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

FINAL REPORT

Project Title	Site-Specific Variable Rate Fertilizer Nitrogen Application in Cotton	**CDFA Contract Number**	01-0507
		Period Covered	1/1/03-12/31/06

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B. Statement of 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. Determine the breakeven acreage at which this method is profitable and the payoff period for purchase of equipment as well as the breakeven custom rate.

C. Abstract

A previous research project, supported by the Fertilizer Research and Education Program, initiated University of California research on site-specific crop management. 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 and/or reduce environmental effects. The initial research focused on establishing the first two of these criteria. The present project focused on the third by establishing site-specific fertilizer management strategies through the use of variable-rate application technology for nitrogen management in cotton.

The project built on preliminary research being carried out by several of the PIs on the Sheely Farm in Lemoore, CA. The project had three primary objectives. The first was to develop a practical methodology for growers or consultants to use in the construction of prescription maps for the site-specific application of fertilizer nitrogen as a side dress. These maps divided the field into application rate zones using one of two to four specified application rates in each zone. The prescription maps are on yield maps from the crop in

the previous year or years, vegetation maps derived from aerial images, soil bulk EC values, and soil nitrate nitrogen levels taken from soil cores collected using directed sampling. The second objective was to carry out replicated field trials in cotton fields to compare yields from variable rate and fixed rate nitrogen fertilizer applications. The third objective was to conduct a thorough economic analysis to determine the short run and long run economic viability of adoption of site-specific cotton fertilization using currently available commercial equipment.

D. 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 if the increased costs associated with the practice can be offset by reduced input costs and/or reduced regulatory pressure.

Prior to this project the potential for variable rate fertilizer application to increase profit and resource use efficiency had not been investigated scientifically for California’s diverse irrigated cropping rotations. Supported by FREP and other agencies, we have been investigating site-specific management of California field and row crops since 1995. This represents one of the longest and most extensive site-specific management research programs in California. Initial research focused on determining whether California fields have high yield variability, since they do not have the topographic variability often associated in the Midwest with high levels of yield variability. Our research (e.g. Plant et al., 1999) and that of others has indicated that many laser leveled, surface irrigated fields in California display a high level of spatial variability in yield. Therefore the potential for improved economic and resource use efficiency of fertilizer exists, either by adding fertilizer to areas in which yield is limited by mineral nutrients or by reducing fertilizer rates in areas where yield potential is sufficiently reduced that high rates are unwarranted.

Results of FREP supported research indicate that in some cases current nitrogen fertilization practices in California may not maximize fertilizer use efficiency (Travis et al., ##). The application of nitrogen fertilizer at a site-specific rate may provide the opportunity for the grower to increase profits and maintain economic viability. At the same time, it provides the opportunity to demonstrate to the public and to regulatory agencies that the agricultural industry can use voluntary methods to reduce potential environmental contamination resulting from inputs to crop production systems.

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 (Silvertooth et al., 1996). 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 hypothesized that the precision of the relationship between soil test nitrate level and plant N response could be improved by a stratified sampling scheme taking into account within-field variation in soil conditions.

The experiments carried out in this research project focused on using high spatial precision bulk data (yield maps, remotely sensed images, and soil EC_a 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. The experiments were carried out in commercial fields and the other aspects of crop management were the same as that of the rest of the field. In particular, any additional N applications based on petiole sampling and/or other information were made at a uniform rate in the same manner as the rest of the field. Each experiment was carried out as a randomized complete block design with three levels: variable N rate, low fixed N rate control, and nominal fixed N rate. The low fixed N rate was based on a rate calculated to maintain a total soil N level of 50 lbs./acre. This rate was used as a control by Travis et al. (##), who found that it provided an adequate control without forcing the cooperating grower to sustain an unacceptable economic loss. The nominal fixed rate treatment was approximately that used by the grower in the rest of the field.

E. Work Description
2002-2003 Workplan

Task 1. Site Selection
Month of initiation: 10/01

Month of completion: 2/02

Sub Task 1.1. Selected cooperators for commercial field experiments. Selection criteria included (in order of decreasing priority): (1) be willing to participate in the experiment; (2) have a cotton yield monitor; (3) have variable rate fertilization equipment; (4) have existing yield maps of fields that will be in cotton in 2002; (5) be willing to devote a field to cotton production in the experiment for more than one year; (6) have other data (e.g., soil EC_a, NDVI) for the field to be used.

Task 2. Field Data Collection
Month of initiation: 2/02
Month of completion: 10/02

Sub Task 2.1. Lay out the experiment. The experimental design was a randomized complete block with three or four replications. Plots ran the length of the row and twice the width of the harvester equipment. Each block consisted of three or four treatments: control (50 lbs./acre total N), one or two fixed N rates, and variable N rate. Plots were laid out to encompass as much variability as possible within a single plot. The central rows were used as data rows and a half harvester width on either side in each plot were guard rows.

Bulk soil EC data were collected. Soil samples were collected from the fields according to a directed sampling plan. Sample point latitude and longitude were determined with a mobile GPS unit. Soil samples (0-20 and 20-40 cm) were collected prior to planting and analyzed for EC_e, and NO_3-N. These were used to draw a variable N rate map for the field.

Sub-Task 2.2 Lay out nitrogen rate trials. Fixed N rate plots were applied by the grower using standard equipment. Variable rate trial was applied either by the grower based on existing soil and yield data.

Sub Task 2-3. Aerial images were taken two times during the season.

Sub Task 2.4. Took leaf tissue analysis at same locations (as determined by GPS) as soil samples. Leaf tissue was analyzed for petiole N levels.

Sub Task 2.5. Collect cotton yield map data.

Sub Task 2-6. Maintain a log of activities for use in economic analysis.

Task 3. Data Analysis and Reporting
Month of initiation: 10/02
Month of completion: 3/03

Sub Task 3.1. Data analysis. ANOVA was used to test for significant differences between yield using the fixed and variable rate methods and then use production functions to quantify costs.

Sub Task 3.2. Annual report and invoice to FREP

2003-2004 Workplan

Task 4. Field Data Collection.
Month of initiation: 2/03
Month of completion: 10/03
Sub Tasks 4.1-4.6. See Sub Tasks 2.1-2.6.

Task 5. Data Analysis and Reporting
Month of initiation: 10/03
Month of completion: 3/04
Sub Tasks 5.1 -5.2 See Sub Tasks 3.1-3.2.

2004-2005 Workplan

Task 6. Field Data Collection.
Month of initiation: 2/04
Month of completion: 10/04
Sub Tasks 6.1-6.6. See Sub Tasks 2.1-2.6.

Task 7. Data Analysis and Reporting
Month of initiation: 10/05
Month of completion: 12/05
Sub Tasks 5.1 -5.2 See Sub Tasks 3.1-3.2.

Task 8. Conduct Outreach Activities and Publish Technical Manual on Site-Specific Farming Information Systems.
Month of initiation: 9/01
Month of completion: 3/04

Sub Task 8.1. In addition to presentations at the Plant and Soil conference and FREP conferences, we presented information at county extension meetings during the course of the project.

Sub Task 8.2. Begin draft of article for extension of method.

2005-2006 Workplan

Task 8. Field Data Collection.
Month of initiation: 2/05
Month of completion: 11/05
Sub Tasks 8.1-8.6. See Sub Tasks 2.1-2.6.
Since we already had three years of experimental data, we elected not to repeat the experiment this year, but instead to focus on analysis of the existing data.

Task 9. Data Analysis and Reporting
Month of initiation: 10/05
Month of completion: 6/06
Sub Tasks 9.1 -9.2 See Sub Tasks 3.1-3.2.

Analysis of yield results was completed for all years and all fields. In no case was there a significant difference in yields between any nitrogen treatment. That is, the low rate control, the variable rate treatment, and the fixed rate treatments never showed any significant difference. There were, however, several fields in which there was a non-significant trend in the direction of decreasing yields with the untreated control.

Task 10. Conduct Outreach Activities and Publish Technical Manual on Variable Rate Application of Nitrogen for Field Crops.
Month of initiation: 9/01
Month of completion: 6/06

Sub Task 10.1. In addition to presentations at the Plant and Soil conference and FREP conferences, present information at county extension meetings and field days during the course of the project.

We made two presentations in 2006. The first was at the Precision Agriculture Field Day held at the Sheely Farm. Lemoore, CA on July 28. The second was at the Central Coast Cotton Conference in San Luis Obispo on 18.

Sub Task 10.2. Continue draft of article on variable rate N application.

The results of Project 00-0505 are going to be published as a chapter in the Rice Management Guidelines being edited by Jack Williams. For this reason we will publish the cotton results separately. After the completion of the economic analysis we expect to publish them as an article in the California Cotton Review.

F. Results, Discussion, and Conclusions (Summary)
In each of the years 2002, 2003, and 2004 three fields were selected for the trials. The general format of each trial was a randomized complete block design with four replications. The treatments were a very low N rate (pseudo-control), a low fixed N rate, a high fixed N rate, and a variable N rate. The specific N rates were based on the

cooperating grower's normal practice for the field. Each plot was harvested with a boll buggy, and, where possible, a yield monitor was used as well.

In 2002 the fields were located on the Woolf, McKean, and Sheely farms. In the following two years, two fields were located on the Sheely farm and one on the McKean farm. In 2003, due to a miscommunication, one of the Sheely fields was fertilized at full rate in all plots before the treatment applications could be made. Therefore data was obtained from a total of eight fields, three in 2002, two in 2003, and three in 2004.

The initial analysis was an analysis of variance to determine whether there was any significant difference between yields in any of the treatments. The lack of a significant difference between VRT and fixed rate yield does not, however, fully address the issue of profitability of variable rate nitrogen application for cotton. If there is no change in yield, then the method will be economically viable in those circumstances where the savings in reduced fertilizer cost are greater than the increased costs in implementing the precision application. These costs include the fixed costs of acquiring the precision agriculture equipment (primarily the yield monitor and the variable rate applicator) and the variable costs of more intense sampling. Therefore the final analysis was an economic one considering these variables. This analysis was carried out in collaboration with Karen Klonsky and Rich De Moura using the Budget Planner software.

G. Results

Each experiment was 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 rate. In 2002 the experiments were carried out in three fields. Due to technical problems only two fields were tested in 2003, and once again three fields were be tested in 2004. The method of determining the variable rate N application map was worked out in 2002 and remained the same throughout the project. Table 1 shows the correlation coefficients of apparent EC and residual N with yield. Based on these, EC at 2 feet had the highest negative correlation with yield among the EC values, and therefore the estimated EC at 2 feet was used to draw the application maps. Figures 1 through 4 summarize the method. Based on the previous year's yield map, the experimental region was divided into three regions: high, medium, and low yield (Fig. 1). Three sampling sites were selected in each region, for a total of nine sites. At each site, residual N and apparent EC were measured. Based on coarse apparent EC characteristics, the field was divided into two or three yield potential zones (two in the case of the field in Figs. 1-4). Yield potential was estimated for each zone, and N demand was then calculated using the rule of thumb that 60 lbs. of N are required per bale of cotton. Based on the residual N level (Fig. 3), the N demand was calculated, and this N demand was then used to determine the amount to apply in each zone (Fig. 4)

Variables	Yield	Ec_3ft	N_3ft	Ec_2ft	N_2ft	Ec_1ft	N_1ft
Yield	1	-0.08	-0.12	-0.22	-0.01	-0.17	-0.06
Ec_3ft	-0.08	1	0.22	0.65	-0.04	0.74	0.18
N_3ft	-0.12	0.22	1	0.33	0.79	0.35	0.85
Ec_2ft	-0.22	0.65	0.33	1	-0.18	0.65	0.33
N_2ft	-0.01	-0.04	0.79	-0.18	1	0.21	0.62
Ec_1ft	-0.17	0.74	0.35	0.65	0.21	1	0.06
N_1ft	-0.06	0.18	0.85	0.33	0.62	0.06	1

Table 1. Correlations of yield with measured soil and residual N values.

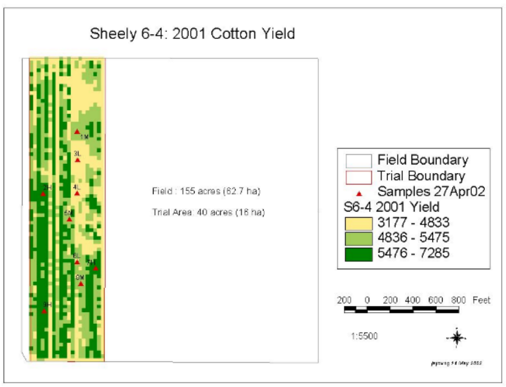

Fig. 1. Yield map showing 3 yield classes and soil sample locations stratified by yield class.

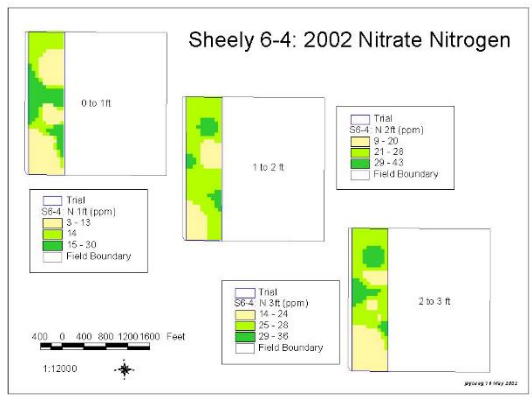

Fig. 2. Estimated residual nitrate N based on interpolated soil samples

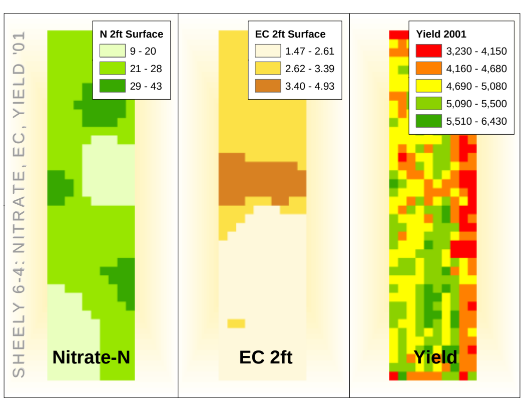

Fig. 3 Measurements used to determine the application map.

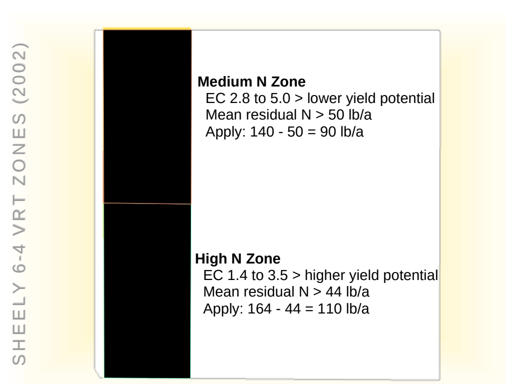

Fig. 4. Variable N rate zones based on estimated residual N and soil bulk EC.

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.

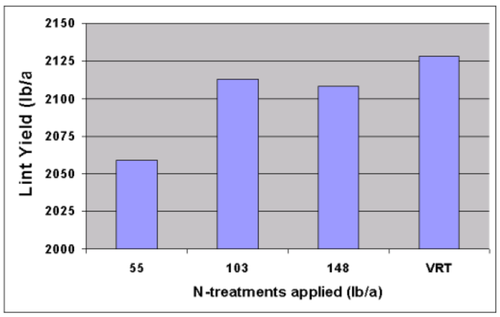

Fig. 5. Mean plot yield for each of the treatments at the Sheely 6-4 site in 2002.

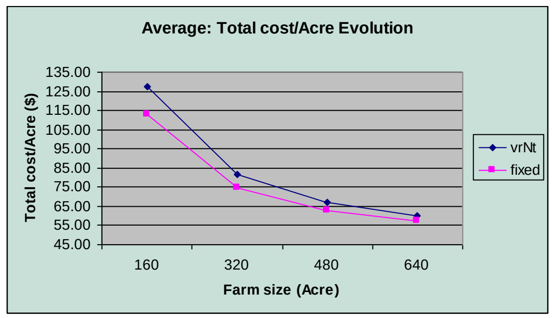

Fig. 6. Costs of VRT and fixed rate program as a function of farm size per unit of equipment (fertilization plus yield monitoring).

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

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.

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 cost we have carried out a partial budget analysis that is summarized in Table 2.

OPERATION	Sheely Fixed	Sheely Variable	Woolf Fixed	Woolf Variable	Mc Kean Fixed	Mc Kean 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.

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 equipment 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.

The tables below show the yield monitor yield (YMY) and boll buggy yield (BBY) for each of the plots in each of the experiments in each year.

2002										
McKean 11-11				Sheely 6-4				Woolf 35-4		
Plot	N	YMY	BBY	Plot	N	YMY	BBY	Plot	N	BBY
1	258	2191	2168	1	62	5842	5420	1	157	3184
2	204	2235	2163	2	115	5721	5212	2	112	3677
3	174	2342	2293	3	166	5768	5768	3	67	3651
4	134	2211	2107	4	VRT	5530	5187	4	VR2	3178
5	VRT	2428	2208	5	VRT	5926	5342	5	VR1	3237
6	174	2043	2103	6	166	5346	5133	6	67	2970
7	204	2181	2322	7	62	5546	5215	7	112	3128
8	134	2272	2017	8	115	5391	5234	8	157	2973
9	VRT	5225	2589	9	115	5036	5044	9	VR1	3242
10	258	2399	2210	10	VRT	4832	5006	10	VR2	3795
11	204	3879	1946	11	166	4752	4965	11	67	3675
12	134	3278	2096	12	62	5160	4714	12	VR2	3234
13	VRT	2777	1993	13	62	5021	4721	13	112	3293
14	174	7252	2385	14	115	5629	5084	14	VR1	3264
15	258	3575	2522	15	VRT	5352	5073	15	157	3736
16	VRT	8008	2351	16	166	5029	4911	16	157	3669
17	174	2068	2237					17	VR2	3656
18	134	2270	1831					18	112	4000
19	204	2752	0					19	VR1	4112
								20	67	4016

2003						
McKean 11-5				Sheely MK30-1		
Plot	N	BBY	YMY	Plot	N	BBY
1	70	1528	1493	1	56	3587
2	170	1563	1673	2	149	3458
4	VRT	1805	1740	3	VRT	3537
5	120	1557	1750	4	198	3620
6	VRT	1828	1723	5	198	3643
7	170	1586	1802	6	198	3665
8	120	1638	1745	7	149	3497
9	70	1782	1746	8	149	3683
10	120	1531	1714	9	VRT	3536
11	VRT	1596	1585	10	VRT	3624
12	70	1414	1600	11	56	3553
13	170	1788	1649	12	56	3583
14	VRT	1672	1765	13	56	3537
15	70	1694	1569	14	VRT	3581
16	120	1418	1552	15	149	3508
17	170	1640	1541	16	198	3511

2004										
McKean 11-2				Sheely MK20-1				Sheely 6-3		
Plot	N	BBY	YMY	PLOT	N	YMY	BBY	PLOT	N	BBY
1	65	1148	1756	1	VRT	3384	5057	1	31	3516
2	185	1306	2005	2	92	3386	5060	2	230	3504
3	125	1204	1647	3	175	3256	4866	3	131	3632
4	VRN	1170	1443	4	124	3695	5522	4	VRT	3412
5	185	1390	1909	5	92	3605	5387	5	131	3430
6	65	1384	1601	6	124	3783	5653	6	131	3710
7	VRN	1275	1712	7	175	3975	5940	7	VRT	3484
8	125	1380	1599	8	VRT	3612	5398	8	VRT	3444
9	65	1258	1568	9	124	3735	5582	9	230	3440
10	125	1400	1780	10	175	3760	5619	10	230	3170
11	VRN	1494	1780	11	VRT	3742	5592	11	31	2924
12	185	1500	2185	12	92	3848	5750	12	31	2922
13	VRN	2034	2034	13	175	3580	5350	13	VRT	3122
14	185	2648	2648	14	VRT	3547	5301	14	31	2930
15	125	1981	1981	15	124	3542	5293	15	131	3214
16	65	1997	1997	16	92	3413	5100	16	230	3164

Analysis of variance revealed no significant difference in any year between any treatment. We do not show the details of all of the fields but instead focus on a typical one, the Sheely field 6-4 in 2002. Figure 1 shows a box-and-whisker plot of the yields for each of the treatments.

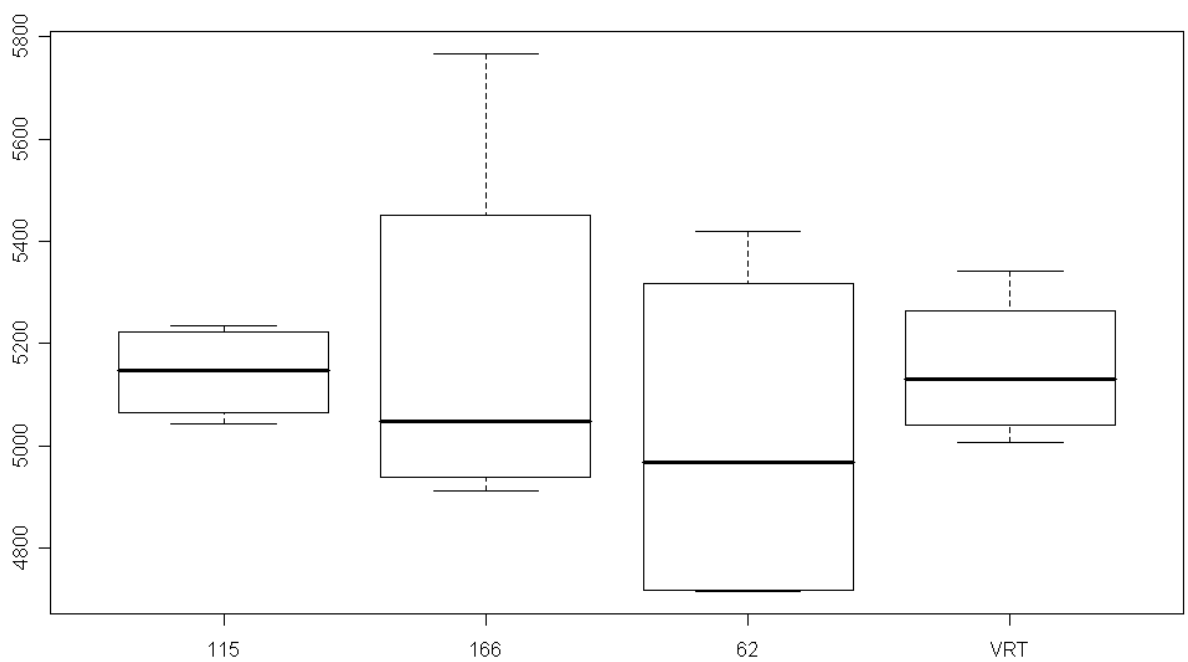

Figure 1. Box-and-whisker plot of yields for each of the N rate treatments for the experiment in the Sheely field 6-4, 2002.

The ANOVA table for the data is as follows:

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
N rate	3	69640	23213	0.297	0.827
Residuals	12	937969	78164		

H. Discussion

The lack of significant yield difference between the variable rate and fixed high rate N treatments is actually a positive result. Since most California cotton growers probably apply sufficient nitrogen for most cases, one would not expect substantial yield increase from variable rate application. Anecdotal evidence indicates that some farmers do indeed find very high yield potential parts of certain fields where yield can be increased, but in general one would expect that the profitability of variable rate N application would come from reduced application of N in low yield potential areas. Analysis of the 2002 data indicated that under those conditions this cost recovery was sufficient to make precision application profitable. The increasing costs of nitrogen fertilizer since this project was carried out should make the variable rate method even more profitable.

The key feature of the method is that it is simple to implement and requires no special software or statistical analysis. Many of the actions are actions that cotton growers would do anyway. Specifically, in its simplest implementation one follows these steps:

1. Collect yield monitor data at the end of the season. If the field is not going to be planted to cotton in the next season, save the data until the next time the field is planted to cotton.
2. Divide the field visually into three zones based on yield (high, medium, and low).
3. In the fall prior to planting to cotton, collect available soil N data using a minimum of three samples in each zone.
4. If salinity is yield limiting, collect apparent EC data in each zone. If salinity is not limiting, just use the yield data.
5. Based on previous yield and on possibly on salinity data, estimate the yield potential in each zone.
6. Compute the N requirement based on the assumption of 60 lbs. of N per bale of cotton, and subtract the estimated available soil N. This is the amount of N to apply in each zone.

Conversations with the participating growers indicate that they have continued to use some from of the variable rate method we developed. These are leading growers in the area, and we can expect that other farmers will follow their example. As individuals become more familiar with the technology, they may be expected to adjust the implantation based on their own practices and circumstances.

I. Project Evaluation

Based on the analysis described in Section G, the breakeven size for a single yield monitor and variable rate applicator is approximately 500 acres (Figure 3).

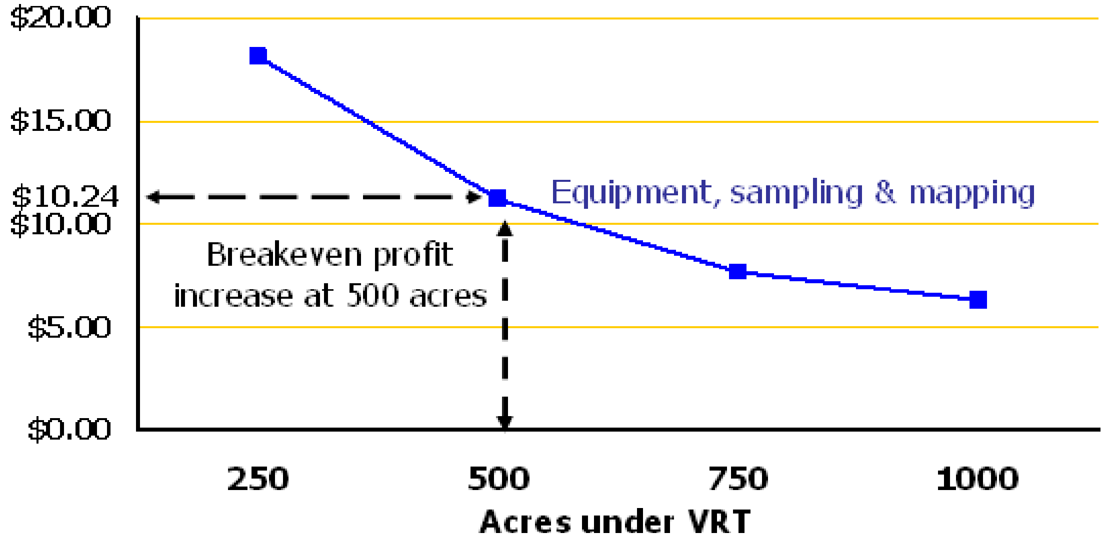

Figure 3. Breakeven acreage under 2002 cost assumptions.

A rule of thumb for cotton growers is that one picker can cover 1000 acres in a season. Since the primary fixed cost is the yield monitor, which is associated with the picker, we can expect this technology to be profitable for most growers. This analysis is based on 2003 fertilizer prices, and the recent increases should make the technology even more economically attractive.

J. Outreach Activities Summary

Presentations were made a the Cotton Precision Agriculture Field Day, held on Sheely Farm, July 26, 2002 and July 24, 2003. Approximately 50 farmers and consultants were in attendance.

A presentation was made at the Cotton Field Day at the West Side Field Station in Five Points in July, 2002. Approximately 100 persons were in attendance.

A presentation was made at the Central Coast Cotton Conference November 18, 2005. Approximately 100 growers and consultants were in attendance.

Presentations were made at the FREP Annual conferences in Tulare in 2002, 2003, and 2004.