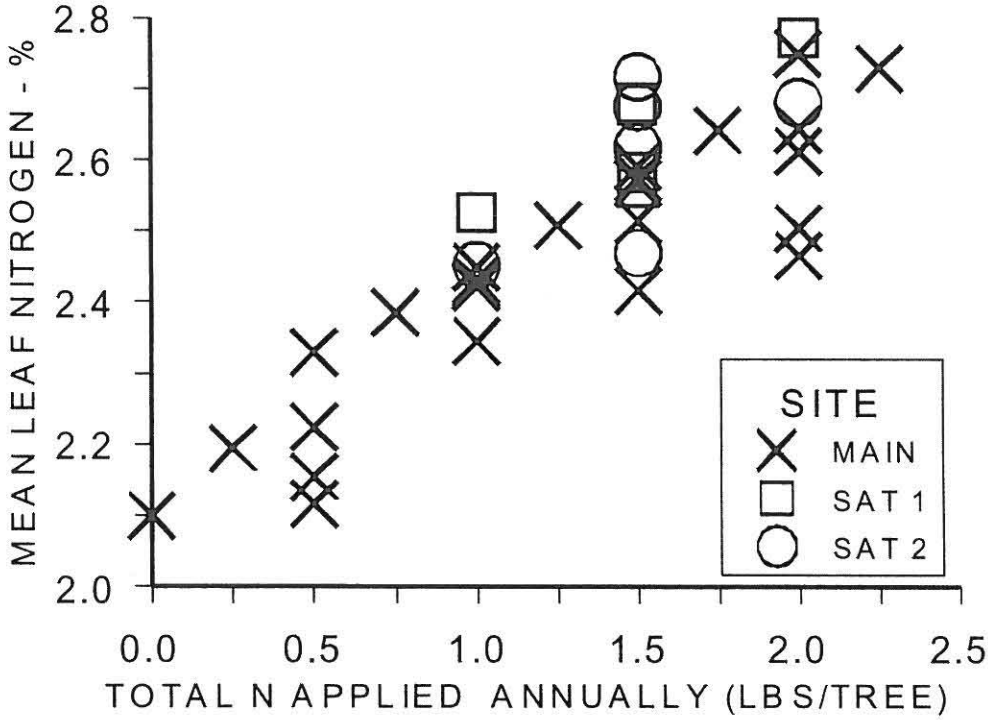


Figure 3. *Average leaf nitrogen content for 1999 – 2001 for the various treatments at the three sites.*

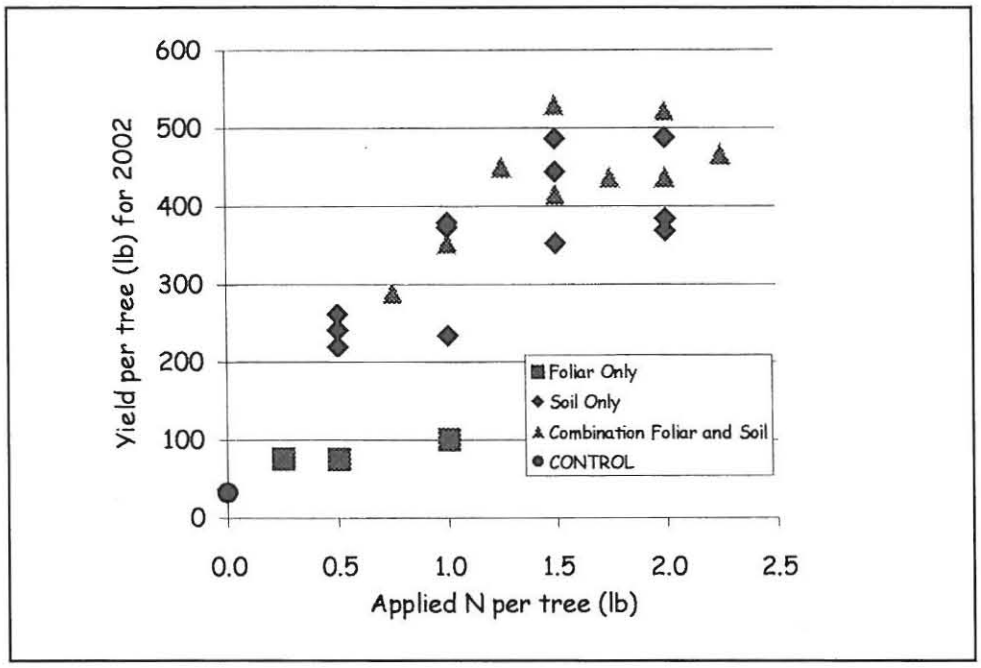


Figure 4. *Average yields (lbs of fruit per tree) from the Main experimental site. Fruit harvested in March 2002.*

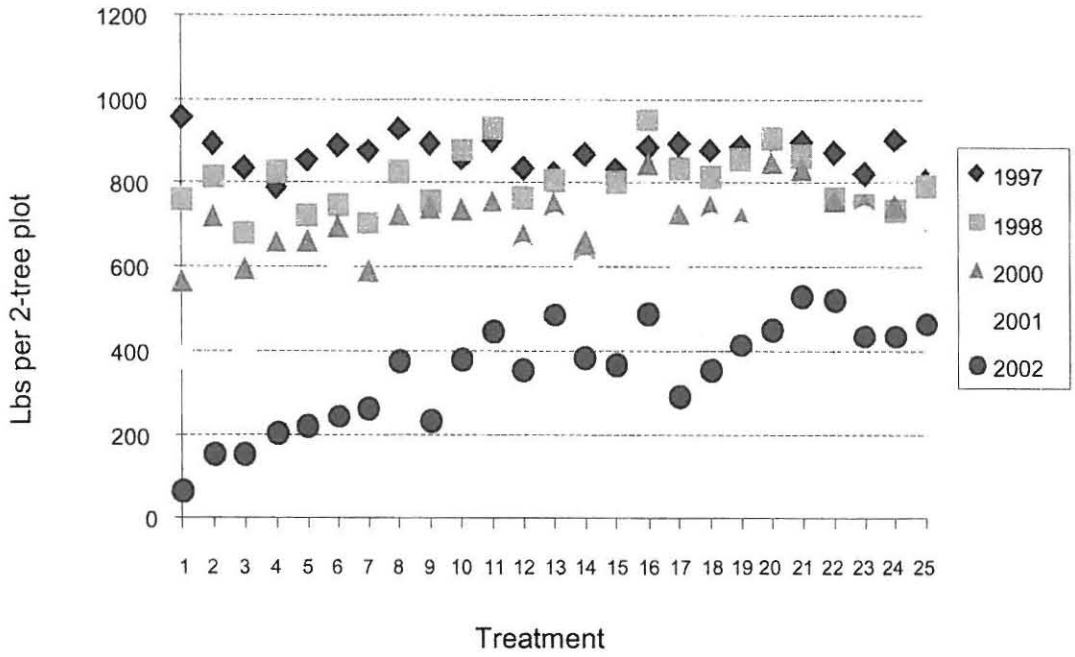


Figure 5. *Average yields (lbs of fruit per 2-tree plot) at the Main site for each year of the study. 1997, 1998 are prior to establishment of differential results in leaf N per tree. 2000 – 2002 are yields from years where there were differential trends in leaf N related to treatment. No yield data was collected in 1999 due to the December 1998 freeze. Fruit harvested in March of each year.*

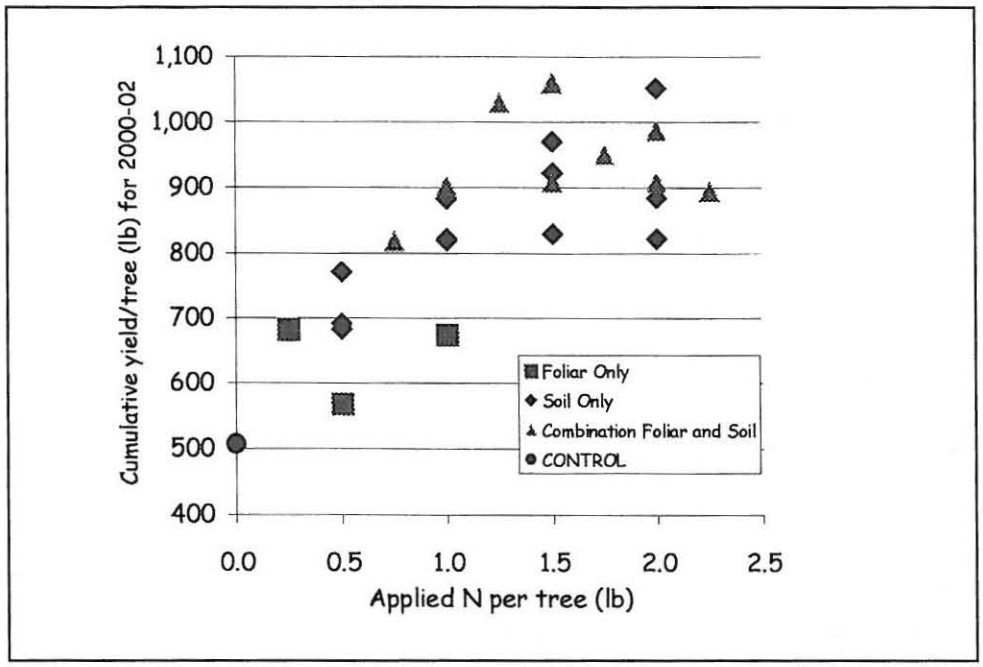


Figure 6. *Cumulative yield (lbs of fruit per tree) from the Main experimental site for 2000 - 2002. Fruit harvested in March of each year.*

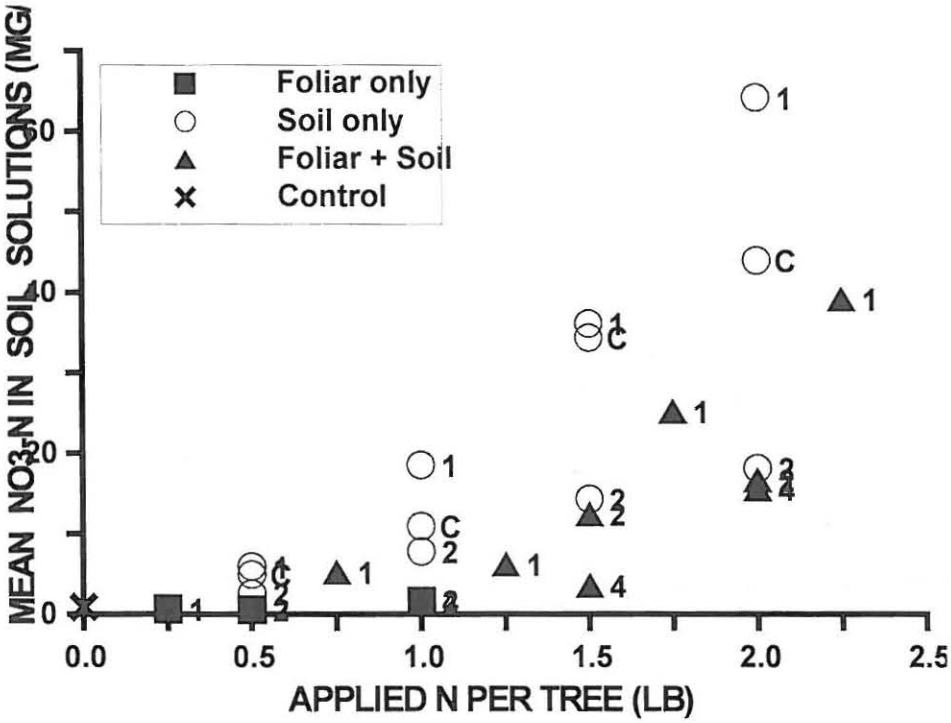


Figure 7. *Mean nitrate N in soil solution extracts collected from 1997 – 2002 from the Main experimental site. In case of soil only, 1 = single application, 2 = split application, C = continuous application. For foliar treatments numbers indicate number of foliar applications.*

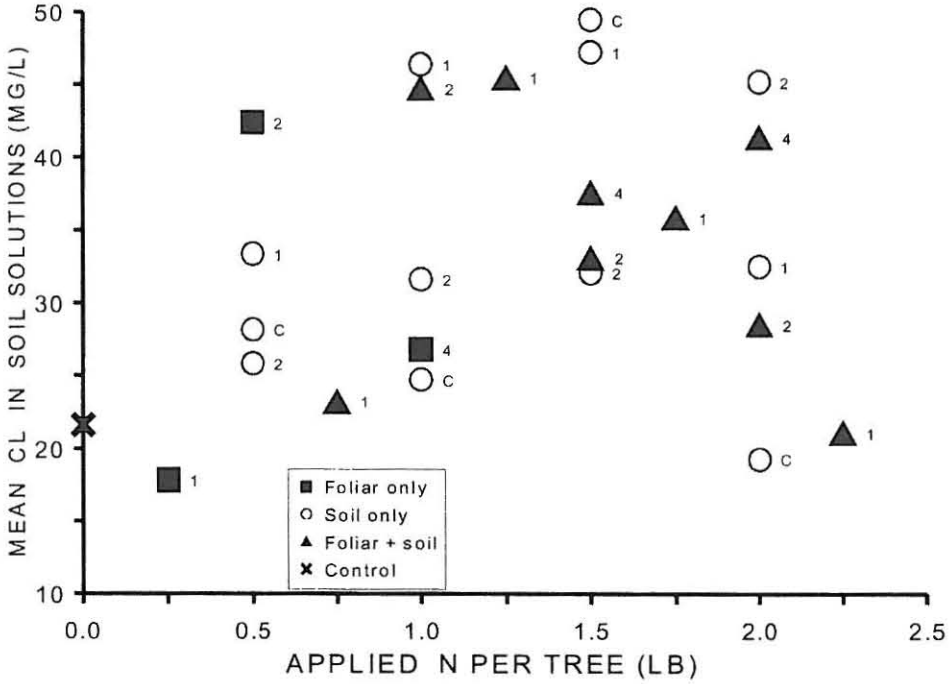


Figure 8. *Mean chloride levels in soil solution extracts collected from 1997 – 2002 from the Main experimental site. In case of soil only, 1 = single application, 2 = split application, C = continuous application. For foliar treatments numbers indicate number of foliar applications.*

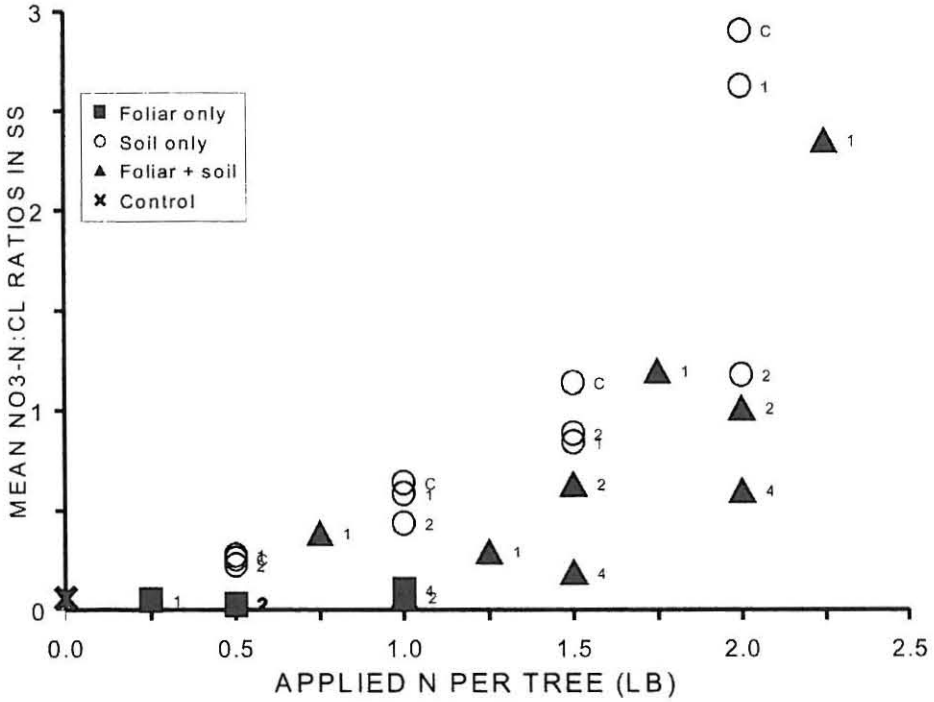


Figure 9. *Mean nitrate-N:Chloride levels in soil solution extracts collected from 1997 – 2002 for the Main experimental site. In case of soil only, 1 = single application, 2 = split application, C = continuous application. For foliar treatments numbers indicate number of foliar applications.*

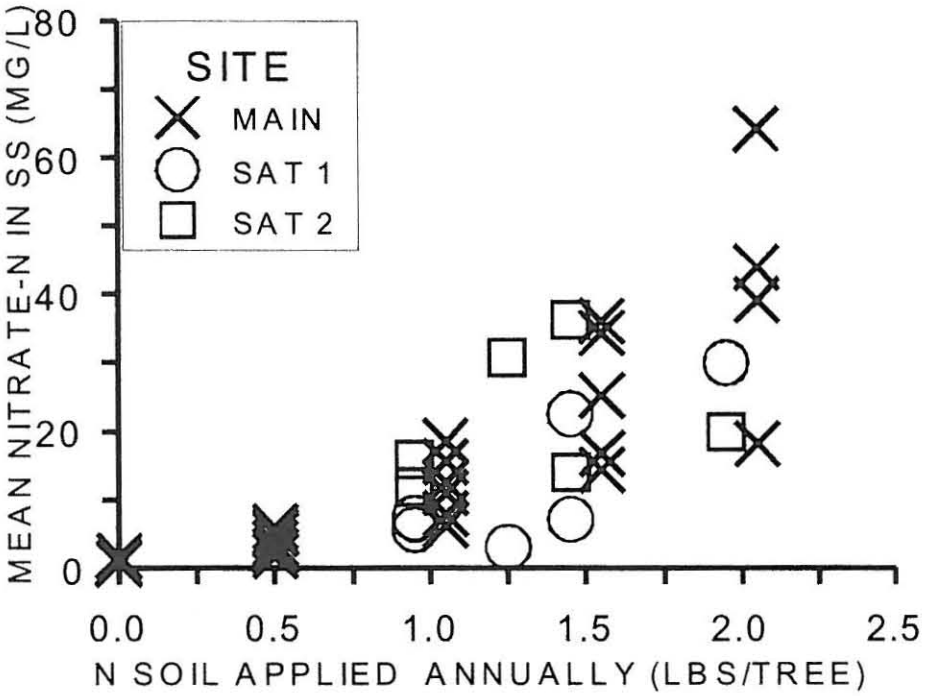
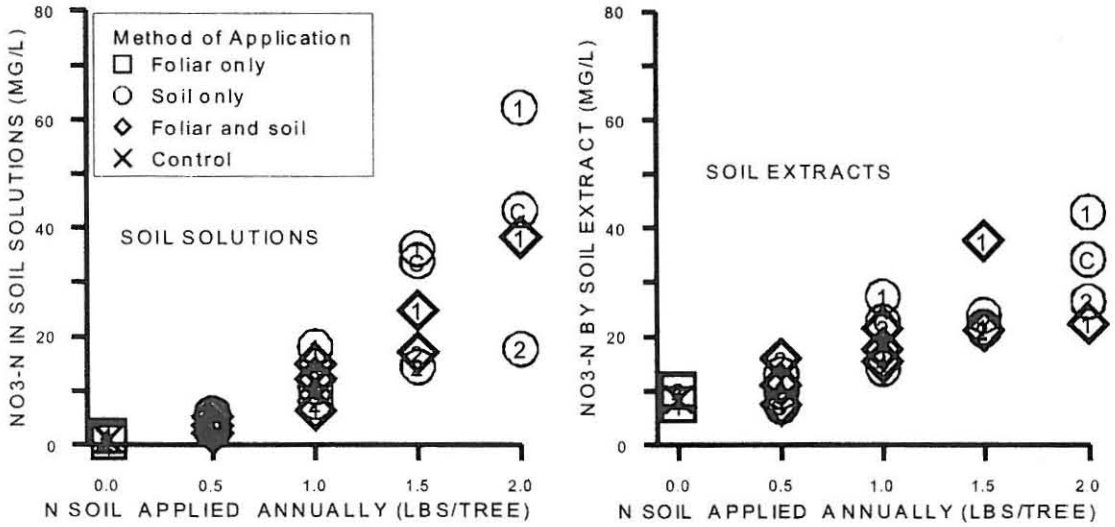


Figure 10. *Mean nitrate-N soil solution extracts for all treatments at the three sites for 1997 – 2002. The data points for 1, 1.5, and 2 pounds per tree have been offset slightly to show the data more clearly.*

Figure 11. *Comparison of mean nitrate-N leaching from soils at main site as assessed by two measurement methods, soil solutions and soil extracts.*



SEASONAL PATTERNS OF NUTRIENT UPTAKE AND PARTITIONING AS A FUNCTION OF CROP LOAD OF THE 'HASS' AVOCADO

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INTRODUCTION

For the 'Hass' avocado (Persea americana L.) industry of California, optimal rates and times for soil fertilization of nitrogen, phosphorus and potassium have not been adequately determined. Fertilization rates and optimal leaf nutrient ranges have been borrowed from citrus. Competition from Mexico and Chile requires the California avocado industry to increase production per acre to remain profitable. Optimizing fertilization is essential to achieve this goal.

The seasonal pattern of nutrient uptake is a key component of fertilizer management. Matching fertilizer application times and rates with periods of high nutrient demand not only maximizes yield, but also increases nutrient-use efficiency and, thus, reduces the potential for groundwater pollution. Experiments on nutrient uptake and allocation are routinely done to develop best management practices for commercial annual crops. However, determining nutrient uptake in mature trees is considerably more difficult, requiring repeated tree excavations at important phenological periods over the season. Thus, few best management practices have been developed for perennial tree crops.

The goal of this project is to determine the seasonal pattern of nutrient uptake and partitioning in alternate-bearing 'Hass' avocado trees. The research will quantify the amount of each nutrient partitioned into vegetative or reproductive growth and storage pools. The research will identify the periods of high nutrient use from bloom to harvest as a function of crop load, and thus identify the amount of each nutrient required and when it is required to produce an on-crop and good return crop the following year. The results will enable us to provide guidelines for fertilization based on maximum nutrient-use efficiency and eliminate applications made during ineffective periods for uptake to thus protect the groundwater and increase profitability for California's 6,000 avocado growers.

PROJECT OBJECTIVES

1. Quantify the seasonal pattern of N, P, K, B, Ca, and Zn uptake and partitioning in 'Hass' avocado trees bearing.
2. Quantify the effects of different crop loads on these seasonal patterns of nutrient uptake, partitioning into vegetative and reproductive growth, and storage.
3. Determine the seasonal patterns of nutrient uptake in alternate bearing avocado trees and develop best management fertilizer practices for the 'Hass' avocado tree.

PROJECT DESCRIPTION

The research was conducted in a commercially bearing avocado orchard in Somis, CA. In June 2001, 60 trees were selected for inclusion in the project based on their trunk diameter, height, canopy size, and fruiting potential. Thirty of these trees were subsequently defruited to establish both lightly fruiting and heavy fruiting trees. The experiment was set up as a completely randomized design, with factors: 1) cropping status (heavily cropping—On and lightly cropping—Off trees), and 2) time of excavation. Two trees (an on- and an off-year tree) were excavated monthly between November 2001 and December 2002 for a total of 13 excavation dates. The entire tree (roots and shoots) was excavated every third month (4 dates), and the above ground dry matter was harvested for the other nine dates. Trees were dissected into the following components, and the total weight of each component determined: leaves, new shoots, inflorescences or fruit (separated into seed and flesh), small branches (£ 2.5 cm), mid-size branches (2.5-5.0 cm), scaffolding branches, scion trunk, rootstock trunk, scaffolding roots, small roots, and new roots. Sub-samples were dried, ground, and analyzed for carbon, nitrogen, nitrate-nitrogen, phosphorus, potassium, calcium, iron, magnesium, manganese, zinc, boron, sulfur, copper, sodium, chloride, and aluminum.

Ten percent ^{15}N enriched ammonium sulfate was applied on three dates (August 15, 2002; November 14, 2002; June 15, 2003) and whole trees were excavated three months after application and analyzed for percent ^{15}N recovery. ^{15}N analyses from the June 15 tree excavation are currently being conducted, and these data will be reported at a later time. These data will be used to determine periods of high N uptake capacity in avocado trees and evaluate the effects of alternate bearing on N uptake and recovery. Such data are required to develop best management N fertilized practices.

Data Analysis

The results obtained were used to calculate gram nutrient per tree by the following equation using nitrogen as the example:

g N/g dry wt tissue X g dry wt tissue/g fr wt tissue X total fr wt tissue/tree = total g N/tree

Nutrient uptake was determined as the difference in total tree nutrient contents from sequential tree excavations and from ^{15}N recovery in the various tree parts

RESULTS AND CONCLUSIONS

Leaf N Concentrations.

Alternate bearing had little effect on the changes in leaf N concentrations over the season (Figure 1). Leaf N concentrations tended to increase over the season; however, few differences were seen between on- and off-year trees. This is surprising since avocado trees accumulated significant quantities of nitrogen in their fruit and this demand was not reflected in lower leaf N concentrations. In other alternate bearing species such as pistachios, leaf N concentrations are frequently lower in on- vs off-year trees. This indicated that avocado leaves are highly buffered against large N demands by the fruit.

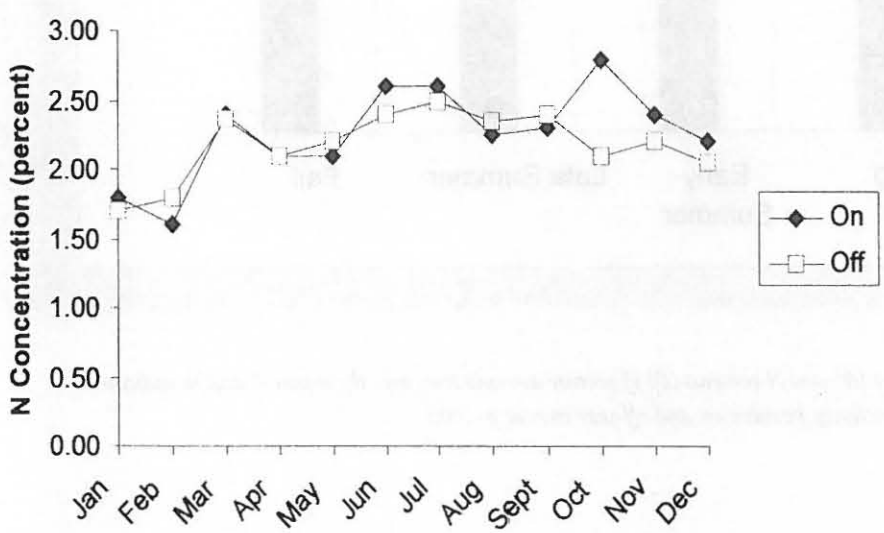

Figure 1. *Effect of alternate bearing on leaf N concentration over the 2002 season.*

Total Tree N Accumulation

Total aboveground tree dry weight and N contents were averaged over a three-month period in the spring (January - March), early summer (April - June), late summer (July -September), and fall

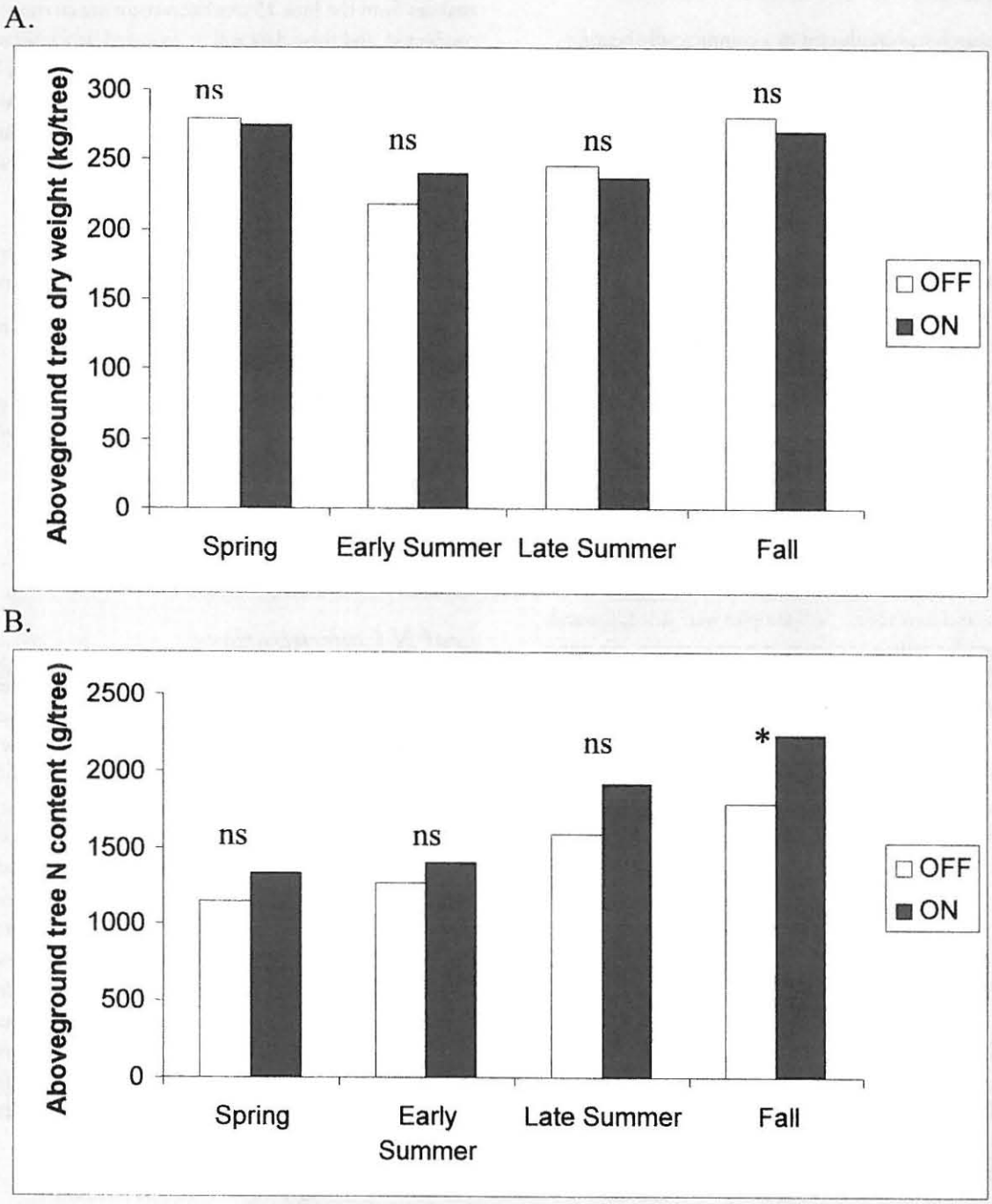

Figure 2. *Aboveground tree day weight (A) and N contents (B) of mature avocado trees over the season. * and ns indicate significance and non-significance, respectively, between on-and off-year trees at p=0.05.*

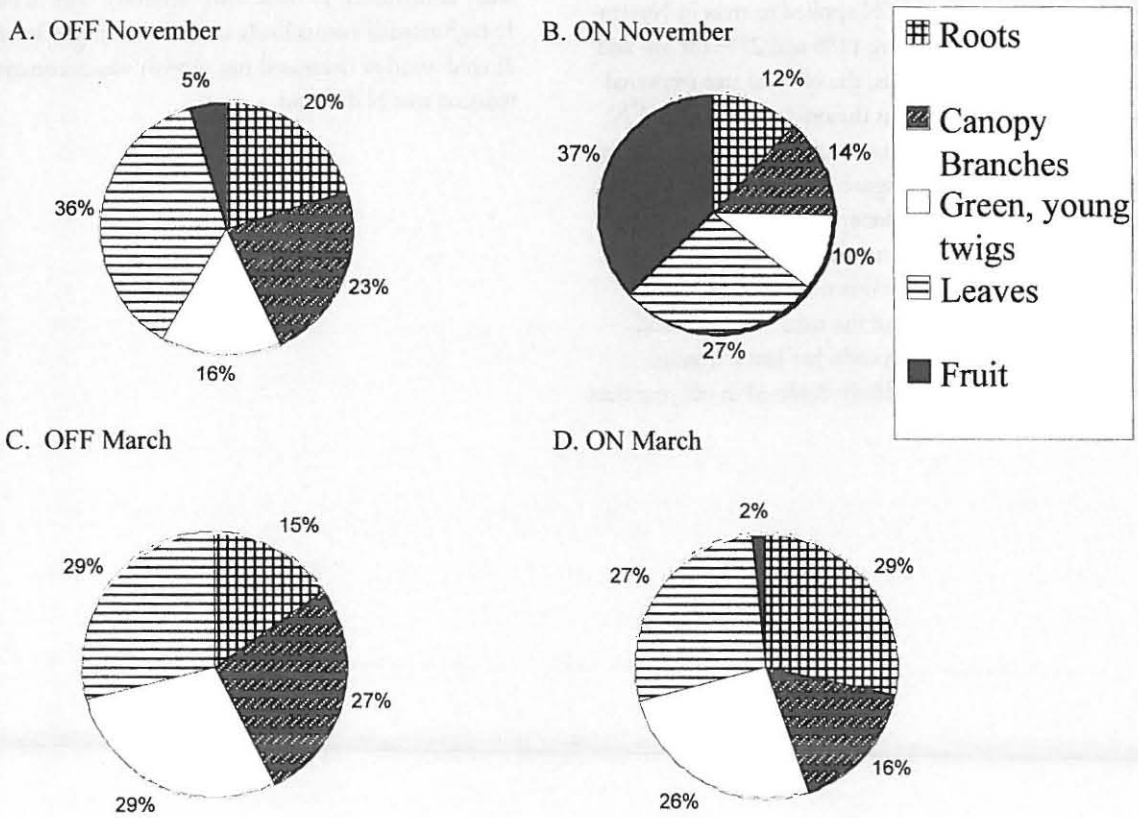

Figure 3. *^{15}N distribution of mature off-(A) and on-year (B) avocado trees, applied August 15, 2002 and excavated on November 14, 2002, and ^{15}N distribution in off-(C) and on-year (D) trees applied November 14, 2002, and excavated on March 15, 2003.*

(October - December) for both on- and off-year trees (Figure 2). No significant differences were found in total tree dry weight over the season. In contrast, tree N contents increased over 50% in both on-and off-year trees between the spring and fall. Increases in leaf N and fruit N (in on-year trees only) pools over the season were the primary factors in producing these increases in tree N status (data not shown). In the fall, heavy fruit loads resulted in on-year trees containing significantly more N than off-year trees (Figure 2B).

^{15}N Uptake and Distribution

^{15}N was applied to an on- and off-year tree in August 2002 and trees were excavated in November 2002. Percent ^{15}N recoveries in November were 59% and 35% for the on and off-year tree, respectively. The on-year tree recovered almost double the amount of ^{15}N as the off-year tree (data not shown). Most of the ^{15}N recovery in the on-year tree accumulated in the fruit, whereas leaves were the main repositories for ^{15}N in the off-year tree (Figure 3). In both the on- and off-year tree, the majority of the ^{15}N was translocated out of roots and accumulated in actively growing tissues such as fruit, leaves, and green twigs (Figure 3). These results support the hypothesis that N uptake is regulated by tree N demand. On-year trees have a large N requirement and therefore more is taken up to meet that demand.

These recovery percentages in both on- and off-year avocado trees are high compared to the typical 15-30% ^{15}N recovery rates reported in the deciduous fruit crop literature. This indicates that August fertilizer N applications are efficiently taken up by roots and mobilized by the tree.

Avocado trees have very dense root mats, which may have contributed to the high ^{15}N recovery rates.

The percent recovery rates of ^{15}N applied to trees in November and excavated in March were 11% and 27% for on- and off-year trees, respectively. Thus, the off-year tree recovered more than twice as much ^{15}N as the on-year tree. The ^{15}N accumulated equally between leaves, green twigs, and canopy branches in the off-year tree (Figure 3). In contrast, the roots accumulated the most ^{15}N in the on-year tree. This lack of ^{15}N translocation out of roots may indicate a lower N requirement for on-year trees at this time. Young fruits accumulated only two percent of the total ^{15}N recovered. Anthesis and fruit growth in avocado has just started in March, whereas N reserves are likely depleted in off-year trees at this time.

The ^{15}N recovery rates were markedly lower when applied in November compared to August. The cold and wet weather likely contributed to these lower recovery rates in two ways: 1) high rainfall events likely increased nitrogen leaching, and 2) cold weather decreased tree growth which concomitantly reduced tree N demand.

EVALUATION OF SLOW RELEASE FERTILIZERS FOR COOL SEASON VEGETABLE PRODUCTION IN THE SALINAS VALLEY

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INTRODUCTION

This project evaluated the performance of slow release fertilizers on cool season vegetable production in the Salinas Valley. Controlled laboratory studies were conducted in the first year of the project (2000-01) and field studies were conducted each of the three years of the project. The evaluations include the effect of two slow release materials at three rates on broccoli grown over the winter during the rainiest time of the year. Broccoli was selected as the test crop because it is a key cool-season vegetable that is extensively planted in the Salinas Valley (54,899 acres in 2001). In addition, significant acreage is grown in the winter when the potential for losses of nitrogen due to leaching, and the risk of being rained out of the field to make sidedress applications is high.

OBJECTIVE (YEAR 3)

Evaluate nitrogen release, yield and the economics of two polyurethan-coated urea slow release fertilizer materials in a field trial conducted on winter broccoli.

DESCRIPTION

Three slow release fertilizer trials were conducted in commercial broccoli fields in the Salinas Valley during the winters of 2001 to 2003. Over-wintered fields with medium textured soil were selected for these trials to provide the greatest potential for exposure to the high rainfall months (i.e. December to February) and greatest potential for nitrogen movement from the root zone. The slow release fertilizer was shanked into listed beds in November and the broccoli was direct seeded within two weeks. Two hundred pounds of nitrogen was applied as all slow release fertilizer, or as

Table 1. Mean nitrate nitrogen in the soil over the season.

Treatment	2001	2002	2003	Over All Mean
Untreated	15.3	21.3	9.08	15.2
Standard	20.2	25.4	27.54	24.4
Polyon 200	36.5	23.6	14.02	24.7
Polyon 150[1]	29.3	25.5	14.91	23.2
Polyon 100[2]	21.7	26.3	10.49	19.4
Duration 200	29.0	27.8	12.87	23.2
Duration 150[1]	28.7	26.3	17.01	24.0
Duration 100[2]	24.7	31.7	24.75	27.5
LSD (0.05)	19.1	4.1	10.4	9.2
Contrasts[3]				
Polyon vs Duration	n.s.	*	n.s.	n.s.
Standard vs Slow	n.s.	n.s.	*	n.s.
200 Slow vs Standard	**	n.s.	*	n.s.
200 Slow vs 100 Slow	**	*	n.s.	n.s.

1: slow release application was followed by one sidedress of 50 lbs N/A; 2: slow release application was followed by two sidedress applications of 50 lbs N/A each; 3: * = 0.05; ** = 0.01

Table 2. Mean yield of broccoli – mean of three years of trials

Treatment	Total No. Heads	Total Wt. (lbs)	Mean Head Wt
Untreated	173.0	80.5	0.46
Standard	177.5	87.3	0.50
Polyon 200	170.4	88.2	0.51
Polyon 150	178.5	89.4	0.50
Polyon 100	177.8	88.8	0.50
Duration 200	173.5	86.1	0.50
Duration 150	171.8	85.6	0.50
Duration 100	173.2	85.3	0.50
LSD (0.05)	n.s.	4.5	0.03
Contrasts[1]			
Polyon vs Duration	n.s.		n.s.
Standard vs Slow	n.s.	n.s.	n.s.
200 Slow vs Standard	n.s.	n.s.	n.s.
200 Slow vs 100 Slow	n.s.	n.s.	n.s.

1: * = 0.05

combinations of slow release fertilizer and sidedress applications of conventional fertilizer. The slow release treatments were compared with a standard treatment that also received a total of 200 lbs N/A and an untreated control.

Biweekly soil samples were collected during the course of the growing season and analyzed for nitrate and ammonium. Broccoli leaf blade and petiole samples were collected three times during the growing season and analyzed for total nitrogen and nitrate-nitrogen. In order to measure the relative amounts of nitrate removed from the soil by plant removal or leaching, soil samples were collected at one-foot increments to three feet at the beginning and at the end of the growing season. The samples were analyzed for nitrate and ammonium. Each trial was harvested by commercial harvesters on multiple dates, and the number and weight of broccoli heads per plot was collected.

RESULTS & CONCLUSIONS

These trials presented challenges for accurately determining the efficacy of the two slow release materials tested. The Salinas Valley is farmed intensively and various studies here have shown high residual soil levels of nitrate-nitrogen in the soil at the end of the season. Mean soil levels down to three feet at the beginning of the trials were 43.6, 40.5 and 31.3 ppm nitrate-nitrogen in the first, second and third years of this project, respectively. A quick calculation of the amount of residual nitrogen in the soil at the beginning of each trial indicates a large supply of nitrogen. In addition, there was low rainfall in each of the three years of the trials: 8.79, 4.70 and 5.79 inches fell during the trials, respectively. Higher rainfall could have reduced the impact of the high residual nitrogen on the trials. In spite of these two factors, we saw a response to fertilization in the soil (table 1). All fertilizer treatments maintained higher nitrate levels in the soil over the course of the growing season over the untreated control, but none of the slow release fertilizer treatments had greater nitrate levels than the standard fertilizer treatment.

The fertilizer treatments improved the yield of broccoli over the three years of trials (Table 2). None of the slow release trials improved the yield over the standard fertilizer treatment, but there is some indication that Polyon treated plots may have had slightly greater yield than Duration.

Table 3. Cost comparison summary for standard and slow release fertilizer applied to winter grown broccoli (232 lbs N/A applied)

Application	Fertilizer Type	Standard Fertilizer Program			Slow Release Fertilizer Programs								
					100% Slow Release			75% Slow Release			50% Slow Release		
		N/A (Lbs)	Costs/A		N/A (Lbs)	Costs/A		N/A (Lbs)	Costs/A		N/A (Lbs)	Costs/A	
			Fertilizer	Labor		Fertilizer	Labor		Fertilizer	Labor		Fertilizer	Labor
Preplant	15-15-15	60[1]	28	15	200[4]	164	15	150[4]	123	15	100[4]	82	15
Sidedress #1	AN 20	60[2]	29	10	0	0	0	0	0	0	50[2]	24	10
Sidedress #2	AN 20	72[2]	34	10	0	0	0	50[2]	24	10	50[2]	24	10
Water run	CAN 17	40[3]	24	8	32[3]	19	8	32[3]	19	8	32[3]	19	8
Subtotal		232	115	43	232	183	23	232	166	33	232	149	43
Total Costs/A				**158**			**206**			**199**			**192**

1 - $0.47/lb N (cost of the 15-15-15 assigned to N); 2 – $0.47/lb N; 3 - $0.59/lb N; 4 – slow release @ $0.82/lb N.

Broccoli tissue samples generally followed the trends observed in the soil nitrogen data (data not shown).

We did not observe reduced leaching from the use of slow release fertilizers in any of the three years of this study. This is presumably due to the high levels of residual nitrogen that were present at the beginning of the trial that may have "washed out" our attempts to detect reduced leaching with the use of slow release fertilizers.

The cost of fertilizer programs that utilize 100%, 75% and 50% slow release fertilizers in a typical broccoli fertilizer program (i.e. 232 lbs N/A) are 31%, 26% and 22% more than the standard fertilizer program (Table 3).

These studies were conducted under "real world" conditions in the Salinas Valley. In spite of the high residual nitrogen, we observed responses to the nitrogen fertilizer treatments. However, these studies do not indicate dramatic benefits from the use of slow release fertilizers in cool season vegetables as has been seen on other crops on sandy soils with low residual nitrogen. Slow release fertilizers cost from 22% to 31% more than the standard fertilizer program. The main motivation for their use in the Salinas Valley may be to reduce the risk of being rained out of the fields to make timely sidedress fertilizer applications in rainy spring weather. Under these conditions, the use of slow release fertilizers may be justified, and we have shown that they can provide yields equivalent to a standard fertilizer program.

EFFECT OF DIFFERENT RATES OF N AND K ON DRIP IRRIGATED BEAUREGARD SWEETPOTATOES

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INTRODUCTION

The use of drip irrigation for sweetpotato production continues to grow in California, and now accounts for about 80% of the land area in production, an increase from just 50% only five years ago. While fertilizer trials were performed in the 1960's and '70s with furrow irrigated fields, no controlled fertilizer trials with drip irrigation had been performed Therefore, a nitrogen and potassium fertilizer trial was established under commercial conditions to essentially answer whether or not the use of drip irrigation changed the fertility requirements of the sweetpotato crop. 2002 concluded fours years of evaluating N and K rates for drip irrigated Beauregar sweetpotatoes. Some of the importan conclusions that have been made from thi project

- Best overall nitrogen rate was found to b 125 – 175 lbs per acre, when injected throug the drip line during rapid vine growth. Thi rate resulted in maximum yield with littl residual N at the end of the season
- There was little response to K fertilizer, even though the soil tested low (below 125 ppm exchangeable K). Because of some problems with the K results, the best recommendation that can be made at this time is to apply to meet nutrient removal (about 150 lbs K_2O per A).
- Petiole NO_3-N and K sufficiency ranges were developed for two different time periods of crop development; at rapid vine growth (about 4-6 weeks after transplanting) and root bulking (about 2 months after transplanting): vining: 3000 – 5000 ppm NO_3-N, 4.5 – 5.5% K; root bulking: 2000 – 4000 ppm NO_3-N, 3.5 – 4.5% K
- Weight loss in storage was unaffected by potash treatment.
- Residual soil nitrate was very low (< 10 ppm) down to 3 feet. This indicates that most of the applied nitrogen is being used by the crop and is not being leached to groundwater.

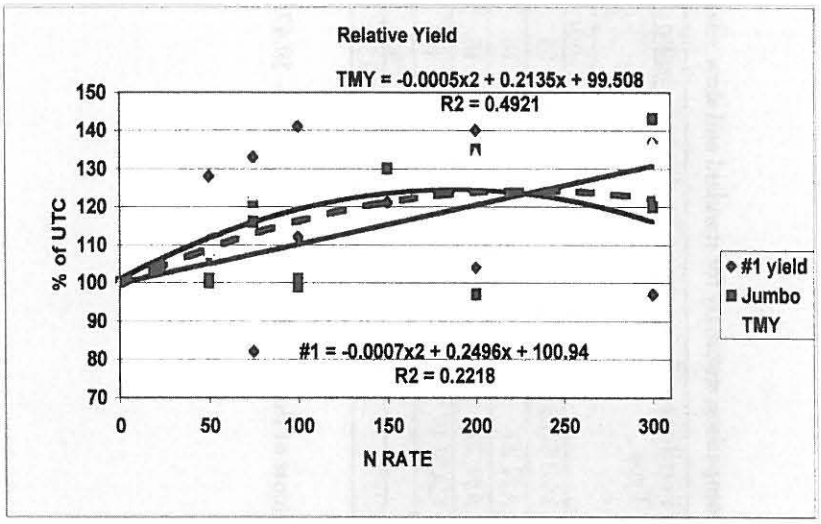

Figure 1. *Relative sweetpotato yield response over 4 years, % increase as comparied to untreated control. Best overall yields occurred at 125 - 175 lbs N/A.*

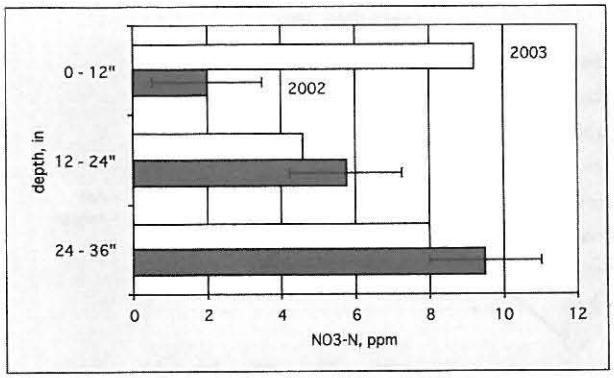

Figure 2. *Spring 2003 (top) and 2002 (bottom) soil samples NO_3-N results in the soil profile for the 200 lbs/A nitrogen treatments. 2002 LSD 0.05 = 3.1 ppm. No stats could be run on the 2003 data.*

OBJECTIVES:

1. Determine the optimal rates of N and K fertilizer for best yield and quality in drip irrigated Beauregard sweetpotatoes.
2. Determine the effect of different rates of potash and nitrogen on moisture loss in storage.
3. Re-evaluate current fertilizer application tissue analysis guidelines.
4. Determine if applications of N with the drip system results in substantial leaching of nitrate beyond the root zone.

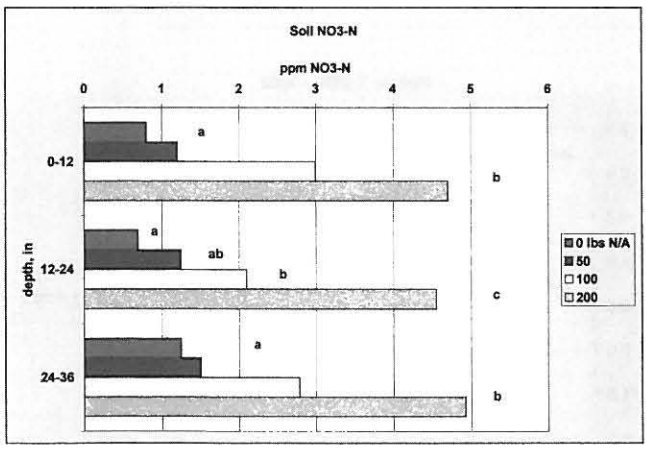

Figure 3. *Fall 2002 soil sample NO_3-N rersults at 1, 2, and 3 feet for the various nitrogen treatments. LSD 0.05 performed on log transformed data. Bars with the same letter are not significantly different.*

PROJECT DESCRIPTION

As in the past, this trial was established in a commercial sweetpotato field. Nitrogen rates were 0, 50, 100, and 200 lbs N per acre, and potash rates were 0, 75, 150, and 300 lbs K_2O per acre. Part of the field was sectioned off from the main irrigation assembly so that the fertilizers could be applied independent of the grower's fertilization schedule. No preplant incorporated fertilizers were applied. Plots were 2 rows wide by 45 feet long and replicated four times. The field was planted with Beauregard cuttings on May 25, 2002, on 12" spacing.

Granular potassium sulfate and phosphorous were applied to the beds under the drip lines at transplanting. Phosphorous rates were 60 lbs P_2O_5 uniformly applied to all plots. Nitrogen treatments began June 26, 2002. CAN17 was injected on a 5 to 7 day schedule for a total of 7 applications. All nitrogen was applied through the drip tubes using a small battery-operated piston pump. The nitrogen rate injection schedule is shown in Table 1.

Sampling: Soil samples were taken in April and late August. The August soil sampling occurred after all nitrogen treatments had been applied. Samples were taken in each plot to three feet and divided into one-foot increments, then analyzed for N (as NO_3-N) and K. Petiole samples were taken four times (June 17, July 25, Aug 15, and Sept 13). Moisture loss in storage measured each month from November to March on 40 lb samples from each plot. Plots were harvested using a commercial harvester on October 31 and November 1, 2002.

RESULTS & CONCLUSIONS

Spring soil test results are shown in Table 2. Nitrate levels in the top foot were moderate, averaging 13.7 ppm (~ 54 lbs NO_3-N), and fairly low at the lower depths. Potassium was below 100 ppm at all depths, indicating that a response to potash fertilizer would be expected.

Petiole sampling results are shown in Table 3. As fertilizer rates increased, the amount of NO_3-N and K in the plants increased significantly at most sampling times.

Yield results are shown in Table 4. Yield of #1's, mediums, and total market yield (TMY) were significantly increased by additional N from fertilizer as compared to the check treatments. Best #1 and TMY occurred at 100 lbs N/A. TMY was significantly increased by K fertilizer, with best yields occurring at 150 lbs K_2O per acre. The N x K interaction was not significant for any size class.

Relative yields, where yields from the check plots are compared to the treated plots and expressed as a percent, can be used to compare treatment effects across all four years of this study. The relative yield chart for nitrogen is shown in Figure 1. Combining all years, best yields for #1's or TMY occurred at 125 – 175 lbs N per acre. Jumbo yields continued to increase as N fertilizer rates increased. A relative yield comparison was not done for potash because there was a response to fertilizer K in only one year of this study.

Soil samples from the spring and fall 2002 are shown in Figures 2 and 3. The spring results show a movement of N from the previous fall from the upper foot to the lower foot of the soil profile; however, the concentration is relatively low, below 10 ppm NO_3-N, even at the highest nitrogen rate. In the fall, soil NO_3-N values were very low for all treatments, at less than 5 ppm. Spring soil NO3-N results are shown in Figure 2.

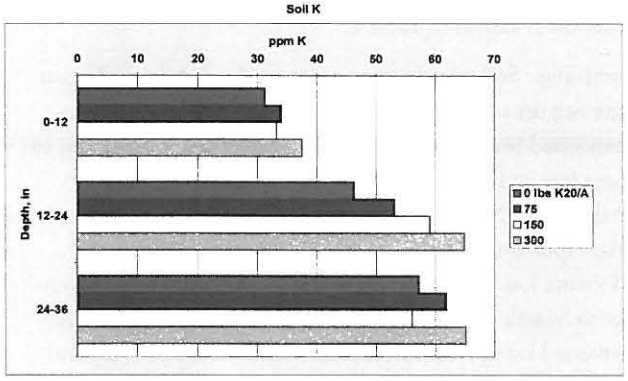

Figure 4. *Soil levels for different depths as affected depths as affected by potash treatment, fall 2002. LSD 0.10 for 1, 2, and 3 feet are NS, 10 ppm, and NS, respectively (means separation performed on log-transformed data).*

Soil sample results for K are shown in Figure 4. In general, K increased with depth and as fertilizer K increased. Soil test K never exceeded 70 ppm, even at the 300 lbs K_2O per acre fertilizer rate. Regression analysis showed a significant positive linear response in soil test K as fertilizer K increased ($p < 0.01$, $R^2 = 15\%$); however, there was no significant correlation between fall soil test K and yield. The lack of yield response to added K and no correlation in any year for this trial, combined with low soil test values, suggest that 1) the soil test guidelines need to be revised for sweetpotatoes; or 2) the soil has high K fixation potential. This soil's K fixation potential ranged from 11% to 36%, which is considered low (Dr. Stu Pettygrove, personal communication), and therefore unlikely to explain the lack of K response in this trial.

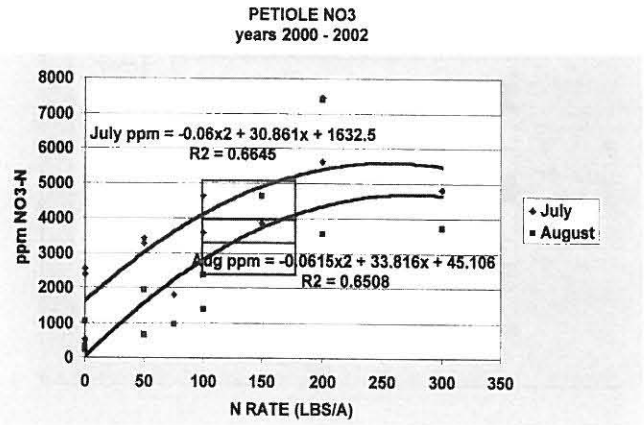

Figure 5. *Correlations between petiole NO3-N and N rate for July (top line) and August (bottom line) for years 2000 - 2002. Boxes correspond to that area where yield was maximized (125 to 175 lbs N/A).*

Current UCCE guidelines state that fertilizer should be applied if the soil K is less than 150 ppm. The data from this trial suggest that soil K levels > 70 ppm are adequate. Even with these low values, the cumulative K_2O content in the soil (from 0 – 3 feet) exceeded 695 lbs per acre.

Very little relationship was found between the petiole N and K analyses and yield. There was a slight positive relationship with both petiole NO_3-N and K to yield at the July sampling, but none with the August plant sampling. Nonetheless, the significant response curves to fertilizer rate suggest zones where levels are sufficient. Using these curves and others from previous years (Figures 5 and 6), new guidelines are listed in Table 5.

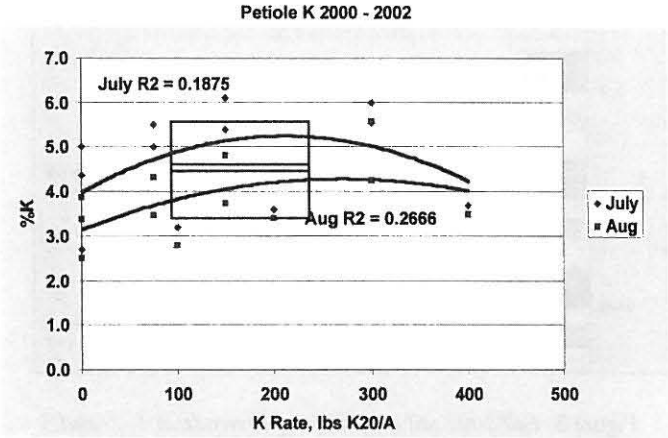

Figure 6. *Correlation between petiole K and potash rate as measured in July (top line) and August (bottom line) from 2000 - 2002.*

Table 1. N fertilizer injection schedule for 2002.

Application	*Date*	*Rate*	*50*	*100*	*200*
			Lbs N per week[2]		
1.	6/26	1/2 x	3.5	7.0	14.0
2.	7/5	1 x	7.0	14.0	28.0
3.	7/10	1 x	7.0	14.0	28.0
4.	7/16	1.5 x	10.5	21.0	42.0
5.	7/23	1.5 x	10.5	21.0	42.0
6.	7/29	1 x	7.0	14.0	28.0
7.	8/2	1 x	7.0	14.0	28.0
8.[1]	---				

1. The 8th application was not made in 2002; instead, rates were increased on the 7th application.
2. Due to rounding, actual total N applied was 5% greater than target rate.

Table 2. Spring initial soil samples, 2002.

Sample depth	*pH*	*EC mmhos/cm*	*CEC meq/100g*	*NO_3-N ppm*	*P ppm*	*Sol K ppm*	*Ca ppm*
0 – 12"	4.7	0.89	3.0	21.5	58.1	51.0	221
12 – 24"	5.0	0.44		6.2	23.8	23.1	160
24 – 36"	5.5	0.62		9.4	15.8	11.9	261
	Low	Good	Low	High	High	Low	

EC = electrical conductivity, a measure of the salinity of the soil.
CEC = cation exchange capacity, a measure of base saturation of the soil.

Table 3. Leaf and petiole sample results, 2002.

N rate Lbs/A	*June 17[1]*	*July 25 NO_3-N ppm*	*Aug 15 NO_3-N ppm*	*Sept 12 NO_3-N ppm*
0		2381	1048	766
50		3436	1953	1393
100		4625	2373	1280
200		7462	7410	4863
LSD 0.10		450	668	1075
K rate Lbs/A	K%	K%	K %	K%
0	7.55	4.35	3.86	2.97
75	7.17	5.00	4.31	3.12
150	7.10	5.40	4.81	2.77
300	7.12	5.55	5.56	2.78
LSD 0.10	NS	0.26	0.39	NS

1. At June 17 sampling, nitrogen treatments had not started. Average petiole sap nitrate was 23,500 ppm.
2. LSD = least significant difference at the 90% confidence level. NS = not significant.

Table 4. Main effect of nitrogen and potash rate on yield and grade of Beauregard sweetpotatoes in 2002.

Treatment	*#1's*	*Jumbos*	*Mediums*	*Total Market Yield*	*% #1's*	*Culls*
N rate		-------- 40 lb boxes/A --------			%	1000lb Bins/A
0	559	336	168	1063	52.7	1.04
50	590	335	180	1105	53.8	1.38
100	629	318	213	1160	53.5	1.14
200	579	324	208	1112	52.1	1.34
LSD 0.10	39.0	NS	25.1	45.4	NS	NS
K rate 0	580	311	185	1076	53.9	1.31
75	594	306	183	1083	55.1	1.00
150	590	347	198	1135	52.1	1.08
300	591	350	203	1145	50.9	1.52
LSD 0.10	NS	36.0	NS	38.4	2.5	NS
N x K LSD	NS	NS	NS	NS	NS	NS
CV, %	8.3	18.3	19.0	5.8	8.0	76.0

US #1's: Roots 2 – 3.5" in diameter, 3 – 9" in length, must be well shaped and free of defects.
Mediums: Roots 1 – 2" diameter, 3 – 7" in length.
Jumbos: Roots that exceed the diameter and length requirements of the above two grades, but are of marketable quality.
% US #1's: Wt. of US #1's divided by the total marketable wt (culls not included).
Culls: Roots >1" in diameter and so misshapen or unattractive as to be unmarketable.
LSD 0.10: Least significant difference at the 90% probability level. NS = not significant.
CV Coefficient of variation, a measure of variability in the experiment.

Table 5. Suggested petiole nitrate and potassium sufficiency ranges as developed from the drip fertilizer trial, 1999 – 2002.

Sampling period	*Petiole NO_3-N*	*Petiole K*
	Sufficiency ranges	
Vining (4 – 6 weeks post transplant)	3,000 – 5,000 ppm	4.5 – 5.5%
Root bulking (8 – 10 weeks post transplant)	2,000 – 4,000 ppm	3.5 – 4.5%

UCCE guidelines currently advise 2500 ppm NO_3-N, and 5% K at mid-growth. Petioles should be taken 6th leaf from the growing tip, with the leaf blade removed (inclusion of the leaf blade dilutes the sample). A minimum of 30 petioles should be collected for a good sample.

Table 6. Storage weight loss for sweetpotatoes as affected by fertilizer treatment for the period November 2001 to May, 2002.

N rate Lbs/A	*K_2O rate Lbs/A*	*6 weeks*	*12 weeks*	*18 weeks*	*24 weeks*	*30 weeks*	*Cumulative*
		Post Harvest Weight Loss, %					
0		3.9	2.3	2.6	1.3	1.9	12.0
50		3.3	2.0	2.5	1.5	1.9	11.1
100		3.6	2.4	2.9	1.6	2.2	12.7
200		3.3	1.8	2.3	1.3	2.0	10.7
LSD 0.10		**NS**	**NS**	**NS**	**NS**	**NS**	**NS**
	0	3.5	2.0	2.1	1.4	1.9	11.0
	75	3.5	2.2	2.7	1.4	1.8	11.6
	150	3.8	2.2	2.8	1.6	2.2	12.7
	300	3.2	2.1	2.7	1.3	1.9	11.1
	LSD	**NS**	**NS**	**0.5**	**NS**	**NS**	**1.3**

LSD = Least significant difference at the 90% confidence level. NS = not significant.

Storage weight losses were measured after the 2001 and 2002 seasons (Tables 6 & 7). There was essentially no significant effect from either N or K fertilizer rate on moisture loss, or shrinkage, for a four to six-month period. In general, the potatoes lost 3.5% of their weight in the first 6 weeks after harvest, and then 1 – 2% each month after that.

Using the data from plant analyses, yield, and soil results, a nitrogen balance was calculated for this system. About 235 lbs N/A was found in the treatments receiving 50 and 100 lbs of N, and 360 lbs N/A at the 200-lb fertilizer rate (Table 8). It has already been shown that the best rate was 125 – 175 lbs N/A for maximum yield; this table shows that nitrogen fertilizer rates over 175 lbs per acre increase vine weight, leaf N, root N, and the amount of NO_3-N in the soil, but do not consistently increase yield.

It is interesting to note that even in the plots that received no nitrogen fertilizer, nearly 163 lbs N/A was accounted for. Much of this, no doubt, came from residual N in the soil profile—based on the soil sample data in Table 2, the 0 – 3 ft

Table 7. Storage weight loss for sweetpotatoes as affected by fertilizer treatment for the period November 2002 to March, 2003.

N rate Lbs/A	*K_2O rate Lbs/A*	*8 weeks*	*18 weeks*	*Cumulative*
		Weight loss, %		
0		4.9	5.1	9.7
50		4.7	4.6	9.6
100		5.0	4.9	10.0
200		5.4	5.6	10.7
LSD 0.10		**NS**	**NS**	**NS**
	0	4.8	4.7	9.3
	75	5.0	5.5	10.8
	150	4.8	5.2	10.1
	300	5.3	4.6	9.8
	LSD 0.10	**NS**	**NS**	**NS**

LSD = Least significant difference at the 90% confidence level. NS = not significant.

Table 8. Partial N partitioning based on vine weight, roots, and soil, 2002.

N rate Lbs/A	*Vine wt Lbs/A*[1]	*Vine N %*	*Vine N Lbs/A*	*Root wt Lbs/A*[2]	*Root N %*[3]	*Root N Lbs/A*	*Soil N Lbs/A*[4]	*TOTAL N Lbs/A*
0	1883	2.29	43.1	12,760	0.85	108	11.7	162.8
50	2459	2.61	64.2	13,270	1.15	153	17.1	234.3
100	2600	2.36	61.4	13,920	1.01	141	40.0	242.4
200	3048	3.15	96.0	13,340	1.50	200	61.5	357.5
LSD 0.1	385	0.28	12.0	545	---	---	10.0	---

1. Vine weight is the total dry weight (12.5% D.M.) of the vine plus leaves at the end of the season (September sampling).
2. Root weights are at 30% D.M. of TMY.
3. Root N% based on 2001 data.
4. Soil N is the sum of N (as NO_3) in the upper 3 feet of soil based on soil bulk density of 1.7, 1.6, and 1.5 g cm^{-3} for the 1st, 2nd, and 3rd foot in the profile, respectively (soil BD values based on USDA NRCS soil survey data). LSD value determined on natural log adjusted values and converted back for this table.
5. LSD 0.10 = least significant difference at the 90% confidence level. Means separated by less than this amount are not significantly different.

profile contained 165 lbs of N (as NO_3-N). While this is not necessarily all available for the subsequent crop, mineralization of soil organic matter would have contributed another 30 – 60 lbs (SOM in these sandy soil is typically very low, < 1%).

In summary, there was a significant yield response to N and K in 2002 as compared to the unfertilized check. Best #1 and TMY yields occurred at 100 lbs N/A and 150 lbs K_2O/A. Significant responses were found for nitrate and potassium in the plant tissue and soil. In general, as N and K rates increased, so did the amount in the plant and soil. However, there was little correlation between plant and soil analyses and yield. Varying N and K rates had no significant effect on weight loss in storage for a period of 4 – 6 months. Little evidence was found that soil nitrate levels were building up in the lower soil profile, even at high nitrogen fertilizer rates.

Based on the results of four years of study, new fertilizer rates for nitrogen are suggested with the cultivar Beauregard grown with drip irrigation. These fertilizer rates are 125 – 175 lbs N per acre. Because a significant response to potassium was observed in only one year, no recommendation is made other than to supply what is removed by the crop. A 30 bin/A yield will remove about 150 lbs K_2O per acre (5 lbs K_2O per 1000 lbs potatoes). Refined tissue analysis guidelines are also suggested that are slightly higher earlier in the season and slightly lower later in the growing season than was previously recommended.

ACKNOWLEDGEMENTS

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EFFICIENT PHOSPHORUS MANAGEMENT IN COASTAL VEGETABLE PRODUCTION

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INTRODUCTION

Decades of heavy phosphorus fertilizer application to vegetable fields in the Salinas and Pajaro Valleys have resulted in substantially increased soil P concentration. Soil test P levels now commonly exceed the threshold for expected crop response to continued P fertilization, based on commonly cited references from the University of California and other sources. While this generally does not cause agronomic problems, it may be a significant contributor to the undesirably high P concentration found in the Salinas and Pajaro River systems. Parts of both watersheds have been listed as 'impaired' for soluble nutrients, based on the prevailing Federal water quality standards. This project was undertaken to reevaluate the current P management recommendations for lettuce production in light of this potentially serious environmental problem.

OBJECTIVES

1) Develop efficient P fertilizer guidelines for coastal lettuce production.

2) Document the relationship between soil characteristics, soil test P levels, and potential loss of P through runoff.

METHODS

To determine the current P status of agricultural land in the Salinas and Pajaro Valleys, soil from 30 fields, most in long-term vegetable rotations, was collected in spring, 2002. The fields, located in Monterey, San Benito, Santa Clara and Santa Cruz Counties, represented both conventionally farmed and organically managed land. These soils were analyzed for Olsen (bicarbonate) extractable P (top 6 inches). Heavy fertilization has reduced the native capacity of coastal vegetable soils to chemically bind applied P. To determine the degree to which these soils' ability to chemically bind P had been reduced, a phosphorus saturation index test was conducted. In this test a 1:100 mixture of soil and 0.01 M $CaCl_2$ solution containing soluble P was incubated for 24 hours with continuous shaking; the amount of soluble P removed from the solution represented the soil's remaining P fixation capacity. The P saturation index was calculated by the formula:

*P saturation index = (Olsen P/(Olsen P + solution P adsorbed)*100*

High index values indicate soils that are nearing P saturation, and potentially represent environmental pollution hazards. The potential for loss of soluble P in runoff was also directly determined for each soil. In the P runoff test, pots of each soil were exposed to a simulated rainfall event; surface runoff was captured and analyzed for soluble P. In six selected soils, the effects of a cover crop on the potential for P loss in runoff was evaluated. Plots with and without an actively growing oat cover crop were subjected to simulated rainfall, and the P concentration of the runoff determined.

Table 1. Soil test P in survey fields.

	Number of fields	
Olsen P (PPM)[z]	Conventional	Organic
< 40	5	3
40 - 80	9	0
80 - 120	7	1
> 120	3	2

[z] top 6 inches

A total of twelve field trials were conducted in commercial lettuce fields in the Salinas Valley in 2002-2003 evaluating whether P fertilization in fields with moderate or high soil test P levels actually affected crop productivity. The fields chosen varied from 53 – 171 PPM bicarbonate P (top 6 inches of soil). Existing recommendations rank these fields as moderate to high P availability. In fields 4 and 10 the grower did not apply preplant P fertilizer; we established 4 plots within each of these fields that received preplant fertilization of 130 lb P_2O_5 / acre. In all other fields the growers applied P preplant, and we established 4 plots per field in which this P application was skipped; the performance of these plots was compared to adjacent plots receiving the preplant P application. The experimental design in each field was randomized complete block, with each plot being 4 beds wide and 200 feet long. All data were collected in the middle 100 feet of each plot, from the middle two beds.

Leaf P concentration was monitored at cupping stage, and at harvest the P concentration of harvested head tissue was determined. Just prior to commercial harvest, 30-40 whole plants per plot were randomly selected and weighed to compare total plant biomass between treatments. These whole plants were then trimmed according to market standards and the marketable weight was recorded. Where possible, counts of plants remaining after commercial harvest were taken, and the % of plants harvested was calculated. In fields in which that was not possible, the % of plants harvestable was estimated by rating plants on 100 ft of bed prior to commercial harvest.

RESULTS

The soils collected in the field survey ranged from 15 – 177 PPM bicarbonate extractable phosphorus, averaging 75 PPM (Table 1). To put these numbers into perspective, soils from the Sacramento Valley that have been

Table 2. Characteristics of the 2002- 2003 trial sites.

Field	Location	Olsen P (PPM)[z]	P application rate (lb P_2O_5 / acre)	Planting date[y]
		Iceberg lettuce		
1	Salinas	54	59	Apr 3, 2002
2	Salinas	124	60	Apr 11, 2002
3	Chualar	72	42	June 12, 2002
4	Chualar	171	130	July 15, 2002
5	King City	57	80	Jan 27, 2003
6	King City	62	75	Jan 27, 2003
7	King City	53	75	Feb 19, 2003
8	King City	82	80	Feb 26, 2003
9	Salinas		60	May 20, 2003
		Romaine lettuce		
10	Soledad	55	130	May 11, 2002
11	Chualar	78	72	July 26, 2002
12	Salinas	98	53	Feb. 10, 2003

[z] top six inches of soil
[y] date of first water

Table 3. Lettuce response to P fertilization.

Field	P treatment (lb P_2O_5 / acre)	% of plants marketable	Whole plant wt (lb)	Marketable plant wt (lb)
		Iceberg lettuce		
1	0	81[z]	2.15[z]	1.46[z]
	59	87	2.29	1.56
2	0	93	2.42	1.58
	60	95	2.52	1.57
3	0	84	2.56	1.66
	42	83	2.64	1.70
4	0	75	1.55	1.06
	130	77	1.56	1.08
5	0	90	2.31	1.35
	80	92	2.29	1.34
6	0	76	2.52	1.49
	75	68	2.43	1.43
7	0	90	2.00	0.98
	75	91	2.20	1.12
8	0	87	2.07	1.35
	80	87	2.00	1.32
9	0	87	2.60	1.83
	60	83	2.49	1.65
Ave	No P	85	2.24	1.42
	Plus P	85	2.27	1.42
		Romaine lettuce		
10	0		1.55	1.07
	130		1.65	1.08
11	0		1.21	0.90
	72		1.17	0.88
12	0		2.31	1.43
	53		2.38	1.47
Ave	No P		1.69	1.13
	Plus P		1.73	1.14

[z] significantly different from the applied P treatment

farmed for an equivalent period of time typically range from 10-25 PPM bicarbonate P. The difference reflects the higher application rates, and more frequent application, of P fertilizers in the coastal valleys. Despite these high soil test P values, many coastal vegetable growers continue to apply P before each crop (as evidenced by the grower P application in 10 of the 12 trial fields), and a substantial number also apply P in sidedressings.

In the first trial, planted in early April, 2002, significant response to preplant P was observed (Table 3). This was

Table 4. Effect of P fertilization on lettuce tissue P concentration.

Field	P treatment (lb P_2O_5 / acre)	% leaf P At heading	At harvest
		Iceberg lettuce	
1	0	0.43	0.64
	59	0.43	0.66
2	0	0.48	0.68
	60	0.51	0.71
3	0	0.51	0.78
	42	0.53	0.81
4	0	0.44	0.55
	130	0.49	0.59
5	0	0.54	0.66
	80	0.52	0.73
6	0	0.46	0.64
	75	0.47	0.65
7	0	0.62	0.72
	75	0.71	0.78
8	0	0.55	0.65
	80	0.54	0.66
9	0		
	60		
Ave	No P	0.50	0.67
	Plus P	0.53	0.70
		Romaine lettuce	
10	0	0.37	0.38
	130	0.40	0.42
11	0	0.56	0.56
	72	0.56	0.56
12	0	0.65	0.56
	53	0.62	0.61
Ave	No P	0.53	0.50
	Plus P	0.53	0.53

somewhat surprising, since the soil bicarbonate P level was 54 PPM, above the response threshold cited in most references. Early planting (cold soil temperature) was undoubtedly a factor, since P bioavailability is reduced at lower soil temperature. In no other field was there a statistically significant crop response to P application. In fields 7 and 10 there was a trend toward larger plants with preplant P application, but those trends were confounded by high spatial variability in crop vigor and were not statistically significant. Averaged across all fields, the productivity of plots receiving no preplant P was virtually identical to that of plots receiving P. Crop growth was poor in several fields (# 4 and 7 in particular), but P fertility was apparently not the growth limiting factor.

Tissue P concentrations > 0.35–0.40% are generally assumed to be adequate for maximum growth, and both treatments in all fields met or exceeded that range. It is interesting to note that field 1 (the only responsive field) and field 10 had the lowest P concentration at heading stage. P application had little influence on crop P uptake. The harvestable portion of the crop contained on average less than 10 lb of elemental P / acre, and the difference between fertilized and unfertilized crops was < 0.5 lb / acre. Since the growers applied an average of 66 lb P_2O_5 / acre (29 lb P / acre), most of that P remained in the soil. This large difference between P application and removal over many years explains the elevated soil test P values now common in the coastal valleys.

The ability of soil to sequester applied P is not limitless. Olsen extractable P in the survey soils was highly correlated with soil P saturation (Fig. 1); soils with lower Olsen P values had a significantly greater capacity to chemically bind applied P than did soils with higher Olsen P. In fact, in two of these soils the P saturation capacity had been exhausted, meaning that the solubility of any further fertilizer P would be limited primarily by the solubility of the fertilizer. The practical significance of these findings is illustrated in Fig. 2. In the runoff study, soils with elevated Olsen P had vastly greater P loss in runoff than soils with lower soil test P. Soil #6 was one in which the P saturation capacity had been exhausted; it is instructive to note that its soluble P in runoff was more than double that of any other soil tested. In soils with elevated Olsen P levels the presence of a cover crop reduced soluble P concentration in runoff by 24-56%. This probably underestimates the overall importance of cover crops in reducing P losses to the environment, since cover crops also tend to significantly reduce runoff volume.

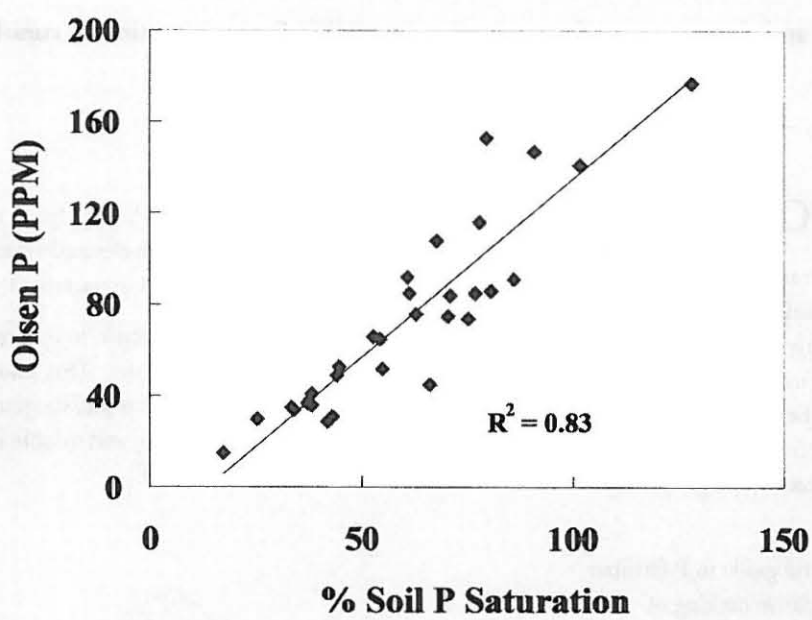

Fig. 1. Relationship between Olsen (bicarbonate) extractable soil P and % soil P saturation.

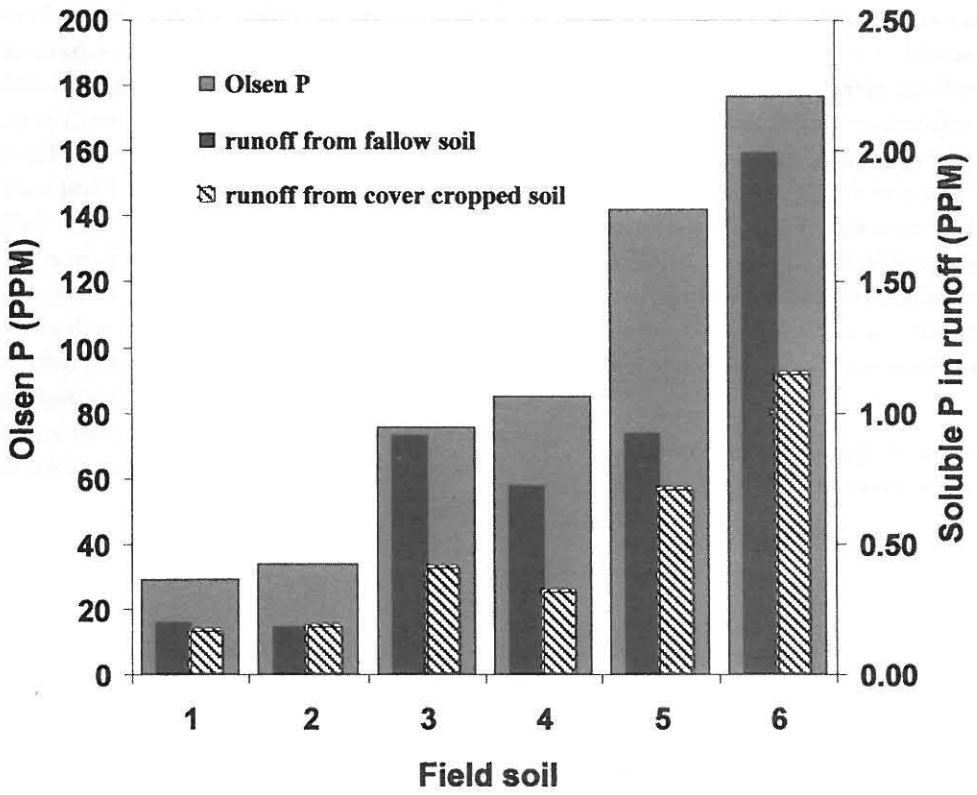

Fig. 2. Effect of soil P and the presence of a cover crop on soluble P concentration in runoff.

SUMMARY/CONCLUSIONS:

1) The probability of obtaining a lettuce growth response from preplant P application in fields with Olsen P > 50 PPM is low. Fields planted in early spring have a greater probability of response, but even in these conditions only a low rate of P application could be justified. Given the modest P removal rate of lettuce, it may take a number of crop cycles of little or no P application to significantly reduce soil test P levels.

2) The Olsen P test is not only a useful guide to P fertilizer management, it also provides a relative ranking of potential P loss to the environment through surface runoff. Management efforts to limit P losses can be most effectively directed at fields with elevated Olsen P levels (perhaps those with > 100 PPM extractable P).

3) Cover cropping is a valuable practice to minimize P loss to the environment during the winter. This study, which supported prior research on this topic, suggests that cover crops will reduce runoff volume, and soluble P and sediment content in that runoff.

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

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OBJECTIVES-YEAR ONE

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.

BACKGROUND

The Central Coast Regional Water Quality Control Board (RWQCB) identified tail water 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

Treatment[1]	n	Placentia sandy loam	Clear Lake clay	Mocho silt loam	Salinas clay loam	Chualar loam
		Infiltration Rate (mm/hr)				
Control (0 ppm)	6	9.17	1.48	46.46	3.91	39.94
Amber 1200D (10 ppm)	6	8.89	1.29	33.96	3.34	27.53
Amber 1200D (20 ppm)	6	7.24	1.28	23.83	2.95	18.88
Soilfloc 100D (10 ppm)	6	6.89	0.83	21.40	2.57	21.22
Soilfloc 100D (20 ppm)	6	4.21	0.52	12.25	0.96	10.16
$LSD_{0.05}$		--[2]	0.24	1.85	0.50	3.46
$p > F$[3]		<.0001	<.0001	<.0001	<.0001	<.0001
CV (%)		11.0	18.1	5.5	14.9	12.0

1. water quality: EC = 1.0 dS/m, SAR = 2 pH=6.2
2. value not presented due to missing data
3. probability of obtaining (by chance alone) an F statistic greater than the computed F value

Table 1. *Infiltrtion rate of soils from Monterey, San Benito, and Santa Cruz counties using water treatd 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

Table 2. *Effect of SAR (sodium adsorption ratio) on infiltration rate in soils from Monterey Counties using water treated with polyacrylamide*

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 concentrations in tail water 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, run off, and sediment and nutrient (ortho and total P, NO_3, K) 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 will screen a larger range of soil types and water compositions than can be accomplished with field studies. Field studies evaluate the effect of PAM on infiltration rate using a recirculating infiltrometer. Trials will be conducted in head lettuce fields to measure the effect of PAM on water penetration depth, runoff, and sediment and phosphorus loss, as well as the effect on yield and quality. Information developed in this project will be extended through field and seminar meetings, bulletins, and newsletters. The target audiences for the project are vegetable growers and farm managers, NRCS and RCD personnel, irrigation industry representatives and consultants, fertilizer dealers and sales representatives, and others that consult or make decisions on irrigation and nutrient management in vegetables.

SUMMARY

Effect of PAM on soil infiltration rate

Column studies were conducted to investigate the effect of PAM (Amber 1200D, Cytec Inc, and Soilfloc 100D, Hydrosorb, Inc.) on infiltration rate of soil types common to Monterey, San Benito, and Santa Cruz counties. Water treated with PAM maintained aggregate structure on the soil surface (*Figures 1 and 2*). However, PAM-treated water was found to reduce infiltration rate in all tested soils types (*Table 1*). Soilfloc 100D reduced infiltration rate more than Amber 1200D (*Table 1*). Also, infiltration rate decreased as the concentration of PAM increased. Pretreating the surface of the soil with PAM, rather than applying PAM continuously in the water, maximized infiltration relative to the untreated control (Figure 3). Infiltration rates increased as the pretreatment volume was decreased.

Interaction of PAM and Sodium Adsorption Ratio on soil infiltration rate

Column studies demonstrated that increasing sodium absorption ratio reduced infiltration rate more in water with PAM than without PAM (Table 2). This result suggests

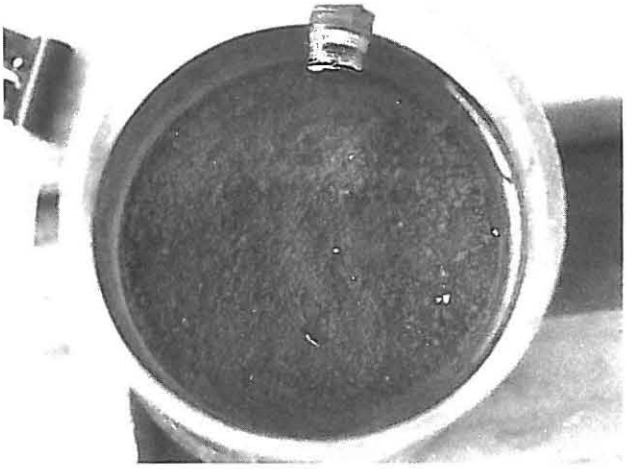

Figure 1. *Infiltration into a Salinas Clay soil after an initial treatment with 10 ppm of amber 1200D polyacrylamide.*

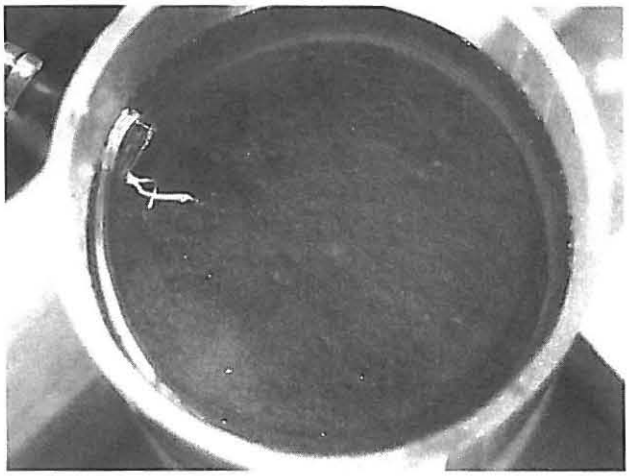

Figure 2. *Infiltration into a Salinas Clay soil without a pretreatment of polyacrylamide (control).*

that the ratio of sodium to calcium and magnesium in the water affects the chemical and/or physical properties of polyacrylamide.

CONCLUSIONS

The results of the column studies demonstrated that polyacrylamide-treated water can reduce infiltration rates in central coast soils by more than 50%. Additionally, the reduction of infiltration by treating water with PAM was enhanced with high SAR. Evidence in the literature suggests that polyacrylamide reduces the infiltration rate into soil by increasing the viscosity of water. Hence, we found that pre-applications, using small volumes of polyacrylamide-treated water, minimized the reduction in infiltration while still enhancing the surface structure of the soil. Under conditions where soils are susceptible to crusting, such as sprinkler irrigation, the pretreatment of PAM may improve infiltration. Future trials will investigate the effects of PAM on infiltration rate and sediment loss under field conditions.

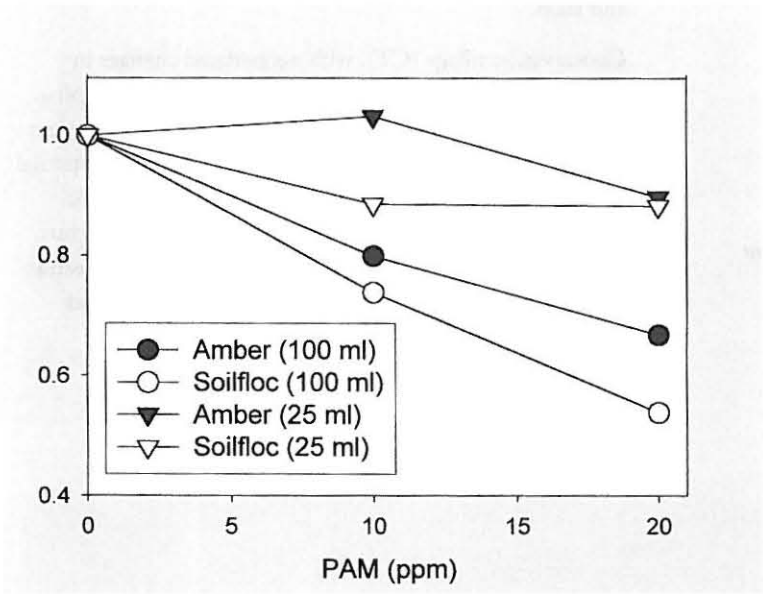

Figure 3. *Effect of PAM pretreatment on infiltration reate in a Salinas Clay relative to the control (0 ppm PAM).*

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

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INTRODUCTION

Agricultural runoff is a major pathway for loss of nutrients from farm soils. Nutrient losses to runoff result in inefficient use of fertilizer and mean both higher costs to farmers, as they pay to replace the lost nutrients, and higher costs to society, as it pays to clean up degraded waterways. Agricultural runoff is the main source of nonpoint source pollution of California's rivers, streams, and lakes.

Conservation tillage (CT), with necessitated changes in irrigation system design and efficiency, and cover-cropping, are two avenues for reducing runoff and decreasing nutrient losses. These management alternatives also have the potential to improve many other aspects of farm management for California growers, including reducing labor and fuel costs, increasing soil water storage, decreasing water usage, decreasing dust emissions, increasing carbon sequestration, and increasing net revenues.

No studies have been done in California to evaluate the separate and/or combined effects of CT and cover-cropping on runoff and consequent nutrient loss to surface waterways, in conventional or alternative production systems. Measurements will be made of runoff from plots at the Sustainable Agriculture Farming Systems (SAFS) research site at UC Davis, a long-term comparison of organic, low-input, and conventional farming systems, and from farm fields provided by SAFS grower-collaborators. Grab samples will be taken from the runoff and analyzed for suspended sediment and nitrogen and phosphorus content. The well-developed SAFS outreach structure will be used to extend the results of the study to farmers, farm advisors, policymakers, and the general public.

In the spring of 2003, the Sustainable Agriculture Farming Systems project moved its study entitled, "Effects of Conservation Tillage on Nutrient Losses to Runoff in Alternative and Conventional Farming Systems", funded by the CDFA's FREP program, to a new location, the site of the Long-Term Research in Agricultural Systems (LTRAS) experiment at UC Davis' Russell Ranch. The purpose of the study is to quantify relationships between tillage and fertility management, and runoff and nutrient loss, from soils farmed using organic, low-input, and conventional practices.

At the LTRAS site, Conservation Tillage and Standard Tillage are being compared side by side, in half-acre plots managed with conventional, cover-cropped, and organic farming systems. The LTRAS experiment is in its tenth cropping year of the planned 100 years. CT/ST comparisons are evaluated in half-acre plots, managed under conventional, cover-cropped, and organic farming systems. The crops grown are processing tomatoes (var. Halley 3155) and field corn (ST 7570RR and ST 7570 in the organic systems). With funding from FREP, as well as several other sources, data are collected on soil biological, chemical, and physical properties; plant growth and crop yields; water infiltration and runoff water quality and quantity; pest and disease incidence; and numerous other characteristics of these systems. In-season data for 2003 have not yet been analyzed and are not available; however, the research team has learned a great deal from observations of production practices and field conditions, in terms of what worked, and what improvements might be made in the future. These observations are reported here.

FIELD OPERATIONS & PROCEDURES

Tomato Production Systems

The onset of spring operations was postponed approximately two weeks by the late rainfall experienced in this area and much of California.

Operations in the CT and ST treatments diverged in early April. In the cover-cropped and organic ST treatments, cover crops (CCs) were flail-mowed slightly above the bed surface. The organic systems received a bed top application of composted poultry litter, a treatment consistent over the preceding 9 years at this site. A relatively lightweight bed-preserving disc (Hahn) was then used to mix the CC residue and the compost in the beds for the respective systems. Final operations were to lightly shank the beds with a cultivating sled and mulch with an AP incorporator to uniformly consolidate the CC residue/compost below the soil surface.

In the CT organic systems, compost was applied on the bed top to the standing CC, which was then flail mowed and allowed to lie as it fell. The initial plan had been to transplant tomatoes directly to the beds with no tillage. However, due to the lateness of the rains and the retention of soil moisture by the CC residue and compost mass, this did not seem possible. The group made a decision to try to open and aerate the planting zone. Strip tillage was emulated using a 3-point Clampco fertilizer applicator with a coulter disc wheel and 2 shanks per bed, on a single pass.

In the conventional (full input) CT/ST tomato systems, beds were established the preceding fall and herbicides were used to control weed development during the winter. In the ST treatment, a Perfecta II was used to aerate the soil surface and for control of minor weed growth. In this wet spring, this proved to greatly enhance our ability to move onto the plots with additional tillage equipment without compacting wet soil. Subsequently, a cultivating sled with various shanks followed by bed center herbicide incorporation/mulching operation provided smooth level beds for transplanting. During the season there were two light mechanical cultivations and an additional layby incorporation. Preplant (15-15-15) and in-season granular fertilizer (ammonium sulfate) was shanked into the beds with a Clampco affixed with a coulter disc. As in the other CT systems, the preplant operation served as a bed center strip till and aided transplanting into wet beds.

Tomato seedlings were transplanted in all systems May 8th, approximately two weeks behind schedule, using typical Holland transplanters affixed with a single coulter disc opener per bed. All tomatoes received approximately 800 gallons per acre of supplemental water at transplanting. This rate would generally be considered high for commercial fields but appropriate to facilitate stand establishment at the site where all subsequent irrigations are furrow run.

Transplanting worked well in all systems, but the high level of moisture in the CT plots, coupled with the weight of the standard transplanting sled, tractor and water tanks, led to heavy compaction. The center furrows were compressed to depths of 14 inches. The extreme depth and non-uniformity of CT furrows created at transplanting led to further difficulties with planned cultivations and irrigations. Irrigation water remained ponded in the furrows for long periods, with lateral movement very limited.

The furrow non-uniformity also later led to mechanical difficulties with harvesting. Post-transplant conditions resulted in a bed center depression, with the plants below the bed top and furrow compaction in the center of the 15 foot passes. In-season herbicide application and substantial hand weeding operations, relative to the ST comparison, were used for weed control. Planned late season and harvest operations were difficult as a result of the uneven beds and furrows in this system. Due to the bed center depression, it was necessary to cut well below the soil surface which resulted in equipment failure. It was also observed that significantly more and larger soil clods were picked up by the harvester.

During this initial CT season, primary emphasis was on reduction or complete eliminations of tillage operations. The decision to forego early season cultivation, coupled with non-uniformity of furrows and beds, reduced weed control options in the organic CT treatment to single row mechanical cultivations or hand weeding crews. This resulted in a higher level of expense for weed control in this system.

Corn Production Systems

Field operations in the CC and organic corn systems are similar to those described for tomatoes with respect to CT and ST treatments. Whether the CC and compost was thoroughly mixed into the soil (ST) or left to remain on the surface (CT), all corn plantings succeeded in establishing excellent stands. In the CT treatment this was achieved using coulters mounted in front of the seed openers, and a combination of smooth and spiked seed cover wheels. The coulters were successful in cutting the vetch/pea residue without sweeping it to the side. It was also possible to plant to depth into adequate soil moisture.

The conventional system CT and ST corn were planted a month earlier than the organic and cover-cropped corn. This was because the conventional systems did not have to wait for full CC biomass development in the spring, or allow typical "set-back" time to planting after mowing. Adequate weed control was achieved in the CT treatment with pre-plant and in-season Roundup applications. In the ST comparison, the beds were lightly harrowed with a Perfecta II to aerate and incorporate a pre-plant herbicide application. This treatment provided adequate weed control. An additional furrow sweep cultivation was used to retain bed/furrow integrity after shank fertilizer application. This ST treatment appeared to substantially increase the late season irrigation uniformity relative to the CT comparison.

Two major problems emerged in the CT organic and CC corn relative to the ST corn in the same systems. One was an apparent nitrogen deficiency in the crop. A pale yellow leaf color and reduced plant height were observed by one month after emergence. These remained until tassel emergence, when early senescence masked these characteristics. Plant tissue analyses that would confirm or deny an actual nitrogen deficiency remain to be completed.

The other main problem was the inability of available equipment to adequately cultivate weeds in the organic CT treatment. Without pre-plant or early season tillage, surface soil solidifies and breaks away as large clods, potentially damaging small seedlings. This situation is highly moisture related. Furrow irrigation in CT plots had difficulty reaching the center of the 60-inch beds.

CONCLUSIONS

In the conventional input systems during this first season, crop performance under both CT and ST treatments was sufficient. After ten consecutive years of annual CC and compost additions in the organic systems at this site, tomato crop development appeared to be similar for both CT and ST treatments. However, crop development in the CT organic and CC corn systems clearly lagged behind the ST comparison plots, presumably due to the differences associated with input incorporation. It may be necessary to incorporate CCs and composted manure with some form of light tillage in the spring, in order to get sufficient nitrogen to the crop in the future.

We learned this year that the nature and timing of early season tillage operations greatly affects the success of necessary later season operations. Appropriate soil moisture is crucial; in this unusually wet spring, the effects of over-wintering beds without spring tillage greatly increased non-uniformity of planting conditions. These adverse conditions were of most consequence in tomatoes, where they led to persistent problems with weed control in the organic systems, non-uniform irrigations in all CT systems, and mechanical difficulties with harvesting. These difficulties were not seen in the corn production systems, which had excellent stands, though the corn crop in the organic and low-input systems seemed to lag behind that in the conventional systems.

FALL PLANS

Fall crop production practices are still being decided by the project leader. Runoff monitoring will begin this rainy season (late fall of 2003). Funding from CALFED's Ecosystem Restoration Program will enable us to set up autosamplers in one plot per treatment, in addition to the grab sampling already planned; this will greatly enhance the quality of data collection.

NITROGEN FERTILIZATION & GRAIN PROTEIN CONTENT IN CALIFORNIA WHEAT

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INTRODUCTION

The nitrogen fertilization requirement for wheat depends on factors such as yield potential, the previous crop and residual fertility from it, soil fertility, and the amount of irrigation planned. Nitrogen fertilizer applications are made preplant, with seed, at tillering and/or at various other growth-stages during the season. In practice, total seasonal nitrogen applications may vary from 0 to over 300 lb nitrogen/acre, with some acreage over-fertilized and some acreage under-fertilized because of the difficulty of matching fertilizer need with yield potential in each growing season. Grain protein content at harvest may be higher or lower than the desirable level regardless of the total amount of nitrogen fertilizer applied. Anthesis-time nitrogen applications, in combination with irrigation, can increase grain protein content and improve baking quality of wheat. Such applications have increased grain protein content by 1-3%. Currently, however, growers are unable to predict what the final protein status of the crop is likely to be under such management – that is, is the potential 3% increase from 11 to 14% or from 8 to 11%? If the former is true, the grower may qualify for a price premium based on grain protein content. If the latter is true, no price premium will be available. Previous research has shown that for optimal production of high protein wheat, the preplant nitrogen amount has to be high enough for the yield potential to be realized, yet not so high that excessive vegetative biomass is produced. Studies also have shown that flag-leaf nitrogen content at anthesis is positively correlated with grain nitrogen content (but not with grain yield) and that if flag-leaf nitrogen content is greater than 4%, additional nitrogen usually is not required to achieve the target (13%) grain protein content. In order to accurately estimate anthesis-time nitrogen requirements, however, it is necessary to be able to predict both final grain nitrogen content and grain yield at anthesis. In order to produce high quality wheat consistently and economically, growers need to be able to determine: 1) if anthesis-time nitrogen fertilization is needed to reach the target (13%) grain protein level and, if so, 2) how much nitrogen fertilizer must be applied.

OBJECTIVES

The primary objective of this two-year project was to link nitrogen status and crop yield potential (based on crop biomass) at anthesis with a desired level of response of grain nitrogen content (i.e., final grain protein content of 13%) to specific rates of anthesis-applied nitrogen. Experiments were designed to measure the response of grain protein content to different rates (0, 30, and 60 lb nitrogen/acre) of anthesis-time nitrogen fertilization under different pre-anthesis nitrogen management practices (thus different yield potentials). Efficacy of broadcast vs. foliar-applied nitrogen also was compared.

DESCRIPTION

The project was managed within the framework of the UC Statewide Small Grain Evaluation program. Experimental sites were among those used in the UC Regional Cereal Testing Program. For the 1999/2000 and 2000/2001 seasons, three sites were established in the Sacramento Valley using the common wheat cultivar "Kern" and three sites were established in the San Joaquin Valley using the durum wheat cultivar "Kronos". The sites in the Sacramento Valley were the Chico State University farm in Chico (Butte County), the Erdman ranch near Grimes (Colusa County), and the UC Davis Agronomy Farm. The sites in the San Joaquin Valley were the Dupont Research Farm (Madera County), the J.G. Boswell farm in Corcoran (Kings County), and the J.G. Boswell Kern Lake Ranch (Kern County).

Experiments at each site were sown in the fall of 1999 and 2000. Treatments at each site consisted of 30 and 60 lb nitrogen/acre as ammonium nitrate and 30 lb nitrogen/acre as foliar-applied urea applied at anthesis. The anthesis-N application was followed with an irrigation. A check treatment of zero applied nitrogen at anthesis was included. Plot size was approximately 300 ft2. Composite soil samples (0-12" depth) were taken at each site at the time of sowing and also just prior to the application of anthesis-nitrogen to provide information on the differing N-status of each site (Table 1). Crop management through anthesis followed accepted grower practices at each site, thus providing differing crop biomass and nitrogen status environments. Crop biomass and nitrogen content of specific tissues (flag-leaf and uppermost stem internode) were measured at the time of anthesis-applied nitrogen, 14 days post-anthesis, and at harvest. Crop biomass samples at each sampling date consisted of plants from one-meter row/plot cut at the ground level. Subsamples of flag leaves and uppermost stem internodes were drawn from the biomass samples for total tissue nitrogen determination.

RESULTS & CONCLUSIONS

The sites and grower practices used provided different N-supply and grain yield environments at each location. Anthesis-N applications did not affect grain yield characteristics despite different yield potentials at each site and different amounts of soil nitrogen available both preplant and at anthesis (immediately prior to the application of anthesis-N) (Tables 1-3).

Average flag leaf N-content at anthesis (just prior to applying the anthesis nitrogen treatments) over all sites/seasons ranged from 2.9 to 4.4%, indicating inherent variability within and between sites (Tables 4 – 5). At the measured levels of flag leaf N-content at anthesis (all lower than 4% except for the Madera Co site in, 2000/2001), responses of grain protein content to anthesis-applied nitrogen were expected. Average uppermost stem internode N-content at anthesis showed a similar level of within and between site variability to flag leaf N-content. Flag leaf N-content, uppermost stem internode N-content, and flag leaf chlorophyll readings (SPAD readings, an assessment of "greenness", were made with a Minolta SPAD-502 Chlorophyll Meter) taken 14 days post-anthesis were not consistently affected by the different rates of nitrogen applied at anthesis. Tissue N-content and flag leaf chlorophyll may have peaked prior to the measurements, and decreased by the time samplings and readings were taken, due to translocation of nitrogen from flag leaf and stem tissues to the developing grain. Flag leaf chlorophyll of the durum wheat cultivar "Kronos" tended to be higher, by 5 to 13 SPAD units, than those of the common wheat cultivar "Kern" at similar flag leaf N-content (Tables 4 – 5). Different critical values for relating SPAD readings to nitrogen content (and ultimately to the need for anthesis-N topdressing to achieve target grain protein levels) may be needed for the different classes of wheat grown in California.

Grain protein content (12% moisture basis) ranged from 9.6 to 11.9% at Butte, from 9.6 to 11.8% at Colusa, from 10.7 to 12.7% at UC Davis, from 9.2 to 15.6% at Madera, from 12.6 to 14.2% at Kings, and from 12.9 to 14.2% at Kern, with a similar pattern each year at each site (Tables 4-5). The ammonium nitrate treatments (30 and/or 60 lb/acre rates of N) increased grain protein content above that of the zero anthesis-N application. The 60 lb/acre rate of N as ammonium nitrate resulted in higher grain protein content than the 30 lb/acre rate of N as ammonium nitrate, while the 30 lb/

acre rate of N applied as foliar urea usually was much less effective than the 30 lb/acre rate of N as ammonium nitrate. Anthesis-N applications, even at the 60 lb/acre rate of N, were not successful in raising grain protein content of "Kern" wheat to the target level of 13.0% under the crop biomass and nitrogen status environments at the Sacramento Valley sites. Conversely, the anthesis-N applications were successful in raising grain protein content of "Kronos" durum wheat to the target level of 13.0% at the San Joaquin Valley sites, although at the Madera site in 1999/2000, only the 60 lb/acre rate of N produced a grain protein content of over 13.0%. Predictability of wheat grain protein content remains elusive.

FOLLOW-UP

In the two years since the conclusion of the project, I conducted a time-course study of SPAD readings and flag-leaf nitrogen content for several wheat cultivars (common wheat and durum wheat) from pre-boot to soft dough stages of growth. The objective was to attempt to identify the peaks of flag-leaf nitrogen and chlorophyll content and to determine if there was a lag-time in their response to nitrogen topdressing (Tables 6-7). Flag-leaf nitrogen content peaked at different times for the different cultivars; maximum SPAD readings didn't always coincide with maximum flag-leaf nitrogen content. Flag-leaf nitrogen and SPAD counts did not increase following nitrogen topdressing; levels decreased with progressive growth stages. SPAD counts, but not flag-leaf nitrogen content, were consistently higher for durum wheat cultivars than for common wheat cultivars. Future work on improving grain protein of California wheat is focusing on inserting a gene conditioning, high grain protein from Triticum dicoccoides into several of California's popular wheat cultivars. This project is part of the marker-assisted selection program of University of California's wheat breeding and genetics program led by Jorge Dubcovsky at UC Davis.

Table 1. Preplant and Anthesis Soil Nitrogen Content, Test Sites

Site	1999/2000		2000/2001	
	NO_3-N ppm	NH_4-N ppm	NO_3-N ppm	NH_4-N ppm
Preplant Samples - Kern Wheat				
Butte Co	21.3	25.4	35.0	4.8
Colusa Co	28.9	10.5	34.5	24.1
UC Davis	16.3	11.4	53.7	4.5
Anthesis Time Samples - Kern Wheat				
Butte Co	1.0	16.0	4.4	6.5
Colusa Co	0.9	6.8	4.2	6.8
UC Davis	2.1	7.4	3.9	4.8
Preplant Samples - Kronos Durum Wheat				
Madera Co	42.4	44.0	21.6	19.2
Kings Co	23.9	37.4	23.8	35.4
Kern Co.	24.3	5.8	6.4	19.1
Anthesis Time Samples - Kronos Durum Wheat				
Madera Co	0.6	2.8	5.8	2.2
Kings Co	5.6	6.5	5.9	20.6
Kern Co.	5.0	22.3	4.0	8.0

Sacramento Valley sites:

Chico State University Farm, Butte Co
Erdman Ranch, Colusa Co
UC Davis Agronomy Farm, Yolo Co

San Joaquin Valley sites:

Dupont Research Facility, Madera Co
J.G. Boswell, Corcoran, Kings Co
J.G. Boswell Kern Lake, Kern Co

Table 2. Effects of Anthesis-Time Nitrogen Applications on Yield Characters of "Kern" Wheat Sacramento Valley: Butte Co, Colusa Co, and UC Davis

		1999/2000			2000/2001		
Site	Anthesis-N Rate (lb/acre)	Yield (lb/acre)	Test Wt (lb/bu)	1000 Kernel Wt (g)	Yield (lb/acre)	Test Wt (lb/bu)	1000 Kernel Wt (g)
Butte Co							
	0	5800 (02)	64.5	44.7	5060 (4)	63.4	46.9
	30 (NH_4NO_3)	5540 (03)	64.4	43.8	5180 (3)	63.6	48.0
	60 (NH_4NO_3)	5910 (01)	64.7	46.3	5410 (1)	63.6	48.3
	30 (Foliar Urea)	5490 (04)	64.6	45.2	5220 (2)	63.5	47.2
	CV (%)	4.6	0.2	2.9	6.9	0.3	1.2
	LSD (.05)	ns	ns	ns	ns	ns	0.9
Colusa Co							
	0	5240 (04)	62.3	49.8	5850 (2)	65.2	45.6
	30 (NH_4NO_3)	5470 (01)	62.5	49.7	5830 (3)	65.1	45.7
	60 (NH_4NO_3)	5310 (03)	62.7	50.8	5720 (4)	64.9	45.7
	30 (Foliar Urea)	5460 (02)	63.1	49.9	6030 (1)	65.2	45.1
	CV (%)	5.0	0.2	0.9	4.9	0.2	2.3
	LSD (.05)	ns	0.5	ns	ns	0.2	ns
UC Davis							
	0	5560 (01)	64.9	46.7	6140 (3)	63.8	43.9
	30 (NH_4NO_3)	5430 (04)	64.6	48.2	6120 (4)	63.3	43.5
	60 (NH_4NO_3)	5530 (02)	64.4	47.3	6430 (1)	62.9	42.9
	30 (Foliar Urea)	5490 (03)	64.8	46.2	6430 (2)	63.5	44.3
	CV (%)	5.6	0.2	1.6	6.4	0.4	2.0
	LSD (.05)	ns	ns	ns	ns	0.4	ns
3-Location Summary (1999/2000)							
	0	5530 (02)	-	-	5640 (04)	-	-
	30 (NH_4NO_3)	5480 (04)	-	-	5710 (03)	-	-
	60 (NH_4NO_3)	5580 (01)	-	-	5850 (02)	-	-
	30 (Foliar Urea)	5480 (03)	-	-	5890 (01)	-	-
	CV (%)	5.1			6.1		
	LSD (.05)	ns			ns		

Numbers in parentheses indicate relative rank in column.

Table 3. Effects of Anthesis-Time Nitrogen Applications on Yield Characters of "Kronos" Durum Wheat San Joaquin Valley: Madera Co, Kings Co, and Kern Co

		1999/2000			2000/2001		
Site	Anthesis-N Rate (lb/acre)	Yield (lb/acre)	Test Wt (lb/bu)	1000 Kernel Wt (g)	Yield (lb/acre)	Test Wt (lb/bu)	1000 Kernel Wt (g)
Madera Co							
	0	5650 (03)	63.4	64.5	4280 (2)	61.2	60.8
	30 (NH_4NO_3)	6000 (01)	63.3	64.9	4330 (1)	61.4	60.7
	60 (NH_4NO_3)	5910 (02)	63.0	66.1	4070 (4)	61.5	62.2
	30 (Foliar Urea)	5580 (04)	63.4	63.1	4270 (3)	61.4	60.8
	CV (%)	11.4	0.4	5.3	11.3	0.4	3.3
	LSD (.05)	ns	ns	ns	ns	ns	ns
Kings Co							
	0	6390 (02)	62.6	63.9	5120 (1)	60.3	53.7
	30 (NH_4NO_3)	6340 (03)	62.4	61.7	5050 (2)	60.4	53.0
	60 (NH_4NO_3)	6510 (01)	62.4	62.9	4870 (4)	60.1	53.3
	30 (Foliar Urea)	6250 (04)	62.3	63.4	4950 (3)	60.7	54.0
	CV (%)	7.5	0.7	3.7	7.2	0.7	2.7
	LSD (.05)	ns	ns	ns	ns	ns	ns
Kern Co							
	0	4110 (03)	58.1	49.0	6200 (2)	62.1	56.5
	30 (NH_4NO_3)	4570 (01)	57.6	48.3	6040 (4)	61.9	56.4
	60 (NH_4NO_3)	3780 (04)	58.0	46.5	6050 (3)	61.8	56.8
	30 (Foliar Urea)	4310 (02)	57.7	47.8	6270 (1)	62.0	57.1
	CV (%)	16.7	1.4	3	3.7	0.4	2.5
	LSD (.05)	ns	ns	ns	ns	ns	ns
3-Location Summary (1999/2000)							
	0	5380 (03)	-	-	5200 (1)	-	-
	30 (as NH_4NO_3)	5640 (01)	-	-	5140 (2)	-	-
	60 (as NH_4NO_3)	5400 (02)	-	-	5000 (4)	-	-
	30 (as Foliar Urea)	5380 (04)	-	-	5130 (3)	-	-
	CV (%)	11.4			7.2		
	LSD (.05)	ns			ns		

Numbers in parentheses indicate relative rank in column.

Table 4. Effects of Anthesis-Time Nitrogen Applications on N-Tissue Content, Biomass, and Grain Protein of "Kern" Wheat Sacramento Valley: Butte Co, Colusa Co, and UC Davis

	Anthesis				14 Days Post Anthesis				Harvest			
Anthesis-N Rate (lb/acre)	Flag Leaf SPAD	Flag Leaf N (%)	Stem N %	Biomass (g) (m-row)	Flag Leaf SPAD	Flag Leaf N (%)	Stem N %	Biomass (g) (m-row)	Flag Leaf N (%)	Stem N %	Biomass (g) (m-row)	Grain Pro % (12% mb)
Butte, 1999/2000												
0	40.3	3.4	1.4	217	42.5	3.1	1.2	212	0.9	0.8	280	10.0
30 (NH_4NO_3)	40.7	3.5	1.5	218	43.8	3.4	1.5	217	1.0	0.8	274	10.8
60 (NH_4NO_3)	40.4	3.5	1.5	216	43.8	3.3	1.4	187	1.3	0.8	286	11.6
30 (Foliar Urea)	42.0	3.7	1.5	212	41.4	3.2	1.3	209	1.3	0.8	229	10.8
CV (%)	3.39	7.5	6.4	7.6	4.4	8.0	12.4	13.5	15.6	8.5	13.9	4.6
LSD (.05)	ns	ns	ns	ns	3.1	0.4	0.3	45	0.3	0.1	59	0.8
Butte, 2000/2001												
0	40.0	3.3	1.5	157	41.6	2.9	1.2	193	0.76	0.48	201	9.6
30 (NH_4NO_3)	37.7	2.9	1.3	148	42.5	3.1	1.3	186	0.87	0.57	275	11.1
60 (NH_4NO_3)	39.5	3.3	1.5	147	45.0	3.4	1.6	165	0.96	0.54	260	11.9
30 (Foliar Urea)	40.8	3.4	1.5	180	42.0	3.0	1.3	176	0.79	0.33	231	9.8
CV (%)	4.2	6.4	4.9	11.1	3.1	3.5	6.1	11.2	14.3	12.2	23.4	9.6
LSD (.05)	ns	0.3	0.1	ns	2.1	0.2	0.1	ns	ns	ns	ns	1.6
Colusa Co, 1999/2000												
0	43.8	3.7	1.5	183	42.7	3.1	1.2	256	1.2	0.9	306	9.9
30 (NH_4NO_3)	45.1	3.7	1.5	222	44.6	3.4	1.3	251	1.5	0.9	325	11.0
60 (NH_4NO_3)	44.4	3.7	1.5	173	44.3	3.4	1.3	208	1.7	1.0	296	11.8
30 (Foliar Urea)	44.2	3.8	1.6	194	45.8	3.6	1.3	241	1.3	0.9	328	10.7
CV (%)	4.19	5.7	7.5	19.0	3.5	6.0	5.7	13.6	9.4	10.2	16.2	6.4
LSD (.05)	ns	ns	ns	ns	2.5	0.3	0.1	52	0.2	0.2	81	1.1
Colusa Co, 2000/2001												
0	39.3	3.3	1.3	134	38.3	2.5	1.1	157	0.98	0.49	225	9.6
30 (NH_4NO_3)	39.6	3.4	1.3	138	39.4	2.8	1.2	171	1.02	0.52	204	10.6
60 (NH_4NO_3)	39.7	3.3	1.3	121	40.0	3.0	1.2	164	1.05	0.55	219	11.3
30 (Foliar Urea)	40.9	3.6	1.3	129	39.8	3.0	1.2	142	1.19	0.50	225	10.7
CV (%)	3.1	6.8	5.6	12.9	4.1	7.8	6.9	13.5	16.2	9.1	14.4	7.1
LSD (.05)	ns	ns	ns	ns	ns	0.4	ns	ns	ns	ns	ns	ns
UC Davis, 1999/2000												
0	43.4	3.6	1.5	195	42.6	2.9	1.1	207	1.2	0.8	329	10.7
30 (NH_4NO_3)	42.4	3.3	1.4	173	44.6	3.5	1.2	195	1.2	0.9	323	11.6
60 (NH_4NO_3)	41.7	3.2	1.4	176	43.9	3.4	1.2	230	1.3	0.9	288	12.2
30 (Foliar Urea)	42.6	3.1	1.4	176	42.3	3.1	1.1	193	1.2	0.8	304	10.8
CV (%)	4.81	6.7	5.6	15.5	2.9	4.0	5.8	10.2	11.6	6.7	13.2	5
LSD (.05)	ns	0.4	ns	ns	1.6	0.2	0.1	34	0.2	0.1	65	0.9
UC Davis, 2000/2001												
0	43.9	3.6	1.6	138	43.5	3.4	1.5	174	1.32	0.53	293	11.3
30 (NH_4NO_3)	43.4	3.6	1.5	127	44.2	3.6	1.6	170	1.56	0.57	266	12.0
60 (NH_4NO_3)	43.4	3.6	1.5	129	43.7	3.5	1.7	158	1.87	0.72	300	12.7
30 (Foliar Urea)	43.1	3.5	1.5	135	45.0	3.3	1.6	143	1.41	0.60	254	11.5
CV (%)	1.9	2.8	4.8	7.2	3.1	5.5	6.5	17.5	9	16.2	12.5	2.8
LSD (.05)	ns	ns	ns	ns	ns	ns	ns	ns	0.2	ns	ns	0.5

SPAD: Minolta SPAD-502 Chlorophyll Meter readings.

Table 5. Effects of Anthesis-Time Nitrogen Applications on N-Tissue Content, Biomass, and Grain Protein of "Kronos" Durum San Joaquin Valley: Madera Co, Kings Co, and Kern Co

	Anthesis				14 Days Post Anthesis				Harvest			
Anthesis-N Rate (lb/acre)	Flag Leaf SPAD	Flag Leaf N (%)	Stem N %	Biomass (g) (m-row)	Flag Leaf SPAD	Flag Leaf N (%)	Stem N %	Biomass (g) (m-row)	Flag Leaf N (%)	Stem N %	Biomass (g) (m-row)	Grain Pro % (12% mb)
Madera Co, 1999/2000												
0	49.2	3.4	1.4	176	50.0	3.0	0.9	256	0.7	0.4	296	9.2
30 (NH_4NO_3)	48.8	3.3	1.4	173	51.1	3.1	1.0	244	0.9	0.5	304	11.3
60 (NH_4NO_3)	50.0	3.3	1.4	188	52.4	3.7	1.1	244	1.1	0.6	319	13.6
30 (Foliar Urea)	45.5	3.1	1.2	171	50.5	3.4	1.1	238	0.9	0.5	290	10.5
CV (%)	5.14	10.1	8.3	12.9	6.4	12.2	13.9	12.7	19.4	21.8	13.2	9.1
LSD (.05)	ns	ns	ns	ns	5.2	0.7	0.2	50	0.3	0.2	64	1.6
Madera Co, 2000/2001												
0	57.3	4.2	1.6	118	57.1	3.1	1.2	152	1.11	0.51	209	13.8
30 (NH_4NO_3)	57.6	4.2	1.5	130	58.4	3.9	1.5	138	1.28	0.55	186	15.0
60 (NH_4NO_3)	57.0	4.1	1.5	103	58.1	3.8	1.7	120	1.54	0.56	192	15.6
30 (Foliar Urea)	57.9	4.4	1.6	130	57.1	3.4	1.4	141	1.16	0.49	219	13.7
CV (%)	4.1	7.6	4.7	20.2	4.2	8.7	10.0	26.5	17.5	15	13.4	8.7
LSD (.05)	ns	ns	ns	ns	ns	0.5	0.2	ns	ns	ns	ns	ns
Kings Co, 1999/2000												
0	53.6	3.9	1.5	222	52.0	3.3	1.0	268	1.0	0.6	331	12.6
30 (NH_4NO_3)	54.7	3.9	1.6	253	52.9	3.7	1.2	242	1.1	0.6	345	13.3
60 (NH_4NO_3)	53.0	3.8	1.5	257	53.9	3.7	1.2	295	1.0	0.6	338	13.5
30 (Foliar Urea)	54.0	3.7	1.6	237	52.7	3.6	1.1	278	1.3	0.6	357	13.2
CV (%)	2.43	5.1	5.2	10.9	1.8	6.6	16.1	14.4	12.2	11.7	17.7	4.8
LSD (.05)	ns	ns	ns	ns	1.6	0.4	0.3	62	0.2	0.1	97	1.0
Kings Co, 2000/2001												
0	46.6	3.4	1.4	116	51.4	2.7	1.0	200	0.77	0.41	342	12.7
30 (NH_4NO_3)	48.1	3.4	1.4	196	52.7	3.0	1.1	224	0.82	0.40	339	13.1
60 (NH_4NO_3)	48.2	3.5	1.5	94	51.1	2.8	1.3	188	0.93	0.41	402	14.2
30 (Foliar Urea)	51.7	3.7	1.6	163	53.3	3.2	1.4	170	0.86	0.41	291	12.9
CV (%)	2.5	4.6	4.3	29.4	2.9	8.7	7.2	36.3	8.6	9.8	28.3	3.7
LSD (.05)	ns	ns	ns	ns	ns	ns	0.1	ns	ns	ns	ns	0.8
Kern Co, 1999/2000												
0	51.2	3.9	1.4	244	46.6	3.2	1.3	265.5	1.4	1.1	336	13.0
30 (NH_4NO_3)	51.3	3.8	1.5	238	45.8	3.1	1.4	302.8	2.1	1.2	354	13.5
60 (NH_4NO_3)	49.0	3.8	1.5	220	45.6	3.4	1.3	258.0	2.7	1.2	347	14.1
30 (Foliar Urea)	50.8	3.8	1.4	239	48.0	3.4	1.3	312.2	1.6	1.0	373	14.1
CV (%)	4.57	5.0	8.1	11.7	4.6	6.7	9.6	15.0	23.0	11.5	15.5	4.8
LSD (.05)	ns	ns	ns	ns	3.4	0.4	0.2	68.5	0.7	0.2	88	1.1
Kern Co, 2000/2001												
0	53.3	3.6	1.3	182	48.6	2.2	1.0	226	0.87	0.51	415	12.9
30 (NH_4NO_3)	53.3	3.5	1.3	182	50.9	2.5	1.0	287	1.10	0.59	412	14.0
60 (NH_4NO_3)	51.9	3.6	1.3	165	51.3	2.5	1.1	279	1.12	0.63	464	14.2
30 (Foliar Urea)	53.6	3.7	1.4	183	50.5	2.4	1.1	316	0.93	0.55	447	13.4
CV (%)	2.8	2.5	5.1	26.1	4	7.6	8.5	23.8	9.2	6.9	8.3	2.7
LSD (.05)	ns	ns	ns	ns	ns	ns	ns	ns	0.1	0.1	ns	0.6

SPAD: Minolta SPAD-502 Chlorophyll Meter readings.

Table 6. Time Course of Flag Leaf N Content and SPAD Counts, 2002 Season, UC Davis

Sample Date	Common Wheat Cultivars						Durum Wheat Cultivars			
	Express		Kern		Summit		Kronos		Orita	
	SPAD Ct	Leaf N %	SPAD Ct	Leaf N %	SPAD Ct	Leaf N %	SPAD Ct	Leaf N %	SPAD Ct	Leaf N %
3/15	42.7	3.21	43.2	3.37	40.9	3.23	49.4	3.26	50.2	3.62
3/22	42.8	3.40	44.9	3.39	43.5	3.59	48.4	3.54	52.0	**4.06**
3/29	**44.7**	**3.62**	46.8	**3.87**	46.5	**3.62**	51.4	3.51	**52.4**	3.79
4/4	44.2	3.19	47.3	3.46	44.8	3.30	50.2	3.32	50.6	3.43
4/12	44.4	3.02	**49.0**	3.47	**47.4**	3.23	**53.0**	**3.54**	50.0	3.30
4/19	43.4	2.98	44.8	3.03	44.6	2.87	51.7	3.15	51.0	3.03
(4/22: Topdressed application of 34 lb nitrogen/acre)										
4/26	39.7	2.65	45.5	2.94	46.8	2.67	51.5	3.06	50.5	3.10
5/3	40.6	2.70	43.3	2.91	46.4	2.71	50.1	2.72	50.5	2.89
5/9	42.4	2.40	41.7	2.58	44.1	2.48	49.4	2.49	51.8	2.80
5/17	24.9	1.86	19.4	1.75	33.1	1.82	37.7	1.96	40.5	2.23

Grain Harvest	Express	Kern	Summit	Kronos	Orita
Yield (lb/acre)	1790	3890	4120	5180	6380
BuWt (lb/bu)	63.3	65.1	63.3	62.5	62.6
Protein %	14.1	12.3	12.7	13.3	13.5

Protein %: 12% moisture basis

Express, Kern, and Summit: Severe grain shatter

Development Stages :

Express: Late joint, 3/18; Headed, 4/4; Anthesis, 4/16; Milk-soft dough 5/2; Soft dough, 5/7; Mature, 5/29

Kern: Late joint, 3/18; Headed, 4/3; Anthesis, 4/16; Milk-soft dough, 5/2; Soft dough, 5/7; Mature, 5/28

Summit: Late joint, 3/18; Headed, 4/4; Anthesis, 4/16; Milk-soft dough, 5/2; Soft dough, 5/7; Mature, 5/28

Kronos: Late joint, 3/18; Headed, 4/3; Anthesis, 4/16; Late milk-soft dough, 5/3; Soft dough, 5/8-5/14; Mature, 6/1

Orita: Late joint, 3/18; Headed, 4/12; Anthesis, 4/16; Late milk-soft dough, 5/3; Soft dough, 5/8-5/14; Mature 6/2

Table 7. Time Course of Flag Leaf N Content and SPAD Counts, 2003 Season, UC Davis

Sample Date	Common Wheat Cultivars						Durum Wheat Cultivars			
	Express		Kern		Summit		Kronos		Orita	
	SPAD Ct	Leaf N %	SPAD Ct	Leaf N %	SPAD Ct	Leaf N %	SPAD Ct	Leaf N %	SPAD Ct	Leaf N %
3/11	42.1	**3.48**	44.4	**3.76**	43.5	3.63	48.6	**3.75**	**51.6**	3.77
(3/12: Topdressed application of 40 lb nitrogen/acre)										
3/18	**43.9**	3.24	**44.8**	3.71	**44.8**	**3.75**	**50.0**	3.61	50.2	**3.84**
3/25	41.3	3.24	38.4	3.29	42.7	3.32	46.8	3.22	45.7	3.39
4/1	36.6	2.84	24.9	2.76	42.3	3.31	41.9	2.90	38.8	3.09
4/7	38.5	2.69	25.2	2.75	41.1	2.98	41.5	2.92	41.0	3.10
4/18	32.4	2.48	16.8	2.35	39.6	2.51	35.5	2.81	37.8	2.75
4/23	31.7	2.28	13.0	2.29	37.2	2.58	37.5	2.60	35.8	2.75
4/30	27.5	2.20	9.8	2.21	30.5	2.29	32.1	2.28	31.9	2.56
5/8	18.4	1.78	6.9	2.23	28.4	1.88	28.2	2.32	25.3	2.50

Grain Harvest	Express	Kern	Summit	Kronos	Orita
Yield (lb/acre)	3550	2290	6260	3600	3690
BuWt (lb/bu)	51.7	48.5	59.8	57.5	57.1
Protein %	13.1	12.1	12.4	13.1	14.9

Protein %: 12% moisture basis

Express, Kern, Kronos, and Orita: Severe stripe rust

Development Stages:

Express: Flag leaf, 3/11; Boot, 3/18; Headed, 3/25; Anthesis, 4/1; Grain fill, 4/18-4/30; Soft dough, 5/8; Mature, 5/23

Kern: Boot, 3/11; Early Head, 3/18; Headed, 3/25; Anthesis, 4/1; Grain fill, 4/18-4/30; Soft dough, 5/8; Mature, 5/23

Summit: Flag leaf, 3/11; Boot, 3/18; Headed, 3/25; Anthesis, 4/1; Grain fill, 4/18-4/30; Soft dough, 5/8; Mature, 5/26

Kronos: Boot, 3/11; Early Head, 3/18; Headed, 3/25; Anthesis, 4/1; Grain fill, 4/18-4/30; Soft dough, 5/8; Mature, 5/21

Orita: Late joint, 3/11; Flag leaf, 3/18; Boot, 3/25; Headed, 4/1; Anthesis, 4/7; Grain fill, 4/23-4/30; Soft dough, 5/8; Mature, 5/27

FERTILIZATION TECHNOLOGIES FOR CONSERVATION TILLAGE PRODUCTION SYSTEMS IN CALIFORNIA

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INTRODUCTION

Conservation tillage production row crop systems have 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 9 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 of 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 potential to eliminate deep tillage, decrease the number of soil preparation operations by as much as 60%, reduce unit production costs, lower soil impedance and maintain productivity in a number of CV cropping contexts using reduced, precision or zone tillage practices that limit traffic to permanent paths throughout a field, thereby 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 decreased.

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 developed 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.

PROJECT OBJECTIVES

The objectives of this research are:

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.
3. To compare crop tissue nitrogen status in standard and conservation tillage production systems.
4. To extend information developed by the project widely to Central Valley row crop producers via field days, equipment demonstrations and written project outcome summaries.

Table 1. Average 2002 tomato fresh yield (±SD). * indicates ^{15}N-labeled input. 'Index' refers to the percent of total fruit which is red (marketable)

System	*Treatment (microplot)*	*Red*	*Unripe*	*Rotten/damaged*	*Index*	*Sum of fruit*	*Vine*
ST	zero N	51 (16)	10 (3)	3 (1)	81	63 (18)	14 (5)
	fertilizer	70 (17)	17 (11)	11 (4)	71	98 (23)	17 (3)
STCC	zero N	49 (14)	12 (4)	4 (2)	75	65 (13)	14 (1)
	*fertilizer + vetch	74 (6)	24 (10)	12 (10)	67	110 (10)	19 (1)
	*vetch + fertilizer	66 (14)	15 (4)	12 (3)	71	93 (17)	15 (2)
CT	zero N	18 (4)	5 (3)	4 (2)	64	28 (5)	7 (1)
	fertilizer	50 (24)	8 (5)	11 (4)	72	69 (29)	13 (4)
CTCC	zero N	19 (4)	12 (8)	3 (2)	56	34 (10)	8 (3)
	*fertilizer + vetch	42 (10)	12 (8)	9 (3)	68	62 (17)	12 (3)
	*vetch + fertilizer	42 (13)	8 (3)	9 (2)	70	60 (17)	12 (3)

PROJECT DESCRIPTION

This project is being conducted in a 5-acre field at the Vegetable Crops and Weed Science Field Headquarters on the UC Davis campus and in an 8-acre field study at the UC West Side Research and Extension Center in Five Points, CA. A corn/tomato/corn/tomato rotation is being pursued at the UC Davis site, and a tomato/cotton/tomato/cotton rotation is used in Five Points. We report here on progress during 2001 and 2002 in the UC Davis study.

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 ^{15}N microplots (4.57m wide band 3m long) were then established during the 2001 – 2002 winter as indicated below.

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

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

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

RESULTS & CONCLUSIONS

Crop yield

ST and STCC microplots were hand-harvested on August, 15, 2002. The CT and CTCC microplots were harvested on August 23, primarily because these treatments were observed to mature later. Table 1 gives the average fresh yield for each treatment in each cropping system. In general, the CT and CTCC systems produced less than the ST and STCC systems, whether considering total yield or marketable yield. The presence of a cover crop did not influence crop yield under either ST or CT management. If the yield of microplots with no N input is used as an indication of the capacity of the soil itself to support a crop, then we might speculate that the ST and STCC systems are superior in this regard. Alternatively, the lower yields of the zero-N (and other) microplots under CT and CTCC management might be the result of a greater capacity of these systems to immobilize nutrients (i.e. nitrogen), reducing availability to a crop during the course of a season. This, in turn, might be related to the large amount of slowly-decomposing crop residue still present during the growing season, while under ST management much of this residue has decomposed during the previous winter.

Table 2. Percent recovery (±SD) of labeled (*) input N in 2002 tomato crop

System	*Treatment (microplot)*	*Red*	*Unripe*	*Rotten/ damaged*	*Sum of fruit*	*Vine*	*Total aboveground*
					%		
ST	*fertilizer	15 (3)	3 (2)	3 (2)	22 (6)	5 (1)	26 (8)
STCC	*fertilizer + vetch	19 (8)	5 (1)	6 (5)	28 (12)	7 (3)	34 (16)
	*vetch + fertilizer	5 (1)	1 (1)	1 (1)	7 (2)	2 (1)	9 (2)
CT	*fertilizer	6 (3)	1 (1)	2 (1)	8 (5)	3 (2)	11 (7)
CTCC	*fertilizer + vetch	9 (3)	2 (1)	2 (1)	13 (4)	5 (1)	17 (5)
	*vetch + fertilizer	2 (1)	0	0.5	3 (1)	1 (1)	4 (1)

The same trends in fresh yield are seen, somewhat more accentuated, in the crop N content (data not shown). The CT and CTCC crops took up approximately one-half to two-thirds of the N that the ST and STCC crops did. This would indicate short-term reduced N availability under conservation management. Machine harvest data of larger plot areas were also collected.

Use of fertilizer and vetch by crop

Table 2 shows what percent of the N applied as vetch or fertilizer was present in the crop at harvest (input use efficiency). The following summary refers to the collective sum of the entire aboveground plant, although the trend is similar for marketable (red) fruit. In all treatments, roughly half of aboveground uptake of input N was in the red fruit and consequently removed from the system; the other half (in unripe, culls, and vine) is returned to the system. Under standard management, the crop took up approximately twice as much fertilizer N compared to conservation management. In both cases, the presence of cover crop slightly (but not significantly) increased uptake of fertilizer N. Uptake of vetch N was also higher in the STCC system compared to the CTCC system; in both cases uptake of vetch N was about one-fourth that of fertilizer N.

It is premature to draw conclusions from this work at this time. While the presently available data indicate that conservation tillage management may present short-term limitations such as reduced nutrient availability and consequent implications for crop yield (based on the microplot data collected here), additional, more long-term studies are going to be required in order to ascertain a fuller picture of the potential and limitations of these alternatives. 2003 data and observations are currently being analyzed.

Photo 1. *No-till planted corn established in vetch cover crop on 60" beds, Davis, CA, 2003*

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 California nitrogen management studies in cotton, and to begin evaluations of the potential to integrate rapid 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.

PROJECT DESCRIPTION

Field studies were set up at four locations in 2001 and 2002, but only three locations were followed to completion in 2002 and 2003. Sites represent a range of initial soil residual nitrogen levels and soil types, and were located in the central and southern San Joaquin Valley. Three basic N application treatments were used at each location:

(1) Trt. #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) Trt #2: one-time treatment receiving a full 150-180 lb N/acre application, with adjustment based upon residual soil nitrate-N in upper two feet of the soil profile; and

(3) Trt #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[9] 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 two and three weeks after first bloom.

(4) Where cooperators allowed, another treatment (Treatment #4) was added in which the initial application rate was between 150 and 180 lbs/acre (adjusted for residual nitrate-N).

Several sites had a treatment added in which no supplemental N was added, in order to allow for yield and petiole nitrate-N analyses where only residual soil N supplies could be utilized. Field sites selected for the experiment differ in soil types 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 NO_3^--N levels, PO_4-P, exchangeable-K, Zn and mineralizable N.

Samples were collected at all sites within two weeks after planting to a depth of four feet for initial NO_3-N and mineralizable N tests to allow for the comparison of residual N made in the upper two feet, upper three 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 NO_3-N, Cl-5 exchangeable K, and PO_4-P. The soil NO_3-N and Cl- data will be used in combination with irrigation water NO_3-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 NO_3-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 NO_3-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. Two methods are being compared 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 100°C for a four-hour period, followed by cooling and determination of ammonium-N. An alternative method developed by Franzluebbers et al (1996) yields potential N mineralization using a 24-hour incubation, with soil samples placed in airtight tubes, water added and a 24-hour incubation done at 25° C. After this period, the amount of CO_2 evolved is determined by titration.

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)			
0-60	41	8	58	10	45	6		
60-90	30	10	19	4	31	7		
90-120	12	3	12	2	26	6		

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

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

Date of petiole sampling (by growth stage)	*2002 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 (Fresno)		Site B (Shafter)		Site C (WSREC)			
	Mg/kg x 1000		Mg/kg x 1000		Mg/kg x 1000			
	Low [1]	High	Low	High	Low	High		
Early bloom (1st bloom+/-5 days)	14.0	15.8	15.0	16.7	16.9	18.6		
15-20 days after first bloom	9.1	10.9	10.4	13.6	8.8	12.3		
28 to 35 days after first bloom	5.3	7.2	5.3	7.0	6.1	8.6		

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

Table 2. *Petiole nitrate-N as a function of growth stage in 2002 sites for treatment 3 (late supplemental N).*

RESULTS & CONCLUSIONS

Field Nitrogen Management Studies – 2001, 2002

In the four field test sites, residual soil nitrate-N analyses done on soil samples collected within three to six weeks following planting yielded the following average quantities in the surface two, three and four foot depths of the soil profile (0-60 cm, 60-90 cm, 90-120 cm, respectively). Based upon our prior five-year study, 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 NO_3-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 NO_3-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 NO_3-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 indicate 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 percentage 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 the location.

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 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 four feet of soil equaled about 165 lbs, this would be assumed adequate for a three bale/acre yield. If plant map data suggested a four 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 treatments # 3 and # 4 at multiple sites during each year of the experiment.

Yield responses to the applied N treatments in 2001 and 2002 indicated significantly higher yields with all N application treatments when compared with no supplemental N in three of the four locations in 2001, and in all three locations in 2002. Yield results were not available for the 2003 growing season at the time of preparation of this report. The yield response data for 2001 and 2002 comparing the no N to other treatments indicates that despite 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 moderatly applied N treatments (Trts. 1, 3), but resulted in a yield decrease due to excessive vegetative growth in the high N application treatment (Trt. 2). At all four sites in 2001, use of the feedback management approach (Trt. 3) resulted in a three to five percent apparent yield improvement over the high N treatment, but this was significant only at two sites, the low residual nitrate-N site at the West Side REC and the high residual N site in Fresno County (Table 3). Use of the feedback approach (Trt. 3) only improved yields over the low N application treatment (Trt. 1) at one site (low residual N site at West Side REC). In 2002, use of the feedback management approach (Trts. 3 and 4) resulted in yield improvements at two out of the three sites when compared with treatments #1 and #2, which received a one time N application.

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 for 2001 and 2002 but are complicated. 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 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 rate used in treatment # 2 (data not shown).

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 where land application of dairy waste or large amounts of crop residue were not part of the management. Only one site in 2002 had any significant land application of organic N applied prior to the 2002 cotton planting.

Site / location	***2001 Field Study Sites***							
	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			

* only 2 replications available'

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

Table 3. *Lint yield and gin turnout percentage data as a function of site and treatment in 2001.*

IMPROVING THE DIAGNOSTIC CAPABILITIES FOR DETECTING MOLYBDENUM DEFICIENCY IN ALFALFA & 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 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 & DISCUSSION

Two sites have been 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 one-third of plant concentrations of molybdenum were in the 0.1 – 0.3 ppm range. Plant tissue samples also indicated that phosphorus, potassium, sulfur, and boron were in the adequate range.

Yield results from site 1 (experiment #1) for 2003 are given in Table 1. No significant yield responses to molybdenum or lime treatments were observed during the year. The strongest trend for a yield response was observed in the second harvest with little, if any, trend indicated in the first or third harvests. Note that the lime alone treatment resulted in equally as high a yield as the molybdenum treatments in the second and third harvest, but not in the first harvest. This is often the case since raising the soil pH increases the availability of molybdenum to plants. 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. Rates greater than 0.6 – 0.8 lbs Mo/A, however, often increase molybdenum concentrations in the forage to undesirable levels the first several years after application considering the needs of animals, particularly if copper concentrations are below the 8 – 10 ppm range. Phosphorus (PO_4-P), potassium, sulfate-sulfur (SO_4-S) and boron were all in the adequate range.

Treatment	Mo (lbs/A)	Lime (tons/A)	June 3 Yield (tons DM/A)	July 14 Yield (tons DM/A)	Sept 3 Yield (tons DM/A)
1. Control	0	0	1.81	1.75	1.48ab
2. Mo	0.2	0	1.85	1.88	1.41 b
3. Mo	0.3	0	1.81	1.86	1.55ab
4. Mo	0.4	0	1.66	1.86	1.47ab
5. Mo	0.6	0	2.01	2.07	1.54ab
6. Mo	0.8	0	1.94	2.06	1.43ab
7. Mo	1.2	0	1.81	1.93	1.50ab
8. Lime	0	2	1.75	2.08	1.59a
$LSD_{0.05}$			NS(0.372)	NS(0.411)	(0.175)

Table 1. *Alfalfa yield during 2003 as influenced by molybdenum and lime treatments applied on March 31, 2000.*

Plant growth stage samples were taken at 6 inches height, 12 inches height, prebud (only a small ball was formed to indicate the new bud) and at harvest (early bud to 1/10th bloom) for the first and third harvests in 2003. All of the plant material of the samples collected at the 6-inch growth stage and only the top 6 inches of the 12-inch high or older plants were analyzed for molybdenum concentrations to develop the relationships between growth stage and molybdenum concentration. Some, but not all, of the plant growth stage samples as well as the harvest plant part samples for the current year, have been processed for laboratory analyses.

To evaluate the effect of molybdenum and lime upon alfalfa forage quality, the analysis for crude protein was conducted.

Table 2 gives the changes in crude protein (total N x 6.25) associated with the increased rate of applied molybdenum and lime. There were no statistically significant differences in crude protein as a result of the treatments. There seems to be a rather consistent trend for the crude protein to be slightly higher for most of the molybdenum and lime treatments. Acid detergent fiber (ADF) analysis was also conducted on all whole plant samples to determine total digestible nutrient (TDN) levels. No statistically significant differences in total digestible nutrient (TDN) levels were observed in any of the four harvests as a result of the molybdenum, boron or lime treatments.

			Crude Protein			
Treatment	Mo (lbs/A)	Lime (tons/A)	May 25 %	July 6 %	Aug 13 %	Oct 1 %
1. Control	0	0	22.13	21.33	23.10	26.47
2. Mo	0.2	0	23.37	22.80	24.67	27.70
3. Mo	0.3	0	23.53	21.10	24.13	26.97
4. Mo	0.4	0	22.77	20.77	24.40	27.00
5. Mo	0.6	0	22.70	21.90	23.93	27.67
6. Mo	0.8	0	23.53	20.93	24.70	27.70
7. Mo	1.2	0	22.77	20.17	26.10	26.37
8. Lime	0	2	22.70	21.93	24.67	26.97
$LSD_{0.05}$			1.632(NS)	3.037(NS)	3.086(NS)	1.774(NS)

Table 2. *Alfalfa crude protein during 2001 as influenced by molybdenum and lime treatments applied on March 31, 2000.*

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 (>2700 ppm midstem PO_4-P), potassium (>4.5 % midstem total K), and sulfate-sulfur (>1250 ppm midstem leaf SO_4-S) were in the above adequate range.

Yield results of the three harvests from site 2 (experiment #2) for 2003 are given in Table 3. Selected treatments of molybdenum and boron resulted in significantly higher yields over the control in the three harvests. 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 harvest (all three 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 seldom results in large vegetative yield decreases but could reduce seed yields by 25-50% or more.

Plant growth stage samples were taken at 6 inches height, 12 inches height, prebud and at harvest (early bud to 1/10th bloom) prior to the first and third harvests in 2003. In some cases, 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 6-inch growth stage and only the top 6 inches of the 12-inch high or older plants were analyzed for molybdenum concentrations to develop the relationships between growth stage and molybdenum concentration. Preliminary data presented in last year's report indicated that molybdenum concentrations in the top 1/3 of the plant, when they are in the deficient range, remain fairly constant during the early growth stage through harvest growth period. 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 1/10th bloom stage.

Treatment	Mo (lbs/A)	B (lbs/A)	Lime (tons/A)	June 9 Yield (tons DM/A)	July 16 Yield (tons DM/A	Aug 27 Yield (tons DM/A
1. Control	0		0	1.66abc	1.35 cd	1.07ab
2. Mo plus B	0.2	4	0	1.68abc	1.73a	1.13ab
3. Mo plus B	0.3	4	0	1.86abc	1.49abcd	1.07ab
4. Mo plus B	0.4	4	0	2.03a	1.58abc	1.05ab
5. Mo plus B	0.6	4	0	1.78abc	1.64ab	1.12ab
6. Mo plus B	0.8	4	0	1.83abc	1.54abc	1.02 b
7. Mo plus B	1.2	4	0	1.72abc	1.64ab	1.06ab
8. Mo	0.4	0	0	1.55 bc	1.25 d	1.09ab
9. Mo	0.8	0	0	1.50 c	1.39 bcd	0.99 b
10. B	0	2	0	1.49 c	1.26 d	0.97 b
11. B	0	4	0	1.70abc	1.51abcd	1.12ab
12. Lime	0		2	1.52 c	1.35 cd	1.06ab
13. Mo + B + Lime	0.2	4	2	1.55 bc	1.53abcd	1.28a
14. Mo + B + Lime	0.4	4	2	1.91ab	1.62abc	1.16ab
$LSD_{0.05}$				0.379	0.281	0.255

*Estimated at 20% dry matter.

Table 3. *Alfalfa yield during 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)	Crude Protein May 18 %	July 2 %	Aug 13 %	Sept 28 %
1. Control	0		0	25.83	20.53	19.47	21.47
2. Mo plus B	0.2	4	0	25.50	20.87	19.00	21.50
3. Mo plus B	0.3	4	0	26.67	21.13	19.27	21.33
4. Mo plus B	0.4	4	0	26.00	20.90	19.70	21.80
5. Mo plus B	0.6	4	0	26.23	20.63	18.87	21.80
6. Mo plus B	0.8	4	0	25.63	21.80	19.37	21.57
7. Mo plus B	1.2	4	0	26.83	20.93	18.80	21.43
8. Mo	0.4	0	0	26.83	21.20	18.87	22.30
9. Mo	0.8	0	0	27.43	20.60	19.30	21.17
10. B	0	2	0	26.53	20.57	19.63	22.23
11. B	0	4	0	25.27	21.53	18.80	21.80
12. Lime	0		2	25.97	21.00	19.30	21.37
13. Mo + B + Lime	0.2	4	2	25.97	20.47	19.03	21.33
14. Mo + B + Lime	0.4	4	2	25.63	21.50	19.23	21.23
$LSD_{0.05}$				1.42(NS)	1.31(NS)	1.15(NS)	1.20(NS)

Table 4. *Alfalfa crude protein during 2001 as influenced by molybdenum, boron and lime treatments applied on March 9-10, 2001.*

Boron concentrations in the top 1/3 of the alfalfa plant are fairly consistent when no boron is applied but varies considerably when it is applied at either the two or four pound per acre rates. Figure 1 illustrates the changes in boron concentrations over the 2001 growing season for treatments receiving several rates of applied boron. The two-pound rate of boron had only slightly lower boron concentration in the top 1/3 of the plant than the four-pound rate. It is expected that the 2003 samples will show much lower concentrations for both the two and four-pound rates as compared to the 2001 results. Some, but not all of the plant growth stage samples, as well as the harvest plant part samples for the current year, have been processed for laboratory analyses.

Alfalfa forage quality analysis for crude protein was conducted on all samples from all four harvests in 2001. Table 4 gives the changes in crude protein (total N x 6.25) associated with the increased rate of applied molybdenum, boron and lime. There were no statistically significant differences in crude protein as a result of the treatments. There was a trend for crude protein to be slightly higher in the first, second and fourth harvests as a result of combinations of molybdenum and boron treatments. Acid detergent fiber (ADF) analysis was also conducted on all whole plant samples to determine total digestible nutrient (TDN) levels. No statistically significant differences in total digestible nutrient (TDN) levels were observed in any of the four harvests as a result of the molybdenum, boron or lime treatments.

All of the plant material collected for analysis is being saved for the preparation of several large bulk samples of known molybdenum concentration. Since this was resulting in only small quantities of alfalfa bulk samples, the entire top 1/3 of plants was harvested from all plots of several treatments at each site to acquire a larger amount of material. After the analyses have been completed, samples having similar molybdenum concentrations will be combined in the range of 0.1-0.3 ppm or 0.5-0.7 ppm. Also, it is intended that a small quantity of a low molybdenum (0.1-0.3 pip)-boron (9-11 pip) bulk sample will be made available. These three standard forage samples are being prepared for distribution to analytical laboratories.

See **Figure 1**, following page.

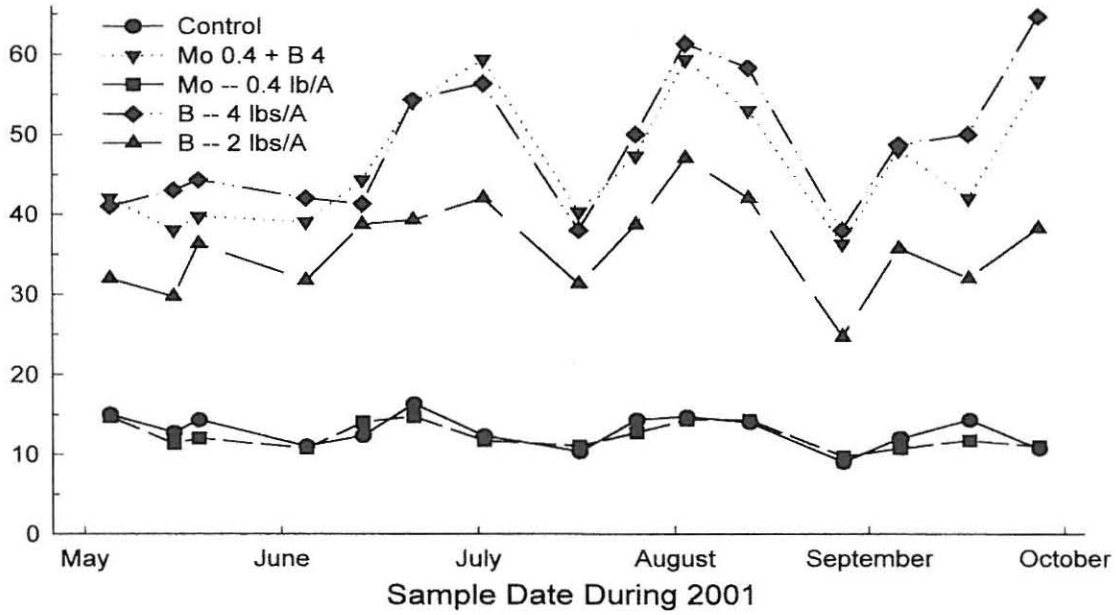

Figure 1. *Alfalfa top 1/3 of plant boron concentration during the 2001 growing season as influenced by applied treatments. Expt. #2*

SITE-SPECIFIC VARIABLE RATE FERTILIZER NITROGEN APPLICATION IN COTTON

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INTRODUCTION

The use of yield monitors, global positioning systems, remote sensing, and other attributes of site-specific crop management is increasing in California. California farmers who have adopted yield monitoring and mapping technology have frequently observed a high level of yield variability in their fields. In some cases, growers have been able to interpret these yield maps based on their knowledge of the field and use this interpretation to improve their management and enhance profitability. However, the level of knowledge of this technology has not yet reached the state where growers can confidently adopt on a wide scale true site-specific management practices, that is, practices in which management is adjusted "on the go" to match the specific needs of each location in the field.

One of the most promising site-specific management practices is variable rate input application. In particular, variable rate application of fertilizers, especially fertilizer nitrogen, has been extensively studied in Midwestern cropping systems. Scientific investigations of the profitability of variable rate nitrogen application in the Midwest have produced equivocal results, with some investigations indicating a profit, and others not. Much of the work in the upper Midwest has been motivated by regulatory concerns associated with potential contamination of ground and surface waters. This is also becoming an issue in California. Variable rate nitrogen application offers the potential for increasing profitability and reducing environmental effects of crop production if the increased costs associated with the practice can be offset by reduced input costs and/or reduced regulatory pressure.

In order to achieve a workable variable-rate fertilizer management program it is necessary to be able to estimate with sufficient accuracy the crop's site-specific nitrogen demand prior to the time of fertilizer application. A number of researchers have found that under growing conditions of the semi-arid and arid West, cotton removes approximately 50 to 60 lbs. N per bale of lint. It requires an additional 100 to 150 lbs./acre of N to support vegetative growth. Most of this latter N is returned to the soil when cotton stubble is disked in. Travis et al. studied over a five-year period the relationship between soil test nitrate levels and crop response to applied soil N. They found that at the field scale there is a general relation in which low soil test nitrate levels correspond to a higher yield response to applied N and high soil test nitrate levels correspond to a lower yield response to applied N. They also found that there was considerable variability in this relationship, which they attributed in part to within-field variability in soil and nitrogen conditions. We hypothesize that the precision of the relationship between soil test nitrate level and plant N response can be improved by a stratified sampling scheme taking into account within-field variation in soil conditions. Based on this working hypothesis, we developed a practical site-specific variable N rate application program for California cotton production.

OBJECTIVES

The overall objective is to determine whether variable rate nitrogen application is economically justified in California cotton production, and if so, to determine a practical method for implementing it. Specific objectives are:

1. Develop a practical method for creating variable rate fertilizer nitrogen application maps based on existing yield maps, remotely sensed NDVI images, and /or soil bulk electrical conductivity maps and soil nitrate N levels obtained through directed pre-season sampling.
2. Conduct replicated experiments in large (typically quarter section) commercial fields in which the treatments are variable rate fertilizer application, fixed rate fertilizer application, and control.
3. Conduct a partial budget economic analysis based on established methods to determine the economic viability of variable rate fertilizer application for California cotton production.

PROJECT DESCRIPTION

The experiments carried out in this research project focus on using high spatial precision bulk data (yield maps, remotely sensed images, and soil bulk electrical conductivity (ECa) values obtained from EM-38 or Veris instruments) together with soil nitrate levels in the top two feet, obtained from soil cores taken through a directed sampling plan, to determine variable application rate in the first N application at layby. Each experiment is carried out as a randomized complete block design with four levels: variable N rate, low fixed N rate control, nominal fixed N rate, and high fixed N

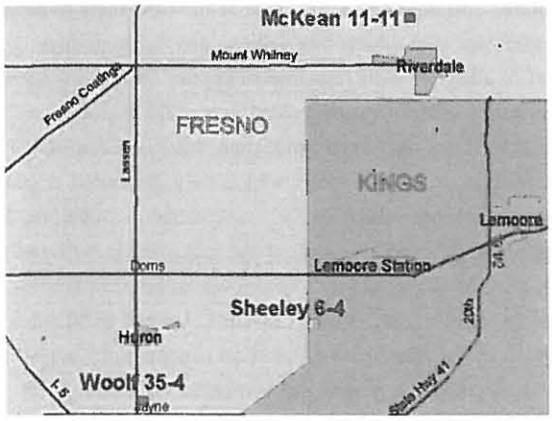

Fig. 1. *Locations where experiments were carried out in 2002.*

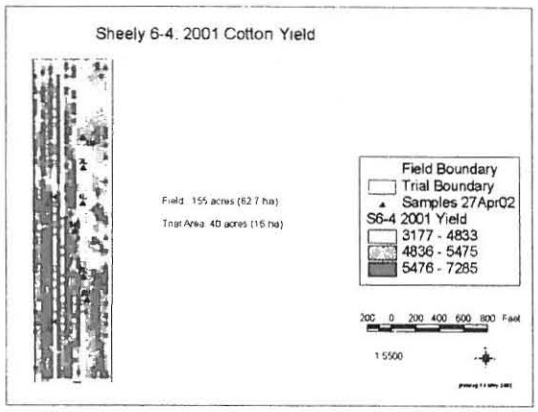

Fig. 2. *Yield map showing 3 yield classes and soil sample locations stratified by yield class.*

rate. In 2002 the experiments were carried out in three fields whose locations are shown in Fig. 1. Due to technical problems only one field was tested in 2003, and we anticipate that two or three fields will be tested in 2004. The variable rate treatment is applied at a rate determined by an application rate map constructed according to soil productivity and estimated residual available N. We begin with relatively inexpensive, high spatial resolution data sets for the field: a yield map and bulk EC (i.e., ECa) map. Based on the yield map the field is subdivided into three regions: high, medium,

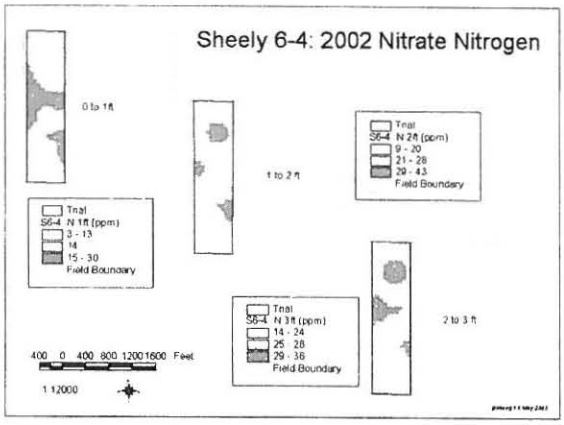

Fig. 3. *Estimated residual nitrate N based on interpolated soil samples.*

and low yield. Three soil sample locations are selected from each of these regions. Figure 2 shows the yield map and soil sample locations for the Sheely 6-4 field.

Based on soil samples taken at these locations an estimated residual N map was developed. This map is shown in Figure 3. Using this map in combination with the soil EC map a set of fertilization zones was developed. These zones are shown in

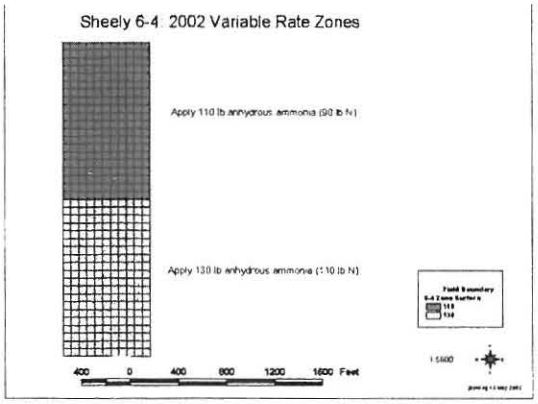

Figure 4. *At the Sheely site there were only two zones, while at each of the other two sites there were three zones.*

Fig. 4. Variable N rate zones based on estimated residual N and soil bulk EC. Figure 5 shows the mean yields of each treatment. There was no significant yield difference between the VRT treatment and the intermediate or high fixed rate treatments. This indicates that there is no loss in profitability by withholding nitrogen from areas in the field with low potential yield.

Although in principle the VRT approach could result in increased yields through more fertilizer being applied to high yield potential areas, in each of our test sites the variation in rate was always due to reducing N application in low yield potential areas. Therefore an increase in profitability must come from a savings in fertilizer costs sufficient to offset the costs associated with the VRT program. The savings in fertilizer expenditures were substantial. Table 1 shows the percent reduction in midseason nitrogen fertilizer expenditures that is obtained through the VRT program at each of the test sites. There is a substantial reduction at each site.

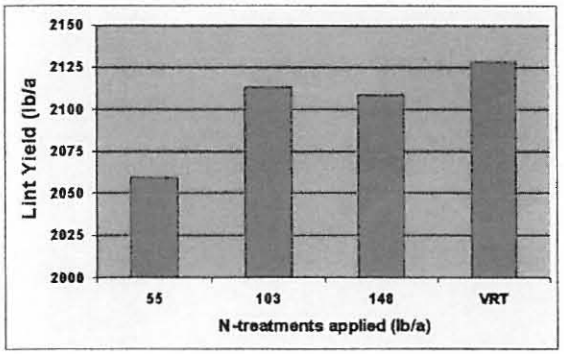

Fig. 5. *Mean plot yield for each of the treatments at the Sheely 6-4 site in 2002.*

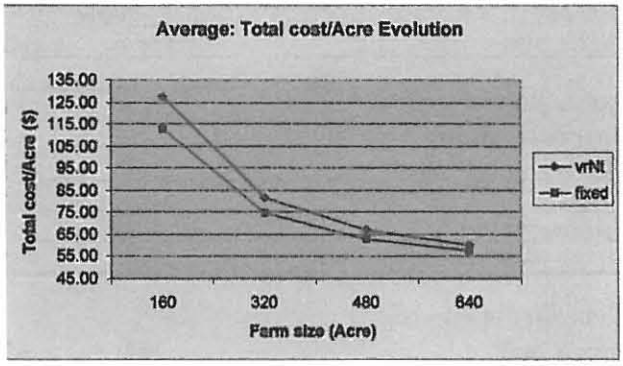

Fig. 6. *Costs of VRT and fixed rate program as a function of farm size per unit of equipment (fertilization plus yield monitoring).*

Table 1. *Percent reduction in midseason nitrogen application costs, in comparison with the fixed rate treatment used on the rest of the field, at each of the sites.*

Sheely	Woolf	McKean
-32.73%	-44.69%	-23.29%

The question of increased costs associated with the VRT program is a subtle one and depends on how these costs are spread over other operations. This in turn depends on the size of the farm, on the other crops grown on the farm and whether they can also be fertilized according to a VRT program, whether a VRT program can be developed for other nutrients besides nitrogen, as well as for other inputs such as soil amendments and pesticides, and for how many years the grower can use the VRT equipment before it becomes obsolete. In order to obtain a conservative estimate of the costs, we have carried out a partial budget analysis that is summarized in Table 2.

As indicated in the table, when all of the costs are assigned to a single quarter section field (the most conservative possible assumption) the VRT program does not pay for itself. The profitability of the program therefore depends on how many fields and how many operations the grower can implement the program on per unit of equipment. For simplicity, if we assume that the same number of fields can be managed with both one fertilizer rig and one cotton picker, then the decline in cost differential as a function of size is shown in Fig. 6. In reality, the situation is more complex since the number of fields per fertilizer rig is different from the number per picker. The primary contribution to equip-

OPERATION	Sheely		Woolf		Mc Kean	
	Fixed	Variable	Fixed	Variable	Fixed	Variable
			$/acre			
Soil Samples	2.64	3.18	2.64	3.18	2.64	3.18
Recommendation Map		2.00		2.00		2.00
Fertilize	29.48	21.40	29.13	18.09	49.73	39.27
TOTAL FERTILIZER COST/ACRE	32.12	26.58	31.77	23.27	52.37	44.45
Operating Interest	1.16	0.98	1.15	0.85	1.89	1.61
TOTAL OPERATING COST/ACRE	33.29	27.56	32.92	24.12	54.26	46.06
CASH OVERHEAD:						
Property Taxes	3.68	4.19	3.68	4.19	3.68	4.19
Property Insurance	2.48	2.83	2.48	2.83	2.48	2.83
Investment Repairs (Yield Monitor)		0.81	0.00	0.81	0.00	0.81
TOTAL CASH OVERHEAD	6.16	7.84	6.16	7.84	6.16	7.84
TOTAL CASH COSTS/ACRE	39.45	35.40	39.08	31.96	60.42	53.90
NON-CASH OVERHEAD:						
Yield Monitor	0.00	5.59	0.00	5.59	0.00	5.59
Equipment	66.66	81.60	66.66	81.60	66.66	81.60
TOTAL NON-CASH COSTS/ACRE	66.66	87.18	66.66	87.18	66.66	87.18
TOTAL COSTS/ACRE	106.11	122.58	105.74	119.14	127.08	141.08

Table 2. *Partial budget analysis of VRT program on each of the three farms, assuming that the equipment is depreciated over five years*

ment expense is the cost of the yield monitor. At 480 acres the VRT program is approximately equal to the fixed rate program. Therefore if the farmer does one of the following: (1) manage more cotton fields than three quarter sections for each piece of equipment, (2) manage other cotton operations besides nitrogen fertilization using the VRT controller, (3) manage and harvest other crops besides cotton using the VRT equipment, or (4) use the equipment for more than five years, then variable rate fertilization should be profitable in the San Joaquin Valley. As the cost of yield monitors and controllers declines, which it is likely to do, the VRT program will become more profitable.

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

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INTRODUCTION

Microirrigation (microsprinklers, drip emitter, drip tape) has the potential for precisely applying water and fertilizer throughout a field both in terms of amount and location. This potential can result in higher yields and profit, reduced water costs, reduced fertilizer costs, and can also reduce leaching of chemicals to the ground water.

Fertigation is the process of applying fertilizers through the irrigation water. The maximum potential field-wide uniformity of the applied fertilizer will reflect the uniformity of the applied or infiltrated water. For microirrigation systems, a recommendation frequently used for injection of fertilizer 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. However, observations of grower practices revealed that injecting for a short period of time, i.e. one or two hours, is common. If the injection starts after irrigation water has reached the furthermost part of the irrigation system or ends such that flushing will occur at the furthermost part of the system, the field-wide uniformity of the applied chemical will equal the uniformity of the applied water. However, the timing of the injection and its duration relative to the start and cutoff of the irrigation can affect the distribution of the fertilizer in the soil. The timing and duration of injection are factors which influence fertilizer leaching below the root zone.

PROJECT OBJECTIVES

1. To determine fertigation strategies for microirrigation systems using state-of-the-art modeling tools to improve water and nutrient use efficiencies and to reduce leaching of nitrates and other nutrients and chemical.
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.

PROJECT DESCRIPTION

Various fertigation strategies for microirrigation systems were examined using the computer simulation model HYDRUS-2D to improve water and nutrient use efficiencies and to reduce leaching of nitrates. Outputs of the model include patterns of nitrate, soil water, water velocity, and soil water tension around the drip line. The model also calculated a mass balance of nitrate in the soil profile. Model results will be used to develop guidelines for proper fertigation management practices.

Fertigation scenarios evaluated by the model are:

Irrigation systems

- microsprinkler (citrus)
- drip irrigation (grapes)
- surface drip irrigation (strawberries)
- subsurface drip irrigation (tomatoes)

Soil Types

- sandy loam
- loam
- silty clay

Injection strategies

- inject for two hours starting one hour after start of irrigation
- inject for two hours in the middle of the irrigation set
- inject for two hours starting three hours before cutoff of irrigation water
- inject during the middle 50% of the irrigation set time
- inject continuously during the irrigation set

RESULTS & CONCLUSIONS

The simulation work has been completed and the analysis of data is progressing. Eighty simulations have been conducted. The effect of the fertigation strategy on the nitrate pattern around the drip line is shown in Fig. 1 for subsurface drip irrigation in sandy loam at the end of an irrigation. Nitrate concentrations are expressed as relative concentrations defined as the ratio of the actual concentration at any point in the soil profile to the maximum concentration, that of the irrigation water. Relative concentrations are shown in the legends at the bottom of the figures. Please note the differences in the scales. Injecting near the beginning of the irrigation resulted in a band of nitrate around the drip line (Fig. 1A) with little or no nitrate in the immediate vicinity of the drip line. This behavior is caused by leaching of the nitrate near the drip line during the remaining irrigation time after fertilizer injection ceased and water movement continued into relatively dry soil above the drip line. Injecting near the end of the irrigation set caused most of the nitrate to remain near the drip line (Fig. 1B) with little nitrate extending out into the soil profile reflecting the small amount of irrigation time remaining after injection ceased. Injecting during the middle 50% of the irrigation set also resulted in a band of nitrate around the drip line (Fig. 1C). However, nitrate concentrations were smaller compared to the two-hour injection at the beginning of the irrigation set, as shown by the legend, because of the longer injection time of this strategy. Leaching in the immediate vicinity of the drip line occurred due to irrigation after injection ceased. A zone of nitrate extending from the drip line out into the soil profile occurred for the continuous injection strategy (Fig. 1D) with little leaching in the immediate vicinity of the drip line.

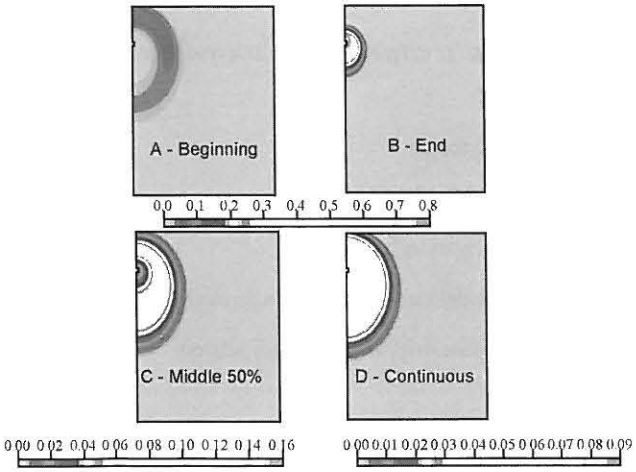

Figure 1. *Nitrate patterns around the drip line at the end of the irrigation for four fertigation strategies.*

A mass balance was conducted for the soil profile above the drip line and for the profile below the drip line. More nitrate was found in the soil profile above the drip line for the scenario in Fig. 1A compared to the other scenarios. The reason for this behavior is that near the beginning of the irrigation, water flow from the drip line into the dry soil above the drip line was greater compared to the flow into the wetter soil above the drip line for the later injections. The injection time of the other strategies occurred after partial wetting of the soil above the drip line had occurred, which reduced flow, and thus nitrate movement, into the soil profile above the drip line. Nitrate accumulation below the drip line was the least for the first scenario, suggesting a potential for less nitrate leaching under this approach compared to the other strategies.

Data evaluation will continue, which will include a sensitivity analysis on the effect of root distribution, initial soil water content, and frequency of fertigation relative to frequency of irrigation on nitrate patterns and nitrate leaching potential.

PRECISION HORTICULTURE:

TECHNOLOGY DEVELOPMENT AND RESEARCH AND MANAGEMENT APPLICATIONS

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To assist in the development of best management practices for tree crops it is essential to have a good understanding of crop yields at as fine a resolution as possible. In tree crops such as Pistachio, however, it has been standard practice to determine yields on the basis of whole orchard blocks which are frequently 40- > 100 acres. This lack of resolution inhibits the development of best practices and is further complicated by the high degree of yield variability that exists in orchards from tree to tree and year to year. Tree crops also demand amongst the highest per acre users of inputs (fertilizers, agrochemicals and water) of any crop. The end result of these factors is that orchard crops are amongst the least efficiently managed of all agricultural systems. Given these fundamental limitations it has been impossible to develop truly efficient orchard fertilizer management systems or to conduct nutritional research experiments properly.

The project described has sucessfully developed new methodology to map yield in an orchard and to use that information to optimize inputs and directly contribute to improved resource use efficiency. The benefits to in-field experimentation would be equally significant. The most direct benefit of this information would be the ability to optimize fertilization strategies on a site-specific basis. This is the key to improving nutrient use efficiency. An example of yield variability is shown in **Figure 1**.

The ability to optimize production systems benefits everyone from producer to consumer, it will allow researchers to conduct better research programs, which will directly benefit research-funding agencies and improve our ability to protect the environment.

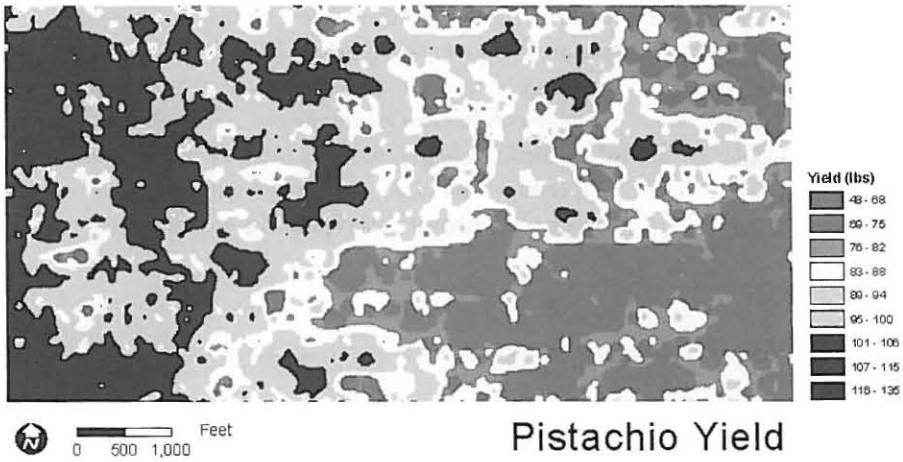

Figure 1. *Yield over entire orchard area of 80. Colors represent average tree yield from 45 lbs per tree to 136 lbs per tree. These yields correspond to 2000 lb /acre to 8000 lb/acre of in-shell splits. This also corresponds to a nitrogen removal of 100 to 400 lbs acre/yr.*

MINIMIZING NITROGEN RUNOFF AND IMPROVING NITROGEN USE EFFICIENCY IN CONTAINERIZED WOODY ORNAMENTALS THROUGH MANAGEMENT OF NITRATE AND AMMONIUM-NITROGEN

Project Leaders

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INTRODUCTION

California agriculture is located throughout essentially all regions of the state. However, over 70% of ornamental production facilities are located in the coastal regions of Southern California, an area of the state where urban communities, agricultural developments, and protected wetlands are in proximity to each other. Due to these geographical constraints, along with the high use of fertilizer and water by the industry, nitrate and phosphate leaching and runoff from agricultural lands can easily contaminate neighboring surface waters and groundwater. The federally enacted Clean Water Act of 1972 and California's Porter-Cologne Water Quality Act of 1969 have developed guidelines and laws to mitigate nutrient runoff from industrial and agricultural sites. Lawsuits have been pending in the regions of San Diego and central coast and many watersheds throughout the state have, or are developing, water quality regulations to clean polluted water resources. Unless fertilization and cultural practices are restructured, many nurseries will be unable to comply with the new water quality control programs.

In the following project, trials are being conducted to determine the fate of nutrients released from different types of coated, controlled-release fertilizers (CRF) and liquid fertilizers (LF) which are injected through the irrigation system. Fertilizer cycling (release from CRF, leaching, binding to media, and uptake) is being studied, determining the effects of different environmental conditions such as pH of the media: acid pH (5.0) and neutral pH (7.0) and temperature regimes on nutrient cycling. The fate of nitrogen (N), phosphorus (P) and the other essential

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

Treatment	Fertilizer Rate	Fertilizer Type
1	100 ppm N as 75% NH_4 and 25% NO_3	LF
2	100 ppm N as 50% NH_4 and 50% NO_3	LF
3	100 ppm N as 75% NO_3 and 25% NH_4	LF
4	3.0 lb N/yd^3	Osmocote
CRF		
5	3.0 lb N/yd^3	Polyon CRF
6	3.0 lb N/yd^3	Nutricote CRF
7	3.0 lb N/yd^3	Multicote CRF

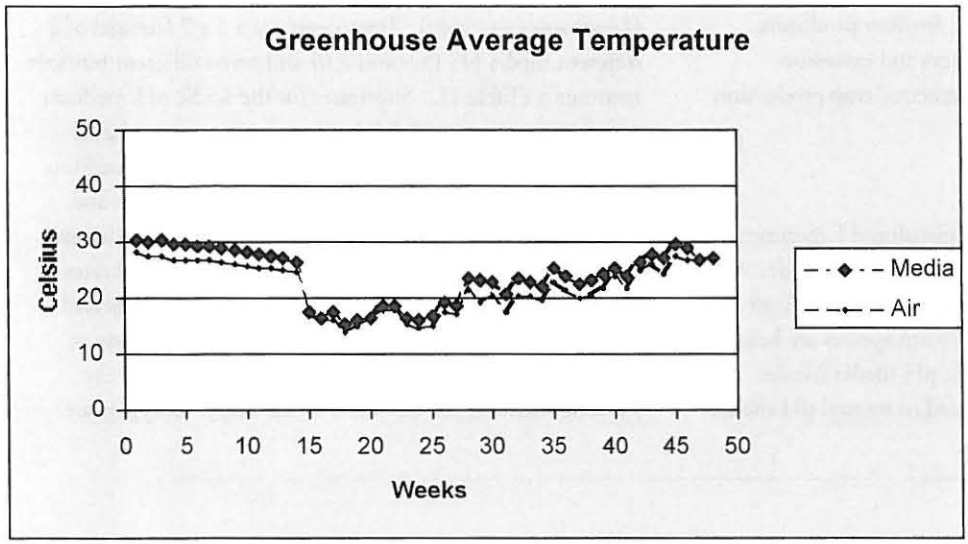

Figure 1. Average greenhouse air and media temperatures from August 15, 2001 (week 1) until July 10, 2002 (week 48). Media temperatures were automatically monitored with three thermocouples: one placed in the center of the pot, one placed 1 inch in from the northeast side of the container and one placed 1 inch in from the southwest side of the containers.

Electrical conductivity. The electrical conductivity of leachates (EC) was relatively stable for most of the CRFs tested (Figure 2). However, EC did exceed 1.0 dS/M for Multicote during the first 17 weeks of the study. The variability and instability of EC for all treatments during the first 15 weeks of the study could be attributed to broken granules in the fertilizers, and impurities in the media that leached out during the first phase of the study, and the lack of a developed root system to absorb nutrients released from the fertilizer. During the remainder of the study from week 20 to week 48, EC was below 1.0 for all CRFs. Irrigation water EC ranged averaged 0.55 dS/M during the entire study.

nutrients during crop production is being determined by conducting weekly measurements of elements in the leachate, and monthly measurements of total nutrients in the media and the plants. With this data, we will be able to determine the fate of nutrients, (whether they are tied up in the media, leached out with the runoff water, or taken up by the plants). Because the duration of each experiment is 11 months, the typical production cycle for 1-gallon woody ornamentals in southern California, we will know the time period in the production cycle when nutrient leaching is most likely and the time period when nutrient uptake into plants is at its optimum. In addition, nutrient release from controlled release fertilizers, nutrient binding in the media, and nutrient uptake into the plants will be correlated with the temperature of the media. Temperature data of the media is critical since nutrient release from most controlled release fertilizers is correlated with soil temperature. The information from this experiment will help us develop fertilization and cultural programs that will minimize nutrient leaching so that nutrient uptake efficiency is optimized. This will not only help growers comply with new water quality regulations but also improve profits through more efficient use of water and fertilizer resources. In addition, the information from these studies will benefit fertilizer companies, as they will be better able to develop controlled release fertilizers that release nutrients based on plant needs rather than media temperature alone. These guidelines will be actively communicated to growers, CE advisors, consultants, the fertilizer industry, teachers and students through extension programs, workshops, seminars, and publications (newsletters, trade magazines and journals).

OBJECTIVES

1. Determine the fate of ammonium (NH_4^+) and nitrate (NO_3^-) and other essential nutrients from controlled release fertilizers (CRF) and liquid feed (LF) fertilizers in containerized woody ornamentals growing in acidic (5.0) or neutral (7.0) pH media during an 11-month period.
2. Develop fertilization and irrigation guidelines for woody ornamental crop production that will minimize nutrient runoff and improve nutrient use efficiency.

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

DESCRIPTION

Research plots are set up at the Agricultural Experiment Station at the University of California at Riverside. A total of 910 plants, at the liner-stage, were obtained from commercial nurseries. Two different plant species are being used, one typically produced in acidic pH media (Azalea 'Phoenicia') and one typically produced in neutral pH media (*Ligustrum japonicum*). Treatments are a 2 x 7 factorial of 2 different media pH (5.0 and 7.0) and seven different fertilizer treatments (Table 1). Substrates for the acidic pH-medium consists of a mixture of 2:1:1 volumes of composted pine bark, peat, and sand, respectively. The neutral pH-medium consists of 3:1 volumes of composted forest products and sand respectively. Lime was added to adjust pH. Micronutrients were added to all treatments at recommended rates. For treatments 1-3, the liquid fertilization (LF) is injected through the irrigation system. For treatments 4-7, one of four different 12-month CRF was incorporated into the planting media at the initiation of the study. Drippers are

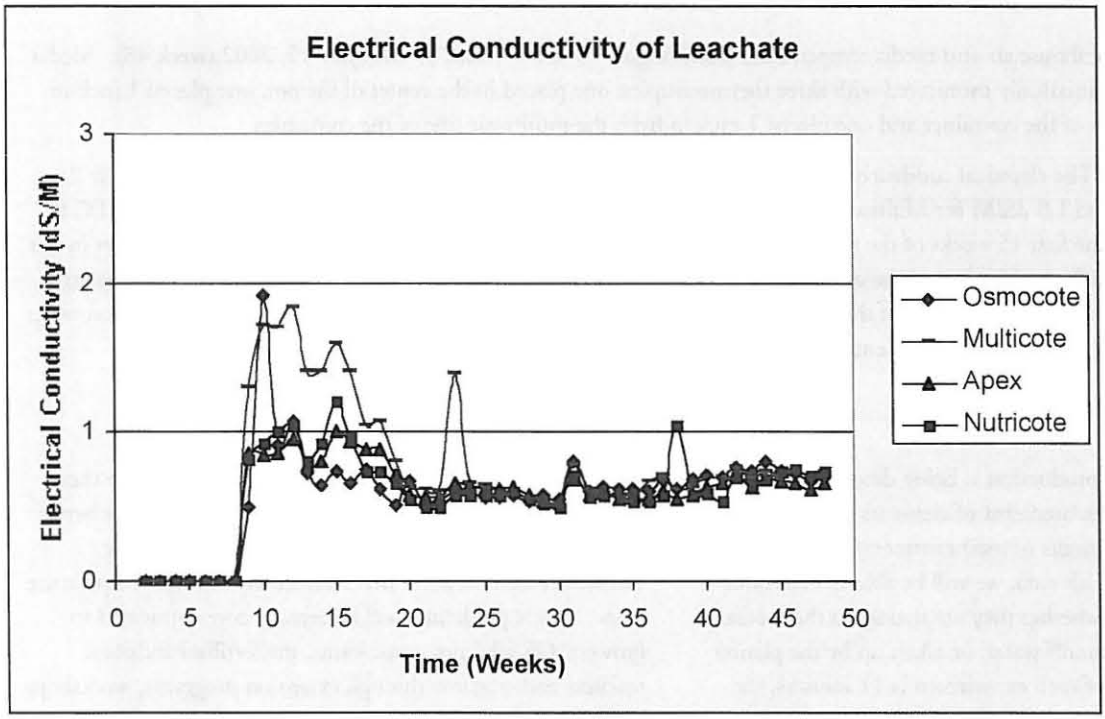

Figure 2. Electrical conductivity of leachates collected from 1-gallon size azalea 'Phoenicia'. Plants were grown from 1-year-old rooted liners and were placed in a greenhouse where high temperatures were controlled with coolant pads. Plants did not receive supplemental heating during the winter. Plants were grown from August 15, 2001 until July 10, 2002. Electrical conductivity measurements were not conducted from weeks 1 to week 9. Irrigation water EC averaged 0.55 dS/M throughout the experimental period.

Ammonium and Nitrate Concentrations of Leachates. Ammonium and nitrate in leachates were elevated during the first 20 weeks of the study and then were relatively low during the remaining 28 weeks of the study (Figures 2 and 3). Higher leaching rates during the first third of the study may be attributed to the higher air and media temperatures experienced during this time, which would result in elevated nutrient release from the CRF. In addition, the lack of a well-developed root system established in the media would limit the ability of the plant to absorb any nutrients released into the container during this time.

located in each container and irrigation is controlled electronically to water at specific time intervals, depending on crop water requirements.

RESULTS & CONCLUSIONS

Media and air temperatures. The temperature of the media was closely correlated with the air temperature (Figure 1). In the greenhouse, where high temperatures are moderated with the use of shade cloth and evaporative cooling pads, average media temperatures did occasionally exceed the temperature range (21°C) at which the nutrient release rates of most controlled release fertilizers are tested. Therefore, during these episodes of high media temperature, nutrient release rates from CRF may have exceeded the needs of the crop.

Based on these preliminary results, it appears that the greatest potential for nutrient leaching is immediately after planting. Therefore, for containerized woody ornamentals such as azalea, planting in the spring is recommended so that roots become established in the media before warmer temperatures of the summer season accelerate nutrient release from controlled release fertilizers. Other cultural recommendations are to keep media temperatures moderated by minimizing sun exposure to containers through overhead shading and can-tight spacing. Irrigation programs should be closely monitored in the beginning of the crop cycle to minimize the potential of nutrient leaching. A recommendation for the fertilizer industry would be to formulate fertilizers for woody ornamental crops such as azalea, so that nutrient release patterns are lower during the first several weeks. This would provide sufficient time for root establishment into the media, and therefore the ability of roots to absorb nutrients released into the media.

See **Figure** 4 on the following page.

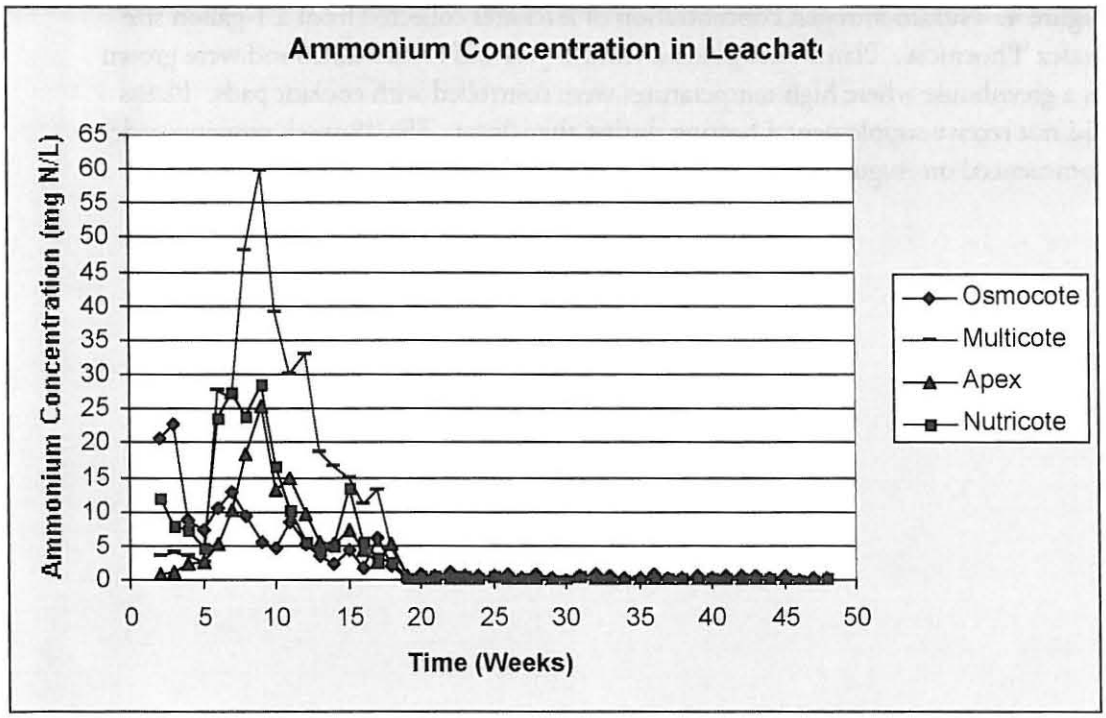

Figure 3. Ammonium concentration of leachates collected from 1-gallon size azalea 'Phoenicia'. Plants were planted from 1-year-old rooted liners and were grown in a greenhouse where high temperatures were controlled with coolant pads. Plants did not receive supplemental heating during the winter. The 48-week growing cycle commenced on August 15, 2001 and ended on July 10, 2002.

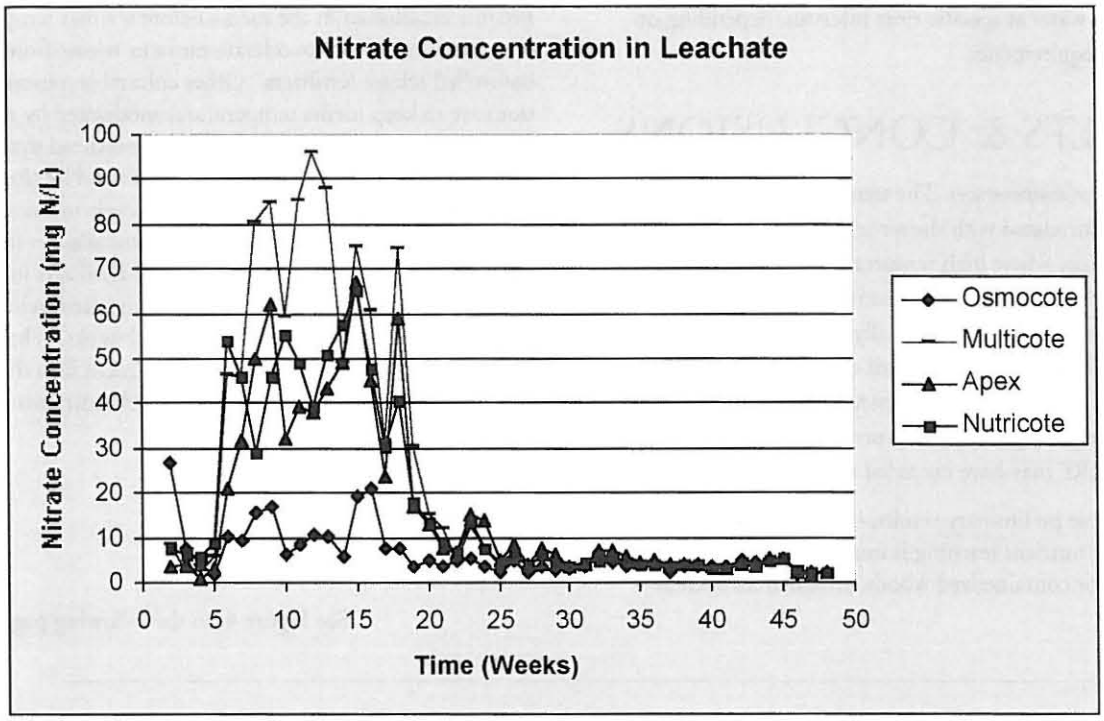

Figure 4. Nitrate-nitrogen concentration of leachates collected from a 1-gallon size azalea 'Phoenicia'. Plants were planted from 1-year-old rooted liners and were grown in a greenhouse where high temperatures were controlled with coolant pads. Plants did not receive supplemental heating during the winter. The 48-week growing cycle commenced on August 15, 2001 and ended on July 10, 2002.

DEVELOPMENT OF BMPS FOR FERTILIZING LAWNS TO OPTIMIZE PLANT PERFORMANCE AND NITROGEN UPTAKE WHILE REDUCING THE POTENTIAL FOR NITRATE LEACHING

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INTRODUCTION

The definition of the phrase "best management practice" (BMP) varies depending on the specific context involved and the currently accepted standards and goals of agronomic management. In general, BMPs are considered to be a set of guidelines or procedures which have been determined, as part of an overall program, to be an effective and practical (technically, socially and economically) method for reducing, preventing, or controlling undesirable effects of management; promoting or maintaining beneficial effects of management; and/or protecting the environment or natural habitat. Turfgrass-related BMPs encompass a wide variety of activities, including fertilization, irrigation, mowing, pest control, and soil management. One of the most important set of turfgrass BMPs are those relating to providing adequate nitrogen (N) to provide the healthy, moderate (i.e., neither minimal or excessive) growth necessary to provide both acceptable visual appearance and the ability to cope with stresses such as drought, traffic, and disease.

Promoting moderate growth (and optimal uptake of N by the plant) is, in fact, one of the best defenses against N sources contaminating the environment. Nitrogen that isn't taken up by the plant is either stored in the soil or thatch, lost to the atmosphere [NH_3 volatilization and denitrification (the reduction of nitrates to gaseous nitrogen)], or lost to surface water in runoff or groundwater via leaching.

In the soil environment, the primary forms of N are organic N (the dominant form), ammonium-N (NH_4^+-N), nitrite-N (NO_2B-N), and nitrate-N (NO_3B-N). Unlike organic N and NH_4^+-N, nitrates do not bind to soils and thus have a high potential for leaching into groundwater. However, it should be noted that organic N and NH_4^+-N are potential nitrate sources, since they can be transformed to nitrate in soil and waters. Nitrate is also likely to remain in the water supply until consumed by plants or other organisms since they do

not volatize. According to the U.S. Environmental Protection Agency (EPA), nationwide over 112 million pounds of nitrate and nitrite were released to water and land from 1991 through 1993. Notably, one of the largest releases of inorganic nitrates (from sources such as fertilizers) was in California.

Excessive N in the environment can have serious consequences, including altering ecosystems, eutrophication [an over-enrichment of water sources with nitrogen and phosphorus which causes accelerated growth of plant life (such as algal blooms) and which can disturb the balance of organisms and water quality], contributing to acid deposition and ozone depletion, and, as already noted, contamination of surface water and groundwater. According to the U.S. Department of Health and Human Services, N fertilizers have contributed to a 40-year trend of increased nitrate levels in surface water and groundwater of agricultural regions.

Given the potential implications of nitrate contamination, turfgrass fertilization BMPs must take into account ways to minimize nitrate contamination of surface water and groundwater. Research has shown that nitrate contamination of surface water due to runoff is rare due to the relatively high infiltration capacity of turfgrass ecosystems (with the exception of severe slopes, which require careful irrigation cycling). The results of research on nitrate leaching, however, are more variable, with soil type, irrigation, N source and rate, and season of application all potentially affecting nitrate leaching.

OBJECTIVES

The objectives of the research project are to 1) evaluate the annual N rate and source on tall fescue to determine which treatments optimize plant performance and N uptake while reducing the potential for nitrate (NO_3B) leaching; 2) quantify the effect of N fertilizer rate and source on visual turfgrass quality and color, clipping yield, tissue N concentration, N uptake, and concentration of NO_3B-N at a depth below the rootzone; 3) develop BMPs for lawns under representative irrigation practices to optimize plant performance and N uptake while reducing the potential for NO_3B leaching; and 4) conduct outreach activities, including oral presentations and trade journal publications, emphasizing the importance of the BMPs and how to carry out these practices for N fertilization of lawns.

DESCRIPTION

The project is being conducted at two sites with different climates and turfgrass maturity, but which are being maintained similarly. One site is a newly established tall fescue plot (sodded late Sept. 2002) in northern California at UC Davis and the other is a mature tall fescue plot (seeded Apr. 1996) in southern California at UC Riverside. Both sites were established to tall fescue, since it is the most widely used lawngrass in California, especially for urban landscapes. The plots at both sites are being irrigated at 110% ET_o, with the amount of irrigation determined weekly based on the previous 7 days= cumulative ET_o (rainfall may cause the cancellation of irrigation events). There are three irrigation events per week, which are cycled to prevent runoff. The experimental design at both sites is a randomized complete block (RCB) design with N treatments arranged in a 4H3 factorial (four N sources and three rates; see Table 1). A no-nitrogen check treatment is also included to allow for additional statistical comparisons. Nitrogen treatments are being applied from 15 Oct. 2002 to 15 Aug. 2004 at UC Riverside and from 15 May 2003 to 1 Mar.2005 at UC Davis.

During the 24-month field phase of this study, several measurements are being collected, including visual ratings, NO_3^--N and NH_4^+-N concentrations of soil water below the rootzone, and others (Table 2). Measurements are being taken from Oct. 2002 to Oct. 2004 at UC Riverside and from Aug. 2003 to May 2005 at UC Davis.

*Continues, following **Table 2b***

Table 1. *Protocol of 13 N fertilization treatments for the CDFA-FREP study (four N sources x three rates plus a no-nitrogen check).*

Date of application	N source[z] ($N-P_2O_5-K_2O$)	Rate (lb N/1000 ft^2)		
		a	b	c
1 Mar.	No nitrogen check	0.0	0.0	0.0
	A. Ammonium nitrate 34-0-0	1.0	1.5	2.0
	B. Polyon 43-0-0	1.0	1.5	2.0
	C. Milorganite 6-2-0	1.0	1.5	2.0
	D. Nutralene 40-0-0	1.0	1.5	2.0
15 May	No nitrogen check	0.0	0.0	0.0
	A. Ammonium nitrate 34-0-0	1.0	1.5	2.0
	B. Polyon 42-0-0	1.0	1.5	2.0
	C. Milorganite 6-2-0	1.0	1.5	2.0
	D. Nutralene 40-0-0	1.0	1.5	2.0
15 Aug.	No nitrogen check	0.0	0.0	0.0
	A. Ammonium nitrate 34-0-0	1.0	1.5	2.0
	B. Polyon 42-0-0	1.0	1.5	2.0
	C. Milorganite 6-2-0	1.0	1.5	2.0
	D. Nutralene 40-0-0	1.0	1.5	2.0
15 Oct.	No nitrogen check	0.0	0.0	0.0
	A. Ammonium nitrate 34-0-0	1.0	1.5	2.0
	B. Polyon 43-0-0	1.0	1.5	2.0
	C. Milorganite 6-2-0	1.0	1.5	2.0
	D. Nutralene 40-0-0	1.0	1.5	2.0
Total	No nitrogen check	0.0	0.0	0.0
	A. Ammonium nitrate 34-0-0	4.0	6.0	8.0
	B. Polyon 43-0-0 and 42-0-0	4.0	6.0	8.0
	C. Milorganite 6-2-0	4.0	6.0	8.0
	D. Nutralene 40-0-0	4.0	6.0	8.0

[z] Ammonium nitrate is a fast-release, water soluble N source; Polyon is a slow-release, polymer-coated N source; Milorganite is a slow-release, natural organic N source; and Nutralene is a slow-release, water insoluble, methylene ureas N source.

Note: K_2SO_4 (0-0-50) and treble superphosphate (0-45-0) will be applied to all plots at an annual rate of 4.0 lb K_2O/1000 ft^2 and 3.0 lb P_2O_5/1000 ft^2.

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Table 2a. *Protocol for measurements collected during the CDFA-FREP study*

Note: *the size of this information requires repeating the "Measurement" data for "Frequency" and for "Method &other comments."*

Measurement	Frequency
1.Visual turfgrass quality	Once every 2 weeks
2.Visual turfgrass color	Same time as turfgrass quality
3.Clipping yield, TKN, and N uptake	Four growth periods, with each period spanning four consecutive weekly clipping yields. All periods start one month following each of the four N-fertility treatment application dates (Table 1). Generally, periods are 1 to 30 Apr., 15 June to 15 July, 15 Sept. to 15 Oct., and 15 Nov. to 15 Dec.
4. NO3—N and NH4+-N concentration of soil water below rootzone	Once every 2 weeks
5. Soil water content	Once every 7 d
6. NO3—N and NH4+-N concentration in soil	Beginning of study (20 Dec. 2002) and at 12 months (1 Oct. 2003) and 24 months (1 Oct. 2004) after initial fertilizer treatments
7. Weather data	Continuous
8. Statistical procedures to date *(See **Table 2b**, facing page)*	

Measurement	Method & other comments
1.Visual turfgrass quality	1 to 9 scale, with 1 = worst quality, 5 = minimally acceptable quality, and 9 = best quality for tall fescue
2.Visual turfgrass color	1 to 9 scale, with 1 = worst color (brown), 5 = minimally acceptable color, and 9 = best color (dark green) for tall fescue
3.Clipping yield, TKN, and N uptake	Weekly clipping yield, representing 7-d growth, is collected from 9.2 ft2 (26% of the total surface area) from each plot with the same mower used for routine mowing, except a specially constructed collection box is attached to the mower. Weekly clipping yields are dried at 60 to 67 °C in a forced-air oven for 48 h and immediately weighed. Yield reported as g·m-2. The four weekly yields within each growth period are pooled by the 52 plots and ground. TKN analysis is conducted at the DANR laboratory located at UC Davis. With appropriate calculations, N uptake during four 4-week growth periods is determined.

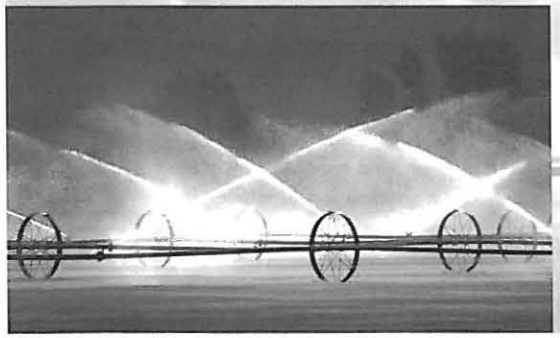
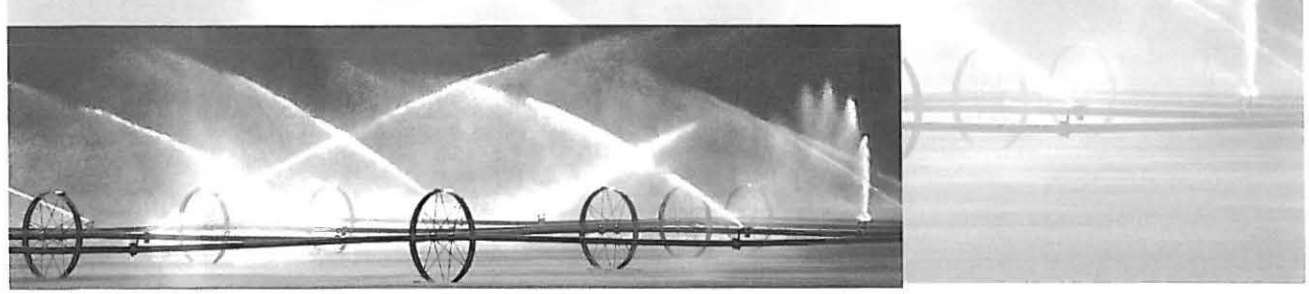


Table 2b. *Protocol for measurements collected during the CDFA-FREP study*

Note: *the size of this information requires repeating the "Measurement" data for "Frequency" and for "Method &other comments."*

Measurement	Method & other comments
4. NO3—N and NH4+-N concentration of soil water below rootzone	One suction plate lysimeter was installed in each plot so the distal tip of the lysimeter cup is at a depth of 2.5 ft below the soil-thatch layer (approximately 0.6 inch deep). The lysimeters were installed at a 45° angle so the lysimeter cup is below undisturbed soil. They were constructed using high-flow ceramic cups (round bottom neck top cups, 1.9-inch diameter, Soil Moisture Equipment Corp. catalog number 653X01-B01M3) and 2-inch diameter PVC pipe. A vacuum of approximately –40 KPa is applied to the lysimeters 24 h before the leachate sampling day. Samples are acidified to pH 2.4-2.8, frozen, and stored until shipped via next-day air to the DANR Laboratory, then stored at 4°C until analyzed for NO3—N and NH4+-N by flow injection analyzer method. Analysis occurs within 28 d of leachate collection.
5. Soil water content	Volumetric soil water content is determined from the 0- to 48-inch soil depth zone at the same time each Wednesday using four time domain reflectometry (TDR) sensors (MoisturePoint MP-917 TDR unit with Type 2 probe) installed in four null plots within the research plot. The most recent irrigation event is on Tuesday mornings.
6. NO3—N and NH4+-N concentration in soil	Two soil cores are taken from each plot and separated into two soil depth zones for the initial sampling: 0 to 12 inches and 12 to 30 inches. For the second and third sampling, cores are separated into four soil depth zones: 0 to 12 inches, 12 to 24 inches, 24 to 36 inches, and 36 to 48 inches. Cores from each plot are pooled by depth, and immediately analyzed for NO3—N and NH4+-N by KCl extraction of the fresh soil. A grid is used to ensure that no part of the plot is sampled more than once for the duration of the study.
7. Weather data	Data obtained from a CIMIS station located at the UCR Turfgrass Research Project. Soil-temperature data loggers also are installed on the research plot.
8. Statistical procedures to date	Most measured variables are statistically analyzed according to a RCB design with 12 treatments arranged in a 4_3 factorial. When the no-nitrogen check treatment is included, a RCB design is used to analyze all 13 treatments.



RESULTS AND DISCUSSION

UC Riverside

Preliminary results from data collected from Oct. 2002 through June 2003 at UC Riverside are listed below:

1. To date, ammonium nitrate and Polyon have produced the better visual turfgrass quality and color. Also, in terms of annual N rate (lb/1000 ft^2), 8 > 6 > 4.
2. Concentration of NO_3^--N and NH_4^+-N in soil water below the rootzone has been low (less than 1 ppm). It should be noted that the average concentration of NO_3^--N and NH_4^+-N in irrigation water is 4.13 and <0.05 ppm, respectively.
3. Plot management is proceeding well, including mowing, irrigation-system checks, fertility, and pest control. Concerning the latter issue, there has been some Rhizoctonia brown patch activity and fungicides have been applied.

The most challenging aspect of plot management has been the irrigation protocol. From 16 Oct. 2002 to 2 July 2003, the protocol was (100% ET_{crop}/DU) minus rainfall, based on the previous 7 d CIMIS ET_o. The goal of this protocol was to irrigate according to plant water use needs and not to over-irrigate nor under-irrigate. However, we gradually realized that in making up rainfall we may have caused some dry soil conditions, especially in the 0- to 6-inch soil depth zone. This issue became more difficult to manage during late spring/early summer 2003. However, visual drought symptoms were not apparent when visual turfgrass quality and color ratings were taken from 6 Nov. 2002 to 20 June 2003.

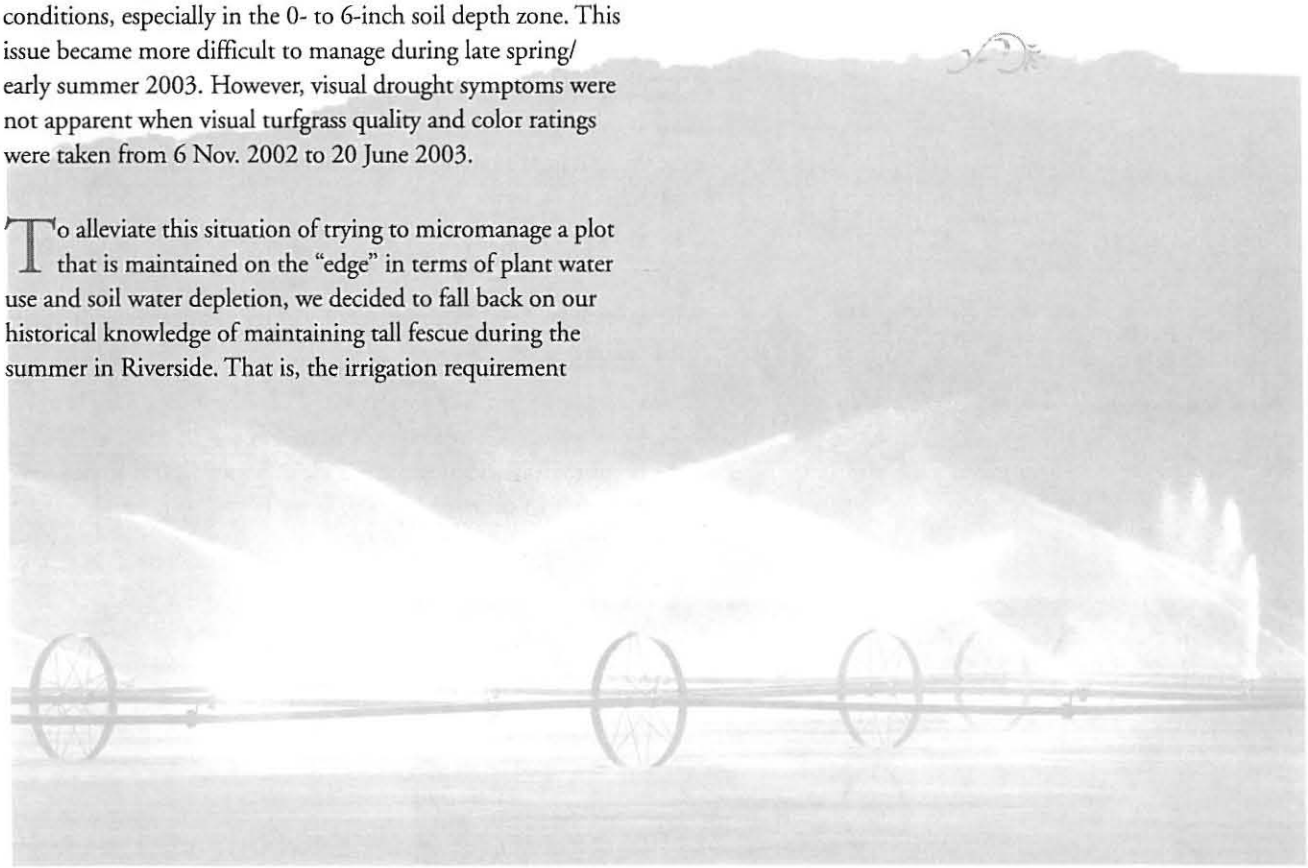
To alleviate this situation of trying to micromanage a plot that is maintained on the "edge" in terms of plant water use and soil water depletion, we decided to fall back on our historical knowledge of maintaining tall fescue during the summer in Riverside. That is, the irrigation requirement (versus turfgrass water use requirement) of maintaining acceptable quality tall fescue is approximately 110% ET_o. Thus, we initiated a new irrigation protocol on 3 July 2003.

UC Davis

1. Nitrogen treatments were initially applied on 15 May 2003 (Table 1). Beginning on that date, irrigation was initiated that was based on ET_o data obtained from CIMIS.
2. Fifty-two lysimeter water samplers (Model 1900L36-B02M2, Soil Moisture Equipment Corp., Santa Barbara, Calif.) were installed below each plot, one per plot. This operation was completed July 2003.
3. Data collection (Table 2) was initiated following the application of N-treatments on 15 Aug. 2003.

For more information about turfgrasses in California, please see

http://ucrturf.ucr.edu



NITROGEN MINERALIZATION RATE OF BIOSOLIDS AND BIOSOLIDS COMPOST

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INTRODUCTION

The disposal of biosolids is one of California's vexing environmental problems. Application on agricultural land represents the most beneficial use of this nitrogen-rich material. However, without a sound understanding of N mineralization behavior of the common biosolids products (dewatered, air-dried or composted) it is impossible to determine the appropriate field application rate to supply the desired agronomic benefit without creating a nitrate pollution hazard. Information on N availability from biosolids under central California field conditions is extremely limited. This project was conducted to develop short- and long-term N availability estimates for representative biosolids products.

OBJECTIVES

a) Determine the short- and long-term N mineralization rates of dewatered, air-dried or composted biosolids.

b) Determine if short-term incubation assays are predictive of field mineralization rates.

METHODS

Microplots (large plastic pots of 2.5 ft^2 volume, containing approximately 200 lb of sandy loam soil) were established in a field at UC Davis in early June, 2000. These microplots were amended over a 3 year period (2000-2002) with various biosolids materials collected from waste treatment plants in several metropolitan areas of California (Table 1). Some microplots were amended only once (in 2000), others received applications of new materials in 2001 and 2002 as well (Table 2). Air-dried and dewatered biosolids were applied to the microplots at a rate equivalent to a field application of 8 dry tons per acre. Due to the lower N content, and assumed slower mineralization rate, composts were applied at a rate equivalent to 16 dry tons per acre. Immediately following application the samples were manually incorporated into the soil to simulate disking in the field.

In each year the biosolids samples were applied to the microplots and manually incorporated in June.

Sudan grass (*Sorghum vulgare* var. *sudanese* cv. Piper) was seeded a few days later. An automated irrigation system was installed to maintain the soil between field capacity and approximately 70 centibar tension. A leaching port was installed in each microplot. In the first two cropping cycles the leachate was collected and analyzed for mineral N concentration (NH_3-N and NO_3-N). In the third crop the leachate was returned to the microplots so that no biosolids N was lost from the cropping system. Sudan was grown over a 4-5 month season, with two biomass harvests per season. The plants were clipped approximately one inch above the soil surface at the first harvest and allowed to regrow; at the second harvest, plants were clipped at the soil surface. The harvested biomass was oven-dried, ground, and analyzed for total N concentration. At the final harvest the soil profile of each microplot was sampled and analyzed for mineral N concentration. The microplots were then covered to prevent winter precipitation from leaching mineral N during the fallow season.

Apparent biosolids N availability was calculated by the following formula:

[(crop biomass N) + (mineral N in leachate) + (mineral N in soil profile at end of season)]

minus those quantities from unamended (control) microplots. This amount of N was expressed as a percentage of total N (organic and mineral forms) initially present in the biosolids materials. For the sudan microplots receiving annual biosolids applications, the apparent N availability from the samples applied in 2001 were estimated by compari-

Table 1. Characteristics of biosolids samples, 2000-2002.

Sample	Type	Initial % dry weight [z]		Analysis after oven drying % C	% total N	C/N ratio
			2000			
A	air-dried	80		33	5.7	5.8
B	air-dried	75		26	4.6	5.7
C	dewatered	19		30	3.9	7.7
D	dewatered	20		32	4.8	6.7
E	composted	63		27	2.2	12.3
F	composted	53		44	0.9	48.9
			2001			
G	air-dried	95		37	6.2	6.0
H	dewatered	13		32	4.7	6.8
I	dewatered	19		32	4.6	7.0
J	composted	73		27	2.3	11.7
K	composted	48		33	0.9	36.7
			2002			
L	air-dried	93		36	6.6	5.5
M	dewatered	21		33	4.8	6.9
N	dewatered	26		30	4.2	7.1
O	composted	63		30	2.4	12.5

[z] calculated as (dry wt / wet wt)*100
[y] calculated on a dry weight basis

son to the microplots that received the same biosolids sample in 2000. The apparent N availability of 2002 biosolids samples were calculated by subtracting the residual contribution of the appropriate 2000 biosolid sample as well as the estimated residual contribution of the 2001 sample; the estimated contribution of the 2001 sample was calculated as the same percentage of N availability of the appropriate biosolids type (air-dried, dewatered, or composted) observed in 2001 from the 2000 samples.

A parallel laboratory study was conducted in which the rate of net N mineralization of organic N in the biosolids samples was estimated from aerobic incubation of biosolids-amended soil under constant temperature and moisture. The sandy loam soil used in the microplot studies was moisture equilibrated in a pressure apparatus at 25 centibars tension (approximately field capacity). Dried, ground biosolids were thoroughly blended with this moist soil at 0.4% by dry weight. After sampling for initial mineral N concentration, these soil/biosolids blends were incubated in sealed glass jars at 77°F; there were 4 replicate jars per biosolids blend, and 4 jars of unamended soil. After 4, 8, 12, and 16 weeks of incubation samples were removed from the jars and analyzed for mineral N concentration. Any change in mineral N from that in unamended soil represented net N mineralization or immobilization of N by the biosolids.

RESULTS:

The initial characteristics of the biosolids samples varied substantially within types, and dramatically among types (Table 1). Air-dried samples were 80-95% solids, while the dewatered material was only 13-26% solids. The moisture content of the composts was highly variable. On a dry weight basis, air-dried biosolids ranged from 4.6 - 6.6% total N, with dewatered samples somewhat lower (3.9 - 4.8% N). All composts were blends of biosolids and municipal yard and landscape waste, but individual samples differed substantially in N content; the samples could be categorized as low N (< 1%, samples F and K), or high N (> 2%, samples E, J, and O).

The three types of biosolids materials behaved quite differently in the sudan assay (Table 3). In the first season after application, dewatered biosolids (samples C, D, I, and M) showed apparent N availability of 22-32% of initial N content, while air-dried biosolids (samples A, B, G, and L) were less active, ranging from 20-24%. The two distinct types of compost performed quite differently. Samples E, J, and O all contained more than 2% N, with C/N ratios of 12-13. By contrast, sample F had very low N (0.9%), and high C/N ratio (49). Sample F was nearly N neutral, with only 3% N availability; the more N-rich composts averaged 7%. The apparent N release from the 2000 samples slowed in the subsequent growing seasons, averaging 10% and 6% of initial N in 2001 for the air-dried and dewatered samples, respectively; in 2002 both types averaged 4% of initial N. Compost sample E showed declining N availability, while sample F caused N immobilization (reduced N availability) in both succeeding seasons, apparently due to the continuing breakdown of the high C/N ratio material.

Table 3. Apparent N availability from biosolids samples in the sudan bioassays.

Biosolids sample	Year applied	Type	Biosolids N availability (% of initial N) 2000	2001	2002
A	2000	air-dried	21 ± 1	13 ± 2	5 ± 4
B	2000	air-dried	20 ± 2	8 ± 2	3 ± 2
C	2000	dewatered	29 ± 4	7 ± 1	2 ± 1
D	2000	dewatered	30 ± 2	5 ± 3	5 ± 1
E	2000	composted	13 ± 1	6 ± 2	1 ± 2
F	2000	composted	3 ± 8	-7 ± 3	-4 ± 3
none			4 ± 1	3 ± 1	2 ± 1
G	2001	air-dried		24 ± 2	
I	2001	dewatered		22 ± 6	
J	2001	composted		5 ± 2	
L	2002	air-dried			20 ± 2
M	2002	dewatered			32 ± 4
O	2002	composed			3 ± 2

± plus or minus standard error

To estimate the extent of volatilization and denitrification N losses, soil samples were collected at the termination of the 2002 sudan crop, dried, ground, and analyzed for total N. More than 60% of total N applied in microplots receiving the air-dried and dewatered samples, and more than 80% of total N applied from compost, was still present. This suggests that N loss through denitrification and volatilization were modest over the 3 year period.

Net N mineralization (N_{min}) from dewatered samples in the incubation assay ranged from 20 - 30 % of initial N (Table 4), very similar to the behavior of these samples in the sudan field assay. Air-dried samples varied more, from 19 - 41% of initial N, somewhat more than in the sudan assay. Air-dried samples G and L had much higher N content (6.2 and 6.6%, respectively) than any other samples evaluated in this study, and they had by far the highest N_{min}. As in the field assays, the two categories of compost behaved differently. The relatively high N samples (E and J) averaged 11% N_{min}; the reason for the lower rate observed for sample O was not clear. Of the samples with low initial N content, sample F was essentially N neutral, while sample K showed strong net

Table 2. Biosolids sample combinations evaluated in the sudan assay.

Number of microplots	Biosolids sample applied 2000	2001	2002
4	A	none	none
4	B	none	none
4	C	none	none
4	D	none	none
4	E	none	none
4	F	none	none
4	B	G	L
4	D	I	M
4	F	J	O
6	none	none	none

N immobilization

This project demonstrated that N release from air-dried and dewatered biosolids was reasonably consistent across numerous sources and samples. In the growing season after late spring application, approximately 20-25% (air-dried biosolids) or 25-30% (dewatered biosolids) of total N applied would be expected to become available for crop uptake under Sacramento Valley conditions. The behavior of composted biosolids was less predictable. Low N biosolids / yard waste composts are at best N neutral, and may have long-term immobilization characteristics that make them problematic for use in production agriculture. Use of these composts as surface mulches may be appropriate in some circumstances, but as soil-incorporated amendments the disadvantages may outweigh any benefits. Composts with a higher N content (> 2%) behaved similarly to manure-based composts of equivalent N content, with N recovery ranging from 3-13% of initial N. These composts have no obvious agronomic drawbacks, but their contribution to crop N fertility is modest. Since the composting process stabilizes the N (and carbon) content, biosolids composts should have more significant long-term effects on soil organic matter content (and presumably soil tilth) than uncomposted biosolids application.

The cumulative effects of yearly biosolids applications were significantly increased soil organic N content, and progressively enhanced crop fertility. Crop N availability in the third year of the study (after 3 annual applications of 8 dry tons / acre) was the equivalent of more than 300 lb N / acre in microplots receiving either air-dried or dewatered biosolids. For sites receiving annual biosolids application, application rates must decline over time to prevent mineral N accumulation in the soil, and associated pollution potential.

Table 4. Net N mineralization from biosolids after 16 week laboratory incubation.

Sample type	Sample	Total N (%)	Total C (%)	% N mineralization
Air-dried	A	5.7	33	25 ± 1
	B	4.6	26	19 ± 4
	G	6.2	37	39 ± 1
	L	6.6	36	41 ± 1
Dewatered	C	3.9	30	25 ± 4
	D	4.8	32	22 ± 2
	H	4.7	32	24 ± 2
	I	4.6	32	28 ± 3
	M	4.8	33	30 ± 2
	N	4.2	30	20 ± 1
Composted	E	2.2	27	14 ± 1
	F	0.9	44	1 ± 1
	J	2.3	27	8 ± 5
	K	0.9	33	-33 ± 3
	O	2.4	30	1 ± 1

± plus or minus standard error

ATMOSPHERIC AMMONIA FLUX PROFILES RELATED TO SOIL FERTILITY MANAGEMENT

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INTRODUCTION

Ammonia is the dominant gaseous base in the atmosphere and a principal neutralizing agent for atmospheric acids. The NH_3 in the atmosphere, along with alkaline soil dust, controls the acidity of precipitation. Volatilized NH_3 can with NO_x and SO_x react to form ammonium nitrate or ammonium sulfate, a component of airborne particulate matter along with smoke, soot and fine mineral dust ($PM_{2.5}$). Estimated patterns of nitrogen deposition suggest that, for California locations close to photochemical smog source areas, concentrations of oxidized forms of N dominate, while in areas near agricultural activities the importance of reduced N forms may increase significantly (Bytnerowicz and Fenn1). NH_3 remains one of the most poorly characterized atmospheric trace compounds in terms of overall sources. This situation persists as a result of several factors, such as, experimental difficulties associated with NH_3 measurements, rapid gas-to-particle conversion of NH_3 in the atmosphere, the capacity of soils, organic matter, and vegetation to act as both sources and sinks for atmospheric NH_3, and variability in nitrogen fertilizer management and related NH_3 emissions (Langford et al.[2]). Consequently, there is a limited amount of published information from which to develop direct emissions estimates of NH_3 for the state of California in general, and the state's Central Valley in particular. Preliminary measurements of NH_3 background concentrations in the San Joaquin Valley by Fitz et al.[3] estimated February levels of 3-16 $\mu g\ m^{-3}$ near alfalfa fields. The magnitude and distribution (both regionally and seasonally) of current NH_3 emissions from fertilizer and other agricultural sources is still largely undetermined for the state of California and many other large regions where agriculture is a major land use (Matthews[4]).

A recent report for the California Air Resources Board (ARB) by Potter et al.[5] provided new emissions inventories of ammonia volatilization from surface applied fertilizers and from native soil sources for the state of California. The NH_3 inventory results were based on a combination of field measurements and computer modeling of major nitrogen transformations in the soil that can lead to NH_3 emission fluxes. A year-round sampling campaign was carried out on a series of farms undergoing typical fertilizer applications for commercial crop production. Emissions of NH_3 for a variety of fertilizer types and application methods were mapped for the major crop types in California's four main agricultural valleys. In this same ARB-supported report a comparison of published emission estimates for natural soils showed many missing data values for major vegetation types common to California. Emission estimates from agricultural soils for periods other than fertilizer application is also very limited. In the absence of a measured data set for fertilizer applications for NH_3, a computer modeling approach was used to estimate statewide annual emission rates of N-NH_3 from native soils and indirectly from fertilizer N sources in cultivated soils. The modeling system used (called CASA) is based on regional data sets (8-km resolution) from a geographic information system (GIS) developed specifically for the ARB-sponsored research on N-NH_3 emissions. Based on an initial inventory estimate, total statewide emissions of NH_3 from soil N sources appear to be just over 30 x 106 kg N- NH_3 annually, which includes a large contribution from cultivated soils. The annual emission from fertilizer applications to cultivated crops was estimated at 12 x 10^6 kg N-NH_3. The range of emission factors for the 19 individual fertilizer applications monitored in the study ranged from 0% for UAN-32 at 100#N/acre applied through a buried drip system on almonds to 6.6% volatile loss for Ammonium

Sulfate at 100#/acre applied in a surface band to almonds on a high pH soil. The average emission factor for all combinations of crop, soil, fertilizer and application method was 2.38% of the applied N.

The emissions estimated by the CASA model are based on well documented relationships between plants and soil microbes known as the Nitrogen cycle. Ammonia is one of the end products of organic matter decomposition by soil fungi and bacteria. Some NH_3 will find its way to the atmosphere and, under certain soil conditions such as high pH, there may be significant volatile losses. The fate of the NH_3 after it reaches the atmosphere is less well known. The formation of secondary particles, $PM_{2.5}$ described above, is certainly one possibility. However, the fate of NH_3 in the micro-climate near active vegetation appears to be complex. The interior structure of the typical plant leaf is adapted to absorb atmospheric CO_2 for photosynthesis. The diffusion characteristics of NH_3 in the atmosphere are likely to be similar to CO_2 suggesting the possibility of NH_3 absorption as well. Harper et al. (1983)[6] found NH_3 losses to the atmosphere from tropical pastures in Australia after fertilization and at various other times through the season. NH_3 losses were correlated with high air temperatures and solar radiation levels. Absorption by vegetation was observed during the same study correlated with dawn and dusk periods. Harper et al. (1996)[7], on a temperate grassland in Georgia, found emissions after fertilization but again measured NH_3 absorption by the vegetation. He estimated 6% of the N in the vegetation was absorbed as atmospheric NH_3 in the cooler part of the growing season and 11% in the summer. An earlier investigation by Harper and Sharpe[8] on irrigated corn in Nebraska used ^{15}N labeled fertilizer to show both emission and absorption of NH_3 by the crop at various times through the season. Some absorption of ^{15}N labeled NH_3 by crops that had not been fertilized was detected; indicating the possibility that emission of NH_3 from fertilized plots was absorbed by nearby vegetation. NH_3 absorption was correlated with air temperature, solar radiation, soil moisture, soil N levels but primarily with NH_3 concentration in the atmosphere. High atmospheric NH_3 resulted in absorption regardless of the other factors. Absorption of NH_3 has been reported in other research, notably Porter et al.[9], where corn seedlings were placed in an atmosphere spiked with labeled $15NH_3$. They found absorption of up to 30% of NH_3 in a 24-hour period.

The somewhat contradictory findings sited above illustrate the complexity of NH_3 transport in the soil-plant-atmosphere system. The data presented below are from a variety of soils and vegetation communities in California. The same sites were sampled at various times of the year. Sampling was continuous over several days and included separate diurnal samples. The results, to date, suggest both emission and absorption correlated with many of the same factors seen in the previous research. Additional sites have been established and further data is to be collected and analyzed.

The active denuder methodology developed at CSU Fresno for the study by Potter et al.[5] was used for the sampling portion of this project. This methodology represents an established technique in air quality studies, and it satisfies the inventory development requirement for continuous sampling of soil gas emissions over relatively long time periods. Denuders and anemometers were co-located at 0.5, 1, 2, 4, and 10 meters above the soil surface, mounted on a portable mast. The denuder is a 47 mm disk of glass fiber filter paper, treated with citric acid (5% in 95% ethanol) and dried. A commercially available, 12-volt air sampling pump is used to pull air through the denuder disk at a regulated rate of 1 to 5 liters per minute. Lower air flow rates were used for long sampling period of several days. The higher air flows were selected when the sampling period was to be limited to a few hours. Filter samples were refrigerated and taken to the Graduate Laboratory of the CSU Fresno College of Agricultural Science and Technology, to be analyzed by project personnel. The NH_4-Citrate was extracted from the denuder with distilled water and analyzed with a spectrophotometer. The amount of ammonia on the denuder disk is reported in mg NH_3. The concentration of NH_3 in the air at the sampling point was determined by dividing the amount of ammonia on the disk by the volume (m_3) of air pumped through the denuder in the sampling period to derive concentrations in units of mg N-NH_3 m-$_3$ air at the sampling point. There was a considerable wind profile over the 10m height of the sampling mast. Wind speeds at 10m were typically higher than the 0.5m sampling point by a factor of 5 or more. The wind speed was significantly different even between the 0.5m and 1.0m sampling elevations. The wide range in wind speed over the sampling profile required the conversion of the concentration in mg NH_3 m^{-3} to a flux in mg NH_3 m^{-2} sec^{-1}. The NH^3 flux was calculated by multiplication of the concentration by the wind speed in m/s.

Sampling locations were selected from cropland, range, natural vegetation and dairies. Five crops, three categories of natural vegetation and a dairy were sampled during the first year of the study. Permanent and annual agronomic crops were sampled several times from the beginning of the crop season through harvest. Two different grazing sites were

sampled every three months. A conifer forest in the Sierra Nevada and a coastal forest have been sampled once and will be again in 2003. The dairy sampling was conducted as part of a long-term project at a facility near Hanford in the San Joaquin Valley. The results reported below are for sampling sites on foothill rangeland, a field with a barley crop that was followed by a corn crop, and a silage sorghum crop around the dairy. These were all in central California, within 100 km of Fresno. Sampling at these and the other locations are continuing. The data reported here are selected as examples of the preliminary conclusions. Results of the complete sampling program and the conclusions from it will be available in late 2004.

RESULTS AND DISCUSSION

A correlation between air temperature and NH_3 levels was anticipated. One of the reasons for sampling the same site at various times through the year was to verify that relationship. The magnitude of the flux and the characteristics of the vertical profile did appear to correlate with the average air temperature. The San Joaquin Experimental Range is a 2000 Ha field site administered by CSU Fresno for the US Forest Service. Two sampling sites were designated and sampled every few months beginning in January of 2002. Some of the data is shown below in Figure 1.

The average air temperature during the sampling in January was 8.6° C. In March the average was 14.6°C, and in June the temperature averaged 24.0° C. The lowest NH_3 values were in January, the highest in June. There were two sampling sites and both sets of flux profiles appear to be correlated with temperature. Site R1 was in an open meadow of annual grasses. Site R2 had brush and trees enclosing a small area of grasses. The NH_3 flux values were higher for the R1 site sampled at the same time as the R2 site, particularly at 10m. The difference may be due in part to temperature.

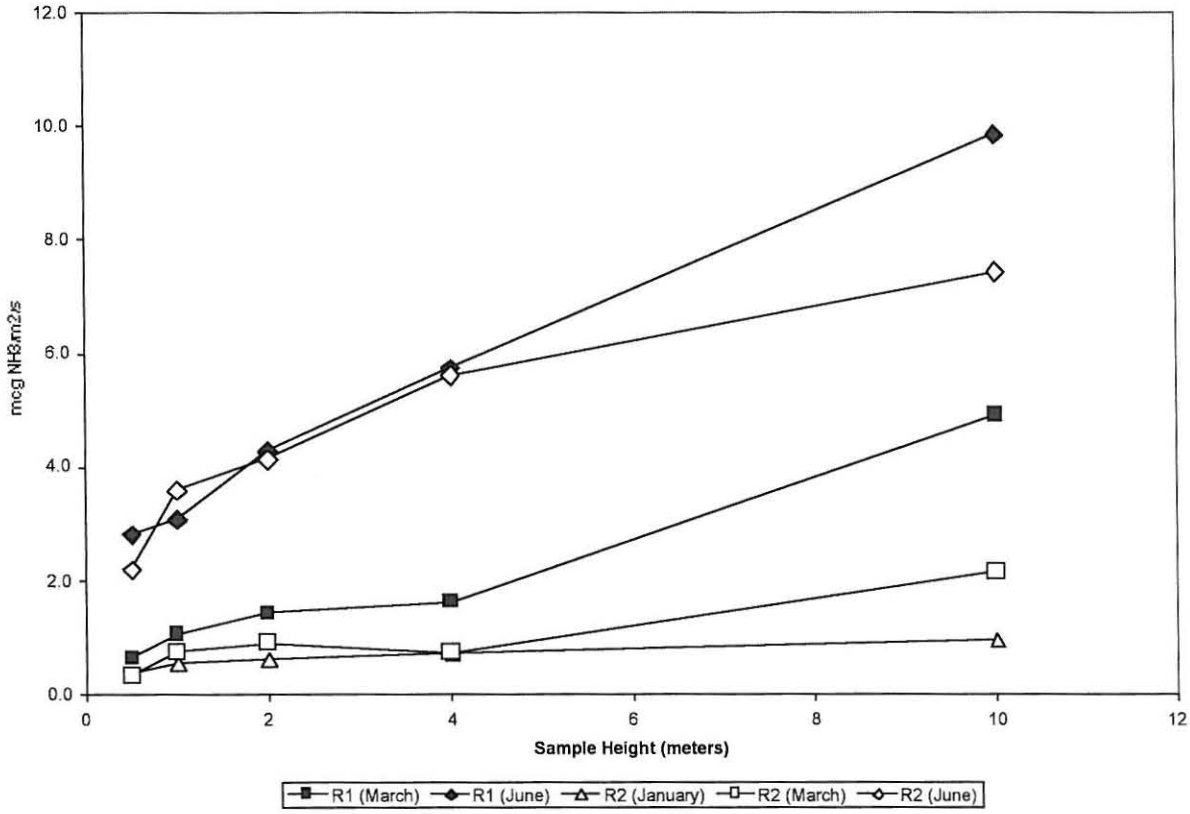

Figure 1. *Ammonia flux profiles for two rangeland sites located 40 km north of Fresno at an elevation of 300m. Each line represents an average of 3 to 5 days of continuous sampling. The two sites were about 200m apart. R1 (closed graph symbols) was an open grassland with no trees or brush within 50m of the mast and R2 (open symbols) had a higher level of vegetation; a mix of grass, brush and trees.*

The R1 site had no tall vegetation within 50m of the mast compared to the R2 site where there were 20m trees within 5m of the mast. Further sampling may be able to distinguish other correlations with environmental factors between the two range sites.

A second relationship between an environmental factor and atmospheric NH_3 flux profiles is the distinct, diurnal difference. In each sampling episode to date, at least one day of collection was divided into a day and night sample. Most of those diurnal sample pairs showed considerably more NH_3 during the day compared to the night sample. Figure 2 is data from a field planted to barley. There were three periods of sampling from the seedling stage in November of 2001 to the harvest in March 2002. The average of the flux profiles for each sampling period showed the same correlation with air temperature as the rangeland in Figure 1. Figure 2 shows the diurnal differences for the last sampling in early March.

The two night samples are lower in magnitude and show less profile difference over the sampling heights. The day sample for March 11 is typical of day samples for most of the vegetation types in the study. The magnitude is considerably higher and there is a more pronounced gradient of flux values between the 10m sample and the 0.5m sample. The other day sample, March 8, appears to violate the postulated correlation. Its profile is more characteristic of a night sample. March 11 was a typical spring day in the San Joaquin Valley. The average temperature was 19.9° C, relative humidity was 41%, with a light wind. March 8 was a cool day (13.5° C) near the end of a storm event that dropped 12mm of rain. The air temperature during the storm was more characteristic of nighttime levels. It is also likely the moisture in the air reduced the NH_3 values. Increased atmospheric moisture, either elevated humidity or precipitation, has been correlated with reduced NH_3 levels in previous work.

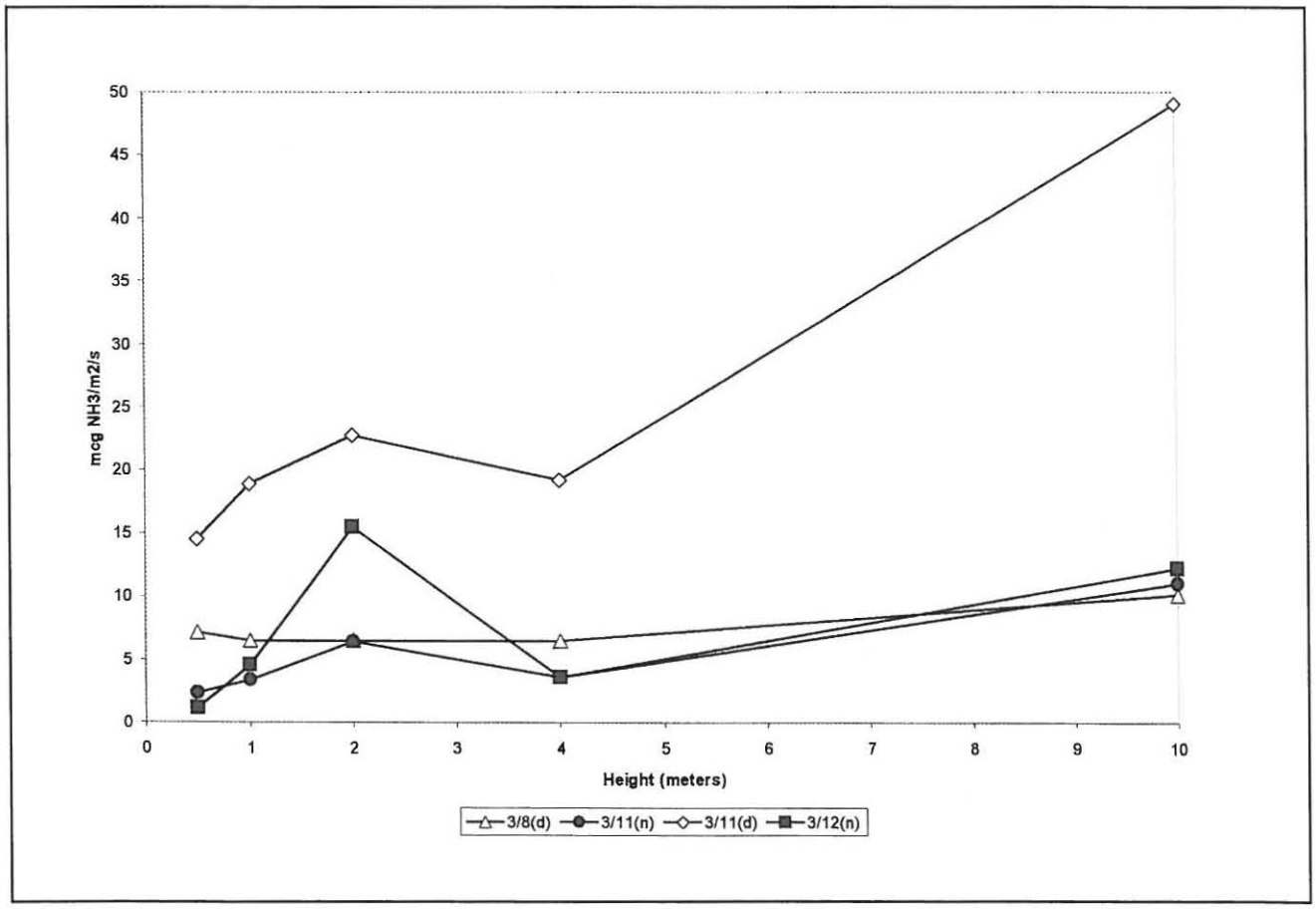

Figure 2. *Ammonia flux profiles over a barley crop just prior to cutting for silage. Plant height was about 1m. Daytime samples are designated by (d) in the legend and an open symbol on the graph. Night data is shown as (n) and a closed symbol.*

The barley was cut for dairy feed a few days after the dates shown in Figure 2. The field was immediately replanted to corn that emerged in late March. By the second week in April, the corn was about 30cm tall and beginning a period of rapid growth. The sampling system was set up at the same location as in the previous crop of barley.

The correlation of air temperature and diurnal conditions with NH_3 flux profiles was expected from the experiences of previous research. Additional data from another season and several other crops will, hopefully, improve the precision of the relationships shown above. The simultaneous NH_3

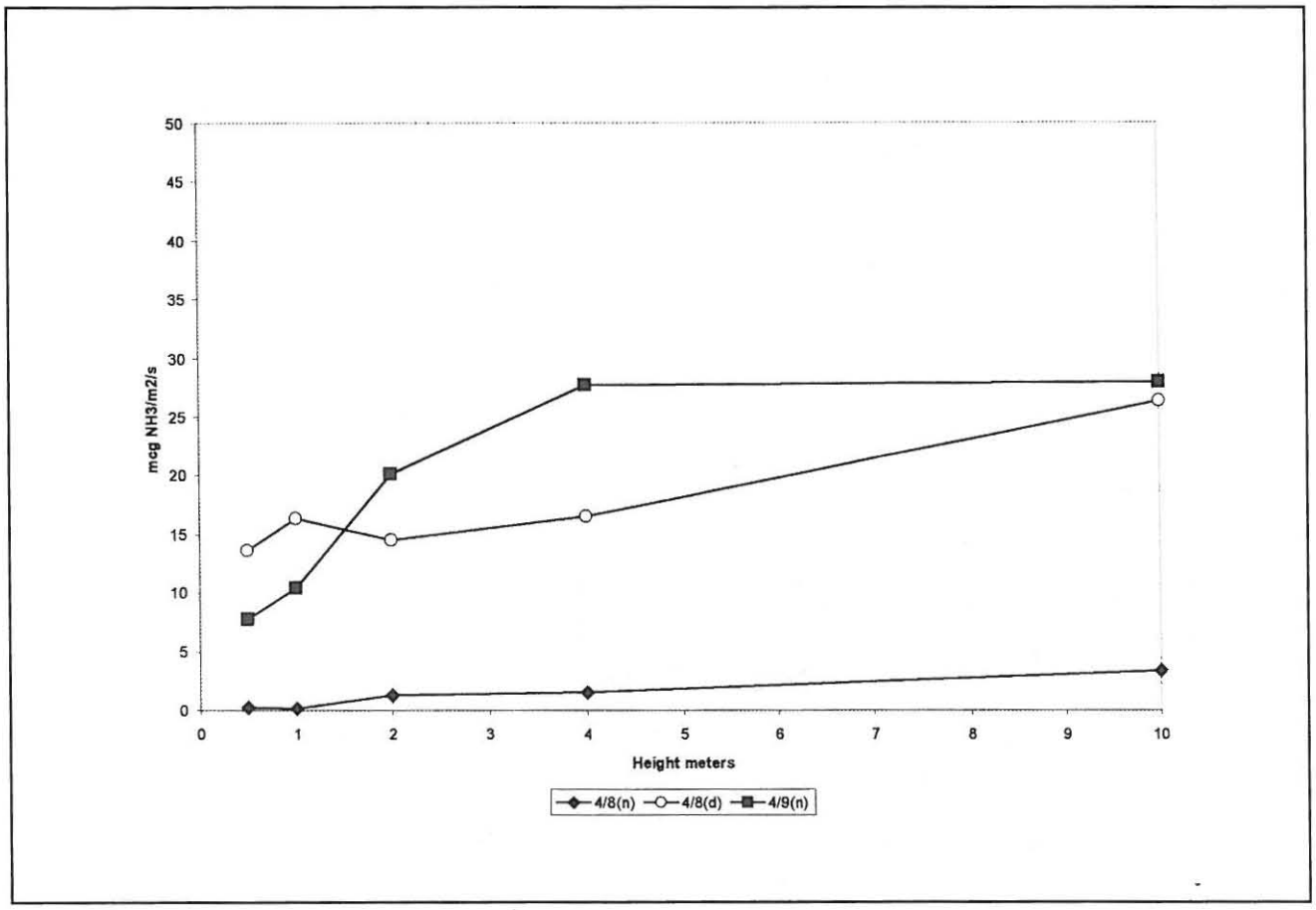

Figure 3. *Ammonia flux profiles from a silage corn crop following the barley crop in Figure 2. The plant height was about 40 cm. The sampling coincided with a fertilizer application and an irrigation.*

The diurnal differences seen in Figure 2 are also apparent for the April 8 day and night samples in Figure 3. The following night sample, April 9 shows higher flux values and a more pronounced profile than the previous day sample. A heavy application of composted manure was applied to the corn during the day on April 9. The application was followed by an irrigation. The combination of the broadcast compost and the applied water appears to have caused a considerable emission of NH_3 in the field. This pattern is consistent with other fertilizer applications monitored in the previous project of 1999-2000.

emissions and absorption by active vegetation that was suggested in Harper's research also appears to apply to the data collected for this study. Many of the flux profiles shown in the previous figures indicate a gradient of NH_3 from the atmosphere to the soil/vegetation surface. While the transport pathways in the microclimate from the surface up to 10m are likely to be complex and variable for different times of the day and season, it is possible to speculate that the vegetation is acting as a net absorber of NH_3 when the flux profile shows a steep gradient from the ambient atmosphere

toward the surface. Both Harper and Porter's work concluded absorption of NH_3 by the plant from the air was related to the amount of atmospheric NH_3 surrounding the plants. Harper[8] noted several factors that sometimes correlated with absorption but stated the concentration of NH_3 in the air was the most consistent factor affecting NH_3 absorption and found it would supersede the other factors. Atmospheric NH_3 concentrations found by Harper to result in measurable absorption were less than most of those monitored at10m in this study. The ability of a vegetation/soil community to both emit and absorb atmospheric NH_3 may be illustrated by data from another sampling location of this project. A dairy near Hanford was chosen for a series of ROG samples, though a variety of constituents including NH_3 were collected. A diagram of the dairy is shown in Figure 4.

The three sampling locations at the Flint Dairy were:

DW1 – upwind of the dairy's confined animal feeding operation (CAFO). The immediate fetch (400m) upwind from DW1 was a field planted to sorghum. The field was part of the Flint Dairy operation. There were fields of various permanent and annual crops for 3km upwind, at which point there were several other dairies.

DW2 – immediately downwind of the CAFO, along the edge of the main lagoon. The normal wind direction passed through the animal holding/feeding area, the milking barn, feed storage and effluent treatment screens and lagoons before reaching DW2.

DW3 – downwind of the CAFO across 300m of a field planted to the same sorghum crop as that upwind of DW1.

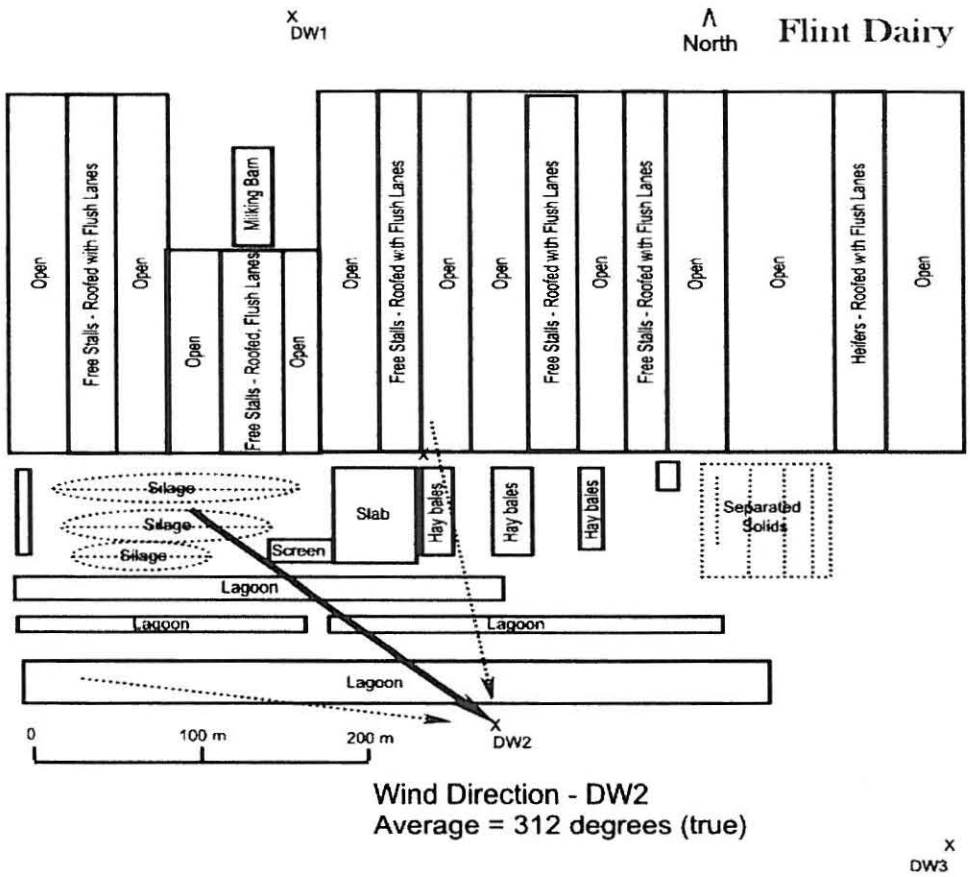

Figure 4. *Diagram of a dairy near Hanford, CA. Ammonia flux profiles were monitored at DW1, DW2 and DW3. The arrows show the typical wind direction (solid arrow) and variation (dotted arrows)*

The CAFO at the Flint Dairy was surrounded by fields planted with the sorghum crop described above. The crop was about a week past emergence (plant height = 10cm) when the sampling began on August 25. The sampling for NH_3 was continuous from that time until October 11 when the crop was harvested (plant height = 150cm) for silage. The averages of NH_3 flux profiles at each location, for the seven weeks that the crop was grown, are shown in Figure 5. Note the magnitude of the flux values on the "Y" axis of the graph. The ammonia levels associated with this CAFO can be an order of magnitude greater than that of the rangeland and field crops shown in Figures 1, 2 and 3. The sorghum crops surrounding the dairy are grown to feed the dairy herd. Effluent from the free-stall areas where the animals are fed is washed into the lagoons and used to fertilize and irrigate the surrounding crops. The nutrients in the effluent are recycled by harvesting the crops as feed for the animals

The NH_3 flux profile for the DW1 (upwind location) resembles those found for similar crops in central California. The sorghum is not unlike the barley and corn crops shown in Figures 2 and 3, and the flux profiles are similar in both magnitude and shape. The Lagoon sampling location, DW2, shows a significant increase in NH_3 magnitude, which is to be expected from the 2000 Holsteins located between the two sampling points. Most of the NH_3 is probably from catalysis of urea by urease in the soil of the free stall and open areas of the CAFO. It is also possible that some NH_3 emission comes from other areas of the dairy, but emission from the main lagoon is not indicated by the flux profile at DW2. The sampling site was located 5m from the down-wind edge of the lagoon. Any significant NH_3 emission from the lagoon should produce a positive flux gradient from the lowest sampling level toward the ambient atmosphere

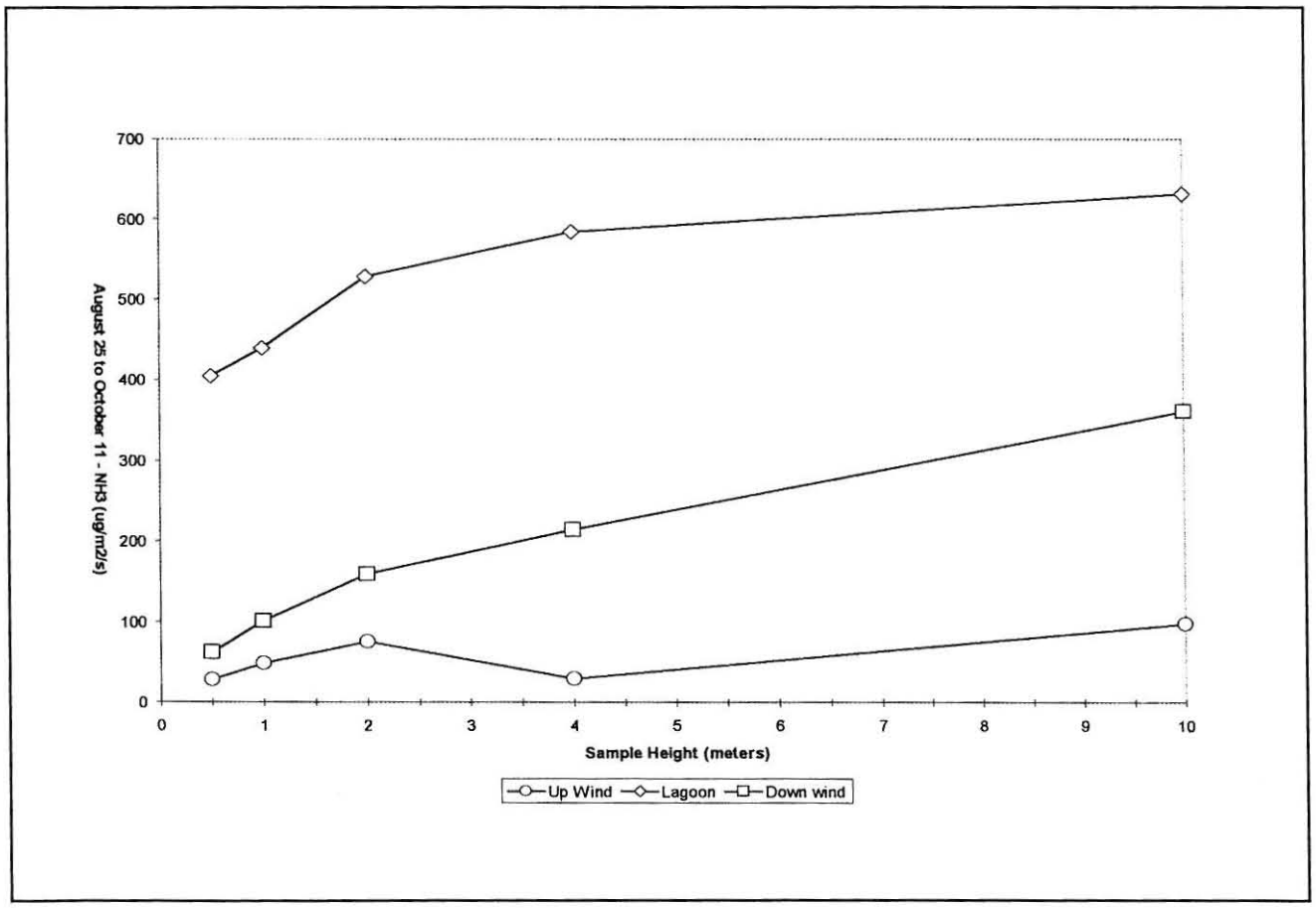

Figure 5. *Ammonia flux profiles from the dairy shown in Figure 4. This data is the average of continuous sampling from late August when the surrounding crops were planted until early October when the crops were harvested.*

sampled at 10m. The flux levels at 0.5m and 1.0m are about 2/3 of those at 4m and 10m. The short fetch across the 30m width of the lagoon is not likely to affect the flux at the higher sampling elevations but should influence the NH_3 concentration in the air at 1m and below. The fact that the surface fluxes are significantly less than those found higher may indicate the water at the surface of the lagoon is absorbing NH_3 emitted by the animals further upwind.

Absorption of NH_3 from the air by a surface across which the air passes may also be indicated by the NH_3 flux profile at DW3, the sampling site downwind from DW2. The typical wind direction as shown in Figure 4 is directly from DW2 to DW3. The primary influences on the NH_3 profile between those two points would be various dispersion mechanisms in the atmosphere and emission/absorption of NH_3 by the surface. The magnitude of the DW3 NH_3 flux at 10m is over six times greater than that sampled at 0.5m and the flux gradient is remarkably uniform with elevation. It would be difficult to suggest significant NH_3 emission took place as the air traveled 300m from DW2 to DW3. The NH_3 level at 10m decreases by about half between DW2 and DW3, due in part to atmospheric dispersion. The fluxes close to the surface, however, are nearly down to those monitored at the upwind site, DW1, which could be considered background. The surface over which the air passed from DW2 to DW3 was the sorghum crop. The high ambient NH_3 levels would, according to Harper, indicate the absorption of atmospheric NH_3 by the leaves of the vegetation. The strong flux gradient in Figure 5, at DW3, from the ambient atmosphere to the vegetation surface supports that indication.

Further sampling at these sites was done after the crops surrounding the dairy were harvested. The fields were disked after cutting and picking up the sorghum. The resulting

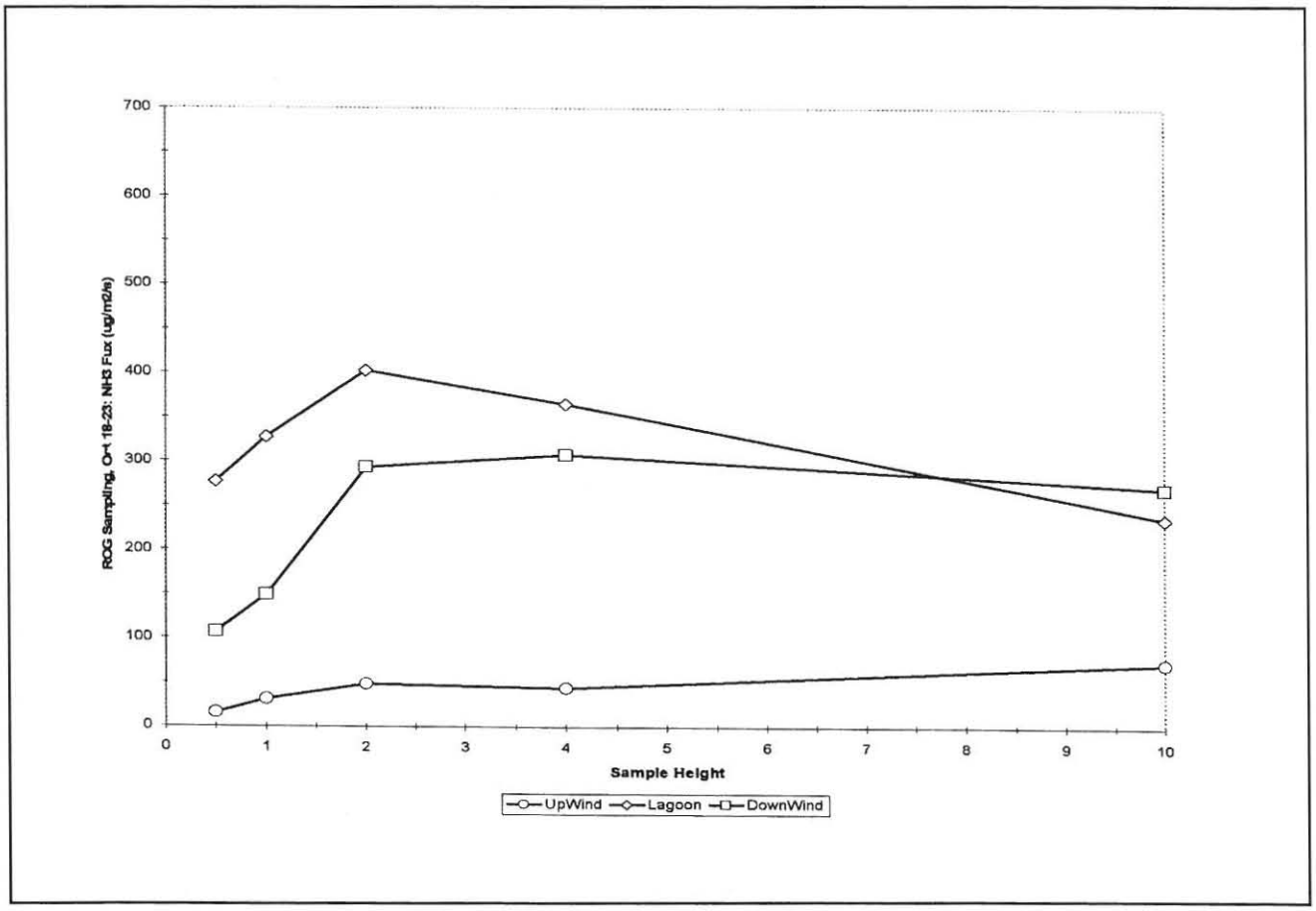

Figure 6. *Ammonia flux profiles associated with the dairy in Figure 4. These samples were taken after the sorghum crops surrounding the dairy were harvested. The fields were disked and the soil was dry.*

surface was relatively smooth and dry through the following sampling period from October 18 to 23. The field procedure was primarily designed to collect dairy ROG samples for this period. However, the NH_3 sampling systems were still in place to provide wind speed and direction data so denuders were also used to determine NH_3 profiles to compare with the ROG results. The NH_3 flux profiles for the three locations of this later sampling program are shown in Figure 6. The results of the NH_3 sampling can be compared with those shown in Figure 5 to evaluate the difference between flux profiles over a crop and profiles over bare soil.

The NH_3 data from this ROG sampling program is not precisely comparable to that from the previous seven weeks of sampling even though the locations and sampling equipment were the same. The ROG samples and corresponding NH_3 samples were taken during selected, 2-hour periods when the wind was consistently from the direction indicated in Figure 4 at a reasonably consistent speed. The data in Figure 6 was collected from mid-day through late evening on each of three days (October 18, 21 and 23). The flux profile differences between the sampling locations can still be evaluated and compared, in a general way, with those from the previous period when the crop was growing.

The flux profile at the upwind location, DW1, is very similar to that from the preceding several weeks. The field immediately upwind from DW1 was cut along with the others surrounding the dairy but most of the land upwind from that field still had active vegetation. It would appear that the presence or absence of a crop immediately upwind from the dairy had little effect on the upwind profile as long as there were other fields of vegetation further upwind. The lagoon flux profile was different from the average at DW2 during the previous seven weeks. The lower flux values at 10m may be due to the lower temperature in mid October compared to that of August and September in the area. The differences in sampling procedure may also have affected the measured profile at DW2 in Figure 6. The profile at DW3, across the harvested field from DW2 is similar in magnitude and characteristics to DW2. The DW3 flux profile was much closer to the background levels found at DW1 in the sampling during the crop season so it would appear the change from active vegetation to bare soil between DW2 and DW3 may have affected the profile. If NH_3 absorption by the growing crop had a significant effect on the profile at DW3 then that effect should have disappeared during the later sampling period shown in Figure 6, as it seems to have done. There is still a gradient toward the surface in both profiles below 2m that may indicate absorption by the lagoon surface as postulated from the data in Figure 5 and absorption by the soil surface between DW2 and DW3. Dry deposition of NH_3 on soil and other surfaces is a process that has been suggested in previous research. The soil surface between DW2 and DW3 may also be capable of NH_3 absorption but it appears that it is not as effective as an actively growing crop. A positive gradient of NH_3 fluxes from the surface to the atmosphere was expected in this data since the decomposition of the residue from the harvested crop should release considerable NH_3. The lack of that expected gradient is possibly due to the fact that the ROG sampling followed the harvest by only a week. The soil microbes require a period of time to respond to a change in environment such as that caused by harvest of the crop and so were not yet rapidly decomposing the residue.

CONCLUSIONS

No definite conclusions can be drawn from the data at this point in the study. A number of the initial assumptions appear to be on the way to confirmation and the significance of some others may be greater than was originally assumed. It certainly appears that atmospheric NH_3 is higher during the day compared to night. The increase in NH_3 emissions with higher air temperatures suggested by Harper and others is also consistent with the data collected in this research. The balance between NH_3 emissions and absorption, particularly in relation to actively growing vegetation is less clear. The characteristic shape of most flux profiles in this and the previous work done in the San Joaquin Valley suggests a net absorption of NH_3 near the surface. Knowledge of the N cycle, particularly for cultivated, fertilized crops would suggest there is a significant amount of NH_3 produced by soil microbes. The fate of the NH_3 produced in the soil is complex and not well documented but emission of a portion of it to the atmosphere is almost a certainty, as modeled by CASA. The intriguing suggestion, originally from Harper and others is the fact that NH_3 absorption by vegetation is as viable a fate for atmospheric NH_3 as is the hydrolysis by rain and dew, dry deposition, or the combination with NO_x and SO_x to form secondary PM2.5 particles.

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TEACH THE TEACHERS:

GARDEN-BASED EDUCATION ABOUT FERTILITY AND FERTILIZERS

Project Location:

Department of Horticulture/Plant and Soil Science
College of Agriculture
California State Polytechnic University, Pomona

Project Director:

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INTRODUCTION

In recent years, there has been a great deal of interest in integrating garden-based learning into K-12 classrooms, stimulated by former Superintendent of Instruction Delaine Eastin's call for "A Garden in Every School". The emphasis is on addressing the various curricular standards such as science, literature, social studies, nutrition, mathematics and art through garden-based curricula. Part of this effort involves the training of teachers in garden practices as well as curricular integration of these topics. In the rush to develop school gardens, the significant interplay of soil, water, nutrients, and pest management is often overlooked. To remedy this oversight, we proposed that a unit of instruction covering soil, water and irrigation, soil fertility, fertilizer materials, cover crops, use of compost, and integrated pest management, as well as the interrelationships of these factors, be included in ongoing teacher training in school gardens.

In addition, through our facility, AGRIscapes, an education and demonstration center for food, agriculture and the urban environment, we proposed to develop school field trip venues that would emphasize the resources that go into the production of our food and fiber, and allow children to observe these processes in an agricultural field setting.

The year 2003 is the third and final year of our FREP funding.

PROJECT OBJECTIVES

The objectives of this project are met within the context and framework of our existing Regional Support Center (RSC) for A Garden in Every School, as designated by the State Department of Education. In particular, the project objectives are integrated with the ongoing programs already established by the RSC such as our annual school gardening conference and resource fair, our hands-on intensive workshop series, and our communication vehicles such as a newsletter and website which are still undergoing development. The opening of AGRIscapes, in 2002, provided a site for additional teacher and student education.

1. Research and gather appropriate curricular materials for K-12 relating to soil science, plant nutrition, soil/water relations, and soil management.
2. Present workshop component on soils, fertility and soil/water relations.
3. Include presentations on these topics at annual conference.
4. Involve appropriate organizations in Teacher's Resource Faire at annual conference.
5. Include resources and information on website, in resource guide, and in newsletter.
6. Research, design, and implement field experiment stations for appropriate grade level(s) for hands-on demonstrations of the principals of soil science, plant nutrition, soil management, and soil/water relations to be installed at AGRIscapes.

PROJECT DESCRIPTION

In this third year of our project, we will have fully implemented the three components of our program: teacher training and resource development, development of field teaching stations, and offering of school field trips.

In Winter 2003, we developed our field teaching stations for use in our spring field trip series. Much of our efforts went into the Ecosystem Garden at AGRIscapes which provides a living laboratory of flowers, fruits, herbs, and vegetables to demonstrate to school children the resources and lifecycles that support the growing of useful plants. We also have established an area for composting, and have plans to build a vermicomposting bin, as well.

Our school field trip program for Spring 2003 took place from March through June. The field trips were designed to take students through 3 rotations: one emphasized good nutrition and 5-a-Day principles; the second focused on a specific crop (wheat or tree fruit crops), and the third reviewed the parts of plants that we eat, and the children made a simple snack with vegetables to reinforce this theme. Children also visited the Farm Store to discuss how food gets to our markets, and they planted seeds and plants to take home. Over 1100 children participated in the Spring 2003 field trips. Reservations are being taken for Fall 2003 field trips which will emphasize harvest themes and pumpkins.

In Summer 2003, in collaboration with science education faculty in the College of Science at Cal Poly Pomona, we offered workshops to middle school science teachers on topics related to agriculture and plant science themes. These included an introduction to soil science; insect taxonomy and ecology; bee science; tissue culture; hydroponics; California native plants; and an introduction to plant biotechnology. These one and two day workshops were developed to enrich the science teachers' abilities to apply life and physical science principles to real-world settings in the garden or school grounds. Forty-five teachers participated in this three-week program.

In Fall 2003, plans are being developed for our third School Gardens Conference which will offer speakers, workshops, and exhibits on the techniques and resources needed to successfully integrate a school garden into the classroom. One workshop will specifically focus on how to improve the fertility and tilth of soil in the development of the garden site. We will also be offering two one-day workshops for teachers this fall, one on teaching nutrition in the garden and the other on how to establish a school garden where one does not currently exist.

RESULTS & CONCLUSIONS

While we have been involved in teacher training since 1999 and the design and building of AGRIscapes since 2000, the year 2003 is when all of the pieces came together to realize our goal of becoming a unique resource for teachers and schools in our area for agricultural literacy and garden-based education. The visibility of our project opens up partnership opportunities both on- and off-campus, such as our collaboration with College of Science for teacher training.

Our school field trip programs have been very well-received by teachers, parents, and children. Not only do children get exposure to the themes we described above, but for many it is an introduction to a college campus. For children from lower socio-economic communities, a chance to come out to the "fresh air and wide-open spaces" at AGRIscapes was a real treat.

The development of AGRIscapes and its exhibits and demonstration gardens is an ongoing process. With seasonal changes and new projects, we will continue to increase the ways we can teach the themes we address. Also ongoing is our grant writing and other fundraising activities to support our efforts.

The three years of funding from the FREP grant has been of great assistance in helping us achieve our goals and we are very appreciative of this investment in our work.

LOCATION OF POTASSIUM-FIXING SOILS IN THE SAN JOAQUIN VALLEY AND A NEW, PRACTICAL SOIL K TEST PROCEDURE

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OBJECTIVES

1. Predict soil K-fixation from soil texture and mineralogy as inferred from soil surveys.

2. Test K extraction methods for predicting K-fixation capacity on soils collected from the San Joaquin Valley.

Results of this project and a recommendation for soil testing will be made available to agricultural laboratories, crop advisors, fertilizer suppliers, and cotton growers in the San Joaquin Valley.

Funding for this project is being provided by the CDFA FREP and the California State Support Committee of Cotton, Inc.

OBJECTIVES & ACTIVITIES IN 2003

1. *Collect soil samples from additional sites and carry out laboratory characterizations.*

Based on observations by UCCE farm advisors and Dr. Bob Hutmacher in August 2002, sites were identified for soil sampling and were sampled in September 2003 when visual symptoms of K deficiency or late decline were present. Sites visited are in western Merced County near Firebaugh and the Waukena and Tulare areas of Tulare County and near Corcoran in Kings County .

2. *Conduct K fixation tests using shorter (1 hour and 24 hour) incubation periods.*

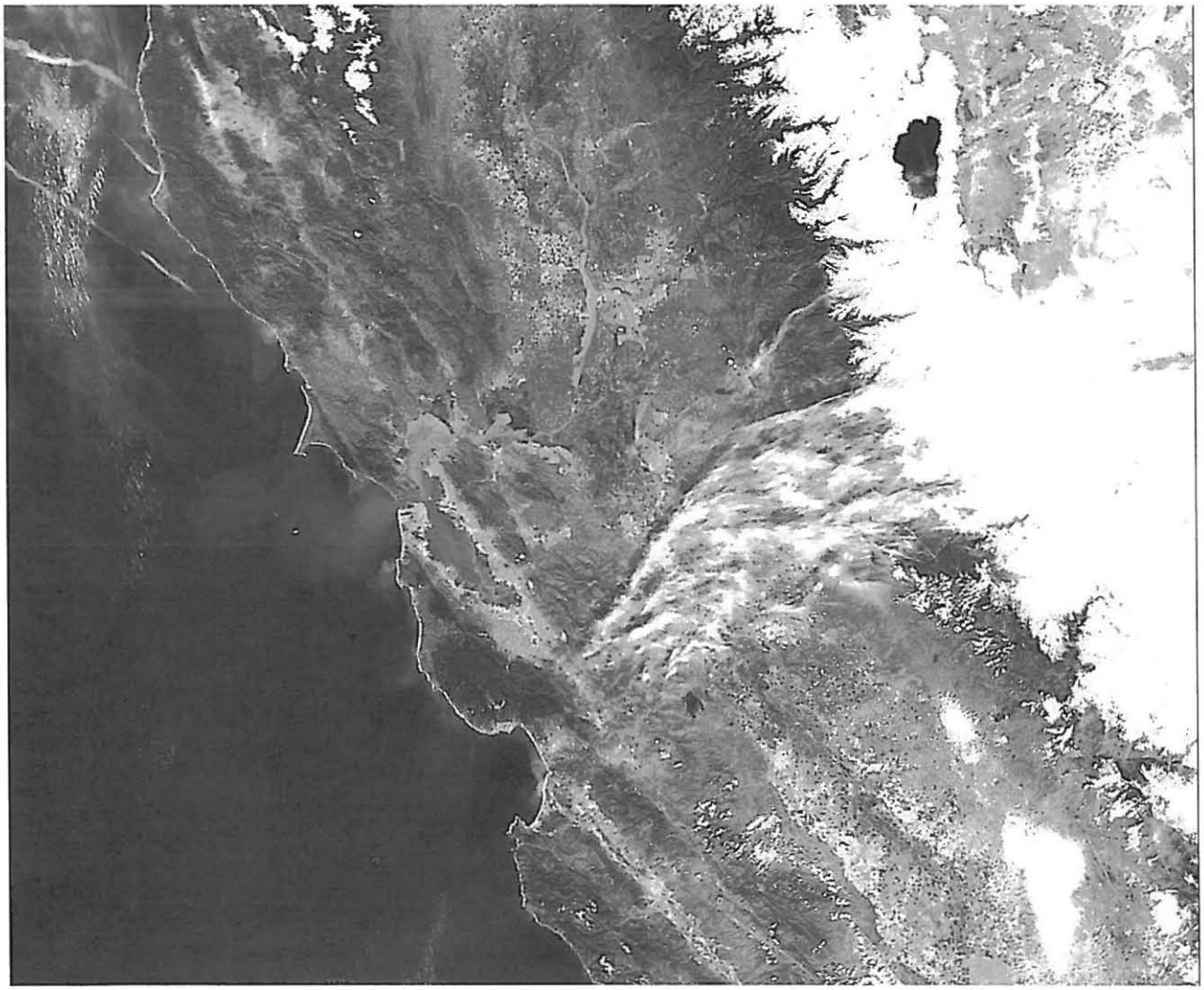
In 2001-2002, we examined use of a sodium-tetraphenyl boron ($NaBPh_4$) procedure for measuring soil K fixation and as a possible alternative to the simple, but time-consuming K sorption method of Cassman et al. The $NaBPh_4$ measures some unknown but significant fraction of fixed K. Our research shows that in soils with low available K levels, the test is not sensitive to variations in K fixation capacity. We are instead using a sorption method (in 18 mM K) with a one-hour incubation period vs. the 7-day incubation used by Cassman et al.

3. *Update our GIS map showing the location of K fixing soils within the San Joaquin Valley and cotton growing areas.*

Our two main findings so far are that (1) Soil K fixation capacity of soils derived from Coast Range parent materials is either negative (i.e., samples release K into the 18 mM K solution) or very low, while K fixation capacity of soils derived from Sierra Nevadan parent material ranges from negative to high; and (2) Soil texture (clay or sand content) shows no significant relationship to K fixation potential within the Sierra Nevada-derived soils, using either a depth weighted average of K fix value or when soil A horizon values (which are affected more by fertilizer and manure inputs) are excluded.

DISCUSSION

Conversations with UCCE farm advisors and growers indicate that K deficiency in cotton tends to occur more often on sandier soils, but this is not supported by our laboratory studies. We hypothesize that soil age and vermiculite content determine K fixation potential. We are exploring the possibility of using information other than texture to identify soils that potentially fix K, such as geomorphic . surface age, landform category, or parent material, as described in the soil series narrative description. In early fall, we will collect soil from six soil profiles from a chronosequence of land surfaces in the eastern Fresno area soil survey. This will help us identify the eastern boundary of the area with K-fixing soils



The Central Valley, spring 1999. Light rectangles are tilled fields. NASA photograph.

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

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INTRODUCTION

Intensive use of agrochemicals has been recognized as a major source of surface and groundwater deterioration and associated ecological problems worldwide. Nitrate is of particular interest due to its widespread use, high mobility, and persistence. Agricultural growth in the San Joaquin Valley of California has led to not only increased demand for groundwater, but also groundwater pollution by intensive use of nitrate. Driven in part by pollution prevention measures, estimation of N budget under particular crop/fertilizer scenarios has been widely used to determine N cycling and to assess risks from potential nitrate leaching to groundwater. Most existing applications focus exclusively on the upper soil (30 cm) or the immediate root zone and assume that N processes are insignificant below the soil profile and that nitrate losses from the root zone represent the amount of nitrate leaching to groundwater. Using these methods for risk analysis of groundwater contamination may not be appropriate in many agricultural areas of Central and Southern California due to a large depth to water table (e.g., 30- 100 ft).

While much attention is now given to the groundwater quality of the Valley, the mechanisms governing the fate and transport of nitrate below the root zone are still poorly understood, yet essential for a proper assessment of the long-term impact of agricultural management practices on groundwater quality. Field scale spatial variability of soil hydraulic properties and its impact of nitrate transport in the deep vadose zone still remain unaccounted for in most groundwater quality assessment studies. In many areas of the Valley, the deep vadose zone is a critical link between agricultural nitrate sources and groundwater, and plays an essential role for the development of nutrient management protocols.

OBJECTIVES

The major objective 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.

DESCRIPTION

The Kearney site is a former orchard of Fantasia nectarine trees at the University of California Kearney Agricultural Center, in Fresno, California. A 12-year fertilizer management experiment (1982-1994) was conducted at the site with five alternative N practices ranging from 0 to 325 lb/ac/yr. The orchard was divided into 14 subplots, each consisting of five trees in a row and treated by a random design of fertilizer application rates. Except 0 lb/ac/yr treatment (replicated twice), all treatments had three replicates. In 1997, three subplots with the 0, 100, and 325 lb/ac/yr treatments (named "control", "standard" and "high" treatment, respectively) were selected for detailed sampling and intensive data analysis. 60 undisturbed soil cores were drilled with a direct-push drilling technique to a depth of 52 ft (~15.8 m). More than 1,000 soil samples were taken based on a complete sedimentologic description in the field. Over 100 undisturbed samples were extracted and grouped by core scale sedimentary characteristics. They were used in multi-step outflow experiment in conjunction with inverse modeling to determine unsaturated hydraulic conductivity and soil water retention functions in the form of Van Genuchten models. The site database has been completed and includes the detailed description of soil hydraulic properties (e.g., K(h), q(h), grain size distribution, soil moisture) and biochemical properties (e.g., , OM, OC, pH, and 15N isotope).

Our project is closely integrated with a previous project (funded by FREP and other grants) conducted at UC Davis and the Kearney Agricultural Center, under the supervision of the PIs Harter, Hopmans and Horwath. Michelle Denton, a graduate student at UC Davis, implemented an extensive analysis of soil hydraulic properties and employed the scaling method which is a physically based averaging or upscaling to assess the degree of spatial variability in hydraulic soil properties. At the beginning of 2002, upon the completion of the previous project, we assembled the outcomes of the field and laboratory analysis of soil core data and additional site data (e.g., climate data, fertilizer and irrigation applications throughout the experiment). The comprehensive database is the basis for developing modeling strategies to study the fate and transport of nitrate in the vadose zone.

To capture important characteristics of the data, we evaluated basic statistics of all soil core data, of both, the ensemble data set and categorized by treatments. We implemented advance geostatistical methods to explore the spatial continuity of nitrate (aqueous-based concentrations) and soil moisture data at each subplot. We computed directional experimental variograms and incorporated the results into geostatistical kriging to create three-dimensional maps of nitrate concentrations and water content in the vadose zone and to estimate the residual NO3- in the vadose zone at each subplot.

Given the heterogeneous and variable nature of our project, our goal is to provide the needed versatility for a wide range of modeling approaches and to offer insight into the uncertainty in predictions of nitrate flux to groundwater. In the first stage of our modeling efforts, we compared the three fertilizer practices (0, 100, and 325 lb/ac/yr) by performing a field scale subsurface nitrate budget and nitrate leaching study to groundwater. We employed two methods: a root zone mass balance (MB) approach and a geostatistical estimation technique. The former is a simplified conceptualization of root zone nitrogen processes and follows the traditional assumption that the amount of residual N in the root zone is the long term annual N leaching below the root zone. The second method accounts for the variability of N throughout the profile and is a more robust alternative to the former method.

Following our leading hypothesis that spatial heterogeneity of soil hydraulic properties can vary significantly with the major stratigraphic units, we examined the correlations between the major stratigraphic units (facies), and soil hydraulic properties (van Genuchten parameters) by analysis of variance (ANOVA). Subsequently, Post Hoc Turkey HSD comparison technique was used to elucidate significant differences for the van Genuchten parameters between the facies. We have recently performed an averaging procedure to obtain effective Van Genuchten parameters corresponding to each layer using a least square optimization.

RESULTS & FUTURE WORK

The textural groups identified in the borehole range from clay, clayey paleosol hardpans to a wide range of silt and sand, occasionally coarse sand and gravel sediments, primarily showing evidence of unconsolidated sediments deposited on a stream-dominated alluvial fan. Nine major stratigraphic units, referred to as facies, were identified in the boreholes. The facies exhibit vertically varying thicknesses, yet are laterally continuous over the experimental site. Both saturated hydraulic conductivity and nitrate are lognormally distributed, varying over several orders of magnitude, while water content data follow an approximately normal distribution. A close examination of the data indicates no spatial trends in nitrate. In contrast to the nitrate dataset, water content at three subplots was characterized by a significant increase with depth. Nitrate concentrations, while subject to a large spatial variability, nonetheless exhibit a statistically significant spatial continuity in the vertical direction. Variograms of trend-adjusted water content residuals indicate a predominantly horizontal layering. In the highly stratified sediment texture dominating the deep vadose zone at the site, such layered feature of soil moisture is expected.

As part of the root zone MB approach, we determined that under uniform flow conditions in the vadose zone, it would take approximately five years for nitrate to travel to groundwater and the resulting N mass in the deep vadose zone (excluding the root zone) would be 60, 240, 925 lb/ac for the control, standard and high subplots, respectively. With the exception of the control plot, the kriged (measured) total N masses are only a fraction of those estimated from the MB method (43, 33 and 79 lb/ac).

The presence of strongly heterogeneous geologic formations at the site, log-normally distributed nitrate concentrations and soil hydraulic properties all suggest that highly heterogeneous (i.e., log-normally distributed) flux conditions are prevalent at the site. The incidence of log normally distributed velocities further suggests that stagnant flow zones occupy a majority of the active flow zone with low flow rates, possibly causing a partial denitrification. On the other hand, highly variable flux conditions generate preferential flow paths that rapidly carry a large portion of nitrate to significant depths and to groundwater during storm events (irrigation and rainfall). Nitrate subject to rapid movement to groundwater would be mostly "invisible" to the nitrate profiles obtained in our field cores, thus explain the difference between the N losses estimated from the mass balance method and the N mass in the deep vadose zone determined from geostatistical analysis.

In the application of ANOVA, we showed that a facies-based approach provides a good basis to conceptualize subsurface heterogeneity, revealing the impact of layered system on flow parameters. Both ANOVA and pairwise comparisons suggest that facies bounding surfaces tend to separate regions with different soil hydraulic properties. This result is fundamental for our modeling efforts.

Currently, we are implementing a detailed stochastic flow and nitrate transport modeling that will build upon the site database to test the hypothesis that highly heterogeneous flow conditions control N distribution and flux to groundwater. If the hypothesis is confirmed, our findings will ensure that the deep vadose zone is relatively low in N content when compared to uniform vertical flow conditions. This will then explain the relatively small amounts of N observed in the vadose zone. Furthermore, our models will address whether, in the absence of measured data of N, traditional root zone MB significantly overestimate both the travel time of nitrate and the amounts of nitrate accumulation in the vadose zone.

DEVELOPMENT OF LIME RECOMMENDATIONS FOR CALIFORNIA SOILS

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EXECUTIVE SUMMARY

Increasingly acid soils have been noted by agronomists and soil testing laboratories on soils of northern and central California. These soils tend to be moderately to highly weathered or poorly buffered and acidified through nitrogen fertilization. Acidity levels below 5.60 are sufficient to impact crop growth and quality, dependent on the crop. Current lime recommendations for California are based on calibration models developed in the eastern United States on soils of distinctly different parent material and growing conditions.

This project will develop lime requirement calibration models for California soils based on six standard laboratory test methods using 120 California soils selected from the San Joaquin Valley, North Coast and Sacramento Valleys of California. Soils will be selected from vineyards, tree crop, forage and row crop areas, where low pH values have been noted by commercial testing laboratories and agricultural consultants. Soils will be characterized for chemical and physical properties and the lime requirement assessed using greenhouse equilibration. All soil analysis will be conducted using California testing laboratories. Models developed will be validated using a second set of 20 soils in 2004.

RESULTS

Beginning in the spring of 2002, 121 soils were collected from across California representing agricultural soils from fields in Amador, Butte, El Dorado, Fresno, Kings, Kern, Madera, Merced, Monterey, Napa, Sacramento, Santa Clara, San Joaquin, San Luis Obispo, Sonoma, Stanislaus, Sutter, Tulare, and Yuba Counties. At each site information was collected on the GPS location, soil series, (if known), method of irrigation, crop, moisture status, and grower farm. Sites included fields planted to lettuce, lemon, heather, pistachio, watermelon, almond, tomato, onion, squash, potato, rice, grapes, pasture and corn crops. Soils were

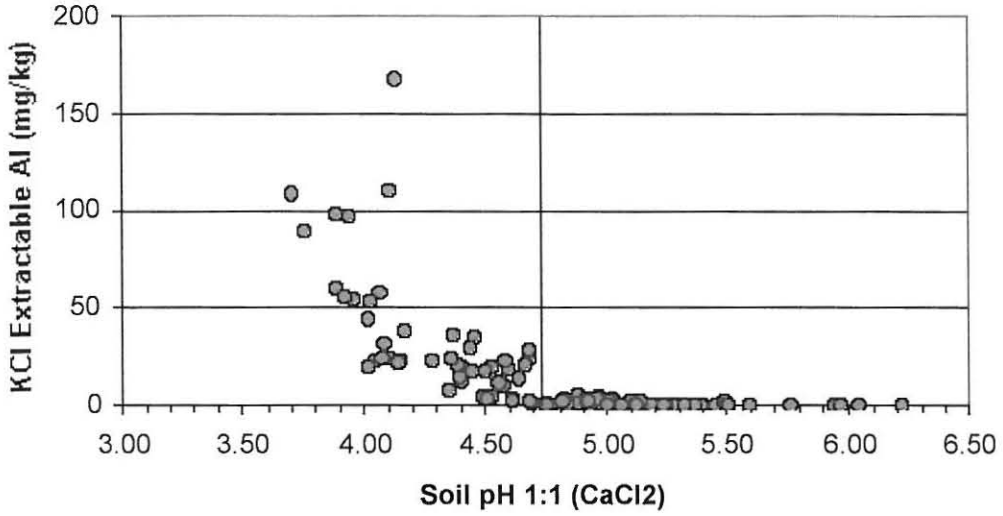

Figure 1. *Relationship of soil pH 1:1 (CaCl2) and KCl extractable Al for ninety-eight soils collected from central and northern California in 2002.*

collected by field men, Ag consultants, and UC personnel. Collection of soils were delayed to late 2002 due to scheduling problems, securing prospective sites, and locating new potential sites.

Of the soils collected, twenty-three had initial pH by the 1:1 method that exceeded 6.70. The remaining 98 soils were analyzed for pH by the 1:1 salt method; pH saturated paste method; saturated paste moisture content; saturated paste EC; KCl extractable Al; ammonium acetate extractable K, Ca, Mg, and Na; DTPA extractable Zn, Mn, Fe and Cu; and sand silt and clay contents. Soil pH 1:1 using the CaCl2 method indicates eight soils had a pH less than 4.0, 39 of the soils collected had a pH less of 4.5 to 5.0, 45 had a pH in the range of 5.0 to 6.0 and three with a pH between 6.0 and 6.3. Results for soil KCl extractable Al, an indicator of strongly acid soils, values indicated eight soils have Al values exceeding 100 mg/kg, 26 soils in the range of 20 - 100 mg/kg Al, 37 soils with 1 - 20 mg/kg Al, and the remainder having concentrations less than 1.00 gm/kg Al. Plotting pH 1:1 CaCl2 against Al content indicates that Al concentrations become significant (> 2 mg/kg) once pH reaches 4.75, and is highly soil dependent, Figure 1. Eighty percent of the soils had an EC, based on the saturated past method of less than 1.00. Fifteen percent of the collected soils contained less than 100 mg/kg extractable K, 35% in the range of 100 - 150 mg/kg and the remainder more than 150 mg/g of K.

Soils for the pH Liming project are currently being evaluated for total exchangeable acidity (TEA) and CEC. Soil buffer pH work will be progressing in the fall of 2003 at Dellavalle Laboratories using six reference methods: SMP Buffer pH; Modified SMP Buffer; Adams-Evans Buffer; Mehlich Buffer; Woodruff Buffer; and the Kissel method being developed at the University of Georgia, by Dr. David Kissel and associates. The Modified SMP buffer is based on the procedure developed at Servi-Tech Laboratories, Dodge City, Kansas for weakly buffered soils. The Kissel method is based on a two point titration using dilute Calcium Hydroxide in a 0.01 M CaCl2 matrix. This method has shown promise in evaluating soils of the Southeastern United States for liming requirements.

Liming studies will commence in late 2003. Calcium Carbonate will be applied at five rates ranging from 250 lbs/ac to 10000 lbs per acre using to 1.2 kg of soil and equilibrated for 60 days, under greenhouse conditions.

Sims, T.J. 1996, Liming Requirements. Ed Sparks, et el. In: Methods of Soil Analysis, Part 3 Chemical Methods. pp 491-517.

COMPLETED PROJECTS

The following is a list of FREP projects completed prior to October 2003. Summaries of many of these projects appear in the 2001 and 2002 FREP Conference Proceedings. Previous conference proceedings and final project reports are available by calling FREP at (916) 445-0444.

FRUIT/NUT & 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 & 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 & 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 & Becky Westerdahl

Relationship between Fertilization and Pistachio Diseases
Themis J. Michailides

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 & 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 & Richard Smith

On-Farm Demonstration and Education to Improve Fertilizer Management
Danyal Kasapligil, Eric Overeem & 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 & Paul Robins

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

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 & Robert Travis

Nitrogen Budget in California Cotton Cropping Systems
William Rains, Robert Travis & 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 & 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 & Charles Sanchez

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

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

HORTICULTURE CROPS

Development of Fertilization and Irrigation Practices for Commercial Nurseries
Richard Evans

IRRIGATION & 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 & Victor Gibeault

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

EDUCATIONAL/ MISCELLANEOUS

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

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

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

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

Education through Radio
Patrick Cavanaugh

Integrating Agriculture and Fertilizer Education into California's Science Framework Curriculum
Mark Linder & 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 & Eric Zilbert

Irrigation & Nutrient Management Conference & 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 & Teresa Winovitch

EDUCATIONAL VIDEOS

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

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

PEER REVIEWED PUBLICATIONS OF CDFA FREP-SPONSORED PROJECTS

Patrick Brown, UC Davis, Department of Pomology

Rosecrance, R.C., S.A. Weinbaum, and P.H. Brown. 1996. Assessment of nitrogen, phosphorus, and potassium uptake capacity and root growth in mature alternate-bearing pistachio (Pistacia vera) trees. Tree Physiology 16:949-956.

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Marita Cantwell, UC Davis, Department of Vegetable Crops

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Larry Godfrey, UC Davis, Department of Entomology

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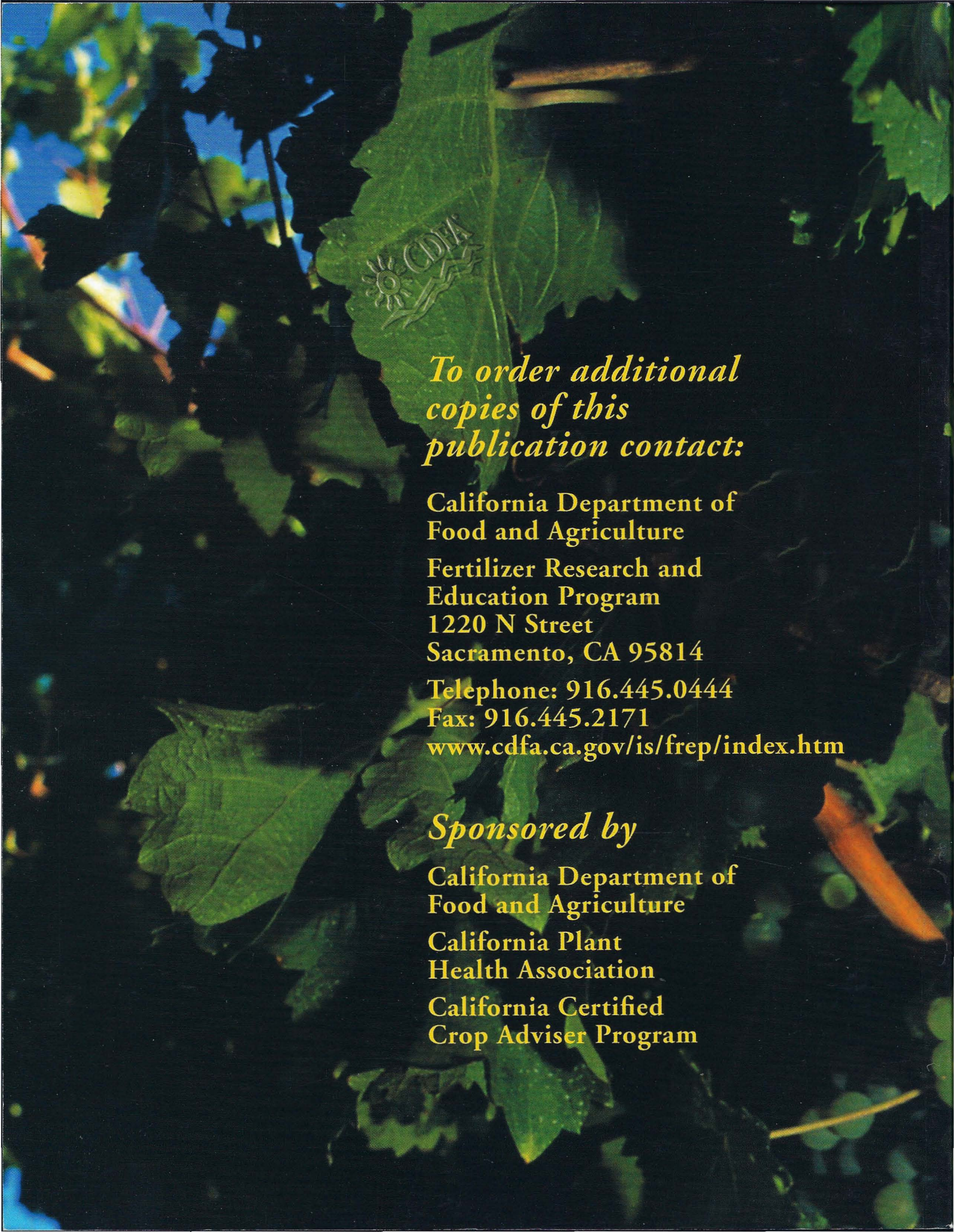

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