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ASSESSMENT OF THE PROFITABILITY OF PRECISION FARMING IN IRRIGATED COTTON PRODUCTION

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Abstract

A dynamic optimization model which introduces an intertemporal nitrate-nitrogen carry-over function in the optimization procedure is used to derive and evaluate optimal nitrogen application rates, average yield, and the net present value of return associated with precision farming and conventional whole-field farming practices for irrigated cotton production in the Southern High Plains of Texas for a 10-year planning horizon. The results allow cotton producers to adopt decision rules concerning nitrogen application rates for a long-term planning horizon. The results of the study also indicate that the nitrogen-cotton-water price ratios vary the optimal nitrogen application rates.

Problem Statement

Input costs are key to the profitability of producers. Efficient use of nitrogen fertilizer is important because excess use is not only detrimental to the environment, but increases input costs. Alternatively, if suboptimal amounts of nitrogen are used, yields decrease, thus decreasing net revenues. Therefore, deriving optimal amounts of nitrogen application under various water prices, cotton prices, and nitrogen prices can decrease unnecessary environmental repercussions as well as increase the net present value of returns (Jokela and Randall, 1989; Makowski, Wallach, and Meynard, 1999; Onken and Sunderman, 1972; Raun, Johnson, and Westerman, 1999; and Varvel and Peterson, 1990).

Objectives

The specific objectives of this study were to:

- Derive a production function for the Lamesa field.
- Derive a residual nitrate-nitrogen forecasting model.
- Determine optimal nitrogen application rates, corresponding average optimal yields, and net present value of returns over a 10-year planning horizon.

Methods and Procedures

Data was collected on test plots in Lamesa, Texas for 1998 and 1999 cotton. Twenty-six locations in the field were identified for data gathering purposes. Four replications for each of the twenty-six locations were taken. A Global Positioning System (GPS) was used to determine the latitude and longitude of the location in the field. Two irrigation water levels were used, one at 50% ET and the other at 75% ET. Altitude was measured for each location as well as for residual nitrate-nitrogen. The residual nitrate-nitrogen was measured from 0-0.3, 0.3-0.6, 0.6-0.9, and 0.9-1.2 meters of the soil depth profile. Nitrogen was applied at three different rates including 0, 80, and 120 lbs./acre. Sand, clay, and silt content in the soil were measured as well. The data for the replications per location were averaged so one value of yield, for example, would be associated with the level of each input or location's characteristics.

Yield was found to be a function of total nitrogen, altitude, sand, silt, water, and year. Yield was hypothesized to have a positive relationship with total nitrogen, which is a function of residual nitrate-nitrogen from 0-0.6 meters and nitrogen application. Yield was also hypothesized to have a positive relationship with water. Altitude and clay were hypothesized to have a negative effect on yield. Silt and year did not have any preconceived relationship either positive or negative. The residual nitrate-nitrogen function that estimated the residual nitrate-nitrogen from 0-0.6 meters in the soil depth profile at the end of the season, was found to be a function of residual nitrate-nitrogen from 0-0.6 meters in the soil depth profile at the beginning of the season, nitrogen applied, water, and year. Nitrogen applied and residual nitrate-nitrogen at the beginning of the season were hypothesized to have a positive relationship with residual nitrate-nitrogen at the end of the season. Water was hypothesized to have a negative relationship with residual nitrate-nitrogen at the end of the season. The years 1998 and 1999 had no preconceived relationships.

The rational behind the relationships for the yield equation is as follows. Nitrogen, whether, applied or residual in the soil, is a fertilizer, which helps cotton to grow, therefore it should have a positive impact on cotton yield. Water accumulates in lower portions of the field and therefore altitude was thought to have a negative relationship with yield. Sand is very permeable as compared to clay and thus allows water to infiltrate into the soil, whereas silt is somewhere between sand and clay in texture. This lends to the positive relationship for sand, negative for clay, and the indeterminate relationship for silt. For the residual nitrate-nitrogen equation, nitrogen applied and residual nitrate-nitrogen at the beginning of the season increase the amount of residual nitrate-nitrogen at the end of the season because they are the same input. Water has the opposite relationship to residual nitrate-nitrogen at the end of the season than with yield because water mixes with the nitrogen and carries residual nitrate-nitrogen deeper into the soil and washes away the nitrogen applied on top of the soil.

Yield was measured in lbs./acre and is represented as Y. Total nitrogen is the sum of nitrogen application in lbs./acre and residual nitrate-nitrogen from 0-0.6 meters of the soil depth profile at the beginning of the season in lbs./acre and is defined as NT. Altitude is measured in feet above a base point and is defined as ALT. Sand, clay, and silt were measured as a percentage of the soil content and total 100%. They are defined as SAND, CLAY, and SILT, respectively. Water is a dummy variable with two levels, 50% ET and 75% ET. It is defined as W, with 0 representing 50% ET and 1 representing 75% ET. Year is a dummy variable as well, with 0 representing 1998 and 1 representing 1999, defined as YEAR. Residual nitrate-nitrogen from 0-0.6 meters in the soil depth profile at the end of the season was measured in lbs./acre and is defined as NR_{t+1}. Residual nitrate-nitrogen from 0-0.6 meters in the soil depth profile was measured in lbs./acre at the beginning of the season is defined as NR_t. The functions for yield, equation (1), and residual nitrate-nitrogen at the end of the season, equation (2), with their parameter estimates and associated t-values are listed below.

$$Y = 516.7237 - 0.0097*NT*NT + .0050*NT*ALT*SAND - 14.0392*NT*SILT + \qquad (1)$$

(6.64) (2.48) (2.95) (-2.27)

$$0.1488*ALT*W + 20.4874*YEAR;$$

(4.26) (0.69) $R^2 = .494$

$$NR(t+1) = 53.3405 + 0.0805*NA*W + 0.2083*NR(t) - 37.3192*YEAR; \qquad (2)$$

(5.63) (1.22) (1.62) (-6.25) $R^2 = .53$

The yield equation has all parameters significant at the 95% certainty level, except year. The residual equation has the intercept and the year significant at the 99% certainty level, NR_t significant at the 89% certainty level, and NA*W significant at the 78% certainty level. The R-squared was .494 for the yield model and .53 for the residual model. This indicates that 49.4% of the variation in yield was accounted for by NT_t*NT_t, $NT_t*ALT*SAND$, NT_t*SILT, ALT*W, and YEAR. NA*W, NR_t, and YEAR account for 53% of the variation in NR_{t+1}. Several functional forms were evaluated, with the quadratic functional form best fitting the yield data. A linear model was used for the NR_{t+1} model. The models were estimated using Generalized Linear Modeling procedures (GLM). These results were then used to formulate non-linear dynamic mathematical operation models using the General Algebraic Modeling System (GAMS) to determine optimal decision rules.

Many scenarios can be created in determining optimal nitrogen application by changing the prices of water, cotton, and nitrogen, the interest rate used to determine net present value of returns, and the initial nitrogen residual level in the soil. The deterministic specification of the empirical dynamic optimization models formulated in this study to derive optimal nitrogen fertilizer is expressed as:

$$\text{Max NPV} = \sum_{t=0}^{n}((PC_t*Y_t - PN_t*NA_t - PW_t*ACIN_t)*(BET^{-t})) \qquad (3)$$

subject to:

$$NT_t = NA_t + NR_t, \qquad (4)$$

$$NR_{t+1} = f(NA_t, NR_t)\,(5)$$

$$NR_0 = NR(0), \qquad (6)$$

and $NA_t, NR_t, NT_t \geq 0$ for all t, Where, NPV is the net present value of returns to overhead, risk, management, and all other cotton production inputs in dollars per acre. The planning horizon used was 10 years. PC_t is the price of cotton in dollars/lb. in year t, Y_t is the cotton yield function in year t in lbs./acre, PN_t is the price of nitrogen in dollars/lb. in year t, NA_t is the nitrogen applied in lbs./acre in year t, PW_t is the price of water in dollars/acre-inch in year t, $ACIN_t$ is the acre-inches of water applied in year t, BET is the discount rate plus 100%, NT_t is the total nitrogen in lbs./acre in year t, NR_t is the residual nitrate-nitrogen in lbs./acre in year t, and NR_0 is the initial nitrate-nitrogen level in the soil.

Equation (3) is the objective function. Equation (4) is the equality constraint that sums nitrogen applied and residual nitrate-nitrogen to obtain total nitrogen. Equation (5) is the equation that updates residual nitrate-nitrogen annually, which is necessary for equation (4). Equation (6) is the initial nitrogen residual condition. Non-negative constraints are also specified.

Assuming perfect competition in both the product and factor markets, optimal input use can be obtained by equating the Marginal Value Product to input price, which is equivalent to equating the Marginal Physical Product of Nitrogen to the ratio of input price to output price (MPP = Price Nitrogen/Price Cotton), (Beattie and Taylor, 1993).

Results

The optimization model was solved for the combinations of following conditions: (1) a ten-year planning horizon, (2) two alternative levels of cotton price ($0.40 and $0.60), (3) two alternative levels of nitrogen price ($0.25 and $0.30), (4) two water prices ($2.68/acre-inch and $3.50/acre-inch), (5) a 5% discount rate and, (6) 94 locations with their corresponding initial nitrogen residual levels for precision farming practices, and the two ET groups described above. The initial nitrogen condition was set at the mean level for each scenario for conventional whole-field farming.

Optimal decision rules for applied nitrogen fertilizer varied across periods in the planning horizon for a given nitrogen, cotton, and water price combination at the different levels of nitrogen residual and soil and location characteristics. An additional constraint equating nitrogen applications across the planning horizon for each price combination was added to obtain a simpler decision rule for producers to facilitate in easier management decision-making. As indicated by Segarra et al., 1989, introduction of this type of constraint has been found to not significantly change the level of net present value of returns.

Solutions for the 96-optimization models (94 for precision farming practices and 2 for conventional whole-field farming practices) were obtained using GAMS and are presented in Tables 1 and 2. These tables list optimal total revenue, optimal yield, optimal nitrogen application, tenth season after-season nitrogen residual level for each location (NR10), the nitrogen applied change over whole-field farming, net revenue change over whole-field farming, and yield change over whole-field farming associated with the two management practices. For simplification, only one scenario will be discussed (price nitrogen = $0.25, price cotton = $0.40, and price water = $2.68) for both ET water levels. The results from the other scenarios were found to be very similar to the scenario discussed.

Using MapInfo, optimal levels of spatial nitrogen application rates for the ten-year planning horizon associated with precision farming are depicted in Figure 4. Optimal levels of spatial nitrogen application on a per-acre, per-year basis range from 48.01 to 104.22 lbs./acre. This map is almost opposite of the NO3-N pre-season residual map (Figure 1). Areas with high preseason-nitrogen residual levels tend to require lower nitrogen application. For example, location 25a, which is located in the northern portion of the map, has an initial nitrogen residual level of 69.94 lbs./acre (high level) and an optimal nitrogen application of 56.264 lbs./acre (low level). Also, location 18a, which is located in the southern portion of the field has an initial nitrogen residual level of 26.18 lbs./acre (low level) and an optimal nitrogen application of 107.41 lbs./acre (high level). When assuming traditional whole-field farming practices in this field, optimal nitrogen application rates are 77.368 lbs./acre for the 50% ET level and 81.507 lbs./acre for the 75% ET level.

Tables 1 and 2 compare cotton lint yields under the two management practices. For precision farming practices, yield ranged from 633.368 to 771.844 lbs./acre, and averaged 706.429 lbs./acre under 50% ET, and ranged from 775.212 to 941.124 lbs./acre and averaged 871.911 for 75% ET. A spatial yield map for precision farming practices is shown in Figure 2. The center of the field tends to have higher yield than either the most northern or most southern portions of the field. For example, 26a, the most northern location in the field has a yield of 846.052 lbs./acre, and 14a, the most southern location in the field, has a yield of 848.162 lbs./acre, while a center location, 21a, has a yield of 902.274.

After-season nitrogen residual from 0-60 cm ranged from 44.523 to 158.049 lbs./acre. Most of the after-season nitrogen remained in the northern portion of the field. This contrasts with the results of Figure 4, which show the optimal levels of spatial nitrogen application on a per-acre, per-year basis for the ten-year planning horizon. This map indicates that more nitrogen would need to be applied in the southern portion of the field. Optimal application levels ranged from 44.323 to

103.72 lbs./acre at the 50% ET level and 46.697 to 109.47 lbs./acre at the 75% ET level on average. Because each location had four replications in the experiment, average values of each location were used to create the maps.

By comparing the yield change at each location in the field, areas where precision farming increased yield can be identified. Figure 5 shows the yield change for a ten-year optimization model by comparing precision farming and conventional whole-field farming practices. In location 5c, yield increased 9.41% when using precision farming practices, in a similar manner, yield decreased by 10.39% in location 22b when using precision farming practices as compared to whole-field farming practices. The center portion of the field seemed to have the greatest positive response to precision farming practices in terms of yield, while the northern and southern extremes did not show as positive of a response.

Spatial net revenues above nitrogen and water costs for the ten-year optimization model for precision farming practices is shown in Figure 6. Total revenue for the ten–year planning horizon ranged from $1750.66 to $2081.33 under the 50% ET level and ranged from $2197.12 to $2622.42 under the 75% ET scenario. Spatial net revenue was the highest in the western most portion of the field. The eastern portion, which is the inner most portion of the field, indicated lower returns. Location 11a (eastern location) had total revenue of $1750.66/acre, while location 19a (western location) had a total revenue of $2547.34/acre. When comparing the two management practices, precision farming tends to increase spatial net revenue in the central and southern portions of the field (See Figure 7). This map resembles Figure 4, the spatial nitrogen application map, where areas requiring higher levels of nitrogen application tend to show higher net revenue under precision farming practices. These same locations also tend not to have much nitrogen residual at the end of the season (See Figure 3).

Table 3 summarizes the comparison of precision farming and whole-field farming at the two water levels of water use. Overall, precision farming, on average, requires less nitrogen application for both water levels. The low water scenario had 0.012% less nitrogen application in the precision farming scenario as compared to whole-field farming, while the high water scenario had 0.004% less nitrogen application. Average nitrogen applied was 77.358 lbs./acre for precision farming and 77.368 lbs./acre under the 50% ET scenario. Average nitrogen applied was 81.503 lbs./acre and 81.507 lbs./acre under the 75% ET scenario. Average net revenue was slightly higher, when precision farming practices are used. For 50% ET, precision farming net revenue was $1919.34, while whole-field farming was $1917.44, for a net change of 0.099%. Under the 75% ET scenario, precision farming net revenue was $2439.56, while whole-field farming was $2430.66, for a net change of 0.365%. Yield was also slightly higher for precision farming practices under both water scenarios. For the low water scenario, yield was 706.428 lbs./acre under precision farming practices and 705.456 lbs./acre for whole-field farming practices. This represented a 0.1379% increase in net revenue for precision farming. Under the high water scenario, yield was 871.911 lbs./acre under the precision farming practice, while yield was 866.357 lbs./acre under the whole-field farming practice. This represented a 0.641% increase in yield for precision farming over whole-field farming.

Conclusion

The dynamic optimization model captures the effect of residual nitrate-nitrogen in the soil from crop years over time. The initial residual nitrate-nitrogen condition and the cotton and nitrogen price ratios were found to have a large impact on the optimal nitrogen application. Overall, this analysis reveals that precision farming increases yield and net revenue. The results also indicate that nitrogen application could be decreased and used more efficiently. The increases in precision farming versus whole-field farming are not very significant. This can partially be explained by the lack of variability in the initial nitrogen residual in the soil at the beginning of the season. Because of the slight increase in profitability and yield, including fixed costs would most likely indicate that precision farming practices are not more profitable. However, if multiple inputs were optimized, the profitability would most likely increase, thus lowering the average fixed costs.

The dynamic optimization model is useful because it allows producers to make optimal decisions, based not on what is best strictly for one year, but for a specific planning horizon. This could avoid short-term optimal decision-making, which may not be in the best interest of the producer in the long run.

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Appendix

Table 1. Comparison of Precision Farming and Whole-Field Farming Scenarios for 50% ET and Water Price = \$2.68/acre-inch, Cotton Price = \$0.40/lb., and Nitrogen Price = \$0.25/lb.

Location	Total Revenue	Yield Lbs./ac./yr	NA	NR10	NA Change	Net Revenue Change	Yield Change
1a	1977.6586	729.04	85.425	20.235	10.4139%	3.1407%	3.3431%
1b	1977.6195	728.759	84.999	20.235	9.8633%	3.1387%	3.3033%
1c	1915.1724	699.1	64.383	20.23	-16.7834%	-0.1181%	-0.9010%
1d	1977.6605	729.114	85.533	20.235	10.5535%	3.1408%	3.3536%
2a	1935.9295	715.368	83.844	20.235	8.3704%	0.9644%	1.4050%
2b	1938.1566	713.274	79.684	20.235	2.9935%	1.0806%	1.1082%
2c	1933.6218	715.86	85.548	20.235	10.5728%	0.8441%	1.4748%
2d	1936.1486	715.296	83.643	20.235	8.1106%	0.9758%	1.3948%
3a	1937.5587	711.679	77.433	20.236	0.0840%	1.0494%	0.8821%
3b	1936.1904	715.454	83.856	20.235	8.3859%	0.9780%	1.4172%
3c	1936.9033	715.188	83.151	20.235	7.4747%	1.0152%	1.3795%
3d	1937.6711	714.751	82.159	20.235	6.1925%	1.0552%	1.3176%
4a	1990.4831	737.67	92.522	20.235	19.5869%	3.8095%	4.5664%
4b	1991.9376	737.239	91.259	20.235	17.9545%	3.8854%	4.5053%
4c	1990.9861	737.548	92.127	20.235	19.0764%	3.8358%	4.5491%
4d	1993.6309	735.254	87.486	20.235	13.0778%	3.9737%	4.2239%
5a	2081.3293	769.138	98.444	20.236	27.2412%	8.5474%	9.0271%
5b	2081.2716	770.35	100.35	20.235	29.7048%	8.5444%	9.1989%
5c	2078.6780	771.844	103.72	20.235	34.0606%	8.4092%	9.4107%
5d	2080.2254	771.282	102.22	20.235	32.1218%	8.4899%	9.3310%
6a	1876.1533	685.58	65.856	20.236	-14.8795%	-2.1531%	-2.8175%
6b	1876.1532	691.934	75.726	20.235	-2.1223%	-2.1531%	-1.9168%
6c	1877.4246	691.604	74.696	20.235	-3.4536%	-2.0868%	-1.9636%
6d	1879.5480	689.768	70.977	20.235	-8.2605%	-1.9760%	-2.2238%
7a	1953.2860	721.442	85.112	20.235	10.0093%	1.8696%	2.2661%
7b	1954.0864	720.83	83.834	20.235	8.3575%	1.9113%	2.1793%
7c	1953.7979	718.335	80.076	20.236	3.5002%	1.8963%	1.8256%
7d	1954.1202	720.789	83.756	20.235	8.2566%	1.9131%	2.1735%
8a	1965.3358	724.084	83.572	20.235	8.0188%	2.4980%	2.6406%
8b	1964.2810	725.727	86.555	20.235	11.8744%	2.4430%	2.8735%
8c	1963.3229	726.149	87.601	20.235	13.2264%	2.3931%	2.9333%
8d	1964.5428	725.562	86.191	20.235	11.4039%	2.4567%	2.8501%
9a	1856.0612	700.032	77.094	20.235	-0.3542%	-3.2010%	-0.7689%
9b	1921.1556	705.168	75.111	20.236	-2.9172%	0.1939%	-0.0408%
9c	1921.3999	707.925	79.294	20.235	2.4894%	0.2067%	0.3500%
9d	1921.8297	707.265	78.093	20.235	0.9371%	0.2291%	0.2564%
10a	1876.9353	687.522	68.7	20.236	-11.2036%	-2.1123%	-2.5422%
10b	1877.0172	687.658	68.878	20.236	-10.9735%	-2.1080%	-2.5229%
10c	1877.2686	688.218	69.645	20.236	-9.9822%	-2.0949%	-2.4435%
10d	1877.3111	688.373	69.87	20.235	-9.6913%	-2.0927%	-2.4216%
11a	1750.6674	633.368	44.323	20.236	-42.7115%	-8.6976%	-10.2186%
11b	1751.9553	635.437	47.011	20.235	-39.2372%	-8.6304%	-9.9254%
11c	1750.6674	637.308	50.443	20.235	-34.8012%	-8.6976%	-9.6601%
11d	1750.7964	637.242	50.288	20.235	-35.0016%	-8.6908%	-9.6695%
12a	1795.3802	657.153	60.078	20.235	-22.3477%	-6.3656%	-6.8471%
12b	1797.1522	654.79	55.686	20.236	-28.0245%	-6.2732%	-7.1820%
12c	1796.5553	653.701	54.237	20.236	-29.8974%	-6.3044%	-7.3364%
12d	1795.3247	652.415	52.742	20.236	-31.8297%	-6.3685%	-7.5187%
PF	**1919.34089**	**706.428896**	**77.35898**	**20.23515**			
WF	**1917.43750**	**705.456**	**77.36800**	**20.23500**			

Table 2. Comparison of Precision Farming and Whole-Field Farming Scenarios for 75% ET and Water Price = $2.68/acre-inch, Cotton Price = $0.40/lb., and Nitrogen Price = $0.25/lb.

Location	Total Revenue	Yield Lbs./ac./yr	NA	NR10	NA Change	Net Revenue Change	Yield Change
14a	2378.0673	848.162	78.12	28.181	-4.16%	-2.16%	-2.10%
14b	2379.6692	847.103	75.825	27.948	-6.97%	-2.10%	-2.22%
14c	2319.5066	819.636	57.526	26.08	-29.42%	-4.57%	-5.39%
14d	2379.4171	847.462	76.486	28.015	-6.16%	-2.11%	-2.18%
15a	2576.7917	925.082	102.98	30.71	26.34%	6.01%	6.78%
15b	2578.9044	921.247	96.165	30.017	17.98%	6.10%	6.34%
15c	2580.2178	923.182	98.64	30.269	21.02%	6.15%	6.56%
15d	2580.0689	923.8	99.66	30.372	22.27%	6.15%	6.63%
17a	2617.9849	941.008	108.03	31.224	32.54%	7.71%	8.62%
17b	2622.4206	939.542	103.96	30.81	27.55%	7.89%	8.45%
17c	2616.7458	941.083	108.65	31.287	33.30%	7.66%	8.63%
17d	2614.8782	941.124	109.47	31.371	34.31%	7.58%	8.63%
18a	2595.5278	933.863	107.41	31.161	31.78%	6.78%	7.79%
18b	2603.0849	931.74	101.05	30.514	23.98%	7.09%	7.55%
18c	2600.2906	933.53	104.96	30.912	28.77%	6.98%	7.75%
18d	2602.2553	932.931	103.23	30.736	26.65%	7.06%	7.68%
19a	2547.3389	913.978	99.759	30.382	22.39%	4.80%	5.50%
19b	2549.1075	913.978	98.444	30.249	20.78%	4.87%	5.50%
19c	2548.7056	913.594	98.791	30.284	21.21%	4.86%	5.45%
19d	2550.4733	913.713	96.57	30.058	18.48%	4.93%	5.47%
20a	2517.3084	912.744	95.996	30	17.78%	3.56%	5.35%
20b	2519.4525	902.328	93.915	29.788	15.22%	3.65%	4.15%
20c	2519.6125	901.548	90.953	29.487	11.59%	3.66%	4.06%
20d	2517.5784	899.684	95.803	29.98	17.54%	3.58%	3.85%
21a	2579.2109	902.274	97.802	30.183	19.99%	6.11%	4.15%
21b	2579.2109	922.341	97.802	30.183	19.99%	6.11%	6.46%
21c	2576.1100	922.341	102.83	30.696	26.16%	5.98%	6.46%
21d	2573.7528	924.772	93.338	29.72	14.52%	5.89%	6.74%
22a	2197.6581	918.046	52.121	25.537	-36.05%	-9.59%	5.97%
22b	2200.7546	776.383	49.045	25.224	-39.83%	-9.46%	-10.39%
22c	2197.3297	775.212	52.321	25.557	-35.81%	-9.60%	-10.52%
22d	2197.1252	776.426	52.441	25.57	-35.66%	-9.61%	-10.38%
23a	2257.7090	776.45	56.226	25.955	-31.02%	-7.12%	-10.38%
23b	2258.0561	797.225	57.114	26.045	-29.93%	-7.10%	-7.98%
23c	2256.5182	797.886	54.805	25.81	-32.76%	-7.16%	-7.90%
23d	2257.9901	796	58.494	26.185	-28.23%	-7.10%	-8.12%
24a	2404.5404	798.757	76.181	27.984	-6.53%	-1.07%	-7.80%
24b	2391.7142	854.984	70.003	27.35	-14.11%	-1.60%	-1.31%
24c	2392.7420	847.664	70.324	27.38	-13.72%	-1.56%	-2.16%
24d	2393.5480	848.138	70.584	27.41	-13.40%	-1.53%	-2.10%
25a	2250.5752	848.516	56.264	25.958	-30.97%	-7.41%	-2.06%
25b	2250.5753	795.053	56.564	25.989	-30.60%	-7.41%	-8.23%
25c	2232.3053	795.246	46.697	24.98	-42.71%	-8.16%	-8.21%
25d	2242.7310	784.007	50.046	25.32	-38.60%	-7.73%	-9.51%
26a	2376.5463	846.052	75.669	27.932	-7.16%	-2.23%	-2.34%
26b	2376.7199	845.535	74.795	27.843	-8.23%	-2.22%	-2.40%
26c	2374.0908	842.429	71.033	27.461	-12.85%	-2.33%	-2.76%
26d	2366.0203	837.911	67.283	27.07	-17.45%	-2.66%	-3.28%
PF	**2439.5613**	**871.9106**	**81.5036**	**28.5245**			
WF	**2430.6573**	**866.357**	**81.5070**	**28.5260**			

Table 3. Comparison of Precision Farming Practices and Conventional Whole-Field Farming Practices in Irrigated Cotton Production at Lamesa, Texas, 1998.

Applied Water Level		**Precision Farming**	**Whole-Field Farming**	**Change**
50% ET	Average Nitrogen Applied (lbs./ac./yr.)	77.358	77.368	-0.012%
	Average Net Revenue above Nitrogen	1919.34	1917.44	0.099%
	Average Lint Yield (lbs./ac./yr.)	706.428	705.456	0.1379%
75% ET	Average Nitrogen Applied (lbs./ac./yr.)	81.503	81.507	-0.004%
	Average Net Revenue above Nitrogen	2439.56	2430.66	0.365%
	Average Lint Yield (lbs./ac./yr.)	871.911	866.357	0.641%

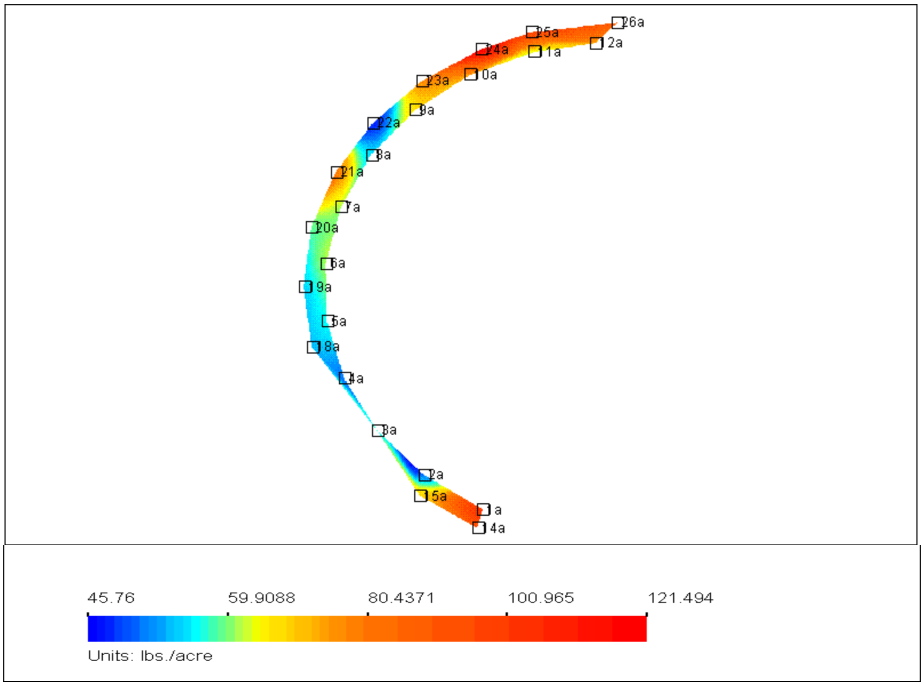

Figure 1. NO3-N Pre-Season Residual Map from 0-60 Centimeters of Soil Depth, Lamesa, Texas, 1998.

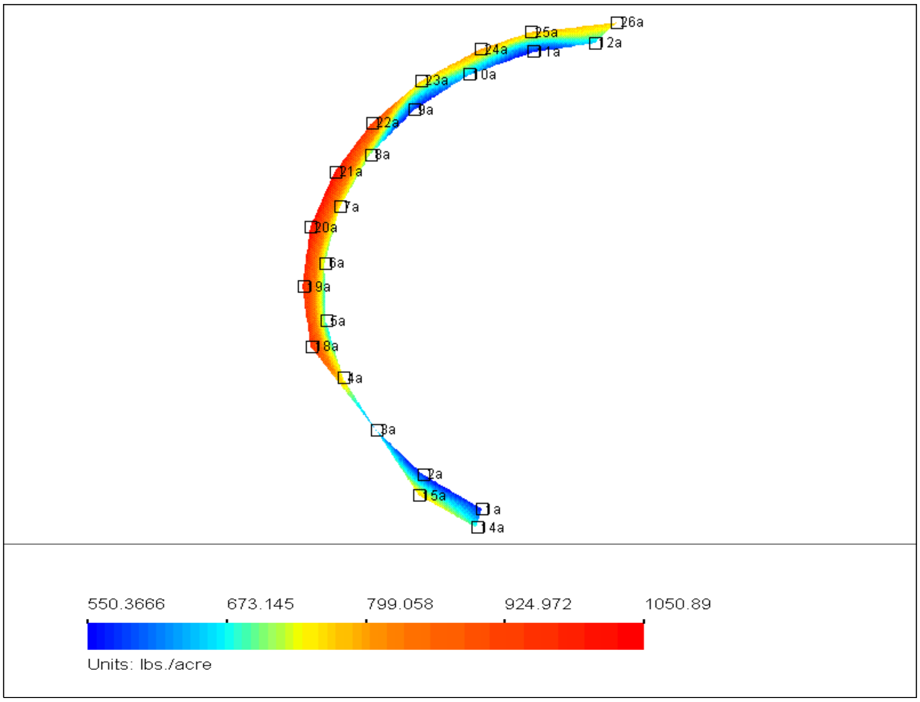

Figure 2. Spatial Cotton Yield Map, Lamesa, Texas, 1998.

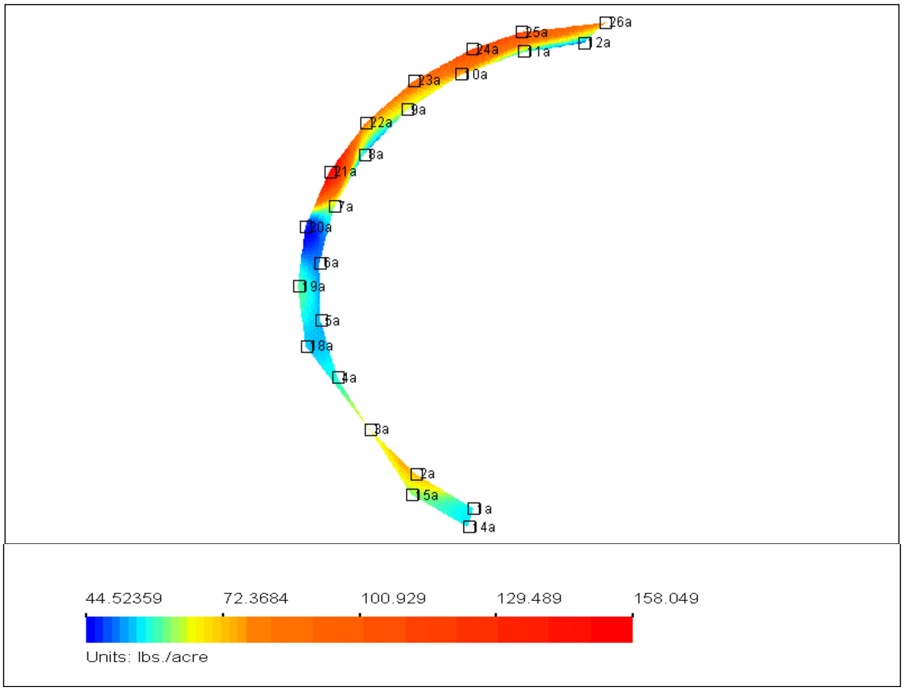

Figure 3. NO3-N After-Season Residual Map from 0-60 Centimeters of Soil Depth, Lamesa, Texas, 1998.

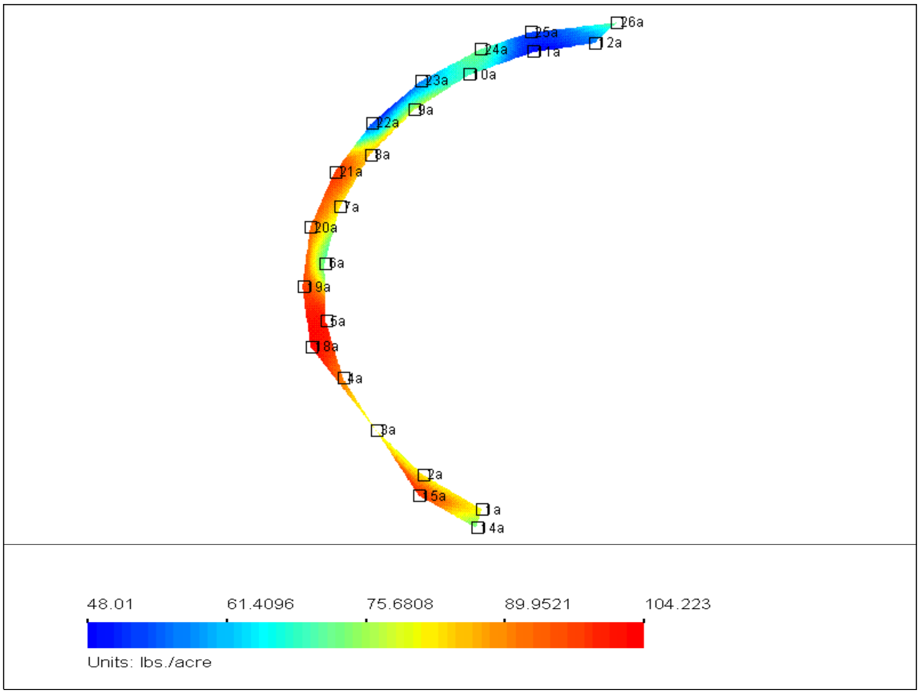

Figure 4. Optimal Levels of Spatial Nitrogen Application Map on a Per-Acre and Per-Year Basis for a Ten-Year Planning Horizon, Lamesa, Texas, 1998.

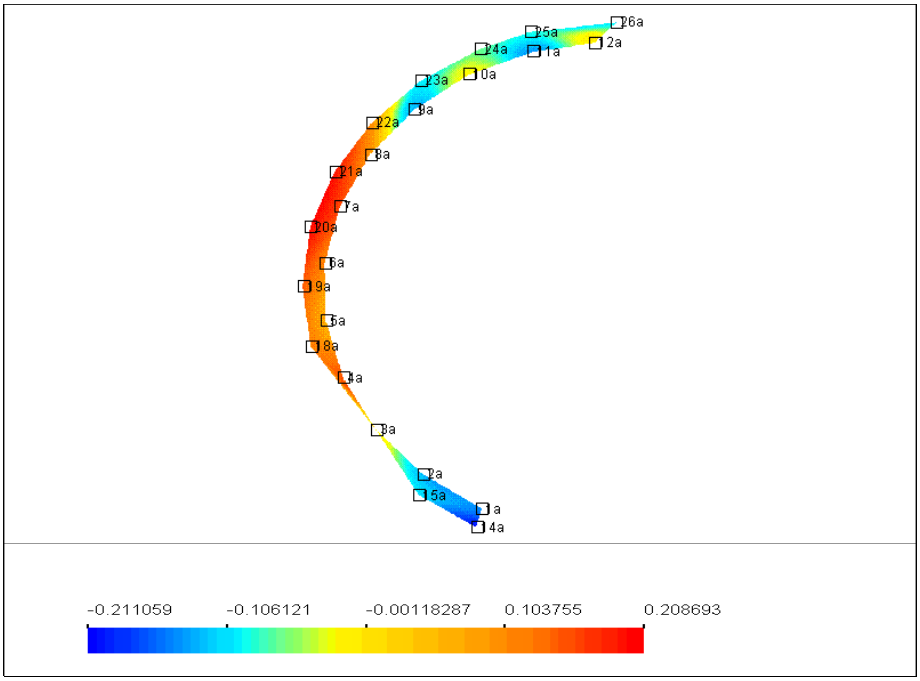

Figure 5. Yield Change for a Ten-Year Optimization Model (Precision Farming and Conventional Whole-Field Farming), Lamesa, Texas, 1998.

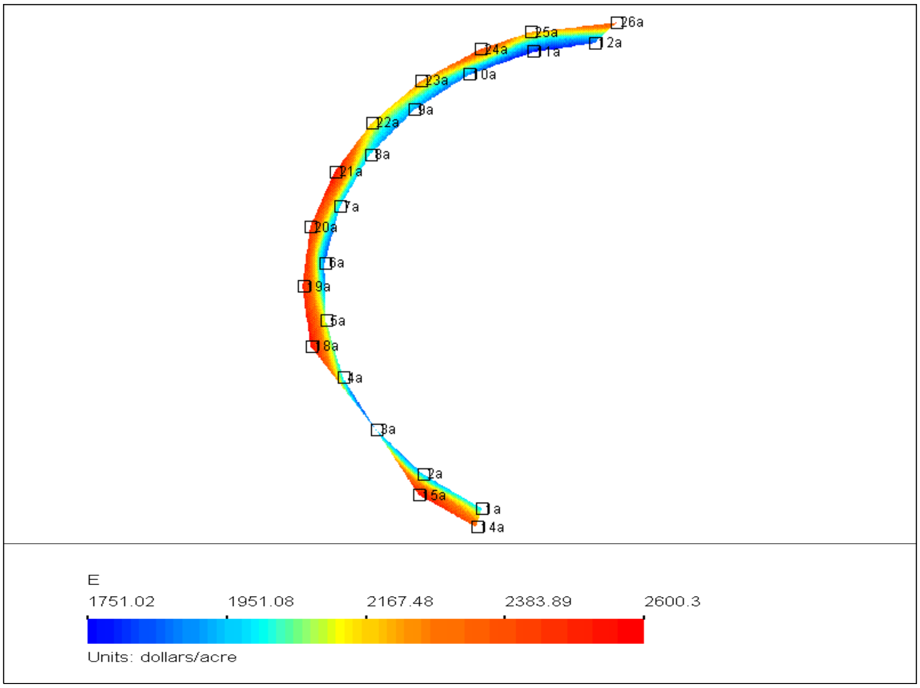

Figure 6. Spatial Net Revenue Above Nitrogen and Water Costs for a Ten-Year Optimization Model for Precision Farming Practices, Lamesa, Texas, 1998.

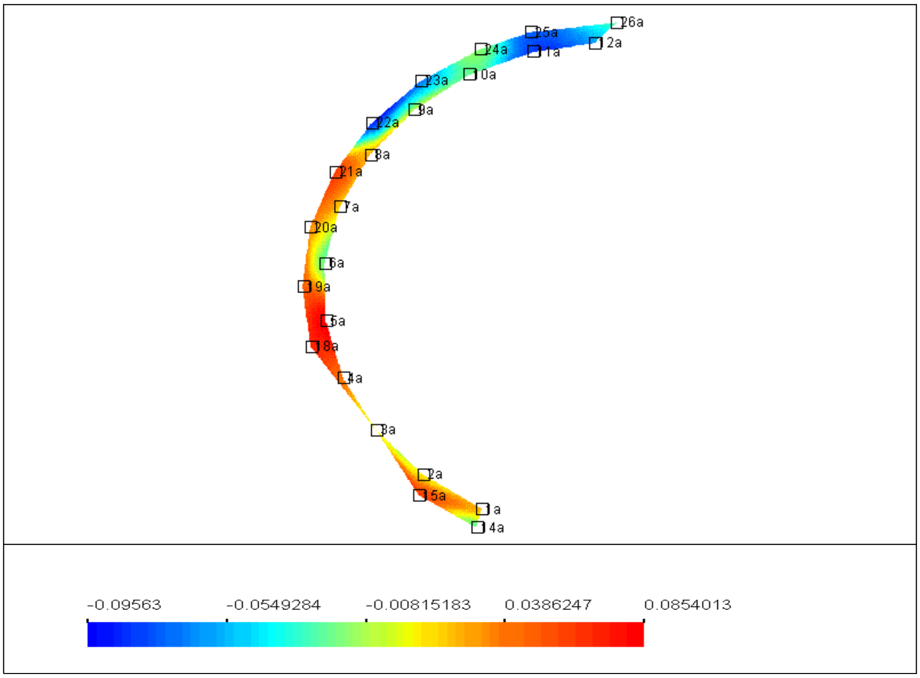

Figure 7. Spatial Net Revenue Change to Nitrogen Use (Precision Farming and Conventional Whole-Field Farming), Lamesa, Texas, 1998.