PRECISION FARMING PRACTICES IN IRRIGATED COTTON PRODUCTION IN THE TEXAS HIGH PLAINS

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Abstract

A dynamic optimization model is used to derive and evaluate nitrogen fertilizer optimal decision rules associated with precision farming practices and conventional whole-field farming practices for irrigated cotton production in the Southern High Plains of Texas. Results indicate that precision farming can improve the profitability and increase the efficiency associated with nitrogen fertilizer use in irrigated cotton production.

Introduction

Increased use of fertilizers, pesticides, and other chemicals have contributed to the enhanced productivity of agriculture in recent decades. Currently, production agriculture is facing challenges, such as increasing costs of production, shortage of irrigation water, and increased public concern on the impacts of agricultural production on the environment. To survive in the highly competitive world market for agricultural commodities, agricultural producers must produce high quality products at low prices while employing environmentally friendly practices. One way to accomplish these objectives is to adopt precision farming technology.

Traditionally, optimal fertilizer input use in agriculture has assumed spatial and temporal field homogeneity with respect to soil fertility, soil moisture, pest populations, and crop characteristics. That is, optimal fertilizer input decision rules do not account for these differences within fields. Precision farming, precision agriculture, or site-specific management recognizes the variability of such factors within fields and seeks to optimize variable input use under these conditions. Robert, et al. (1995) states that precision farming for site-specific management is an advanced information-technology-based agricultural management system designed to identify, analyze, and manage site-soil spatial and temporal variability with fields for optimum profitability, sustainability, and protection of the environment. The development of precision farming practices is closely related to many new technologies that have been utilized in agricultural production in recent years. These new technologies involve microcomputers, microprocessor based control systems, satellite positioning technologies, and various kinds of sensors. With the help of these technologies, spatial soil testing, variable rate application of fertilizers, variable rate spraying, and yield mapping are becoming increasingly available.

In this study, soil fertility in irrigated cotton production stemming from optimal nitrogen fertilizer application is addressed. Thus, the primary objective of this study is to evaluate the economic implications of precision farming practices with respect to nitrogen fertilizer use in irrigated cotton production in the Southern High Plains of Texas (SHPT). In particular, a dynamic optimization model which introduces an inter-temporal nitrate-nitrogen carry-over function is used to derive and evaluate optimal nitrogen application rates, yield, and net present value of returns for a 10-year planning horizon.

The SHPT is a semi-arid region located in the northwestern part of Texas. It encompasses approximately 22 million acres in 42 counties. Cotton is the most important crop produced in the areas in terms of both acreage and crop value. Annual cotton plantings vary between 2.6 and 3.3 million acres in a 25-county region within the SHPT, with approximately 50 percent of these acres being irrigated (Yu et al., 1999). The soil types in the SHPT include: hardlands, composed of fine-textured clays and clay loams, which represent 54% of the area; mixedlands, composed of medium-textured loams and loamy sands, which represent 23% of the area; and sandylands, composed of coarse-textured sand, which also represent 23% of the area.

Materials and Methods

Contemporary studies have shown that both nitrogen and phosphorous fertilizer applications and residual fertility generally have positive impacts on cotton yields (Segarra et al., 1989; Carter et al., Bosman, 1974; Onken and Sunderman, 1972; Yu et al., 2000). Westerman and Kurtz (1972) discussed nitrogen residual in the soil in relation to soil types. They found that total nitrogen (nitrogen application plus nitrogen residual) is higher in heavy soils as compared to sandy soils. They also found that two-thirds of the nitrogen residual is in the top 10 centimeters of the soil.

This manuscript summarized the analysis of using site-specific technologies to address the impacts of nitrogen fertilizer application and nitrogen residual on irrigated cotton production under different levels of initial soil fertility, and soil and location characteristics. That is, a dynamic optimization model is developed to evaluate the relationship between nitrogen application optimal decision rules and nitrogen residual, and other soil and location properties. The model can be expressed as follows. Cotton yield is a function of total nitrogen available to the plants. Total nitrogen available to the plants is equal to applied nitrogen and nitrogen residual at a given time. Nitrogen residual at a given time is a function of the previous nitrogen applications and previous levels of nitrogen residual. Given these relationships, the optimization model takes the following form:

$$\text{Max } Z = \sum_{t=0}^{n} \{[P_t \cdot Y_t(NT_t, X_1, X_2, \ldots, X_n) - CP_t \times NA_t] \cdot (1+r)^{-t}\} \tag{1}$$

Subject to:

$$NT_t = NA_t + NR_t, \tag{2}$$

$$NR_{t+1} = \mathcal{F}_t[NA_t, NR_t], \tag{3}$$

$$NR_0 = NR(0), \text{ and } NA_t, NR_t \geq 0 \text{ for all t.} \tag{4}$$

Where Z is the per-acre net present value of returns to risk, management, overhead, and all other inputs in the production of cotton ($/acre) in n periods; n is the length of the decision-maker's planning horizon (years); P_t is the price of cotton in year t ($/lb.); Y_t is the cotton yield function in year t (lbs./acre); NT_t is the total nitrogen available to the crop in year t (lbs./acre); $X_1, X_2, \ldots, X_n$ are other variables that influence the crop yield; CP_t is the price of nitrogen in year t ($/lb.); NA_t is nitrogen applied in year t (lbs./acre); NR_t is nitrogen residual in year t (lbs./acre); and r is the discount rate.

Equation (1) represents the objective function, or performance measure, of the optimization model. Equation (2) is an equality constraint which adds up the applied nitrogen and nitrogen residual at time t, and it is being used in equation (1) to calculate the cotton yield at time t. Equation (3) is the equation of motion which updates nitrogen residual. Equation (4) is the initial condition on the level of nitrogen residual at the beginning of the planning horizon.

The primary source of data for this study is from an experiment conducted at the Texas Agricultural Experiment Station at Lamesa, Texas in 1998. It is an approximately 50 acre cotton field. At the beginning of the experiment, 104 locations within the field were chosen. Because of missing data, only 100 locations were considered in this research. At each location, the nitrogen residual level in the soil at a depth of 0 to 90 centimeters was

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measured on June 3, 1998. Using MapInfo, a desktop mapping software that provides a mapping technique for calculating and displaying the trends of data which vary over geographic space (Vertical Mapper Manual), the 100 locations and their pre-season nitrogen residual levels are shown in Figure 1. As depicted in that figure, the nitrogen residual levels in the soil at a depth of 0 to 90 centimeters ranged from 0 to 283.14 pounds per acre at the beginning of the season.

In the experiment, the whole field was treated equally, except for irrigation water, which was applied at two different levels of evapotranspiration (ET), 50% ET and 75% ET, and nitrogen fertilizer, which was applied at three different rates (0, 80, and 120 pounds per acre). Other production inputs, such as pesticides, phosphorus fertilizer, and herbicides, were applied at the same rates across the whole field.

At the end of the growing season, a cotton stripper equipped with sensors and a Global Position System (GPS) was used. Then, data were downloaded into a computer and analyzed using MapInfo. Cotton lint yields associated with the 100 locations were obtained. Figure 2 shows the cotton lint yield map for the field. As depicted in Figure 2, cotton lint yield in this field ranged from 392.63 pounds per acre to 1086.67 pounds per acre.

After the cotton was harvested, the nitrogen residual level in the soil at a depth of 0 to 90 centimeters was measured for each of the 100 locations on November 19, 1998. The data was analyzed and is shown in Figure 3 using MapInfo. The nitrogen residual level ranged from 19.01 pounds per acre to 407.67 pounds per acre.

Results

Using GLM (General Linear Model) procedures (SAS, 1982), several functional forms including double logarithmic, semi-logarithmic, Mistscherlich-Spillman, quadratic, and cubic were used to estimate a cotton yield production function. The functional form found to best fit the data and which provided economically sound estimates was the quadratic form. The estimated cotton yield production function can be expressed as:

$$
\begin{aligned}
Y = {} & 257.40 + 5.05*10\text{-}1*NT*W*SD \\
& (3.06) \quad (9.66) \\
& -7.03*10\text{-}5*NT*NT*ELEV*CL + 28.03*PN \qquad (5) \\
& (-8.33) \qquad\qquad\qquad\qquad (3.67) \\
R^2 = {} & 0.5321.
\end{aligned}
$$

Where Y is cotton lint yield in lbs./acre; NT is total nitrogen available to the crop (lbs./acre), which equals applied nitrogen (NA) during the cotton growing season plus nitrogen residual (NR) in the soil at the beginning of cotton growing season; W is the available water to the crop at either 50% or 75% ET; SD and CL represent the sand and clay percentage in the soil; ELEV represents the elevation of each location in feet; PN are the number of plants per acre. The values in parenthesis below the estimated parameters in equation (5) represent the associated t-values, where the terms NT*W*SD, and NT2 *ELEV*CL were significant at the 0.0001 level; the PN term was significant at the 0.0005 level; and the intercept term was significant at 0.005 level.

From the function estimated, it can be seen that there are significant interaction effects among nitrogen fertilizer, water, location property (elevation), and soil properties (including the available clay and sand percentage in the soil) in explaining cotton yield variability. The R2 value indicates that 53.21% of the variation in cotton lint yield was explained by the independent variables included in the regression.

Based on the information of pre-season and post-season nitrogen residual (NRt and NRt+1) in the soil, and nitrogen application level (NAt) during the cotton growing season, the nitrogen carry-over function was estimated to be:

$$
\begin{aligned}
NR_{t+1} = {} & 4.28 + 4.74*10^{-1}\,NA_t + 4.17*10^{-1}\,NR_t \qquad (6) \\
& (0.30) \quad (4.21) \qquad\qquad (3.01) \\
R^2 = {} & 0.2932.
\end{aligned}
$$

Where the variables NR and NA are defined as before and the parameter t-values are reported as before. All the estimated parameters, except the intercept term in equation (6) were significant at the 0.05 level. The R2 value indicates that 29.32% of the variation in post-season nitrogen residual variation can be explained by the nitrogen application level during the cotton growing season and pre-season nitrogen residual level.

The dynamic optimization model formulated above was solved under two scenarios. The first scenario represents the optimality conditions under the precision input application technology. This was done to mimic possible scenarios of fertility that could be faced under precision farming practices within fields. That is, under precision farming practices, optimal input decision rules according to spatial differences within fields would be desired. For this scenario, 100 optimization models were built for the 100 locations within the field with their associated pre-season nitrogen residual levels, and soil and location characteristics (elevation, and the available sand and clay percentage in the soil).

The second scenario represents the optimality conditions under conventional input application technology, i.e., whole-field farming. Because water (W) was applied at only two different levels (50% ET and 75% ET, and equally separated for 100 locations) in the experiment, water was introduced as a dummy variable in the mathematical model. In order to mimic possible scenarios of fertility that could be faced under whole-field farming practices, the 100 locations were separated into two groups (50 locations for each group), according to their water application levels. For each group, average initial nitrogen residual level, and average soil and location characteristics were calculated and used in the optimization model.

The optimization model depicted in equations (1) through (4) was solved for the combinations of following conditions: (1) a ten-year planning horizon, (2) a 5% discount rate (r = 0.05), (3) a water price of \$2.68/inch, (4) a cotton lint price of \$0.60/lb., (5) a nitrogen fertilizer price of \$0.30/lb., and (6) 100 locations with their corresponding initial nitrogen residual levels for precision farming practices, and the two ET groups described above with average initial nitrogen residual levels for whole-field farming practices.

As expected, the optimal decision rules of applied nitrogen fertilizer varied across periods in the planning horizon for a given nitrogen and cotton price combination at the different levels of nitrogen residual and soil and location characteristics. However, because a stable optimal decision rule was desired to simplify management implementation, for a given nitrogen and cotton price combination and initial nitrogen soil fertility, an additional constraint of equating nitrogen applications across time periods within the planning horizon was introduced.

Solutions to the 102 optimization models (100 models correspond to scenario one [precision farming practices], and 2 models correspond to scenario two [whole-field farming practices]) were also obtained by using GAMS (General Algebraic Mathematical System) and are presented in Tables 1 and 2. These tables list total net per-acre present value of returns above nitrogen and water costs (Total Revenue), optimal levels of nitrogen application (NA), cotton yield (Yield), and the tenth year after-season nitrogen residual level for each location (NR10) in the field associated with both precision farming practices and whole-field farming practices. Also, a comparison of revenue and crop yield change associated with two farming practices at each location is presented.

Using MapInfo, the optimal levels of spatial nitrogen application rates for a ten-year planning horizon within the field associated with precision farming practices are depicted in Figure 4. As shown in this figure, optimal nitrogen application rates range from 20.59 pounds per acre to 122.76 pounds per acre per year. Also, there seems to be no clear relationship between the optimal nitrogen application map (Figure 4) and the nitrogen residual map before the cotton growing season (Figure 1). These differences can be explained by the interaction effects among water, nitrogen, and soil and location characteristics. For example, at some locations, such as 18B, which has a high level of nitrogen residual level at the beginning of the season, additional nitrogen fertilizer would be required. At some other locations, such as 11A, which has a high level of nitrogen residual level at the beginning of the season, no additional nitrogen fertilizer should be applied to maximize net revenue. However, at some locations with a low nitrogen residual level at the beginning of the season, such as 22D, additional nitrogen fertilizer would be required. But at some locations with a low nitrogen residual level at the beginning of the season, such as 4A and 4B, no additional nitrogen fertilizer should be applied to maximize net revenue. When assuming conventional whole-field farming practices in this field, the optimal nitrogen application rates are 46.70 pounds per acre per year for the 50% ET water application scenario, and 84.17 pounds per acre per year for the 75% ET water application field.

Tables 1 and 2 list cotton lint yields under the two technologies of nitrogen application scenarios. For a ten-year planning horizon, under precision farming practices, cotton yield ranged from 6,176.88 to 8,428.23 pounds per acre under 50% ET and 7,946.14 to 10,526.62 pounds per acre under 75% ET. Under whole-field farming practices, cotton yield ranged from 6,029.95 to 7,700.29 pounds per acre under 50% ET, and 7,848.77 to 9,995.83 pounds per acre under 75% ET.

By comparing the yield change at each location in the field associated with the two scenarios, it was found that the average yield for a ten-year planning horizon would be improved from 6,980.02 pounds per acre with conventional whole-field farming practices to an average yield of 7,057.22 pounds per acre with precision farming practices under the 50% ET scenario. Under the 75% ET scenario, the average cotton lint yield for a ten-year planning horizon would be improved from 8,970.29 pounds per acre with conventional whole-field farming practices to an average yield of 9,048.96 pounds per acre with precision farming practices. That is, average cotton lint yield would be increased by 1.11% under 50% ET and 0.88% under 75% ET, when comparing precision farming practices to whole-field farming practices. The yield percentage change at each location in the field from precision farming is shown in Figure 5. As shown there that yield change ranged from a decrease of 0.29% (Location 10C) to an increase of 10.39% (Location 7D) under 50% ET, and ranged from a decrease of 0.24% (Location 16B) to an increase of 5.34% (Location 20A) under 75% ET. Taken as a whole, 72% of the field shows a yield increase, and 28% of the field shows a yield decrease.

Net revenues above nitrogen fertilizer and water costs were also derived for the two technologies of nitrogen application scenarios and listed in Tables 1 and 2. Net revenues associated with precision farming practices are also depicted in Figure 6. As shown in that figure, spatial net revenue levels for a ten-year planning horizon ranged from $2,846.37 per acre (Location 11C) to $3,711.83 per acre (Location 7D) under 50% ET, and ranged from $3,503.20 per acre (Location 26A) to $4,582.97 per acre (Location 20A) under 75% ET. In this figure, the western side of the field shows much higher net revenue than in the inside. This is a direct result of higher levels of irrigation water applied on those locations. For conventional whole-field farming practices in the same field, spatial net revenue levels for a ten-year planning horizon ranged from $2,708.39 per acre (Location 11C) to $3,499.16 per acre (Location 6A) under 50% ET, and ranged from $3,399.79 per acre (Location 26A) to $4,414.09 per acre (Location 20A) under 75% ET.

Comparing the net revenue change at each location in the field, it was found that the average net revenue for a ten-year planning horizon would be improved from $3,138.43 per acre with conventional whole-field farming practices to an average net revenue of $3,169.58 per acre associated with precision farming practices under the 50% ET. Under the 75% ET, the average net revenue for a ten-year planning horizon would be improved from $3,942.13 per acre with conventional whole-field farming practices to an average net revenue of $3,976.07 per acre with precision farming practices. That is, average net revenue for a ten-year period would be increased by 0.99% under 50% ET, and 0.86% under 75% ET, when comparing precision farming practices to conventional whole-field farming practices. The net revenue above nitrogen fertilizer and water costs percentage change at each location in the field is shown in Figure 7. As shown there, net revenue change ranged from an increase of 0.00% (location 2B) to an increase of 7.28% (location 7D) under 50% ET, and ranged from an increase of 0.0005% (location 15D) to an increase 3.82% (location 20A) under 75% ET. Note however, that at every location in the field an increase in net revenue would be expected from the adoption of precision farming practices. A summary comparison of the overall results between precision farming practices and conventional farming practices is presented in Table 3.

Conclusions and Discussion

Overall, this analysis revealed that precision spatial utilization of nitrogen fertilizer, as compared to conventional whole-field farming, would result in an increase in crop yield, net revenue, and productivity on a per acre basis. That is, this study found that nitrogen fertilizer could be used more efficiently, implying higher yields, net revenue, and output per unit of input used. More importantly, it was found that precision farming practices would either build up or lower nitrogen residual levels at the end of the crop growing season, according to the net revenue potential of different parts of the field. This can significantly improve yields, net revenue and input use efficiency, and have the potential to decrease the environmental impacts of agricultural production.

As stated in this research, the levels of net revenues associated with the adoption of precision farming practices in this study do not show much increase. This can be partially explained by the fact that the field does not have much variability with respect to initial soil nitrogen residual levels, and other spatial and soil properties. Future studies should be conducted to evaluate the relationship between the variability of these variables and net revenue.

Also, because of information limitations, this study only considered variable costs associated with the use of nitrogen fertilizer and water application and did not consider the fixed costs associated with the adoption of precision farming practices. If fixed costs were to be considered in this study, it could be expected that precision farming practices would be unprofitable and should not be adopted, compared to conventional whole-field farming practices. In reality, if precision farming practices were to be adopted in the future, this technology could also be used to control the variable application of other inputs, including seed, phosphorus fertilizer, potassium fertilizer, pesticide, herbicide, and other inputs. In this case, application of multiple inputs with precision farming practices could help to lower the average fixed costs associated with this input application technology. Thus, future studies should incorporate more variable inputs and fixed costs.

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Note: A copy of following figures in a color format can be seen at the Web site of Department of Agricultural and Applied Economics, Texas Tech University (http://www.aeco.ttu.edu/publicationpage.htm).

Table 1. Comparison of Precision Farming and Whole-Field Farming Scenarios for 50% ET and $P_{water}=\$2.68$/inch, $P_{cotton}=\$0.60$/lb., $P_{nitrogen}=\$0.30$/lb.

		Precision-Farming Practices				Whole-Field Farming Practices					
Number	PLOT	Total Revenue	Yield lbs/ac/yr	NA lbs/ac/yr	NR10	Total Revenue	Yield lbs/ac/yr	NA lbs/ac/yr	NR10	Revenue Change	Yield Change
1	1A	3125.53	694.56	45.42	44.24	3125.27	312.53	46.70	45.27	0.0082%	-0.0896%
2	1B	3223.90	717.25	50.38	48.26	3221.77	322.18	46.70	45.27	0.0661%	0.3356%
3	2A	3105.08	690.75	45.88	44.61	3104.97	310.50	46.70	45.27	0.0035%	-0.0562%
4	2B	3147.80	699.73	46.62	45.21	3147.80	314.78	46.70	45.27	0.0000%	-0.0060%
5	2C	3147.51	701.75	50.03	47.98	3145.73	314.57	46.70	45.27	0.0566%	0.2876%
6	2D	3185.77	710.04	51.22	48.94	3182.55	318.26	46.70	45.27	0.1009%	0.4167%
7	3A	3012.92	665.81	33.89	34.87	2982.34	298.23	46.70	45.28	1.0252%	-0.1135%
8	3B	3267.61	731.58	60.42	56.41	3242.11	324.21	46.70	45.27	0.7865%	1.6940%
9	3C	3114.56	692.67	45.93	44.64	3114.46	311.45	46.70	45.27	0.0031%	-0.0537%
10	3D	3276.02	731.48	57.11	53.73	3260.18	326.02	46.70	45.27	0.4858%	1.1930%
11	4A	3083.21	684.68	42.69	42.01	3080.31	308.03	46.70	45.27	0.0940%	-0.2039%
12	4B	3177.70	708.49	51.48	49.16	3174.21	317.42	46.70	45.27	0.1099%	0.4462%
13	4C	3152.12	701.66	48.25	46.53	3151.72	315.17	46.70	45.27	0.0127%	0.1229%
14	4D	3097.47	687.02	41.87	41.35	3093.53	309.35	46.70	45.27	0.1273%	-0.2554%
15	5A	3292.24	734.06	55.89	52.74	3279.89	327.99	46.70	45.28	0.3765%	1.0245%
16	5B	3297.82	736.96	59.23	55.45	3276.09	327.61	46.70	45.27	0.6633%	1.5168%
17	5C	3275.45	732.88	59.73	55.85	3251.45	325.14	46.70	45.27	0.7382%	1.5931%
18	5D	3448.97	776.64	75.81	68.91	3352.63	335.26	46.70	45.27	2.8737%	4.6812%
19	6A	3700.20	836.83	93.71	83.46	3499.16	349.92	46.70	45.28	5.7453%	8.6755%
20	6B	3278.67	734.66	61.78	57.52	3247.89	324.79	46.70	45.27	0.9479%	1.9269%
21	6C	3068.12	681.13	41.93	41.40	3064.13	306.41	46.70	45.27	0.1300%	-0.2317%
22	6D	3051.42	675.98	38.70	38.78	3040.23	304.02	46.70	45.27	0.3682%	-0.2847%
23	7A	3290.97	737.15	62.12	57.79	3259.90	325.99	46.70	45.27	0.9531%	1.9763%
24	7B	3090.20	685.02	40.83	40.50	3083.95	308.39	46.70	45.27	0.2028%	-0.2574%
25	7C	3376.63	755.97	65.04	60.17	3334.76	333.48	46.70	45.28	1.2554%	2.5040%
26	7D	3711.83	842.82	99.81	88.40	3459.98	346.00	46.70	45.27	7.2790%	10.3877%
27	8A	3465.98	780.64	77.33	70.15	3366.31	336.63	46.70	45.27	2.9610%	4.9194%
28	8B	3253.24	726.24	55.95	52.79	3240.60	324.06	46.70	45.27	0.3902%	1.0217%
29	8C	3188.14	710.49	51.14	48.87	3185.02	318.50	46.70	45.27	0.0979%	0.4078%
30	8D	3398.72	764.09	71.57	65.47	3326.27	332.63	46.70	45.27	2.1783%	3.7619%
31	9A	3310.52	740.39	60.97	56.86	3283.91	328.39	46.70	45.27	0.8102%	1.7894%
32	9B	3041.16	672.67	36.07	36.65	3020.66	302.07	46.70	45.28	0.6788%	-0.2382%
33	9C	3170.96	705.69	48.89	47.05	3170.19	317.02	46.70	45.27	0.0240%	0.1834%
34	9D	2993.00	661.09	32.90	34.07	2955.14	295.51	46.70	45.27	1.2809%	0.0764%
35	10A	3078.81	681.50	38.36	38.51	3066.17	306.62	46.70	45.28	0.4121%	-0.2837%
36	10B	3105.75	688.17	40.68	40.39	3099.39	309.94	46.70	45.28	0.2053%	-0.2830%
37	10C	3061.11	677.97	38.66	38.75	3049.76	304.98	46.70	45.28	0.3723%	-0.2907%
38	10D	2929.05	645.83	28.51	30.50	2863.28	286.33	46.70	45.27	2.2971%	0.5859%
39	11A	2964.18	653.79	29.60	31.39	2905.97	290.60	46.70	45.28	2.0028%	0.3752%
40	11B	3133.88	696.28	45.44	44.25	3133.63	313.36	46.70	45.27	0.0081%	-0.0889%
41	11C	2846.37	625.68	22.36	25.50	2708.39	270.84	46.70	45.27	5.0948%	2.6316%
42	11D	3115.09	693.01	46.43	45.05	3115.08	311.51	46.70	45.27	0.0004%	-0.0194%
43	12A	3124.82	695.07	46.45	45.07	3124.81	312.48	46.70	45.27	0.0003%	-0.0181%
44	12B	2962.14	654.08	31.47	32.91	2918.46	291.85	46.70	45.28	1.4967%	0.1227%
45	12C	2932.02	645.70	26.61	28.96	2844.85	284.49	46.70	45.28	3.0641%	1.0664%
46	12D	3009.41	665.07	33.66	34.69	2978.43	297.84	46.70	45.28	1.0402%	-0.1360%
47	13A	3127.30	694.85	45.22	44.07	3126.94	312.69	46.70	45.27	0.0116%	-0.0999%
48	13B	3059.53	680.14	43.03	42.29	3057.17	305.72	46.70	45.27	0.0774%	-0.1905%
49	13C	3152.03	701.36	47.83	46.19	3151.82	315.18	46.70	45.27	0.0067%	0.0878%
50	13D	3056.25	678.72	41.83	41.32	3052.08	305.21	46.70	45.27	0.1368%	-0.2291%
Average		**3169.58**	**705.72**	**49.33**	**47.41**	**3138.43**	**313.84**	**46.70**	**45.27**	**0.9812%**	**1.0476%**

Table 2. Comparison of Precision Farming and Whole-Field Farming Scenarios for 75% ET and $P_{water}=\$2.68$/inch, $P_{cotton}=\$0.60$/lb., $P_{nitrogen}=\$0.30$/lb.

		Precision-Farming Practices				**Whole-Field Farming Practices**					
Number	**PLOT**	**Total Revenue**	**Yield (lbs/ac/yr)**	**NA (lbs/ac/yr)**	**NR10**	**Total Revenue**	**Yield (lbs/ac/yr)**	**NA (lbs/ac/yr)**	**NR10**	**Revenue Change**	**Yield Change**
51	14A	3794.05	864.04	79.12	71.60	3790.00	865.63	84.17	75.70	0.1068%	-0.1837%
52	14B	4260.92	973.30	105.58	93.09	4203.61	950.77	84.17	75.70	1.3632%	2.3697%
53	14D	3996.01	909.93	88.06	78.86	3993.76	907.55	84.17	75.70	0.0561%	0.2627%
54	15A	4007.47	914.05	90.70	81.00	4001.18	909.64	84.17	75.70	0.1574%	0.4844%
55	15B	3690.76	836.28	66.97	61.74	3638.75	834.60	84.17	75.71	1.4294%	0.2021%
56	15C	4007.39	909.85	83.68	75.31	4007.35	910.09	84.17	75.70	0.0010%	-0.0264%
57	15D	4006.72	910.23	84.51	75.98	4006.70	910.06	84.17	75.70	0.0005%	0.0193%
58	16B	3948.75	894.31	76.93	69.83	3940.11	896.44	84.17	75.71	0.2194%	-0.2373%
59	16C	3657.18	831.48	70.07	64.25	3621.12	830.58	84.17	75.70	0.9958%	0.1087%
60	16D	3833.80	869.44	74.52	67.87	3818.46	871.34	84.17	75.71	0.4018%	-0.2184%
61	17A	3549.86	804.78	61.07	56.94	3437.88	792.23	84.17	75.70	3.2572%	1.5847%
62	17B	3731.21	846.52	70.66	64.73	3699.10	846.64	84.17	75.70	0.8680%	-0.0133%
63	17C	3804.41	866.26	78.56	71.15	3799.09	867.75	84.17	75.70	0.1400%	-0.1718%
64	17D	4218.01	964.76	104.16	91.93	4163.81	944.26	84.17	75.70	1.3018%	2.1711%
65	18A	3922.39	897.42	91.59	81.72	3914.58	892.36	84.17	75.70	0.1994%	0.5662%
66	18B	3979.95	903.75	82.77	74.57	3979.64	904.39	84.17	75.70	0.0078%	-0.0710%
67	18C	3858.63	876.56	77.48	70.26	3850.78	878.11	84.17	75.70	0.2040%	-0.1764%
68	18D	4183.80	952.30	95.26	84.70	4165.83	943.14	84.17	75.70	0.4314%	0.9707%
69	19A	4011.64	913.18	87.34	78.28	4010.04	911.34	84.17	75.70	0.0399%	0.2012%
70	19B	4083.53	931.28	94.25	83.88	4069.13	923.41	84.17	75.70	0.3538%	0.8525%
71	19C	4318.93	986.57	107.46	94.61	4248.77	960.77	84.17	75.70	1.6513%	2.6855%
72	19D	3905.64	887.82	81.29	73.37	3904.33	888.98	84.17	75.70	0.0335%	-0.1305%
73	20A	4582.87	1048.42	121.89	106.33	4414.09	995.31	84.17	75.70	3.8235%	5.3366%
74	20B	4485.16	1025.36	116.93	102.31	4357.95	982.85	84.17	75.70	2.9191%	4.3253%
75	20C	3804.58	862.12	71.86	65.71	3778.01	862.98	84.17	75.71	0.7035%	-0.0990%
76	20D	4053.70	925.15	94.00	83.68	4040.04	917.59	84.17	75.70	0.3381%	0.8230%
77	21A	4304.57	978.40	98.47	87.31	4275.63	965.12	84.17	75.71	0.6769%	1.3763%
78	21B	4068.96	924.16	87.05	78.04	4067.70	922.43	84.17	75.71	0.0310%	0.1878%
79	21C	3865.85	880.68	82.50	74.34	3865.41	881.38	84.17	75.70	0.0114%	-0.0796%
80	21D	4278.08	973.19	99.42	88.09	4248.02	958.78	84.17	75.71	0.7075%	1.5026%
81	22A	3581.52	816.45	71.09	65.07	3553.31	816.74	84.17	75.70	0.7941%	-0.0360%
82	22B	4185.63	956.24	102.30	90.43	4143.54	938.58	84.17	75.70	1.0156%	1.8817%
83	22C	4072.67	930.28	95.84	85.18	4053.38	920.79	84.17	75.70	0.4758%	1.0307%
84	22D	4194.47	963.89	112.42	98.64	4103.64	931.63	84.17	75.70	2.2133%	3.4629%
85	23A	4322.63	985.35	104.80	92.46	4268.19	963.58	84.17	75.70	1.2755%	2.2599%
86	23B	4071.06	926.91	91.45	81.62	4063.54	921.68	84.17	75.70	0.1850%	0.5676%
87	23C	4014.81	915.42	91.95	82.02	4006.90	909.75	84.17	75.71	0.1972%	0.6235%
88	23D	3872.93	883.38	85.68	76.93	3872.61	882.56	84.17	75.70	0.0083%	0.0924%
89	24A	3584.25	812.05	62.28	57.93	3497.05	805.47	84.17	75.71	2.4935%	0.8174%
90	24B	3580.23	810.71	60.00	56.09	3477.37	803.30	84.17	75.71	2.9579%	0.9218%
91	24C	3693.89	836.05	64.21	59.50	3623.99	832.98	84.17	75.71	1.9290%	0.3685%
92	24D	4293.69	974.64	95.84	85.19	4275.23	964.38	84.17	75.71	0.4317%	1.0646%
93	25A	3557.44	807.51	64.18	59.47	3487.07	803.00	84.17	75.70	2.0180%	0.5608%
94	25B	3850.58	877.18	82.68	74.49	3850.25	877.86	84.17	75.70	0.0084%	-0.0771%
95	25C	3791.03	859.30	70.84	64.89	3762.84	861.12	84.17	75.71	0.7492%	-0.2108%
96	25D	4304.37	979.87	101.98	90.17	4264.74	962.09	84.17	75.71	0.9291%	1.8486%
97	26A	3503.20	794.61	60.64	56.60	3399.79	784.88	84.17	75.70	3.0417%	1.2406%
98	26B	4004.62	910.41	85.81	77.03	4004.21	909.50	84.17	75.70	0.0102%	0.0996%
99	26C	4154.56	946.10	95.91	85.24	4136.48	936.19	84.17	75.71	0.4371%	1.0584%
100	26D	3955.26	896.84	79.11	71.60	3951.35	898.84	84.17	75.71	0.0990%	-0.2230%
Average		**3976.07**	**904.90**	**86.06**	**77.24**	**3942.13**	**897.03**	**84.17**	**75.70**	**0.8740%**	**0.8395%**

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

Applied Water Level		Precisioin Farming	Whole-Field Farming	Change
50% ET	Avearge Nitrogen Applied (lbs/ac/yr.)	49.33	46.70	5.33%
	Average Lint Yield (lbs/ac/yr)	705.722	698.02	1.11%
	Average Net Revenue above Nitrogen and Water Costs ($/ac/yr)	316.96	313.84	0.99%
75% ET	Averge Nitrogen Applied (lbs/ac/yr)	86.06	84.17	2.20%
	Average Lint Yield (lbs/ac/yr)	904.90	897.03	0.88%
	Average Net Revenue above Nitrogen and Water Costs ($/ac/yr)	397.61	394.21	0.86%

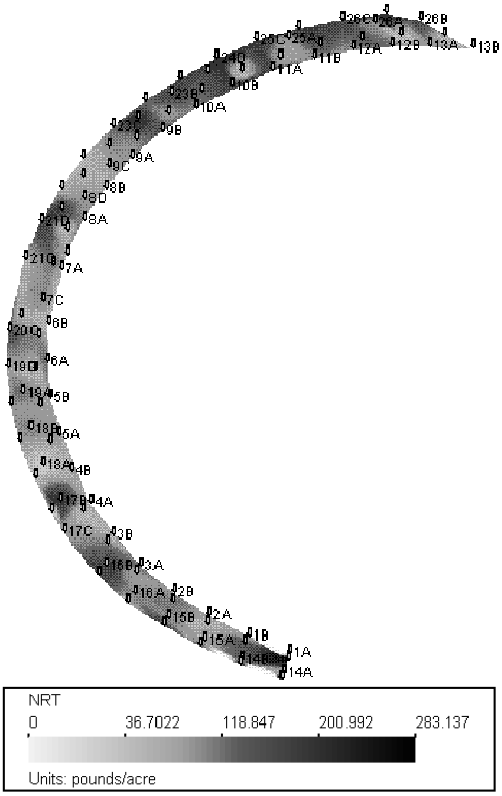

Figure 1. NO3-N Pre-Season Residual Map from 0 to 90 Centimeters of Soil Depth, Lamesa, Texas, 1998.

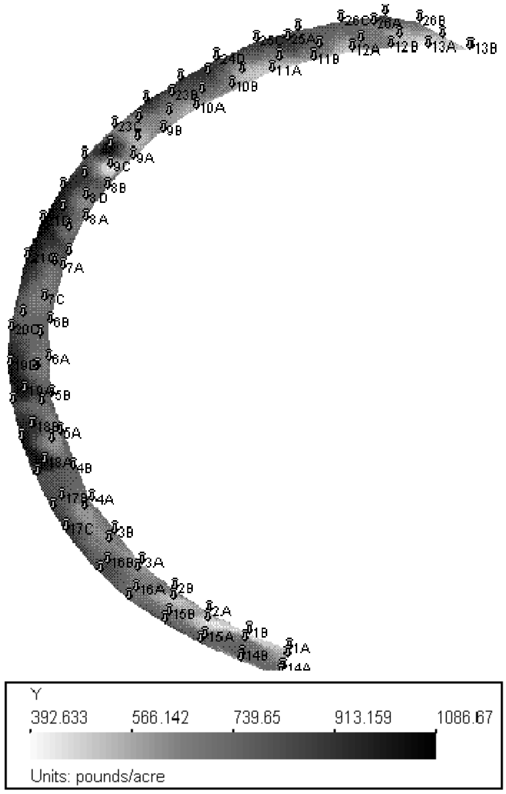

Figure 2. Spatial Cotton Yield Map, Lamesa, Texas, 1998.

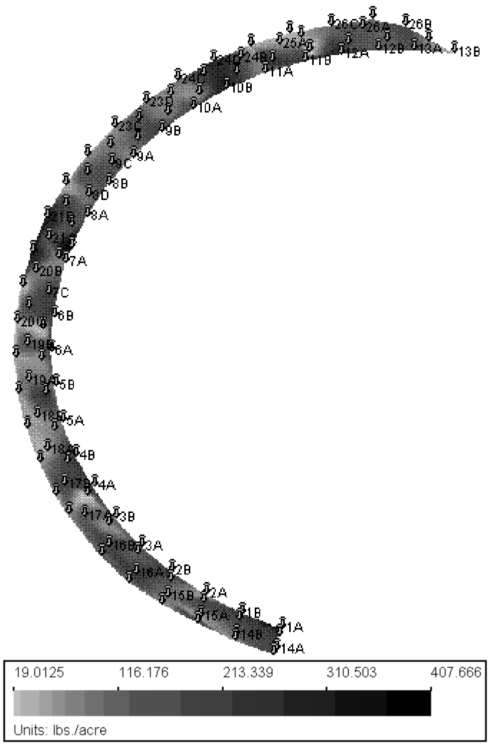

Figure 3. NO3-N After-Season Residual Map from 0 to 90 Centimeters of Soil Depth, Lamesa, Texas, 1998.

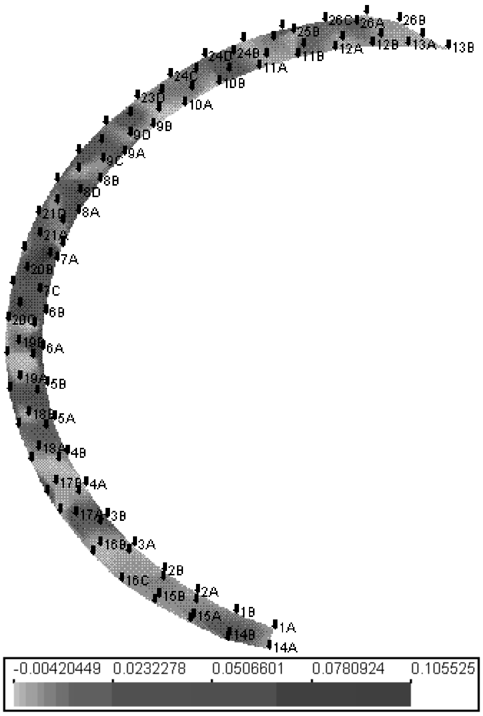

Figure 5. Yield Change for a Ten-Year Optimization Model (Precision Farming and Conventional Whole-Filed Farming), Lamesa, Texas, 1998.

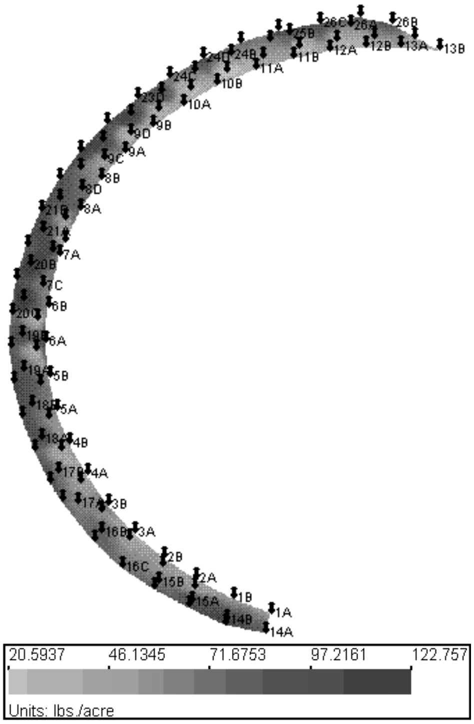

Figure 4. Optimal Levels of Spatial Nitrogen Application Map on a Per-Acre and Per-Year Basis for a Ten-Year Planning Horizon, Lamesa, Texas, 1998.

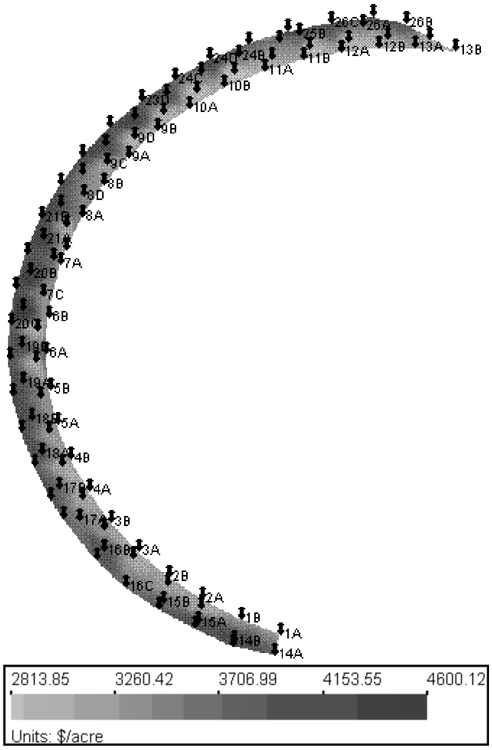

Figure 6. Spatial Net Revenue Above Nitrogen and Water Costs for a Ten-Year Optimization Model For Precision Farming Practices, Lamesa, Texas.

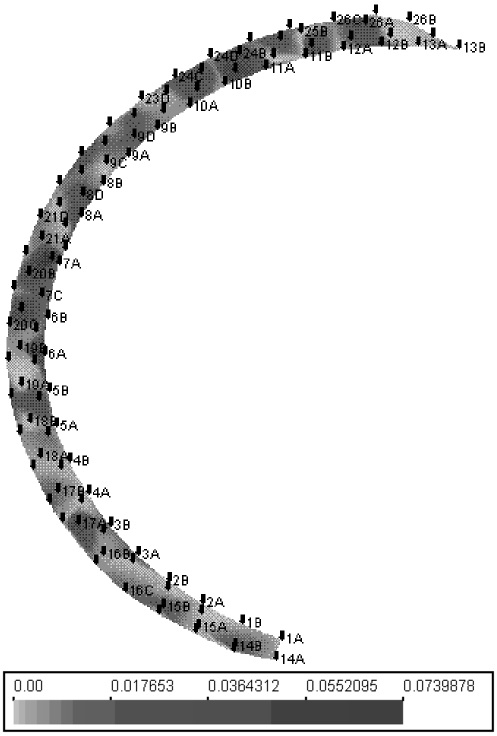

Figure 7. Spatial Net Revenue Change to Nitrogen Use (Precision Farming and Conventional Whole-Filed Farming), Lamesa, Texas, 1998.