

Comparison of commercial and reduced N fertilizer programs for impacts on vegetable crop yield, partial N balance, and soil and groundwater nitrate-N concentrations

Authors: George Hochmuth, Don Graetz, and Wendy Graham

Summary:

Water quality has been the subject of concern and attention in the Suwannee River Basin for a number of years. Recent data have indicated increasing trends in concentrations of nutrients in ground water, spring water, and private drinking water wells in this region. This has brought a needed focus of agency efforts to find nutrient management solutions to the problem. In addition, the state's participation in the Total Maximum Daily Load (TMDL) Program will require new initiatives for managing nonpoint sources (e.g., for nutrients) for agriculture, and for measuring the use and effectiveness of nonpoint source controls. An on-farm study was conducted to compare the effects of the commercial-farm nitrogen (N) management practice with a reduced-N program for effects on crop yield, and groundwater nitrate-N and soil pore water N concentration. A seven-year cropping cycle was monitored in one large field under center-pivot irrigation. Potato was grown in three of the seven years and yield was monitored. There was no effect of N management program on potato yield; a reduced-N program resulted in the same yield as with the commercial program. Nitrate-N concentration in the soil pore water was not affected by fertilizer treatment, but groundwater nitrate-N concentration was reduced slightly under the field with the reduced-N fertilizer program. Results measured over several years showed that adoption of best management practices can result in a reduction in groundwater nitrate-N concentrations.

The Suwannee River, designated as an "Outstanding Water Body" is the second largest river in Florida with a mean annual flow of 6.7 billion gallons per day. The Suwannee River basin comprises an area of 25,770 km² with 43% of the total area located in north central Florida. The Suwannee River is used for recreation, fishing, potable water, and provides habitat for a diverse ecosystem. The primary land use in the Florida portion of the basin is agriculture, including forestry, pasture, row crops, and livestock such as dairy and beef cattle (Hornsby, 2000).

The basin has karst characteristics that result in a direct linkage between the surface and ground waters (Katz et al., 1999). Over the past 40 years, the nitrate-N concentrations in many of the springs in the Suwannee River basin have increased from less than 0.1 mg/L to more than 5 mg/L (Hornsby and Ceryak, 1999; Katz, 1992; 2000; Maddox et al., 1992), leading to high nitrogen loading rates in the Suwannee and Santa Fe Rivers (Katz, 2000).

Row crops, including vegetables are important agricultural enterprises in the Suwannee River basin. Potato, watermelon, and sweet corn are among the more important vegetable crops in the region. Potatoes are commonly planted in January to February in north central Florida and average potato yield in Florida is currently around 24.7 Mg/ha (Hochmuth et al, 2000). Fertilization rates and irrigation can vary significantly by cultivar and geographic location. Currently the Institute of Food and Agricultural Services (IFAS) recommends a target fertilization rate of 224 kg/ha (200 lbs/acre) (Hochmuth and

Cordasco, 2000; (Hochmuth et al, 2000). The N is split in several application in the growing season with some N applied at planting and the remainder between 20 and 50 days after planting. A survey of fertilization practices by Florida potato growers performed in the 1980s showed average N fertilization rates of about 300 kg/ha (Hochmuth and Cordasco, 2000).

A more recent review of the potato fertilization research literature was made by Hochmuth and Hanlon. This review of the research supported the current recommendation of 200 lb/acre N as a target N rate for the season. The N amount can be adjusted up or down based on growing conditions and leaching rainfall. Recent research on new fertilizer materials was also reviewed, documenting the possibility of reducing the total amount of N applied with controlled-release fertilizers. There is a need to document the performance of new and revised N fertilizer best management practices in a commercial farm setting.

The research summarized herein was conducted to evaluate the effects of two fertilizer management practices on crop production and soil and groundwater nitrate-N concentrations on a commercial farm in northern Florida. This farm rotates several crops during a annual growing period, for example a vegetable such as potato or sweet corn with peanut, silage corn and a winter cover crop of oats or cereal rye.

The goal of this project was to implement BMPs at the farm level to reduce nutrient loadings to ground water from agricultural activities and to evaluate their water quality improvement effectiveness.

The objectives to meet this goal were to:

1. Evaluate water quality impacts (primarily ground water) from a row cropping system on a commercial farm.
2. Evaluate the impacts Best Management Practices (BMPs) on potato crop yield for a row cropping farm,

Materials and methods

BMPs were evaluated on a 140-acre center pivot irrigated field where the landowner applied normal practices on half of the field and project-selected BMPs were used on the other half of the field. The project BMPs consisted of reductions in fertilizer N amounts and improved timing of fertilizer applications to anticipate crop needs.

Wells were constructed in the field to monitor groundwater nitrate-N concentrations beneath the field. The wells are described in Table 1. Well positions in the field are shown in Figure 1.

Table 1. Well characteristics at the row crop farm.

well #	driller reported well depth (ft)	measured well depth (ft)	depth to rock (ft)	depth of conductor casing (ft)	top of stand-pipe (ft above MSL)	bottom of open hole (ft above msl)	top of open hole (ft above msl)	Open interval
1	53	41	36	36	53	0	12	12
2	38	35	28	28	45	7	17	10
3	30	36.6	20	20	47	15	25	10
4	30	32.8	20.5	20	48	16	26	10
5	45	44.6	34.5	35	52	6	16	10
6	40	38.7	19	20	47	5	25	20
7	50	37.8	33.5	35	49	-3	12	15
8	40.5	40.3	19	20.5	46	5	25	20
9	40.5	39.8	25	20.5	44	4	24	20
10	40.5	41.7	20	20.5	50	8	28	20
11	40.5	41.4	27	23	49	7	24	17
12	38	38.8	22	20.5	53	13	31	18
13	38	38.6	20	20.5	48	8	26	18

Suction lysimeters were installed at selected points around the field for collecting soil pore water samples for nitrate-N analyses (Figure 1). Suction lysimeters consisted of a porous ceramic cup on the end of a PVC pipe with plastic sampling tubing allowing the sampling of soil pore water drawn into the cup by applying a vacuum to the apparatus. Suction lysimeters were installed at two depths, 1 and 2 meters.

Soil samples were collected at over a 2 meter depth for an average nitrate-N concentration. Samples were collected with a bucket auger. Soil samples were extracted with 2M KCl and analyzed for nitrate-N.

Potato crops were monitored for yield at the end of the growing season. Yields for each half of the field were obtained from the farm records.

The row crop farm produced primarily vegetable crops such as potatoes and sweet corn plus cotton and peanuts (Table 2). The BMPs addressed N fertilization management practices. The landowner was encouraged to follow the fertilization and irrigation management practices recommended by the Institute of Food and Agricultural Sciences at the University of Florida. BMPs involving nitrogen and irrigation application rate and timing were evaluated with initial emphasis on potatoes (a heavily fertilized and irrigated crop) over three growing seasons. These activities resulted in the development of crop management guides for these two crops. These guides are farmer friendly and were developed to allow the farmer and his field supervisors to implement the plans with minimum input from external aid.

BMPs generally consisted of reduction in fertilizer amounts and improved timing of fertilizer applications to anticipate crop needs (Table 2). These BMPs were demonstrated on a 140 acre

center pivot irrigated field where the landowner applied is normal practices on half of the field and the BMPs were used on the other half of the field.

As part of the irrigation management program, new nozzles were installed on the center pivot irrigation systems. These new nozzles were designed to cause less bed erosion and yet have high efficiency and uniformity. These nozzles have produced the desired results as evaluated by the Suwannee River Mobil Irrigation Laboratory and are now being recommended by many of the irrigation equipment dealers in the watershed.

Production practices at the row crop farm used a crop sequence that utilized a variety of crops annually. The general sequence was a high value vegetable crop (potatoes, sweet corn) in the Spring (February – June), followed by a crop such as cotton or peanuts in the Summer (July – September), and a cover crop for the winter. However, this sequence varied depending on market conditions for various crops. The actual sequence used on the demonstration field is shown in Table 2. For the project, more emphasis was given to the crops that received the most N, i.e., potatoes and sweet corn. However, ground water monitoring and soil sampling continued through-out the year.

Cropping history:

Over the period of spring 1999 to summer 2007, seven crops plus cover crops were grown in this field (Table 2). Varying amounts of N fertilizer were applied to the crops by the commercial farmer. In most cases these amounts were greater than the recommended rates of fertilizer from the University of Florida. The BMP rate of N selected for comparison was decided after consultations with the farmer, resulting from a compromise between current commercial practices and the recommended rate.

Table 2. Cropping history and N application rates for the grower-managed and BMP halves of pivot 12 at the row crop farm.

Crop	Season	N lbs/acre		
		Grower	BMP	IFAS rec
Cover Crop	Spring 1999	0	0	0
Peanut	Summer 1999	0	0	0
Cover Crop	Fall 1999	0	0	0
Sweet Corn	Spring 2000	345	345	225
Cotton	Summer 2000	214	214	60
Fallow	Fall 2000	0	0	0
Potato	Spring 2001	280	250	230
Tropical Corn	Summer 2001	243	243	210
Fallow	Fall 2001	0	0	0
Potato	Spring 2002	260	230	230
Peanut	Summer 2002	0	0	0
Cover Crop	Fall 2002	0	0	0
Sweet Corn	Spring 2003	400	360	225
Fallow	Summer 2003	0	0	0
Carrots	Fall 2003	232	220	175
Sweet Corn	Spring 2004	297	244	225
Peanuts	Summer 2004	0	0	0
Cover Crop	Fall 2004	0	0	0
Sweet Corn	Spring 2005	304	320	225
Potato	Spring 2006	251	203	200
Sweet Corn	Summer 2006	242	246	225
Oats	December 2006	117	117	
Peanuts	May 2007	0	0	0
		3185	2992	2230

Suwannee Farm

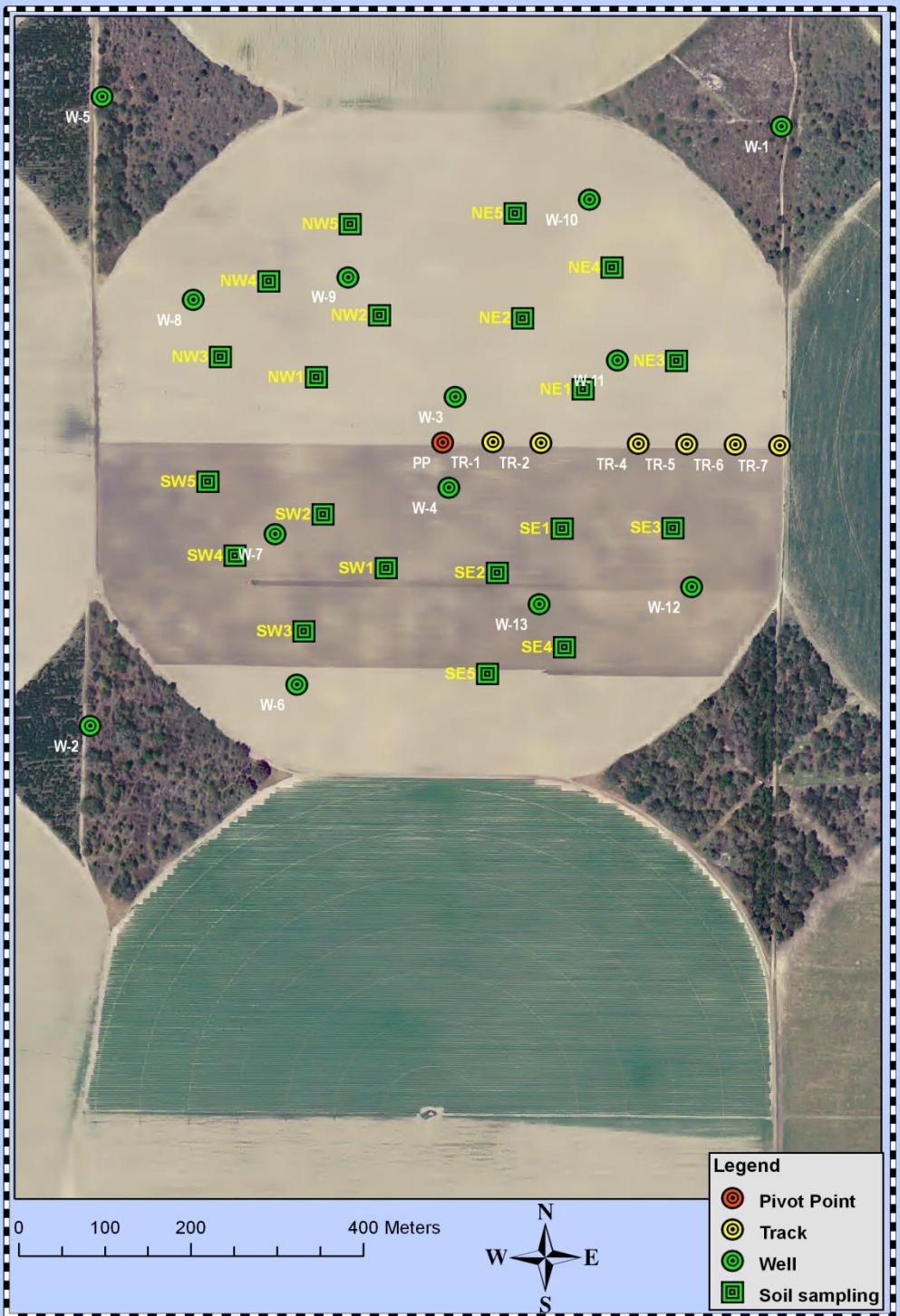


Figure 1. Diagram of positions of groundwater monitoring wells and soil sampling locations in a center-pivot irrigated field.

Results and discussion

Rainfall data over the study period are shown graphically (Figure 2) and averaged by year (Table 3). Average rainfall for the area is 130 cm/year so rainfall at the row crop farm was generally near average during the study period except for 2006 when it was below average.

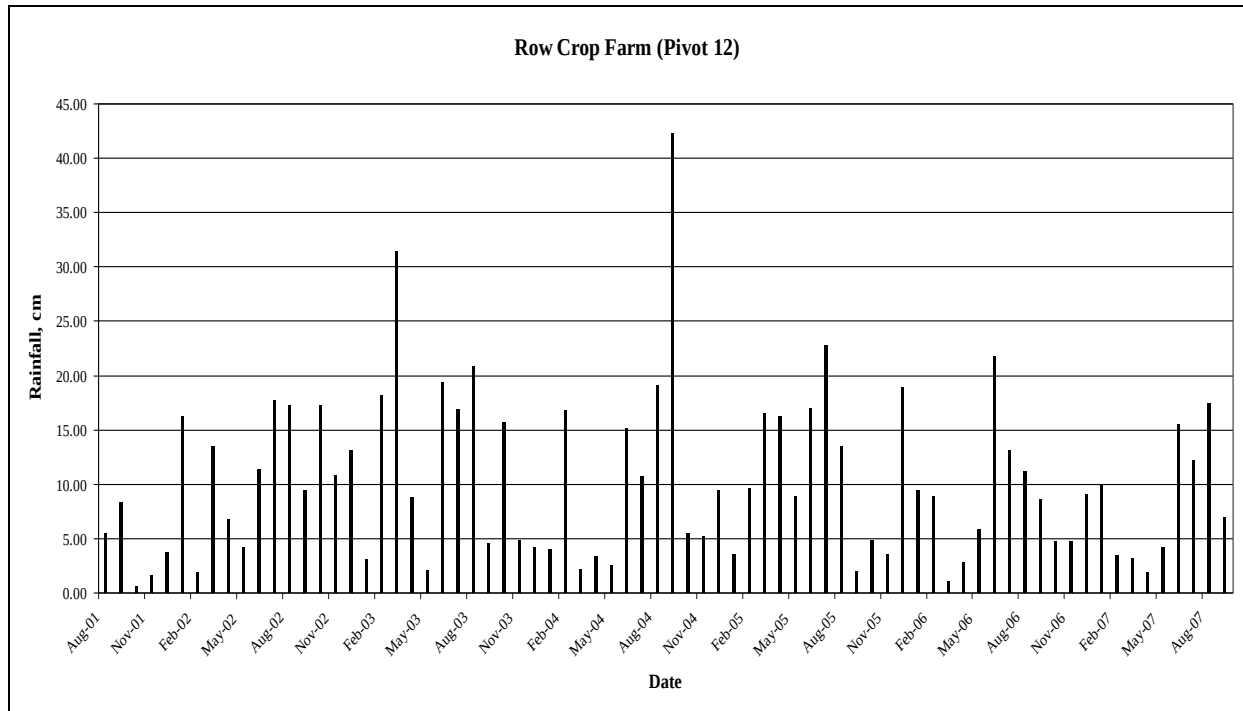


Figure 2. Monthly rainfall totals at the row crop farm.

Table 3. Monthly rainfall totals at the row crop farm*.

	2001	2002	2003	2004	2005	2006	2007
	----- cm -----						
January		16.23	3.07	3.94	3.53	9.40	9.91
February		1.83	18.21	16.84	9.65	8.92	3.51
March		13.41	31.50	2.16	16.48	1.09	3.12
April		6.78	8.79	3.35	16.23	2.82	1.85
May		4.14	2.13	2.51	8.89	5.87	4.17
June		11.30	19.33	15.14	16.99	21.74	15.49
July		17.65	16.92	10.77	22.76	13.13	12.22
August	5.49	17.27	20.83	19.15	13.49	11.18	17.40
September	8.28	9.42	4.57	42.27	1.98	8.64	6.96
October	0.58	17.22	15.72	5.49	4.80	4.75	0.00
November	1.63	10.82	4.83	5.18	3.53	4.72	0.00
December	3.71	13.08	4.17	9.50	18.82	9.04	0.00
Total	19.69	139.17	150.06	136.30	137.16	101.30	74.63

* Data obtained from the Suwannee River Water Management District monitoring sites at the row crop farm.

The crop responses will be summarized for each of the three potato crops, since including all crops in a single paper will be excessive. Groundwater, soil pore water, and soil nitrate-N results will be presented for the entire cropping sequence.

Spring 2001 Potato Crop

The 2001 potato crop, the first crop that was intensively monitored under this project, was managed with little deviation from the farmer's historic irrigation and N management practices. The goal for this crop was one of primarily observation and not optimization of management practices. A secondary goal for this crop was to develop a comfortable working relationship with the land owner. Small adjustments in N application rates (313/280 kg/ha) were made between the two halves of the pivot (Table 2) and observations of the irrigation management program were made. Fertilizer was applied in 5 split applications including 38 and 29 kg/ha approximately one month prior to planting Table 4.

Periodic plant biomass sampling was conducted to obtain moisture content, dry matter content, total nitrogen content and weight of the leaves, stems and tubers. Soil samples were taken biweekly from the soil surface to a depth of 90 cm during the spring potato growing season in addition to the deep soil samples that were taken every six weeks throughout the year. The samples were taken at 10 locations in the center of the potato plant beds at depths of 0-15, 15-30, 30-60, and 60-90 cm.

Table 4. Spring 2001 approximate nitrogen fertilizer schedule and amounts for potato.

Date	Julian Day	Applied Nitrogen (kg/ha)		Fertilizer Type/Application Method
		Grower Half Nitrogen Applied	BMP Half Nitrogen Applied	
01/18/2001	18	38.2	29.2	34-0-0 pre-plant, in bed
02/15/2001	46	16.8	16.8	10-34-0 starter, at plant
03/05/2001	64	112.3	105.5	18-0-0-3 sidedress, liquid
03/25/2001	84	112.3	94.3	18-0-0-3 sidedress, liquid
04/28/2001	118	33.7	33.7	30-0-0, fertigation
Total N		313 kg/ha	280 kg/ha	

Total final yields were 38.7 Mg/ha for the grower half and 33.7 Mg/ha for the BMP half. N fertilizer efficiency ranged from 30 to 53 % over the three potato crops. The unaccounted-for N could have been lost to volatilization, denitrification, or leaching. In this sandy soil, leaching to the ground water is likely to be the largest component of the three possibilities. Table 5 summarizes the N applied and the field measured N uptake and yield for the 3 seasons of potatoes monitored at the row crop farm.

Table 5. Summary of Nitrogen Application, Uptake and Potato Yield 2001-2003.

Crop	N Applied (kg/ha)	N Uptake (kg/ha)	N Lost (kg/ha)	N fertilizer use efficiency (% applied)	Yield (cwt/ha)
Potatoes North Half 2001	313	101	212	32	342
Potatoes South Half 2001	280	84	196	30	296
Potatoes North Half 2002	292	155	137	53	326
Potatoes South Half 2002	261	132	129	51	321
Potatoes 2003 (Pivot 35)	279	118	161	42	349

Spring 2002 Potato Crop

In the normal crop rotation followed by the land owner, potatoes would not have been grown on this pivot in 2002 due to increased crop disease potential. However, in winter meetings with the land owner, he agreed to assume the higher level of risk and to accommodate the requests of the project leaders. We negotiated a management plan for the BMP half of the pivot that would involve intensive oversight by project participants for both fertilization and irrigation management. The nutrient management program for the BMP half targeted the IFAS recommended rate for potatoes of 200 lbs of N per acre (approximately 225 kg/ha) and modification of the timing of application. The irrigation of the BMP half was targeted for a 20% reduction compared to the land owner's irrigation on the grower half.

The spring 2002 potato crop had similar planting details as those of the 2001 crop. Two different management practices were used on the grower and BMP halves of the field in 2002 (Table 6). The grower half of the field received 292 kg/ha of N fertilizer with the farmer's typical irrigation management. The BMP half of the field received 261 kg/ha of nitrogen fertilizer with a 21% reduction in applied irrigation. The BMP half irrigation was managed according to weather conditions and crop status, which was monitored daily from the University of Florida Research Center located in Live Oak, FL. Weather data were collected weekly from an onsite weather station adjacent to the field, which include hourly solar radiation, rainfall, and temperature.

Table 6. Spring 2002 approximate nitrogen fertilizer schedule and amounts for potatoes.

Date	Julian Day	Applied Nitrogen (kg/ha)	Fertilizer Type/Application Method
Grower			
1/10/2002	10	41	4-10-27, pre-plant in bed
1/15/2002	15	28.5	19-0-0, pre-plant in bed
2/13/2002	44	17	10-34-0, at plant
3/13/2002	72	101.5	19-0-0, sidedress
3/25/2002	84	104	19-0-0, sidedress
BMP			
1/16/2002	16	90.5	19-0-0, pre-plant in-bed
2/16/2002	47	17	10-34-0, at plant
3/15/2002	74	56	19-0-0, sidedress
3/26/2002	85	97.5	19-0-0, sidedress

As part of the irrigation management program, new nozzles were installed on the pivot (Figure 2). The new nozzles were designed to cause less bed erosion, yet have high efficiency and uniformity. The Suwannee River Mobile Irrigation Lab performed an evaluation of the pivot after the new nozzle installation confirmed both excellent efficiency and uniformity of the system. Decisions of how much to irrigate were based on tensiometers reading, current weather conditions, calculated potential evapotranspiration rates, weather forecasts and physical examination of the beds. During the first part of the growing season (through April 18th), irrigation had been reduced by 34% as compared to the grower half. However, to achieve the agreed upon 20% overall reduction, irrigation rates were increased for the remainder of the growing season.



Figure 2. New nozzles placed on the center pivot irrigation system to improve water application characteristics.

Yield results indicated that there was no difference between the two management schemes (Table 5). Total pack out information from the land owner showed a yield of 326 cwt/acre on the grower half and 321 cwt/acre on the BMP half. However, it was the consensus of the project team, that the potato quality was higher on the BMP half due to fewer enlarged lenticels on the tubers. The team estimated that the marketable yield was 3,675 kg/ha on the grower half compared to 5,260 kg/ha on the BMP half, a 1,585 kg/ha difference. Enlarged lenticels are generally attributed to excessive soil moisture levels. Nitrogen recovery was about 42% for both halves, but there was about 25 kg/ha more N available for leaching on the grower half of the field.

Spring 2003 Potato Crop

Based on the information obtained to this point a nutrient and irrigation management guide was developed (Table 7).

Table 7. Common potato fertilization practices and BMP fertilization program used for the 2003 potato crop.

Crop Stage	Common Fertilization Practice	BMP Fertilization Practice
Pre-Bed and Bedding	35 lb/acre	0 lb/acre
Planting	15	30
Emergence (cracking)	100	80-90
Plant Height of 4-8 Inches	100	80-90
Supplemental*	30	30
TOTAL	280	220-240

This management guide was subsequently used by the land owner for his entire potato crop in 2003. Since it was not acceptable to grow another crop of potatoes on the demonstration field, we decided to monitor a similar nearby pivot planted to potatoes. Both the fertilizer application and the irrigation were followed very closely by project personnel. It appeared that the management plan developed by the project was being followed quite closely by the farm managers. The one exception to this was an application of 35 lbs of N/acre at the post-bloom stage. This was in response to slight loss of leaf color which the land owner addressed with additional nitrogen. However, the color change was more likely due to the plant's physiological maturation process. It should be noted, however, that the IFAS recommendations do allow for 30 lbs/acre of additional nitrogen if the field has received a leaching rainfall event and this did occur on at least two occasions (26 inches of rainfall occurred during the growing season). Thus, the N applied to this field only exceeded IFAS recommendations by 20 lbs/acre.

This field was the highest yielding field on the farm (320 cwt/acre)(Table 5). According to the packing shed supervisor, it also maintained the highest quality of potatoes. The next highest yield was 284 cwt/acre and the range was 209 – 320 cwt/acre for the farm.

Partial N mass budget for three potato crops:

Partitioning of N sources and fates is presented in Table 5. N for potato production is mostly supplied from fertilizer. The potential fates on this farm include plant uptake, leaching, volatilization, and denitrification. N fertilizer use efficiency is the proportion of the fertilizer applied that is taken into the plant. In these studies N use efficiency (NUE) ranged from 30 to 53%. These values are on the low side of most published ranges for NUE. A probable loss pathway for the unaccounted-for N would be leaching on this sandy soil.

Dye studies to evaluate potato root distribution and nitrogen movement in potato beds

We used a water soluble marking dye to mimic the movement of nitrogen in potato beds and root zones in a commercial potato field. The photos show how the dye is used to mark fertilizer bands in the bed (Figure 3 A and B). Dye tracing illustrated the movement of water in the bed. Following irrigation from the center pivot system, the dye begins to move downward and laterally from the bands (Figure 3 C and D). A dry area forms in the center of the bed directly below the plant crown (Figure 3 E and F) and most of the active roots are in the upper part of the bed (Figure 3 G and H). Managing irrigation to apply water replaced by evapotranspiration maintained the dye (fertilizer) in the root zone for uptake by the plant, even though this management practice led to a somewhat dry area directly below the plant crown. Potato roots were observed extending to a depth of about 12 inches and laterally to the row middle, the area between adjacent beds (Figure 3 G and H). In addition, potato roots were prevented from penetrating the hard pan (plow pan) about 12 inches below the bed surface (Figure 3 H). Roots can be observed growing into the crack in the hardpan caused by the chisel plow tip (Figure 3 H).

The following observations were made about potato root growth from the dye studies:

- Soluble nutrients can move rapidly in the soil in the potato bed when irrigation water is applied.
- Applying correct amounts of water minimizes the movement of water below the root zone. Correct irrigation amounts and timing kept the N in the upper portions of the bed.
- Dye tests showed that potato roots were largely found in the upper 12 inches of the bed and extended laterally into the area between the rows.
- A hardpan in the field prevented deeper root distribution.

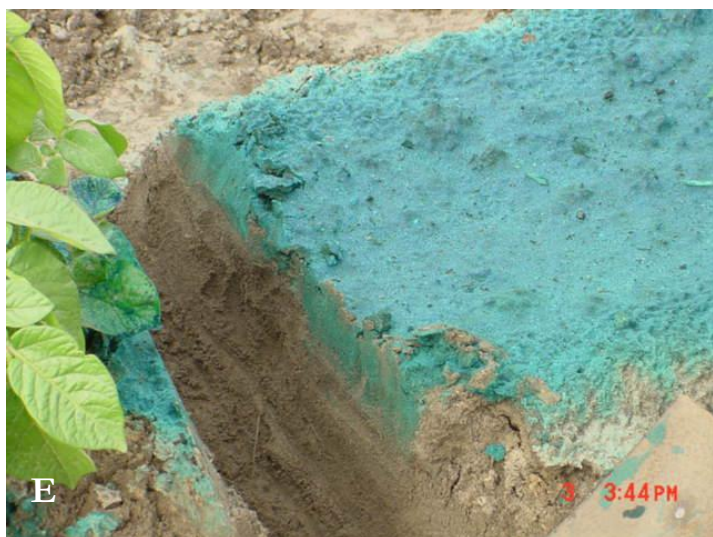


Figure 3. Use of water-soluble blue dye tracer to visualize N and water movement in a potato bed.



Figure 3 (continued). Use of dye tracer to mimic N and water movement in a potato bed.

Overall crop responses-summary:

Crop yield and quality were not adversely affected by any of the BMPs implemented. In fact, in the case of the potato crops, potato quality was improved because the improved irrigation management reduced the number on lenticels resulting in more potatoes being graded as marketable.

Based on the improved efficient use of both fertilizer and irrigation water, it is anticipated that an additional small reductions in groundwater nitrate concentrations will be observed over time. Because of the environmental conditions present in the basin (sandy soils, karst topography, intense leaching rainfall) it may be difficult to achieve acceptable nitrate conditions without the implementation of additional BMPs. The use of additional BMPs that incur additional costs such as slow-release fertilizers is likely to have significant economic implications for the producers.

BMPs for Row Crop Farms:

A “farmer-friendly” potato management guide was developed based on our results and experience. It is anticipated that the fertilization and irrigation BMPs recommended in this management guide will result in a 30% fertilizer reduction and 20-30% irrigation reduction without decreasing yields. The cooperating farmer implemented the BMPs recommended in the guide on his entire potato crop and it is anticipated that other growers in the area will implement these BMPs as they are made aware of them through field days being held in the area.

Groundwater nitrate-N concentrations:

Ground water monitoring data for the row crop farm (Figure 4) are presented for the grower half of the pivot field (grower managed), the BMP half (project managed), and perimeter wells outside of the cropped area. Sweet corn (SWC), cotton (COT), Potatoes (POT), tropical corn (TC), peanuts (Pnuts) and carrots were the crops grown during this evaluation period. Emphasis for management was given to the two crops that are heavy users of fertilizer, i.e., sweet corn and potatoes. Fertilizer and irrigation management were emphasized in the BMP program for the project-managed half of the field. Fertilizer BMPs consisted of decreasing the amounts of fertilizer used and improving the application time relative to crop needs. Irrigation BMPs involved improved management of the amount and timing of irrigation applied. Fertilizer and irrigation BMP details are given in the appendices. The effects of the cropping activities are readily seen by comparing the nitrate concentrations in the perimeter wells to those in the cropped areas. In the perimeter wells, nitrate-N concentrations were generally near 5 mg/L until the middle of 2003 when the concentrations started to approach 10 mg/L. We were not able to ascertain the reason(s) for this increase although there were significant amounts of rainfall during the preceding months. It should also be noted that this field is surrounded on all sides by similar center pivot systems growing similar crops which may potentially influence the perimeter wells.

Nitrate-N concentrations in the ground water were affected by crop fertilization as evidenced by the greater concentrations in wells within the field compared to the perimeter wells. Nitrate concentrations tended to respond (increase) to the heavily fertilized crops (sweet corn and potatoes) within a few months after growing these crops. They then tended to decrease subsequent to the low nitrogen requiring crops cotton, tropical corn, and peanuts.

Averaged values for the grower-managed and project-managed halves suggest that we were able to reduce nitrate-N concentrations in the ground water with the BMPs (Figure 5). The average annual nitrate-N concentrations for the years 2000 to 2006 are shown in Table 8 and Figure 5. Overall, there were only small decreases in groundwater nitrate concentrations in the BMP side of the field compared to the grower-managed side. On an annual basis, reductions ranged from 5.4 to 21.1% with an average over the whole period of 13.0%. Nitrate-N concentrations for the grower, BMP and perimeter wells differed significantly for each of the years. Concentrations for the BMP side were always significantly lower than those for the grower-managed side, however, the differences were relatively small as a percentage of the total nitrate-N in the groundwater. The small differences probably can be attributed to the fact that, over the monitoring period, the amount of N fertilizer applied to the two sides of the pivot was not very different (See Table 2). Over the years, the grower tended to reduce the amount of fertilizer used on his part of the pivot as he observed that the BMP side was producing similar crop yields with less N fertilizer. Nitrate-N concentrations in the perimeter wells showed an increasing trend during the study period while concentrations in the grower-managed side and the BMP side remained relatively stable, especially during the last four years of monitoring.

As a specific example, the fertilization and irrigation BMPs implemented on the second season potato crop resulted in a 30% N fertilizer reduction and 20-30% irrigation reduction without decreasing yields. N losses, as predicted by modeling, were reduced by about 35% over previous practices.

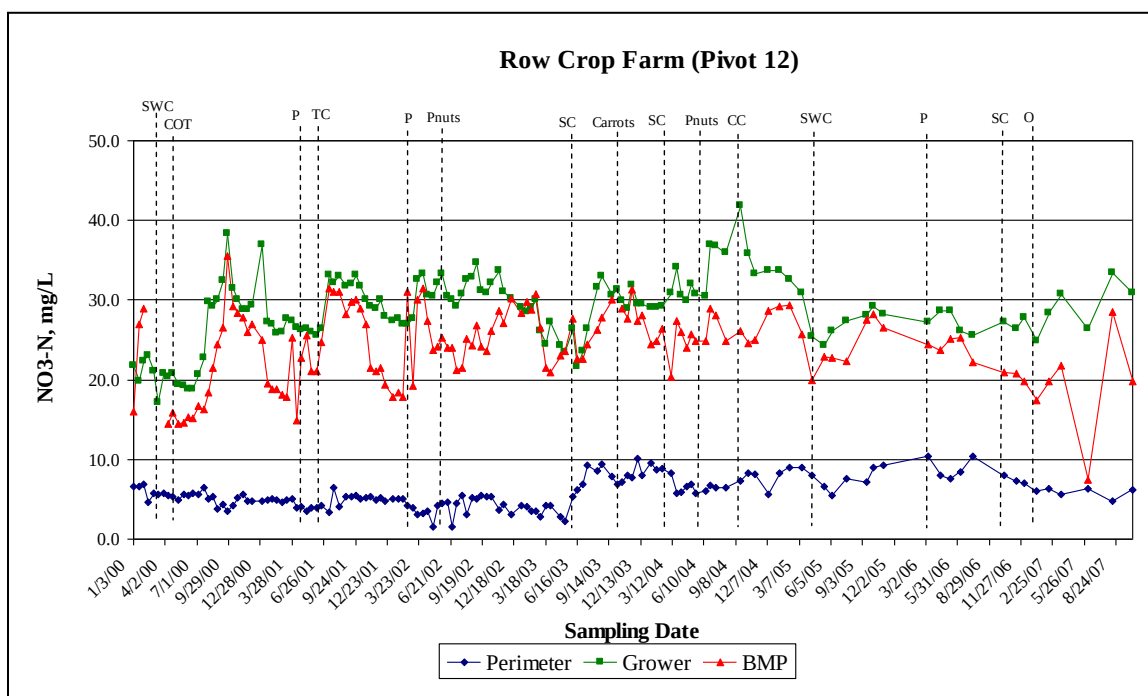


Figure 4. Nitrate-N concentrations in ground water monitoring wells at the row crop farm. Perimeter represents the three wells outside of the cropped field. The grower and BMP halves of the field represent areas that were managed by the grower and by the project staff, respectively.

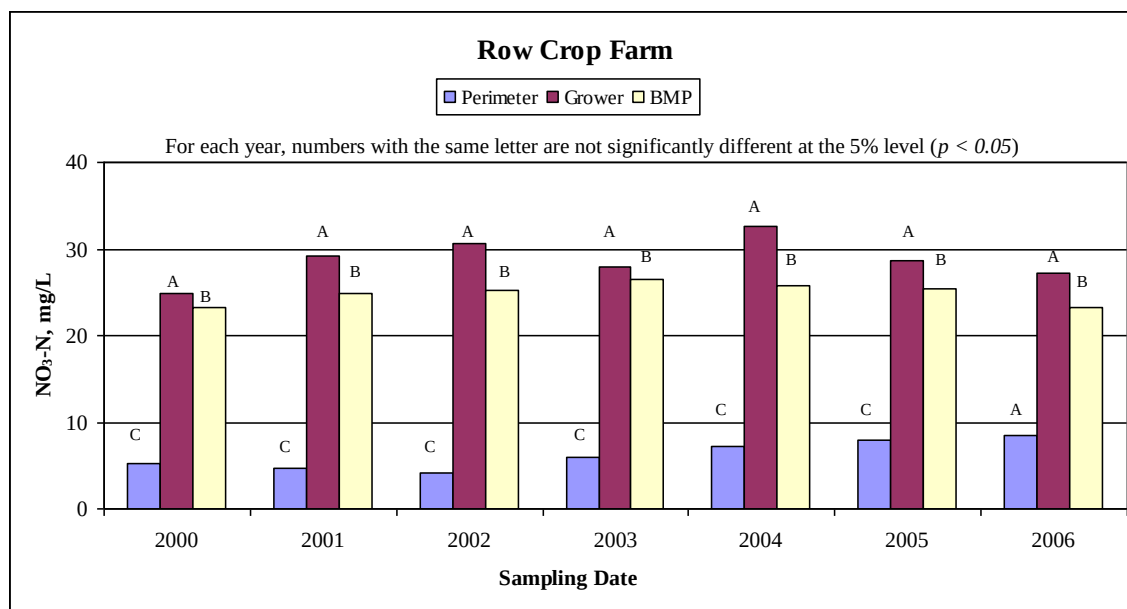


Figure 5. Average annual nitrate-N concentrations in ground water monitoring wells at the row crop farm.

Table 8. Average annual nitrate concentrations in the groundwater monitoring wells at the row crop farm.

Location	2000	2001	2002	2003	2004	2005	2006
	----- NO ₃ -N, mg/L -----						
Perimeter	5.3CD ^c	4.7CD ^c	4.2D ^c	6.0BC ^c	7.2AB ^c	7.9A ^c	8.4A ^c
Grower	24.8E ^a	29.1BC ^a	30.7B ^a	28.0CD ^a	32.7A ^a	28.7CD ^a	27.2D ^a
BMP	23.2A ^b	24.9A ^b	25.3A ^b	26.5A ^b	25.8A ^b	25.4A ^b	23.2A ^b
Percent Difference*	6.4 %	14.6 %	17.6 %	5.4 %	21.1 %	11.3 %	14.7 %

Uppercase letters represent significant differences ($p < 0.05$) among annual means for each location

Lowercase letters represent significant differences ($p < 0.05$) among means for each year

* Percent Difference between the annual means of the grower and the BMP halves

Soil pore water nitrate-N concentrations:

Nitrate-N concentrations in the one- and two-meter lysimeters at the vegetable farm by sampling date are shown in Figures 6 and 7, respectively. The average nitrate-N concentrations over all sampling dates at the one-meter depth were 39 and 37 mg/L for the grower-managed and BMP sides, respectively. Comparable concentrations at the two-meter depth were 35 and 38 mg/L. These were not significantly different for either depth. Concentrations for the grower-managed and BMP sides at the one-meter depth mirrored each other relatively closely but differences were observed at the two-meter depth. During the 2003-2004 seasons, the grower-managed side showed several peak concentrations that were much greater than observed on the BMP side. During the 2006 season, peak concentrations were observed earlier in the season for the BMP side than the grower-managed side. Reasons for these differences were not apparent from any of the irrigation and fertilizer management schemes used at these two periods. When averaged on an annual basis there were also no significant differences observed at the one-meter depth (Figure 8 and Table 9) or the two-meter depth (Figure 9 and Table 10).

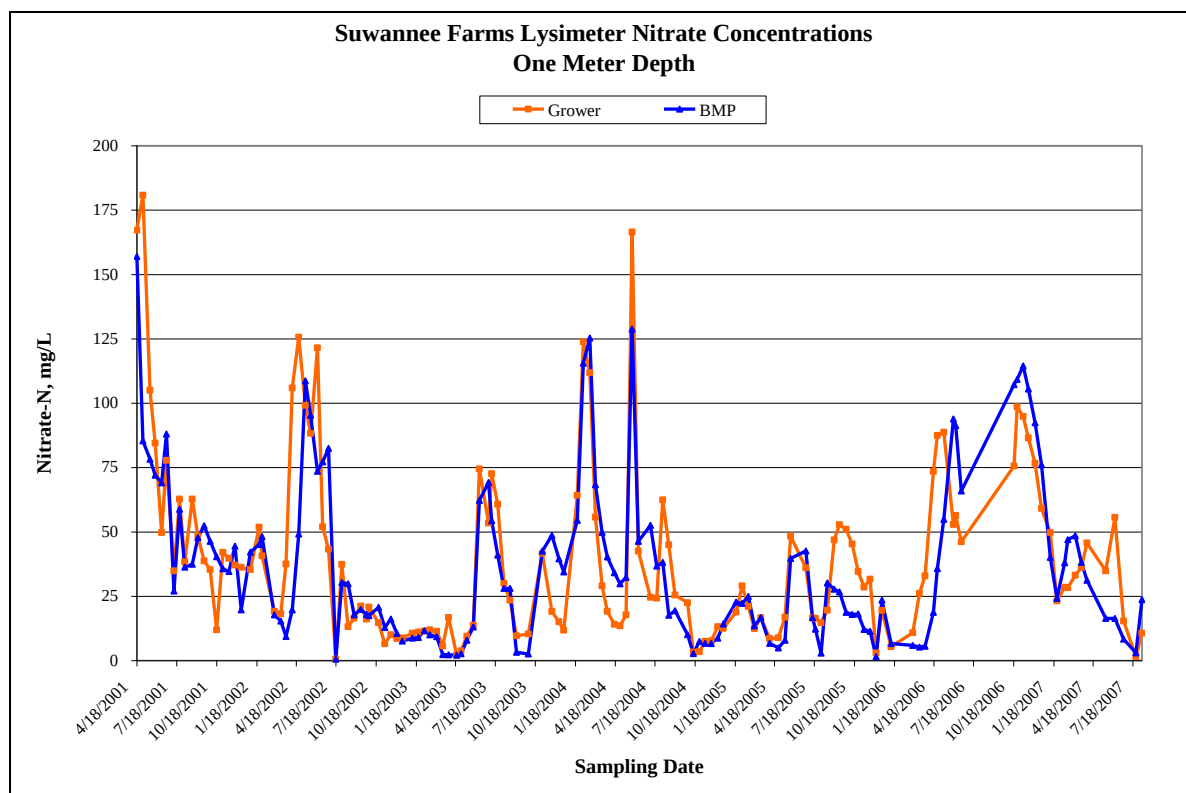


Figure 6. Nitrate-N concentrations in the one-meter lysimeters samples (soil solution) for the “grower” and “BMP” sides of the pivot.

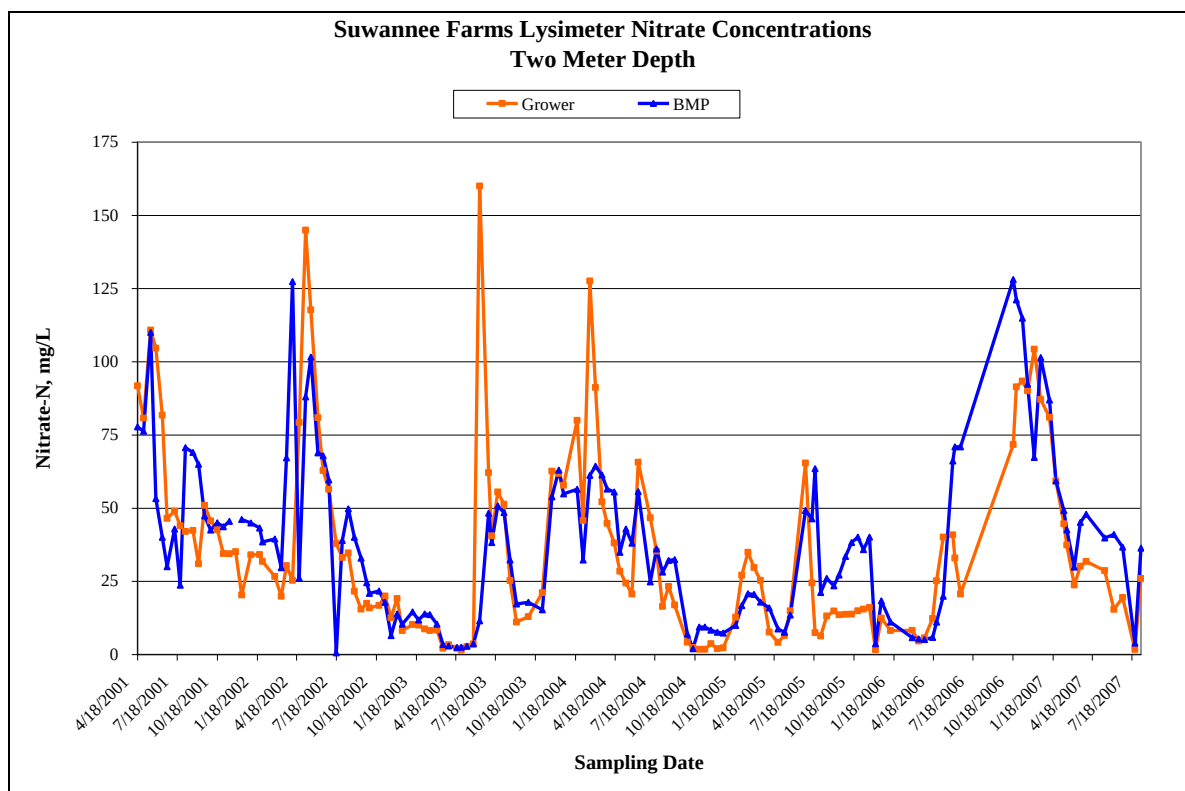


Figure 7. Nitrate-N concentrations in the two-meter lysimeters samples (soil solution) for the “grower” and “BMP” sides of the pivot.

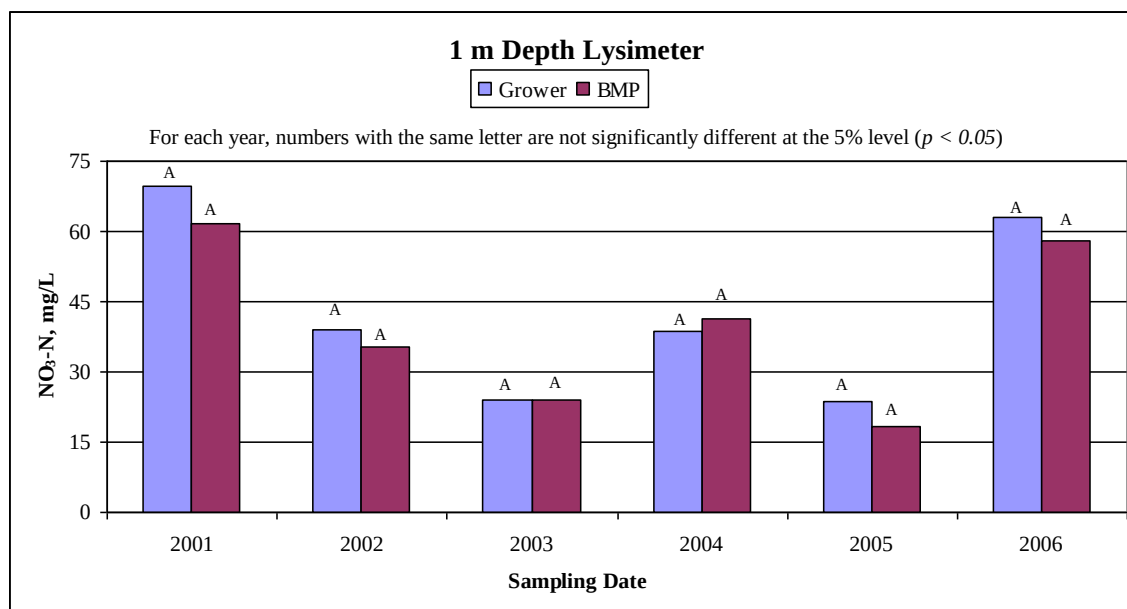


Figure 8. Average annual Nitrate-N concentrations in the one-meter lysimeters samples (soil solution) for the “grower” and “BMP” sides of the pivot.

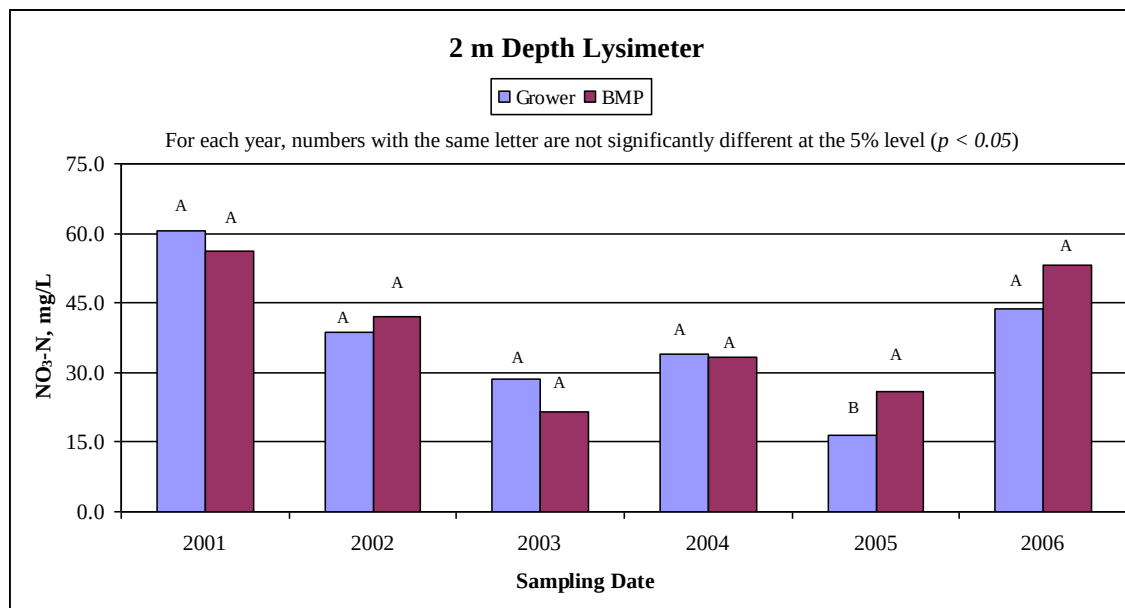


Figure. 9. Nitrate-N in the two-meter lysimeters samples (soil solution) for the “grower” and “BMP” sides of the pivot.

Table 9. Average annual nitrate-N concentrations in the one-meter lysimeters at the row crop farm.

Location	2001	2002	2003	2004	2005	2006
	----- NO ₃ -N, mg/L -----					
Grower	69.5Aa	39.1Ba	23.9Ca	38.7Ba	23.6Ca	63.1Aa
BMP	61.6Aa	35.2BCa	23.9CDa	41.3Ba	18.2Da	57.9Aa

Uppercase letters represent significant differences ($p < 0.05$) among annual means for each location

Lowercase letters represent significant differences ($p < 0.05$) among means for each year

Table 10. Average annual nitrate-N concentrations in the two-meter lysimeters at the row crop farm.

Location	2001	2002	2003	2004	2005	2006
	----- NO ₃ -N, mg/L -----					
Grower	60.5A ^a	38.8B ^a	28.5BC ^a	34.1B ^a	16.6C ^b	43.8B ^a
BMP	56.1A ^a	42.1B ^a	21.5D ^a	33.4BC ^a	26.0CD ^a	53.2A ^a

Uppercase letters represent significant differences ($p < 0.05$) among annual means for each location

Lowercase letters represent significant differences ($p < 0.05$) among means for each year

Several sinkholes opened up in the field during the course of the study (Figure 10). These sinkholes provided direct observation of open channels in the soil that were also observed during soil sampling. On several occasions during soil sampling, the soil augur would freely drop several meters as it hit one of these channels. We suspect that these open channels could direct water toward some of the wells and may be responsible for some of the variability that we observed in the nitrate-N concentrations in the wells, particularly on the BMP half of the pivot.



Figure 10. An example of a sinkhole that opened in the demonstration field during the course of the project. Also note the open channels that were exposed by the sinkhole.

Since the 2003 potato crop was moved to a different field (without monitoring wells), we installed vacuum lysimeters in the field to monitor soil solution nitrate-N concentrations. Lysimeters were installed at 1 and 2 meter depths and at the surface of the clay layer which was generally in the vicinity of 5 meters deep. Ten locations were sampled within the pivot. The average $\text{NO}_3\text{-N}$ concentration in the lysimeter water samples for each depth is shown in Figure 11. Nitrate-N concentrations begin to increase at the one-meter depth during April with major increases noted during the May sampling dates. This nitrate began showing up at the two-meter depth during May. The deeper lysimeters at the clay layer did not reflect any increased nitrate concentrations during the study period. Lysimeter sampling was suspended on May 25th as the lysimeters had to be removed from the field prior to harvesting. The relatively high nitrate-N concentrations at the one meter depth, which is below the root zone of potatoes, are indicative of the difficulty of keeping nitrate in the root zone of crops such as potatoes.

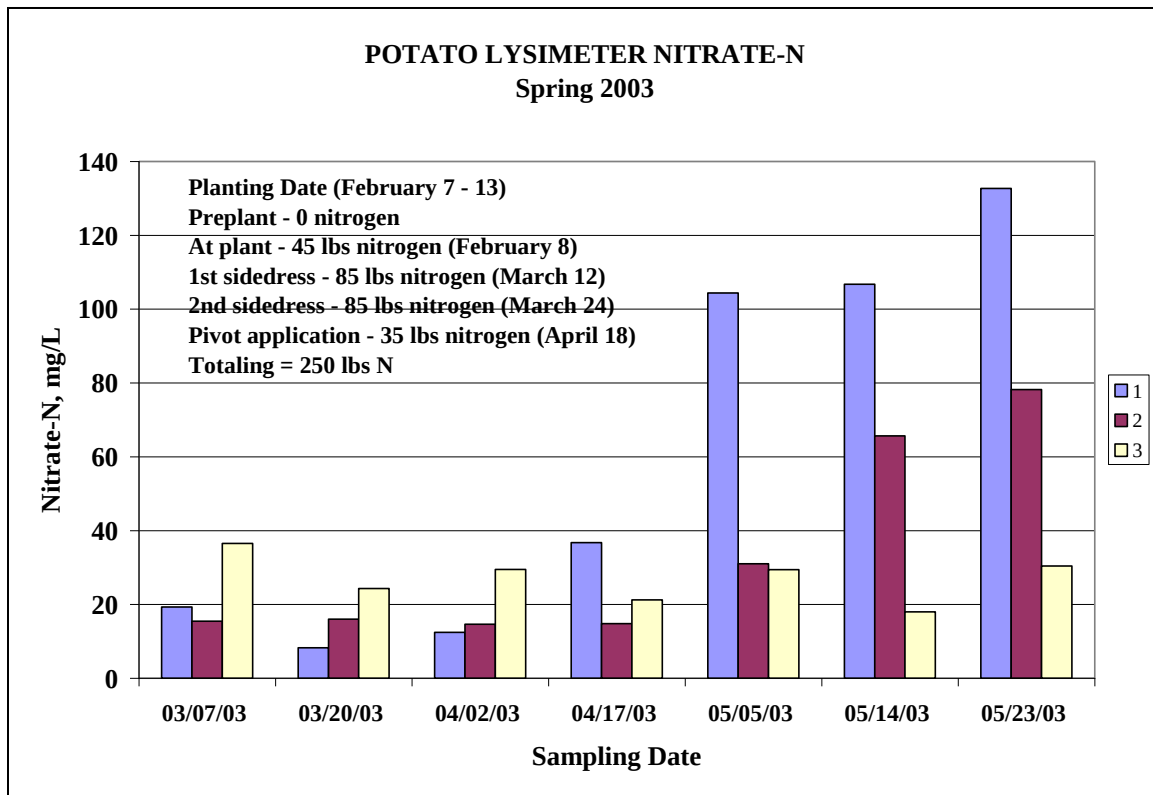


Figure 11. Nitrate-N concentrations in the soil solution extracted with vacuum lysimeters in the 2003 potato field. Lysimeters were installed at 1 and 2 meters depths plus at the upper surface of the clay layer within the soil profile (#3 in the legend).

Soil nitrate-N concentrations:

The average depth to the clay layer is shown in Figure 12. Clay depths ranged between 2.5 and 4.5 meters and showed considerable fluctuation. The clay layer at the vegetable farm also showed some discontinuities. Thus, there appears to be more opportunities for direct movement of water and nitrate into the groundwater at the vegetable farm.

Average soil profile nitrate concentrations (2 m depth) at the vegetable farm reflected the cropping activities on the field (Figure 13). Highest concentrations were observed during the periods when potatoes and sweet corn were grown reflecting the high fertilize use with these crops. We did not observe differences in soil nitrate-N concentrations between the farmer-managed and project-managed sides of the pivot. This is also true when concentrations are averaged on an annual basis (Figure 14 and Table 11). The relatively small differences in amount of N applied between the two halves of the pivot have made it difficult to see differences in both soil and groundwater nitrate-N concentrations. However, we observed a continuing trend in decreasing soil nitrate-N concentrations for both the grower-managed and BMP sides of the field through 2005. This may be attributed to the farmer fine tuning his fertilization and irrigation practices each year so that both management programs, taken together, resulted in lower soil nitrate-N concentrations each year. The increase observed in 2006 can be attributed to higher amounts of N fertilizer applied to both sides of the pivot.

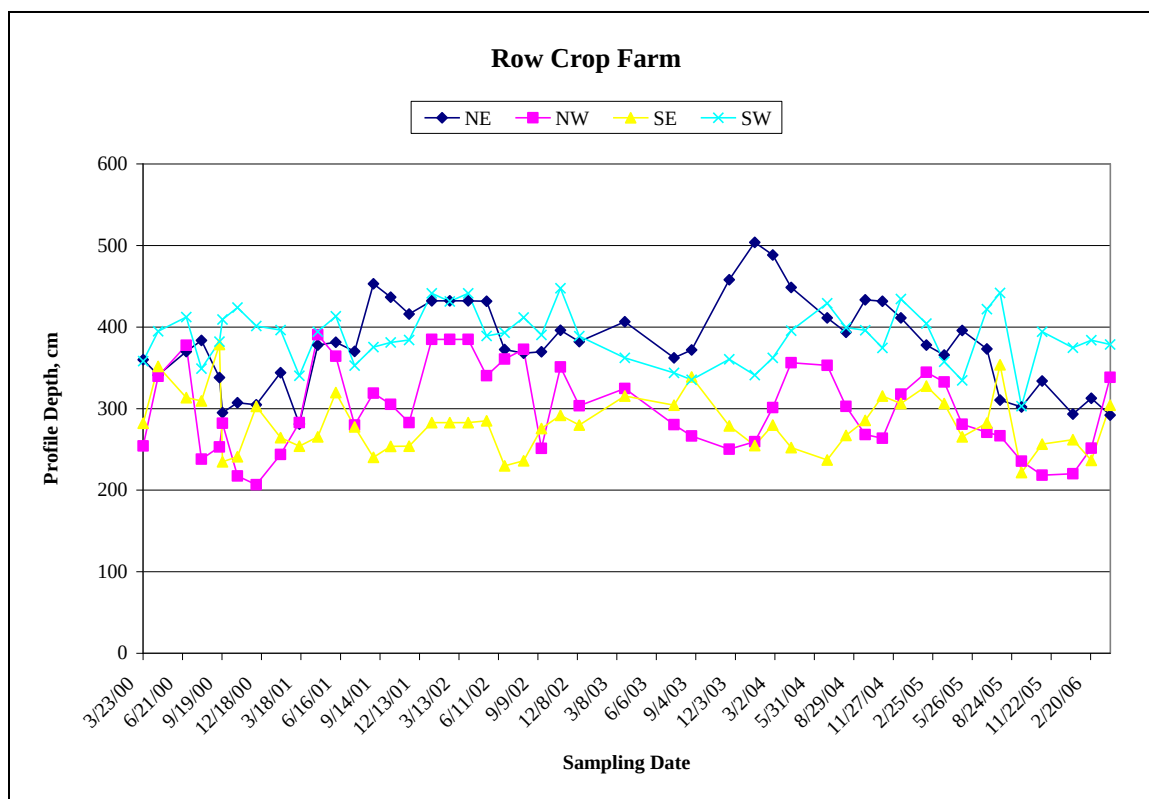


Figure 12. Average depth to the clay layer for the northeast, northwest, southeast and southwest quadrants of the vegetable farm center pivot field.

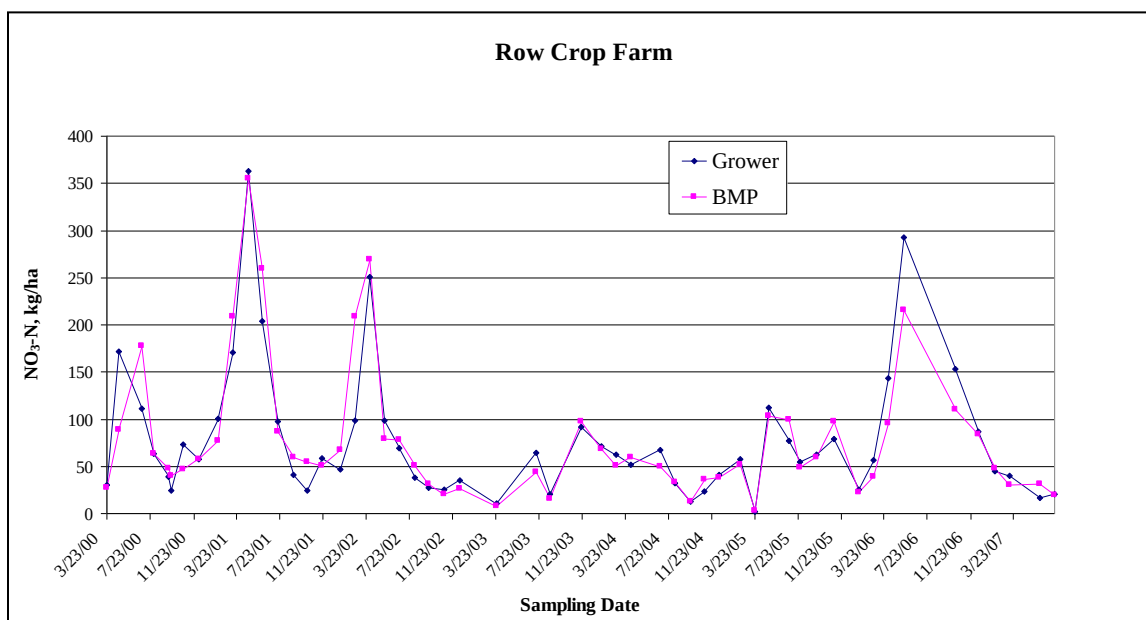


Figure 13. Average nitrate-N concentrations in the soil profile (2 m depth) of the farmer-managed (grower) and project-managed vegetable farm center pivot field.

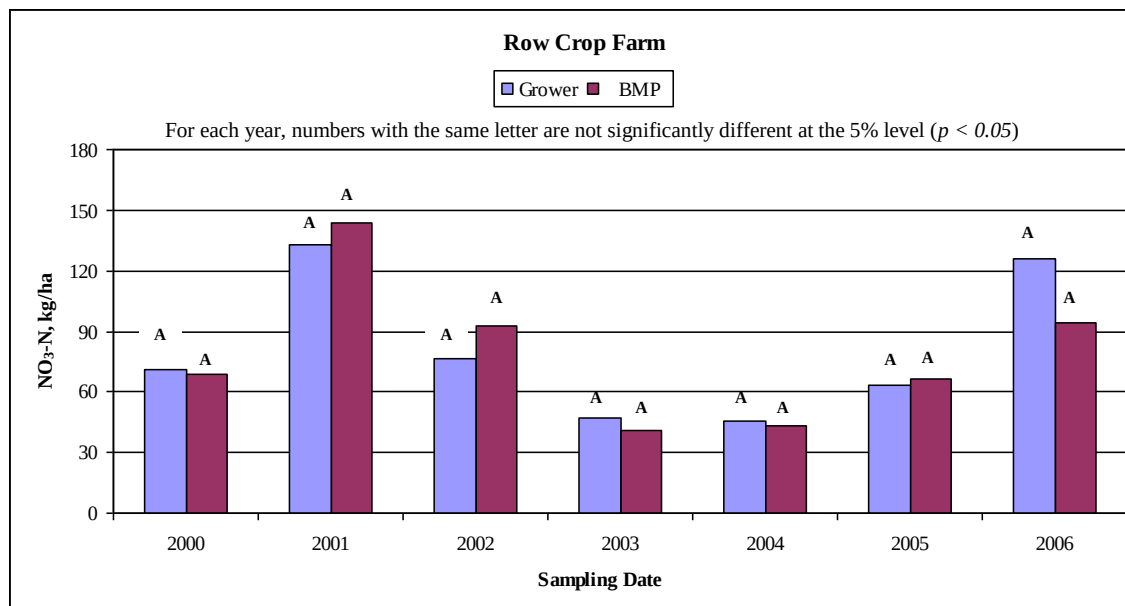


Figure 14. Average nitrate-N concentrations in the soil profile (2 m depth) of the farmer-managed (grower) and project-managed vegetable farm center pivot field.

Table 11. Nitrate-N in the soil profile (2 m depth) on a yearly average basis at the row crop farm.

Location	2000	2001	2002	2003	2004	2005	2006
	----- NO ₃ -N, kg/ha -----						
Grower	71.20A ^a	132.57A ^a	76.60A ^a	47.05A ^a	45.31A ^a	63.70A ^a	126.28A ^a
BMP	68.73AB ^a	144.01A ^a	92.55AB ^a	41.17B ^a	43.49B ^a	66.36AB ^a	94.52AB ^a

Uppercase letters represent significant differences ($p < 0.05$) among annual means for each location

Lowercase letters represent significant differences ($p < 0.05$) among means for each year

Modeling nitrate N responses:

The soil, crop and groundwater data were used to test and calibrate models that predict water and nitrate movement through the root and vadose zones. Two existing models, the DSSAT crop model and the Leaching Estimation and Chemistry Model (LEACHM) were used. DSSAT is a shell tool containing several crop models. The SUBSTOR potato model contained within the DSSAT shell was used to predict N and water uptake/leaching in the root zone, evapotranspiration, as well as crop yield and phenological response to water and nutrient management practices. The LEACHM model is a hydrologic model that has more rigorous vadose zone and water flow and contaminant transport routines than the DSSAT model. LEACHM was used to predict water/nitrogen transport within the root zone, through the vadose zone, and to the groundwater.

Modeling was conducted for the potato crops grown in 2001, 2002, and 2003. Figures 15 through 20 summarize the accuracy of the model predictions for nitrogen uptake, nitrogen leaching and total yield for each year.

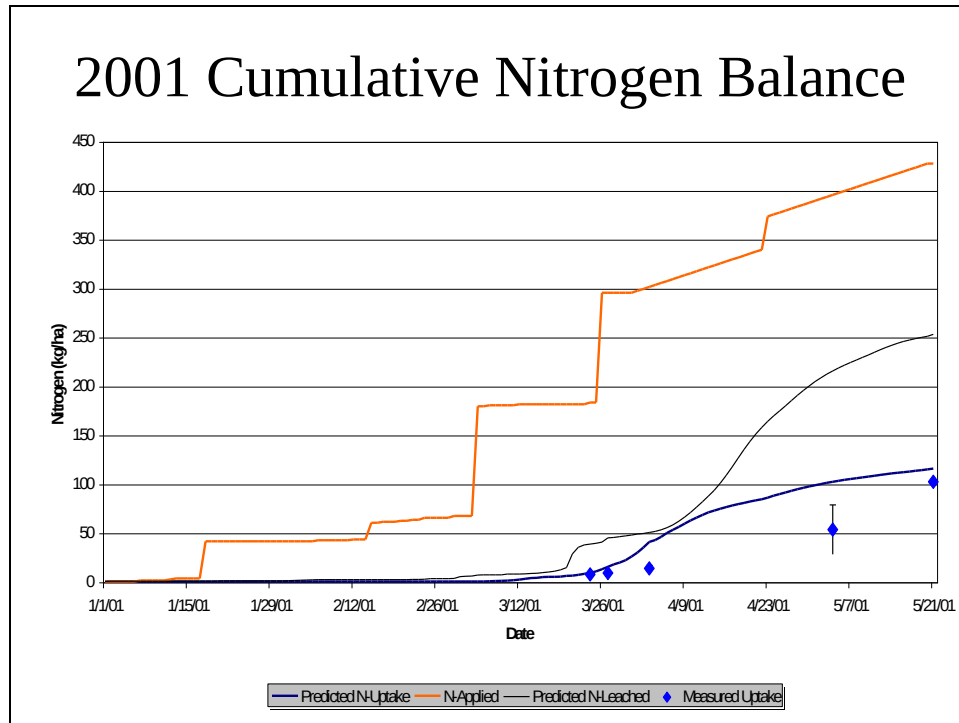


Figure 15. Predicted nitrogen balance and observed nitrogen uptake for the Spring 2001 potato crop.

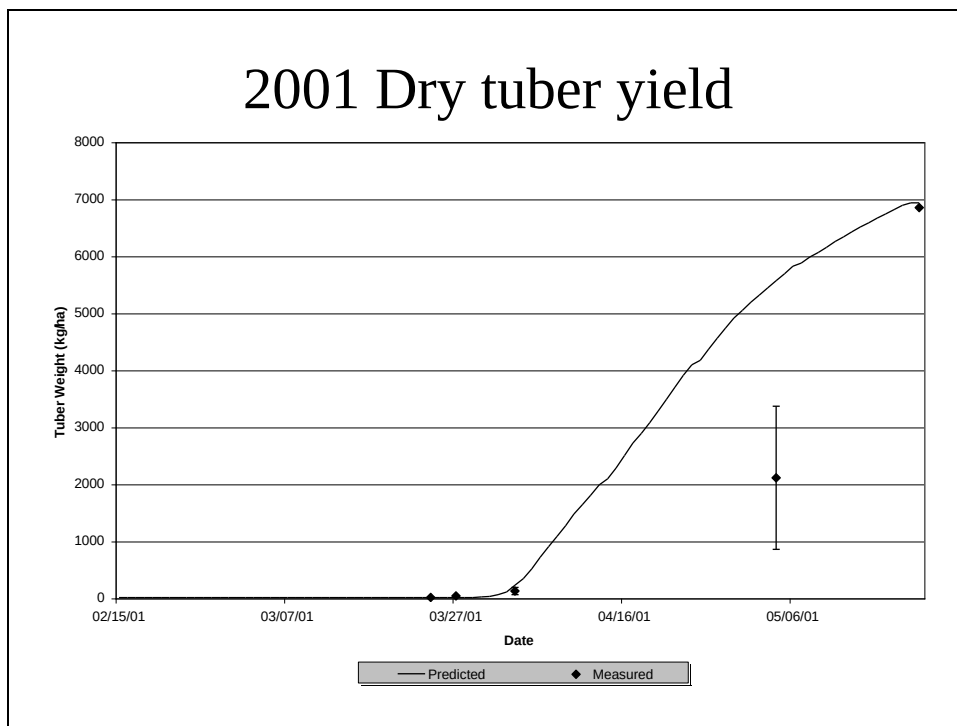


Figure 16. Measured versus predicted yield for the Spring 2001 potato crop.

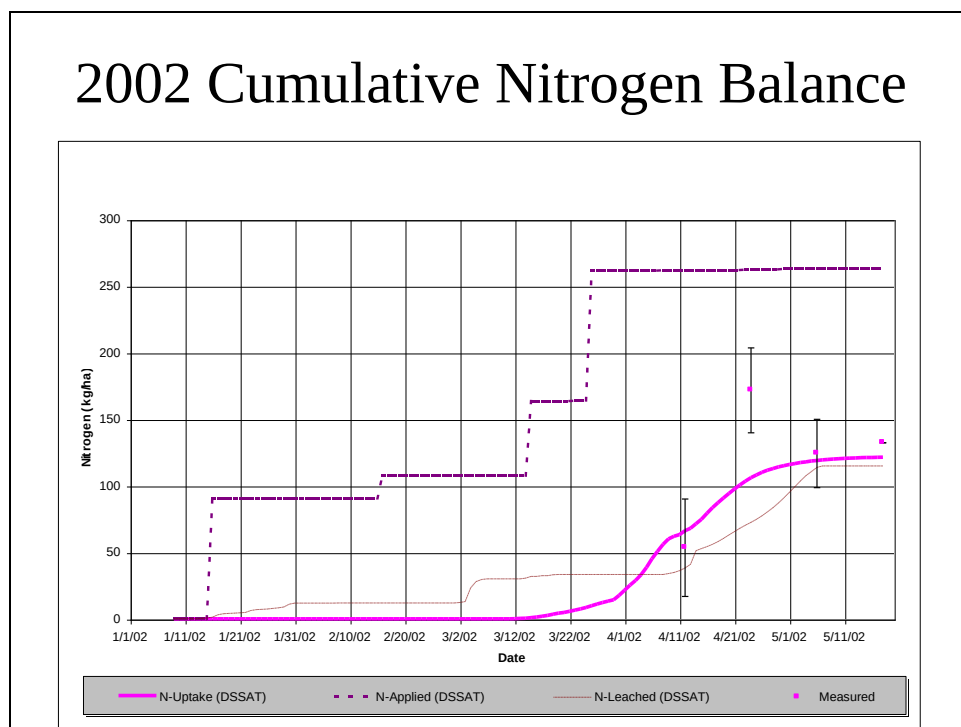


Figure 17. Predicted nitrogen balance and observed nitrogen uptake for the Spring 2002 potato crop

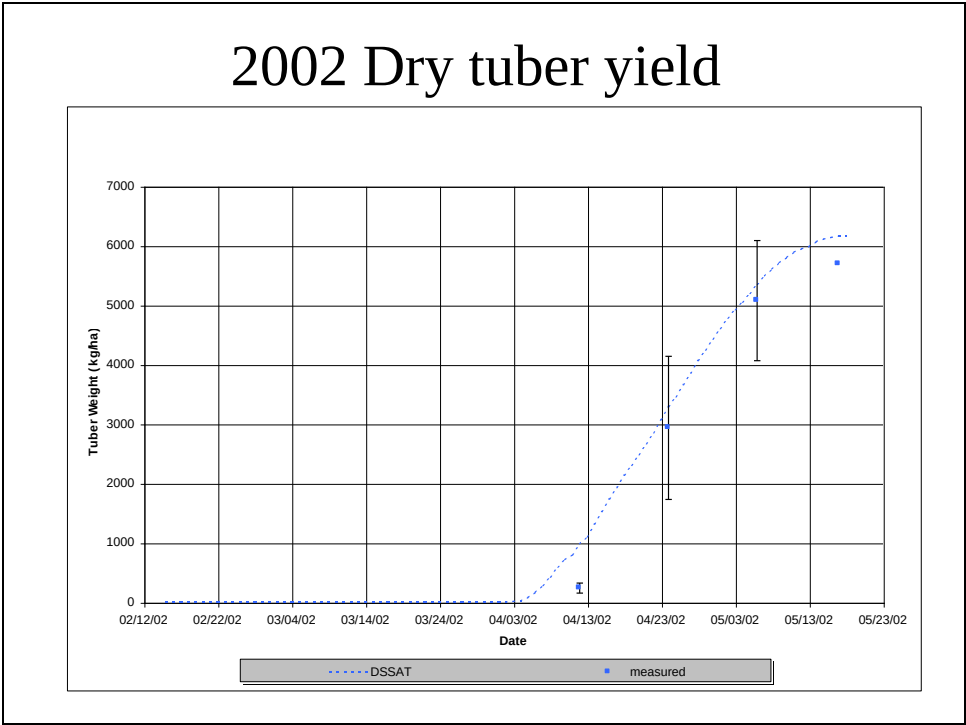


Figure 18. Measured versus predicted yield for the Spring 2002 potato crop.

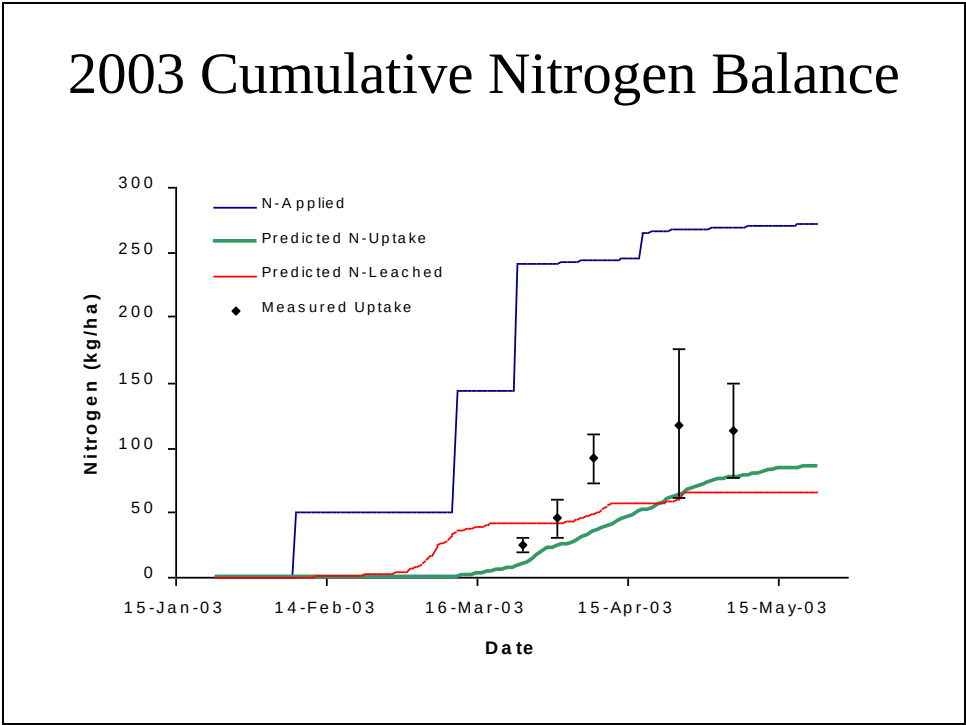


Figure 19. Predicted N balance and observed N uptake for the Spring 2003 potato crop.

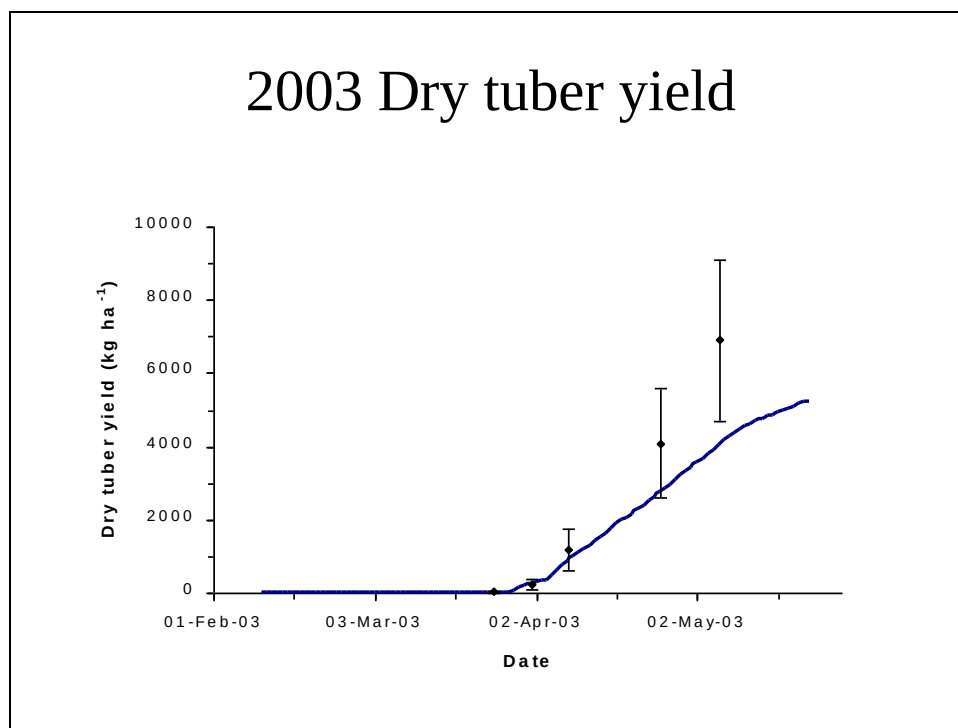


Figure 20. Measured versus predicted yield for the Spring 2003 potato crop.

Results in Figures 15 through 20, show that the model predictions and observed data are in good agreement with each other. Nutrient and water data collected in the field compared well with observed fertilization dates and rates, and closely matched model predictions for both DSSAT and LEACHM. The crop growth model accurately predicted dry tuber yield, phenological development, and plant N concentration but overestimated stem weight and underestimated leaf weight. Simulations run with the crop model appeared consistent with trends observed in other potato studies and provided much insight into plant –nutrient interactions.

Both model predictions and measured data demonstrated the rapid leaching caused by rains and/or over-irrigation in the well-drained sandy soils at the row crop site. The model demonstrated that in general fertilizer applications are completely leached below the root zone within two weeks of the application. Rapid leaching due to applied irrigation can be avoided by taking precautions to insure no excess water is applied above field capacity which lies at about 6-7% volumetric water content for soil at the row crop site. Modeling results suggested that irrigation historically applied by the farmer could be cut by as much as 30% without stressing the plants. Model predictions and measured data both indicate only about 30% of the N applied was taken up by the potatoes, which is supported by the literature reviewed.

After the model was tested against the observed field data, it was used to predict crop and water quality response for alternative management practices (Figure 21). The results show that by reducing the amount of irrigation, reducing the fertilizer application rate, and improving the timing of fertilizer applications, nitrogen leaching could be reduced by approximately 50% while maintaining acceptable crop yields. Yields seem to stabilize at around the 225 kg N/ha fertilizer rate which is the IFAS recommendation (a reduction of 29% from historic management practices). However, all scenarios modeled indicate that average nitrate concentrations leaching

below the root zone will exceed the EPA MCL of 10 mg/L NO₃-N during the potato cropping season, even with BMPs implemented during the 2002 season. Thus, it is important to recognize that a cropping system that rotates crops requiring high amount of N with crops requiring low amounts of N, such as various cover crops, peanuts, and cotton may be required to meet the EPA MCL.

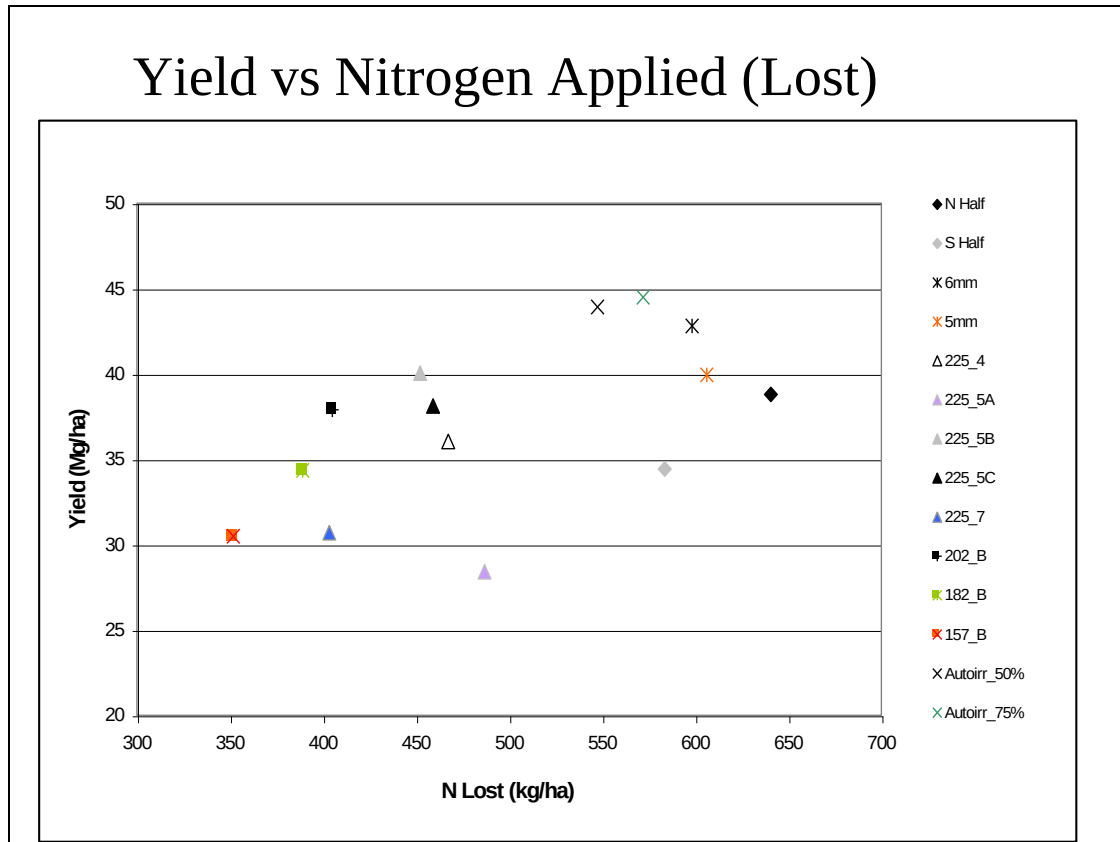


Figure 21. Yield versus N lost of alternative potato management practices.

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