CALIFORNIA DEPARTMENT OF FOOD AND AGRICULTURE
FERTILIZER RESEARCH AND EDUCATION PROGRAM (FREP)

FINAL REPORT

Project Title: Site-Specific Variable Rate Fertilizer Application in Rice and Sugar Beets CDFA

Contract Number: 00-0505

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Objectives

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

1. For specialty rice, determine whether the spatial distribution of crop nitrogen demand can be forecast with sufficient precision on a site-specific basis using aerial photographs, yield monitor data, or other data readily obtainable by the farmer.

2. If the spatial distribution of crop nitrogen demand can be forecast for specialty rice can be adequately forecast for rice, determine whether the improvement in quality and/or yield is sufficient to offset the increased cost of the variable rate technology.

3. For sugar beets, determine whether crop nitrogen demand can be forecast with sufficient precision using electrical conductivity, soil texture, remotely sensed images from the previous crop, or other available data.

4. If the spatial distribution of crop nitrogen demand can be forecast for sugar beets can be adequately forecast for rice, determine whether the improvement in quality and/or yield is sufficient to offset the increased cost of the variable rate technology.

5. If economically justified, develop a set of practices for implementing variable rate nitrogen application on these crops. Produce a bulletin or technical manual on variable rate nitrogen application. We will target this manual to fertilizer companies, precision ag companies, and growers.

Executive Summary

A previous research project by the first two investigators, supported by the Fertilizer Research and Education Program, initiated university research on site-specific crop management in California. This project identified three criteria necessary for site-specific crop management to be adopted by growers. These are: (1) that sufficient variability exist in field properties or environment to cause significant spatial variability in economic yield, (2) that these properties are capable of being identified and measured, and (3) that management actions are possible that respond to this variability to increase economic yield. The initial research focused on establishing the first two of these criteria. The present project will focus on the third by establishing site-specific fertilizer management strategies through the use of variable-rate application technology.

In this research project we will focus on nitrogen management. To maximize its economic utility and prospects for rapid adoption and impact, an initial variable-rate nitrogen management research program should focus on systems for which a substantial economic advantage accrues to the use of site-specific management. Maximum economic payoff is obtained in those crops for which there is a relatively large economic penalty for both under- and over-fertilization and a relatively narrow range of optimal fertilizer rates. We have selected as two such crops: specialty rice (Koshihikari and Akitakomashi) and sugar beets. For both of these crops the primary economic penalty associated with over-fertilization is in quality reduction. In the case of specialty rice, increases in nitrogen levels have been identified with increased protein content, which in turn has been associated with poor flavor. In the case of sugar beets high levels of soil nitrate are associated with reduced sugar concentration. In both crops the factor causing a reduction in quality is readily quantifiable and therefore subject to rigorous experimental analysis.

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 (Lowenberg-DeBoer and Swinton, 1997). Much of the work in the upper Midwest has been motivated by regulatory concerns associated with potential contamination of ground and surface waters. Variable rate nitrogen application offers the potential for increasing profitability and reducing environmental effects of crop production.

To maximize its economic utility and prospects for rapid adoption and impact, an initial variable-rate nitrogen management research program should focus on systems for which a substantial economic advantage accrues to the use of site-specific management. Maximum economic payoff is obtained in those crops for which there is a relatively large economic penalty for both under- and over-fertilization and a relatively narrow range of optimal fertilizer rates. Two crops that meet these criteria are specialty rice (Koshihikari and Akitakomashi) and sugar beets. For both of these crops the primary economic penalty associated with over-fertilization is in quality reduction. In the case of specialty rice, increases in nitrogen levels have been identified with increased protein content, which in turn has been associated with poor flavor. Research carried out by R. Mutters and reported in the Annual Report: Comprehensive Rice Research (1997, pp 31-32,) documents this effect. In the case of sugar beets high levels of soil nitrate are associated with reduced sugar concentration (Kaffka et al., 1999). In both crops the factor causing a reduction in quality is readily quantifiable and therefore subject to rigorous experimental analysis.

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. Nitrogen influences yield quality through plant nitrogen concentration, which is in turn determined by native soil available N and applied fertilizer N. The first phase of the project will be to establish on a firm and widely applicable basis the relationships between yield quality and level of plant N, and between plant N and a measurable indicator of soil available nitrogen level. Preliminary analyses indicate that for sugar beets electrical conductivity may be reliably associated with soil N level. The relationship between soil N level and quality is confounded by the potential crop yield, which partially determines N uptake rates. The second part of the research project will be concerned with development of variable-rate nitrogen application strategies. These strategies will be based on prescriptions for application rate developed in a GIS using a nitrogen budget. We will base this budget on guidelines developed in the first phase of the project, taking into account yield potential as a function of soil properties. We will test these VRT strategies using replicated field trials in which one treatment is uniform N application, the second treatment is VRT N application, and the third treatment is an untreated control. We will use the economic analysis methods of Loewenberg-DeBoer and Swinton (1997) to determine the economic returns of precision N application.

2000-2001 Workplan

Task 1. Field Data Collection in Sugar Beet Crop

Month of initiation: 9/00
Month of completion: 6/01

Sub Task 1.1. *Lay out the experiment. Plots will be located at two sites (Imperial Valley and Kings County) that have been the subject of study for several years. Soil and plant samples will be collected from the fields along transects that pass down the plot rows. Sample point latitude and longitude will be determined with a mobile GPS unit. Soil samples (0-20 and 20-40 cm) will be collected just prior to irrigation and analyzed for nitrate, EC_e, SAR, SP, and NO_3-N. Petiole samples for N analysis will be collected at 5 growth stages. Weed ratings and stand density counts will also be recorded. Completion 9/01*

The field work for the Imperial County trial in Rutherford has been completed. The trial had two N rates crossed with a gypsum - no gypsum treatment. Harvest took place in May and data analysis is beginning.

Sub-Task 1.2 *Lay out nitrogen rate trials. Fixed N rate plots will be applied by the grower using standard equipment. Variable rate trial will be applied by Precision Farming Enterprises based on existing soil and yield data.*

The N rate trial has been established in El Nido, Merced County. The crop has been planted and the treatment locations have been laid out. The N treatments will be applied at side dress.

Sub Task 1.3. *Aerial photographs will be taken three times by W.E. Wildman, Davis CA, or an equivalent service if he is unavailable, with color-infrared 70-mm emulsion film.*

Aerial photography has been completed by OKSI Inc. Analysis of the data is underway.

Sub Task 1.4. *Take leaf tissue analysis at same locations (as determined by GPS) as soil samples. Leaf tissue to be analyzed for petiole N levels.*

Data has been collected and analysis is in progress.

Sub Task 1.5. *Sugar beet yield will be mapped by Precision Farming Enterprises. Progress report and invoice to FREP. Completion 6/01 in Imperial Valley, 9/01 in Central Valley*.

This has been completed in the Imperial County trial.

Task 2. Field Data Collection in Rice Crop
Month of initiation: 4/01
Month of completion: 9/01

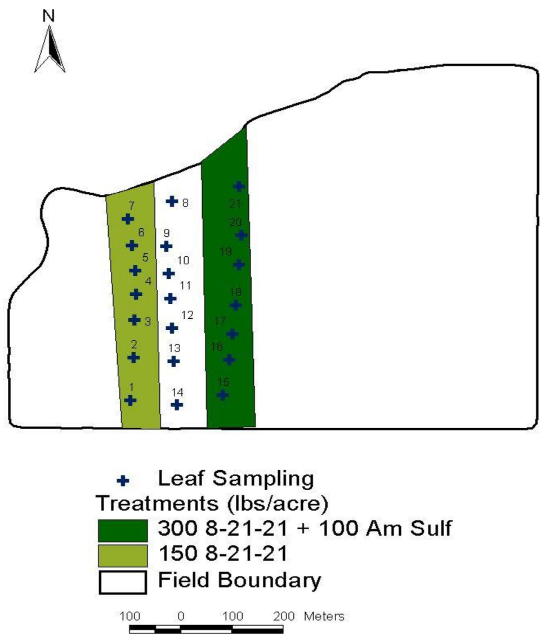
Sub Task 2.1. *Design experiment in rice fields. Experimental design will be similar to that of Sub Task 1.1: randomized complete block with four treatments consisting of control, two fixed N rates, and one variable N rate. Plots will run the length of the field with width being determined by the width of the fertilizer application equipment. Take soil samples along center of plots.*

Experimental plots were been laid out in three cooperators fields: Mathews Farm in Marysville, Gorrill Ranch in Nelson, and Schohr Ranch in Gridley. The Mathews Farm is in Koshihikari, the Gorrill Ranch is in Akitakomashi, and the Schohr Ranch is in M202, a standard variety. This enables us to detect a variety effect which should allow us to extend our results to standard California varieties more easily.

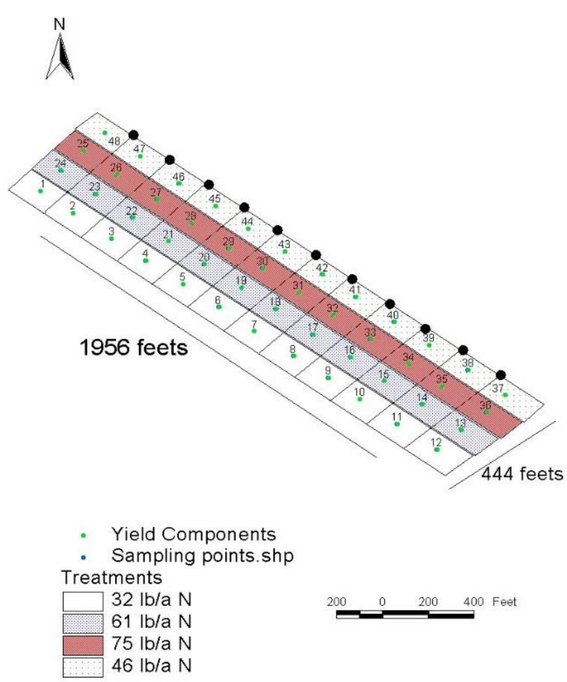
The experimental design had to be modified somewhat from that laid out in the proposal. All cooperators were unwilling to apply fertilizer in a pattern whose complexity was that of a randomized block design. Therefore we specified an unreplicated experiment in which experimental variability will be measured by recording yield within each plot using a yield monitor, Statistical analysis will be carried out using regression rather than ANOVA.

Sub Task 2.2. *Similar to Sub Task 1.2. Estimates of N demand will be based on yield and soil analysis for previous year's rice crop.*

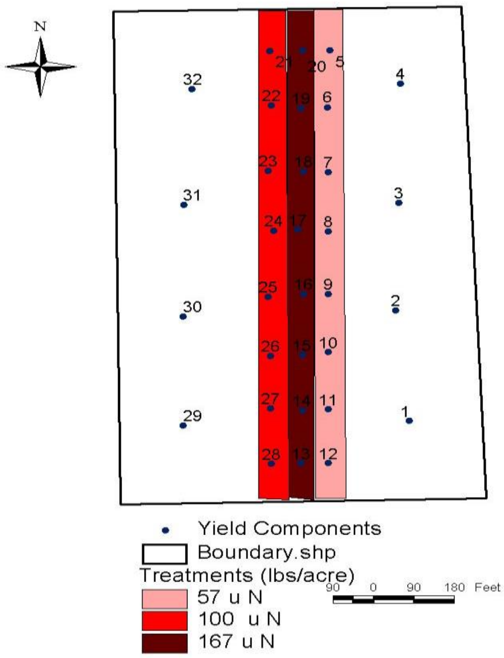
It was decided that in this initial year we would not apply variable rate treatments in rice, but rather we would determine yield variability in each plot. These will be used next year to lay out variable rate treatments. The treatments were as shown here:



Mathews Farm, Marysville CA



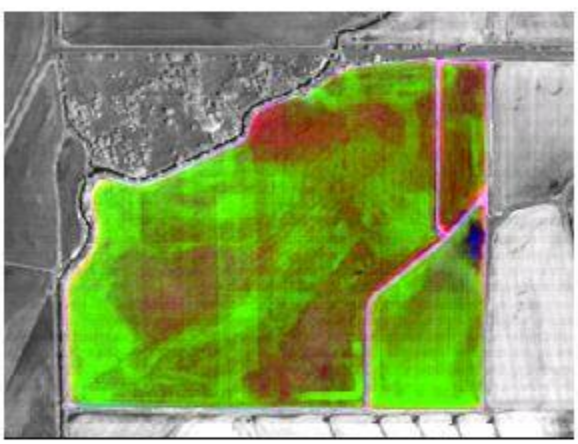
Gorrill Ranch, Nelson, CA



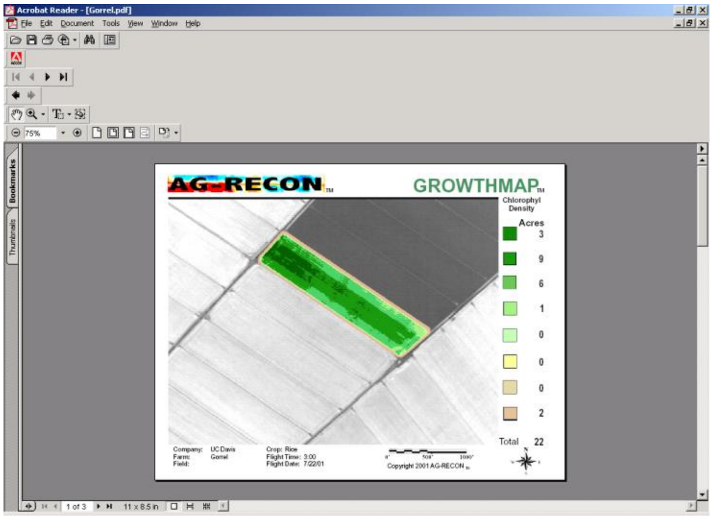
Schohr Ranch, Gridley, CA

Sub Task 2.3. *Take aerial photos as in Sub Task 1.3*.

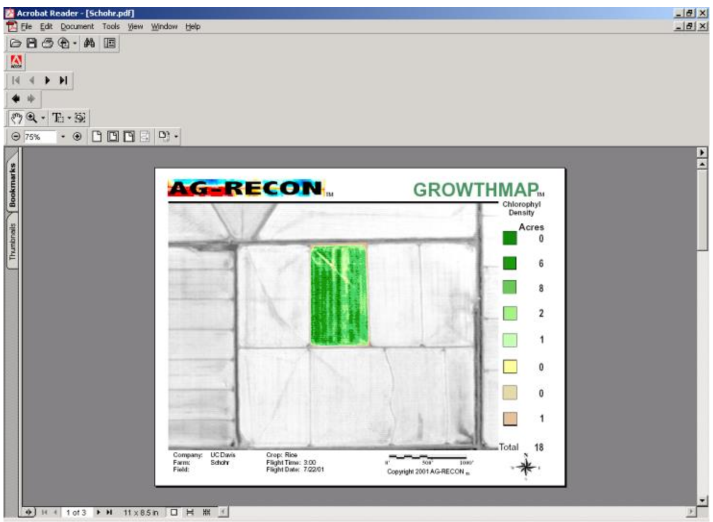
A set of three aerial images of each field was collected.



Mathews Farm, Marysville CA. Multispectral Infrared Image July 1, 2001



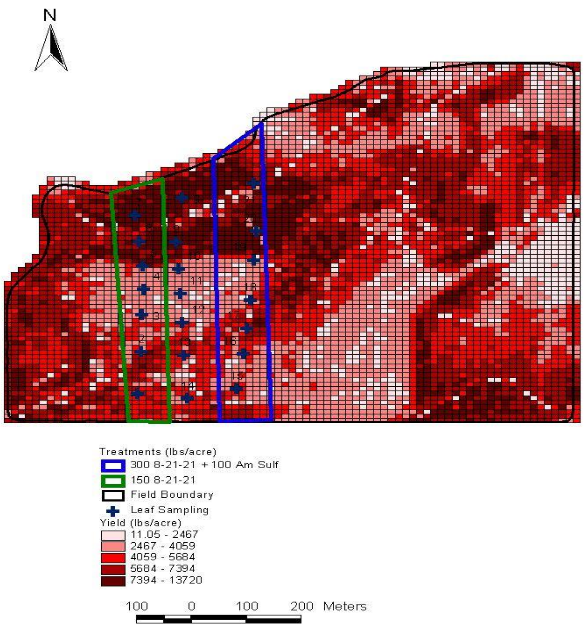
Gorrill Ranch, Nelson, CA Growth map, July 22, 2001.



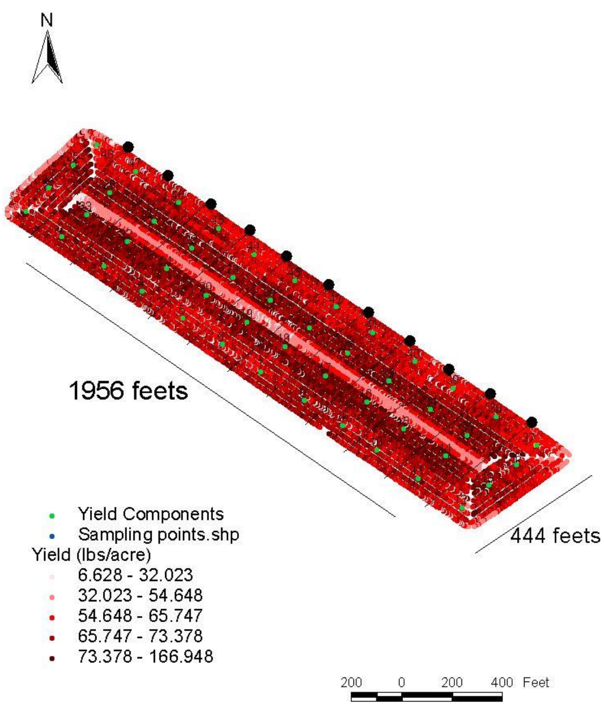
Schohr Ranch, Gridley, CA Growth map, July 22, 2001

Sub Task 2.4. *Take leaf tissue analysis at same locations (as determined by GPS) as soil samples. Take SPAD meter readings at the same locations.*
Tissue samples were analyzed for:
N-Total (%)
P-Total (%)
K-Total (5)
Zn-Total (ppm)

Sub Task 2.5. Yield mapping to be carried out by the cooperating grower using his yield monitoring equipment. Yield components data collected and analyzed.



Yield map Mathews Farm, Marysville CA



Yield map Gorrill Ranch, Nelson, CA

Task 3. Data Analysis and Reporting
Month of initiation: 6/01
Month of completion: 12/01

Sub Task 3.1.
Yield monitor data only became available in mid-November, so analysis of the data has not yet been completed.

Sub Task 3.2. Annual report and invoice to FREP. Completion 12/01.

Results, Discussion, and Conclusions
Sugar beets:
Imperial Valley site:

1. Previous yield maps and a new electrical conductivity survey were carried out and used to to develop a treatment plan for the Imperial Valley site.
2. Gypsum at the rate of two tons per acre was applied to the tops of beds in 20 plots (four 30" rows, 60 feet long) chosen using the ESAP v2.01 software created by Scott Lesch. These twenty sites represent the range in salinity conditions found in the field.
3. Supplemental nitrogen fertilizer (at the rate of 100 lb N per acre, applied in addition tothe baseline rate of 150 lb N per acre) was applied to half of the twenty sites, which were divided to reflect approximate balance between each group of ten plots with respect to salinity conditions.
4. Prior to planting and irrigation, soil cores were collected to three feet at each of the twenty sites and analyzed for salinity and clay content for calibration with the conductivity maps made earlier by Corwin and Lesch.. An additional set of soil samples to six feet was collected at harvest in late May and are being analyzed analyzed for salinity, clay content and nitrate.
5. Seedling emergence was counted at each of the twenty sites two weeks after initial irrigation. Soil samples were taken at each site on the same day at the two to three inch depth and are being analyzed for salinity and sodium content.
6. Petiole samples were collected at most of the plot sites during the spring and at harvest to follow changes in plant nitrate content and see if those changes are related to soil conditions.
7. At harvest, a yield monitor was used to map sugarbeet yields and those yield maps will be combined with the previous year's maps for sugarbeet and wheat and soil electrical conductivity to evaluate the effects of soil variability, including residual and applied N on on crop performance.
8. Hand harvests were be taken at the twenty plot sites and analyzed for yield, quality, and root characteristics, root NO3 content.
9. All data are being combined and analyzed.

El Nido site:

1. In the spring of 2000, an EM 38 survey was carried out on a 60 acre site in El Nido, California by Dennis Corwin.
2. Following the survey, soil samples were collected at 16 sub sample locations chosen using the ESAP v2.01 software. Samples are being analyzed for salinity, texture and nitrate.

3. Sugarbeets were planted at the El Nido site in May, 2001. They will be harvested in spring 2002.
4. Stand counts were made and will be correlated with soil properties.

5. Supplemental fertilizer applications at rates of 50 or 100 lbs N per acre were side dressed to young beets before canopy closure. Two 50 rows were fertilized at each of 16 sub sample locations. Sites were divided into two approximately equal groups, half receiving the larger rate, and half the smaller. Results will be compared to neighboring rows using hand harvests at each location. Background variation in soil residual N and the variable amounts surface applied will be used to assess crop fertilizer response.

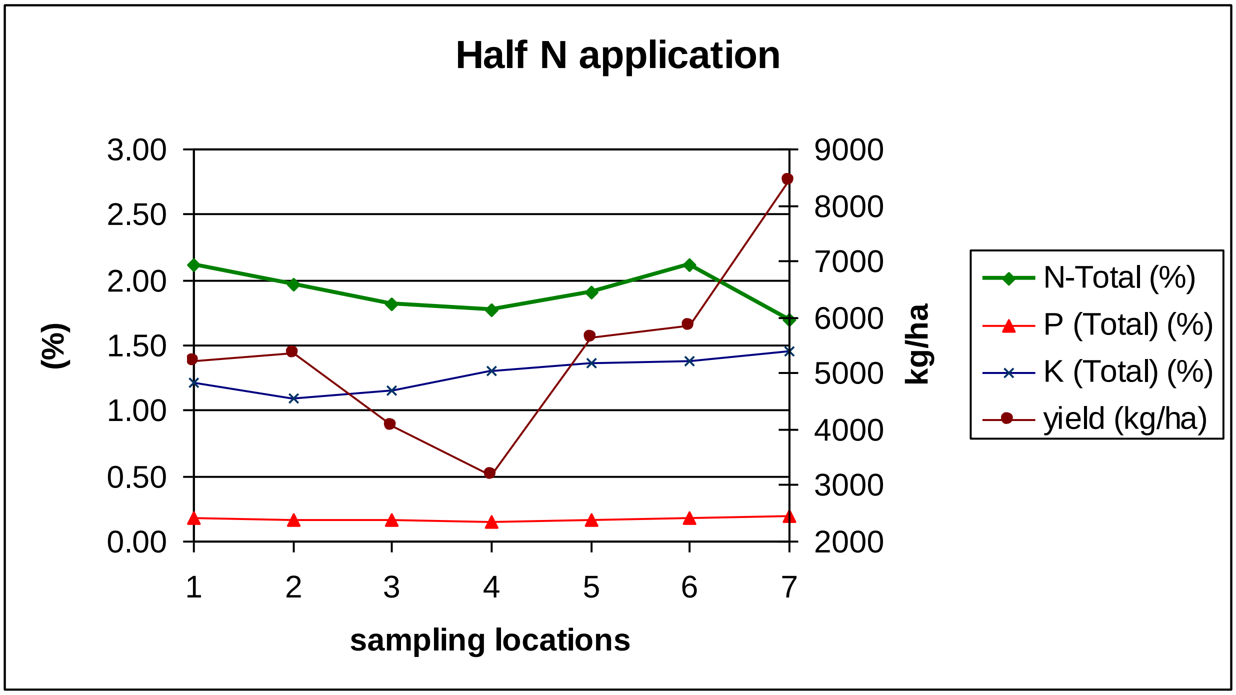
Neither fertilizer N nor gypsum affected sugarbeet root yields significantly at the IV and EN sites. Petiole NO_3-N levels were increased, and sugar contents decreased with increasing fertilizer N. or amendments were applied (gypsum and N in the IV, and N only in El Nido). Soil physical and chemical conditions limiting crop growth and yield could not be significantly modified to overcome salinity and drainage limitations at the IV site, nor soil structural and hardpan problems at the EN site. A complete report is in preparation.

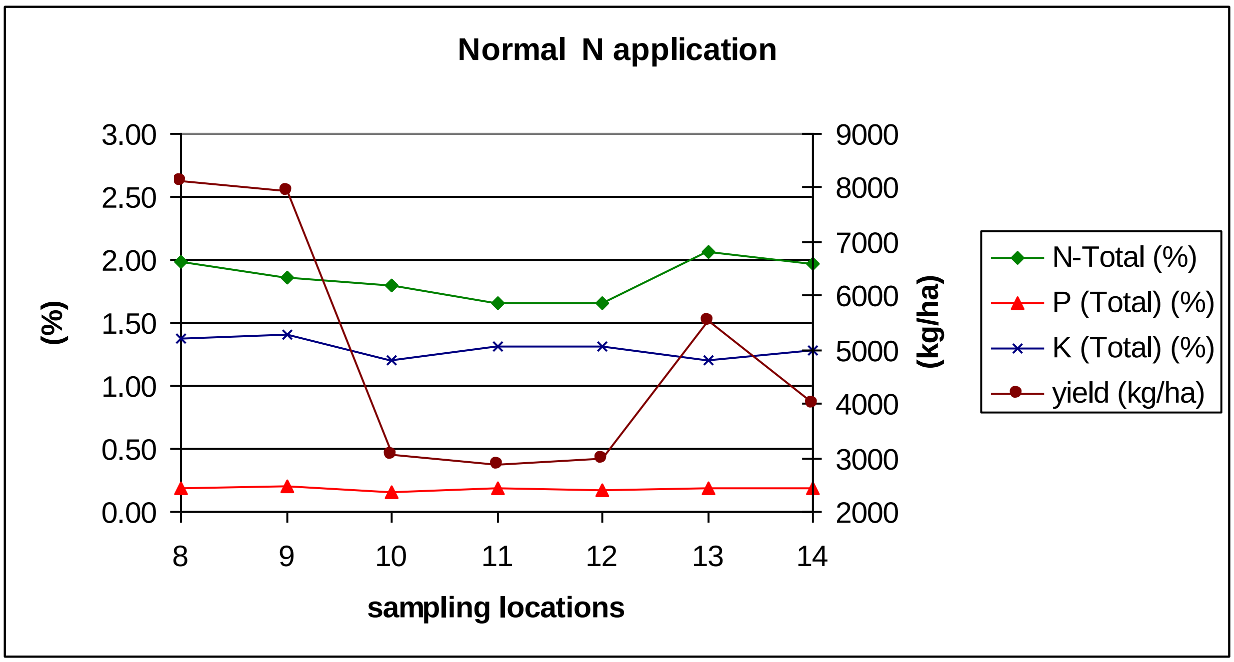
Rice:

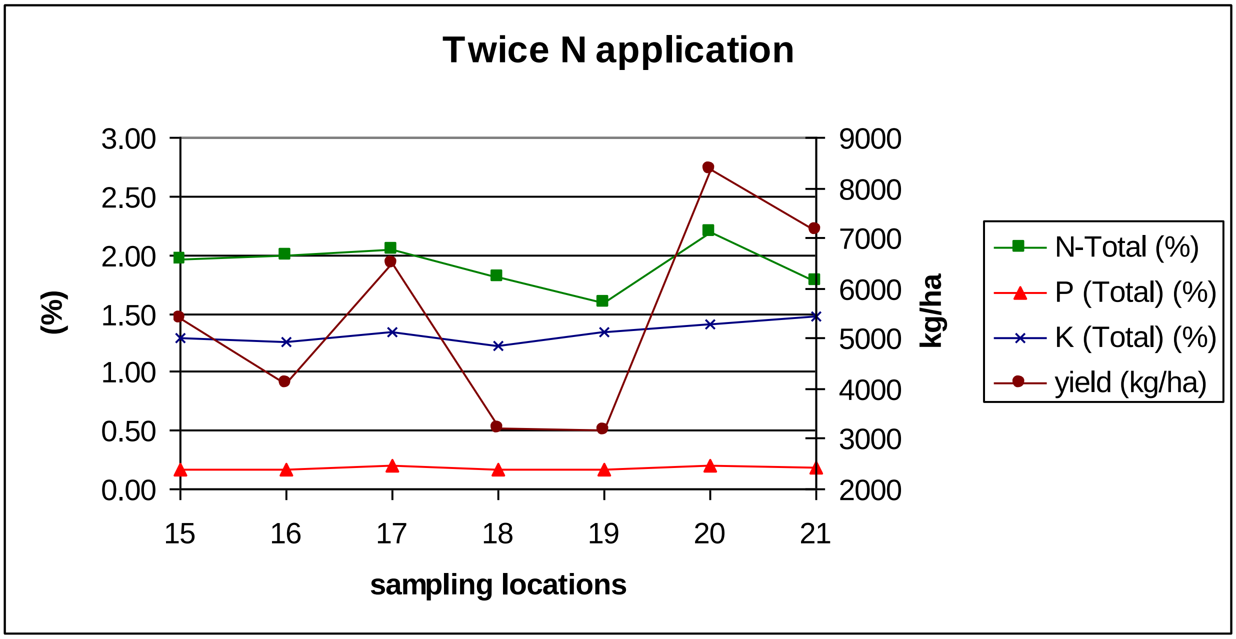
Statistical analysis of yield data has not yet been completed, but some preliminary comments can be made based on visual examination of the data. Aerial images of the fields indicated that the high N treatments had a higher level of vegetative development early in the season, but that this difference declined later in the season. Two of the fields in the study had clearly discernable regions of higher and lower yield. One of the key questions is the extent to which higher N rates can permit rice to attain higher yields on poor soil. Visual examination of yield monitor data provides some potential support for this idea, but statistical analysis of the data is necessary to achieve an acceptable conclusion.

An exploratory analysis of the plant tissue samples collected at Mathews farm was performed. Interestingly, although they were visual growth and color differences along the different transects where the samples were collected none statistical differences were found in sample nutrient values between treatments. There is also no significant within treatments variability in the value of the different nutrients.

Based on preliminary analysis of data together with last year’s data, some preliminary conclusions can be drawn. In 2001, we found that in relatively productive soil in M202 nitrogen fertilizer could be applied at a lower rate without significantly reducing yield. Some economic advantages accrued to this practice, including reduced weed levels and reduced rice straw. The benefits of reduced straw included reduced disposal needs, ability to harvest at a higher speed, and less wear on the combine. Since N was applied at the same rate in all treatments this year, we will be able to see if the reduced N rate can be sustained. There was some evidence that an increased N rate improved yields in poor soils. We expect the analysis of the 2002 data to provide additional evidence as to whether this is a real effect.


Half N application
3.00
2.50
2.00
1.50
1.00
0.50
0.00
(%)
9000
8000
7000
6000
5000
4000
3000
2000
kg/ha
1 2 3 4 5 6 7
sampling locations
N-Total (%)
P (Total) (%)
K (Total) (%)
yield (kg/ha)


Normal N application
3.00
2.50
2.00
1.50
1.00
0.50
0.00
(%)
9000
8000
7000
6000
5000
4000
3000
2000
(kg/ha)
8 9 10 11 12 13 14
sampling locations
N-Total (%)
P (Total) (%)
K (Total) (%)
yield (kg/ha)


Twice N application
(%)
kg/ha
3.00
2.50
2.00
1.50
1.00
0.50
0.00
9000
8000
7000
6000
5000
4000
3000
2000
15
16
17
18
19
20
21
sampling locations
N-Total (%)
P (Total) (%)
K (Total) (%)
yield (kg/ha)