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Technological Efficiency Gains in Irrigated Cotton Production

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ABSTRACT

Precision farming technology in irrigated cotton production has the potential to precisely manage inputs and outputs. This success of this technology depends on the economic efficiencies gained over traditional whole-field farming. The overall objective of this study was to evaluate the profitability of precision farming and optimal decision rules for production of cotton in the Southern High Plains of Texas. A dynamic optimization model with a nitrate-nitrogen carryover function allowed for the derivation of optimal input application levels, yield, and net present value of returns (NPVR). On the average, precision farming increased yield and NPVR by 4.01% and 4.50%, respectively, as compared to whole-field farming. However, precision farming also used 0.1564% more nitrogen application on the average. Yield and net present value of returns also had less variability under precision farming management practices. This study suggests that nitrogen fertilizer can be used more efficiently to maximize NPVR under precision farming.

KEYWORDS: Cotton Economics, Mathematical Optimization, Precision Farming, Technology Adoption

The adoption of technological advances in agricultural production has the potential to increase yields and profitability, while positively impacting the environment (Moreenthaler 2003). Adoption of technological advances in agriculture is necessary because with a highly competitive market structure, where the producer is a price-taker, consumers demand high quality products at low prices. These demands can be met through the adoption of precision farming practices. Therefore, the objective of this study was to evaluate the economic impacts of using precision farming technology.

Traditional whole-field farming assumes spatial and temporal field homogeneity, and optimal levels of input use do not account for inherent differences within fields (Weiss 1996, Shanahan 2004). However, fields are not homogeneous, indicating that many field characteristics, such as nitrogen, sand, clay, and silt content levels, vary within the field. In general, optimal input use under traditional whole-field farming optimizes for average characteristics, for example, average nitrogen residual levels, within the field. In other words, traditional whole-field farming optimizes input use on what is best for the field as a whole, or “on average”. Optimal application rates are uniform across the field, regardless of the specific characteristics and requirements of any particular location within the field. This may not be efficient if there is significant spatial variability of characteristics. Given that all locations do not necessarily have the same yield potential, a uniform application may not necessarily result in optimal yields or profitability (Onken 1972, English et al. 2001).

Inherent differences within fields have been addressed with precision farming. Precision farming involves the sampling, mapping, analysis, and management of specific areas within fields in recognition of spatial and temporal variability with respect to soil fertility, pest populations, and crop characteristics (Weiss 1996). Precision farming optimizes input use under these conditions.

Precision farming involves the use of many site-specific technologies that can aid producers in management decisions. Global Positioning System (GPS) is a technology that allows site-specific information to be collected through interface with satellites. Many of these site-specific technologies are commercially available as separate components. This allows individual producers to assemble a package of technologies specifically tailored to their operation. Basic technologies include aerial photography and soil survey maps. Other advanced technology includes optical sensors that collect, process, and dispense inputs according to a decision rule as a tractor moves through the field, and Variable Rate Application, which is the ability to apply various amounts of inputs while moving across the field (Khanna et al. 1997).

There are several commodities, including cotton, that lead the state’s agricultural industry in importance in terms of production and generation of revenue. Therefore, cotton is addressed in this study due to its importance in Texas. The Southern High Plains of Texas (SHPT) is the region in this study; largely due to the emphasis and importance it commands in agricultural production in Texas. The SHPT is a semi-arid region, which encompasses 22 million acres, located in the northwestern portion of the state.

Cotton is the most important crop in this area in terms of value and acreage. Of the approximately 6 million acres of cotton planted annually in Texas, 2.6 to 3.3 million acres are planted in the SHPT region, with approximately half of these acres irrigated (Segarra et al. 1989). Cotton earns more dollars per gallon of irrigation water applied than any other crop grown in the region. Cotton lint yields in Texas have averaged approximately 450 pounds per acre since 1992 (National Agricultural Statistics Service). Cotton is also unique in that it adapts to poor soils and uses fertilizers efficiently (National Cotton Council).

Potential advantages of precision farming may include higher average yields, lower farm input costs, and environmental benefits from applying fewer inputs (English et al. 2000, Batte and Arnholt 2003). Thus, there is potential for increased profits if inputs can be allocated with greater economic efficiency across the field. This idea of "farming by the inch" provides a better understanding of the many factors that affect yields and profitability. Precision farming minimizes the likelihood of over-application or under-application of inputs because optimal input levels are not based on average conditions within a field. Inefficient use of inputs can cause producers to lose money and the environment to suffer.

The acceptance of precision farming practices in cotton production will ultimately depend on its economic performance as compared to conventional whole-field farming (Bullock et al. 2002). Research efforts have been directed toward the new technologies involved with precision farming. There has been an expressed need for more information on the economic performance of precision farming.

The overall objective of this study is to evaluate the profitability of precision farming and evaluate optimal decision rules for production of cotton in the Southern High Plains of Texas. The following are the specific objectives of this study:

(1) To assess the spatial relationship between input utilization and cotton yields;

(2) To derive optimal levels of spatial input use and develop decision rules for input application.

MATERIALS AND METHODS

Optimal decision rules for specific inputs are desired to maximize the net present value of returns to risk, management, overhead, and all other inputs in the production of cotton. The deterministic specification of the empirical dynamic optimization model formulated in this study, which will be used to derive optimal decision rules of input use for the cotton experiment, is shown in equations (1) through (4):

$$MaxNPV = \sum_{t=0}^{n} (PC_t \times Y_t(NT_t) - (PN_t \times NA_t))/(1+r)^t \tag{1}$$

subject to:

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

$$NR_{t+1} = f_t(NA_t, NR_t) \tag{3}$$

$$NR_0 = NR(0) \tag{4}$$

and NA_t, NR_t, $NT_t \geq 0$ for all t

Where, NPV is the net present value of returns to land, irrigation water, overhead, risk, and management from production; the length of the decision-maker's planning horizon is n years; PC_t is the price of cotton in year t; Y_t is the cotton yield function in year t; PN_t is the price of the input in year t; NA_t is the amount of input applied in year t; r is the discount rate; NT_t is the total amount of input available for crop growth in year t; NR_t is the residual amount of input already available in the soil in year t; and NR_0 is the initial residual amount of input available in the soil at the beginning of the planning horizon.

Equation 1 was the objective function, or performance measure of the optimization model. Equation 2 was the equality constraint that summed the amount of input applied and residual input to obtain the total amount of input available for cotton growth in any given year. This equation was used in the objective function to calculate cotton yield. Equation 3 was the equation that updated residual input annually, which was necessary for equation 2. This equation was the equation of motion because it updated the input residual at time $t+1$ depending on residual input at time t and input application at time t. Equation (4) was the initial input residual condition, which represented the residual level at the beginning of the planning horizon. Non-negativity constraints were also specified for input application, residual, and total amount of input.

Data for cotton were collected in Lamesa, Texas over two years. Twenty-six locations in the field were identified for data points. Four replications for each of the twenty-six locations were taken. Two water levels were used, one at 50% evapotranspiration (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 in increments of 12 inches, up to 48 inches of the soil profile. Nitrogen was applied at three different rates including 0, 80, and 120 lbs per acre. Sand, clay, and silt content in the soil were also measured. A cotton stripper equipped with sensors and GPS was used to harvest the cotton.

The data were used to estimate the production function, $Y = f(X)$, and the input carry-over function, $NR_{t+1} = f(NA, NR_t)$. Using GLM (General Linear Model) procedures in SAS, alternative functional forms were evaluated to find the best statistical fit between yield (dependent variable) and crop characteristics, input levels, location characteristics, and other variables in the experiment (independent variables) (SAS, 2002). The carry-over function was also estimated in SAS to represent the relationship between time $t+1$ input residual and the independent variables input residual in time t and input application in time t.

The economic feasibility of the two management practices were analyzed and compared with respect to input use, net present value of revenue above nitrogen and water costs, and yield. Optimal decision rules for a dynamic ten-year planning horizon were then derived.

The optimization models in equations (1) through (4) were used in the cotton analysis. Combinations of two water, nitrogen, and commodity prices were solved for both precision farming and whole-field farming practices. A 5.0% discount rate (average discount rate for the time period studied) under a 10-year planning horizon was used. Under the precision farming scenario, the initial residual nitrogen conditions varied across locations in the field. Under the whole-field farming scenario, the initial residual nitrogen conditions were held at the average initial condition across the whole field for all locations.

The optimal decision rules derived in this study for nitrogen use varied across time periods in the planning horizon for a given input and output price combination. However, given that a stable decision rule was desirable to simplify management implementation, an additional constraint of equating nitrogen input applications across time periods within the planning horizon was introduced. Without this constraint, application recommendations would vary both spatially and temporally for the entire management horizon. Therefore, to condense the sheer volume of data into a useable amount for management implementation, the constraint allowed for the optimal application for the 10-year planning horizon for each location in the field. Cotton yield, net per-acre present value of returns above nitrogen and water costs (NPVR), and ending residual nitrogen levels for the 10-year planning horizon were obtained. GAMS (General Algebraic Modeling System), a mathematical optimization software system developed by the World Bank in Washington D.C., was used to solve the optimization models for both farm management practices.

Due to the changing prices of technology and region specific application costs, no costs for implementing precision farming above whole-field farming were included in the analysis. Thus, the cost of collecting the site-specific information, analysis of the data, and variable rate application costs have not been accounted for in this study. The decision to exclude these costs allows the change in profitability per acre when employing precision farming technology to be compared to the current cost of implementation in the SHPT to determine the feasibility of implementing the new technology into farm management practices. For example, if precision farming technology gains 7% efficiency, which translates to $14 per acre, then the producer has $14 per acre to spend implementing this technology. With the cost of technology changing so rapidly, it would be inefficient to include this price in the model and re-calculate every time technology fees change. Instead, efficiency gains tell the producer the amount gained from the new technology. The producer would adopt precision farming if the technology could be implemented in their area for something less than the efficiency gain.

The cotton models were solved under a high irrigation water scenario with all possible combinations of two cotton prices, $0.40 and $0.60 per pound, two nitrogen prices, $0.25 and $0.30 per pound, and two water prices, $2.68 and $3.50 per acre-inch. However, the results obtained did not vary much as input and output prices changes, therefore, one representative scenario with water price of $2.68 per acre-inch, cotton price of $0.40 lb. and nitrogen price of $0.25 are reported. Percentage changes in net revenues above nitrogen and water costs, cotton yields, and nitrogen application levels were also analyzed to obtain an overall picture of the impacts of one management practice over the other.

RESULTS

Three overall scenarios were analyzed: 1) precision farming, 2) naïve whole-field farming, and 3) actual whole-field farming. Under the precision farming scenario each individual location's characteristics within the field were used in the optimization modeling to determine the optimal nitrogen application level for each location. Under the naïve scenario, the initial nitrogen condition and location characteristics were set at the mean level of the field to determine a single optimal nitrogen application level for the entire field. The actual whole-field farming scenario used the optimal nitrogen application level determined under the naïve scenario and each individual location's characteristics. This scenario was evaluated because it provides the most realistic comparison of whole-field farming to precision farming.

In the experiment, cotton yield was found to be a quadratic function of total nitrogen, which was defined as the addition of residual nitrogen from 0 to 12 inches of soil depth and nitrogen applied during the season, altitude, sand, silt, irrigation water, and year. The residual nitrogen function, which estimated the residual nitrogen from 0 to 12 inches of soil depth at the end of the season, was found to be a linear function of nitrogen applied, irrigation water, residual nitrate-nitrogen from 0 to 12 inches of soil depth, and year.

Yield was measured in lbs per acre and was defined as Y. Total nitrogen was measured in lbs per acre and was defined as NT. Altitude was measured in feet above a reference point and was defined as ALT. Sand and silt were measured as a percentage of the soil content. They were defined as SAND and SILT, respectively. Irrigation water was introduced as a dummy variable that represented two irrigation water levels, 50% ET and 75% ET. Irrigation water was defined as W, with 0 representing 50% ET and 1 representing 75% ET. Year was also introduced as a dummy variable, with 0 representing Year #1 and 1 representing Year #2, defined as YEAR. Residual nitrate-nitrogen from 0 to 12 inches of soil depth at the end of the season was measured in lbs per acre and was defined as NR_{t+1}. Nitrogen applied was the amount of nitrogen applied during the season in lbs per acre and was defined as NA. Residual nitrate-nitrogen from 0 to 12 inches of soil depth was measured in lbs per acre at the beginning of the season and was defined as NR_t. The functions for yield and residual nitrate-nitrogen at the end of the season with their parameter estimates are shown in equations (5) and (6), respectively.

$$\begin{aligned} &Y = 516.7297 - 0.0097 \times NT^2 + 0.0050 \times NT \times ALT \times SAND - \\ &14.0392 \times NT \times SILT + 0.1488 \times ALT \times W + 20.4874 \times YEAR \\ &R^2 = 0.494 \end{aligned} \tag{5}$$

$$\begin{aligned} &NR_{t+1} = 53.3405 + 0.0805 \times NA \times W + 0.2083 \times NR_t - \\ &37.3192 \times YEAR \\ &R^2 = 0.530 \end{aligned} \tag{6}$$

The R-squared was .494 for the yield model and .530 for the residual model. This indicates that 49.4% of the variation in irrigated cotton yield was explained by NT*NT, NT*ALT*SAND, NT*SILT, ALT*W, and YEAR. NA*W, NR_t, and YEAR account for 53.0% of the variation in NR_{t+1}. The models were estimated using the Generalized Linear Modeling procedures (GLM) in SAS. The results were then used to formulate the optimization models in GAMS to determine optimal input application decision rules (equations 1 through 4). The constraint to equate nitrogen application across all time periods was included as well for simpler management decision rules.

Solutions to the 97-optimization models (48 for precision farming, 48 for actual whole-field farming, and 1 for the naïve whole-field farming approach) are presented in Table 1. This table corresponds with a water price of $2.68 per acre-inch, a cotton price of $0.40 per lb, and a nitrogen price of $0.25 per lb under a high level of irrigation water.

Several water, nitrogen, and cotton prices were used in the study and the results were very robust, therefore, a representative scenario was chosen for detailed discussion in the paper.

The scenario discussed in Table 1 corresponds to Figures 1 through 6 generated with MapInfo (Vertical Mapper, Version 1.50, Capital Region, NY). Table 1 shows the nitrogen residual (NRES), net present value of returns above nitrogen and water costs for precision farming (NREVpf), yield for precision farming (YIELDpf), optimal nitrogen application under precision farming (NApf), net present value of returns above nitrogen and water costs for whole-field farming (NREVwf), yield for whole-field farming

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

Location	NRES lbs/ac.	NREVpf $/acre	YIELDpf lbs/ac./yr.	NApf lbs/acre	NREVwf $/acre	YIELDwf lbs./ac./yr.	NAwf lbs/acre	NREV CH	YIELD CH	NA CH
1a	48.44	2378.07	848.16	78.12	2330.98	835.99	81.51	2.02%	1.46%	-4.16%
2a	65.76	2379.67	847.10	75.83	2331.26	836.08	81.51	2.08%	1.32%	-6.97%
3a	203.89	2319.51	819.64	57.53	1657.70	628.39	81.51	39.92%	30.43%	-29.42%
4a	60.78	2379.42	847.46	76.49	2333.11	836.65	81.51	1.98%	1.29%	-6.16%
5a	41.34	2576.79	925.08	102.98	2526.22	896.20	81.51	2.00%	3.22%	26.34%
6a	92.80	2578.90	921.25	96.17	2578.99	912.47	81.51	0.00%	0.96%	17.98%
7a	74.12	2580.22	923.18	98.64	2579.11	912.50	81.51	0.04%	1.17%	21.02%
8a	66.42	2580.07	923.80	99.66	2572.76	910.55	81.51	0.28%	1.46%	22.27%
9a	36.96	2617.98	941.01	108.03	2550.34	903.63	81.51	2.65%	4.14%	32.54%
10a	67.73	2622.42	939.54	103.96	2619.83	925.06	81.51	0.10%	1.57%	27.54%
11a	32.28	2616.75	941.08	108.65	2534.54	898.76	81.51	3.24%	4.71%	33.30%
12a	26.08	2614.88	941.12	109.47	2511.52	891.66	81.51	4.12%	5.55%	34.30%
13a	26.18	2595.53	933.86	107.41	2496.91	887.16	81.51	3.95%	5.26%	31.78%
14a	74.22	2603.08	931.74	101.05	2605.15	920.53	81.51	-0.08%	1.22%	23.97%
15a	44.67	2600.29	933.53	104.96	2555.74	905.30	81.51	1.74%	3.12%	28.77%
16a	57.71	2602.26	932.93	103.23	2584.32	914.11	81.51	0.69%	2.06%	26.65%
17a	41.59	2547.34	913.98	99.76	2499.67	888.01	81.51	1.91%	2.92%	22.39%
18a	51.51	2549.11	913.98	98.44	2520.49	894.43	81.51	1.14%	2.19%	20.78%
19a	48.89	2548.71	913.59	98.79	2515.59	892.92	81.51	1.32%	2.32%	21.20%
20a	65.66	2550.47	913.71	96.57	2539.46	900.28	81.51	0.43%	1.49%	18.48%
21a	44.51	2517.31	912.74	96.00	2476.75	880.94	81.51	1.64%	3.61%	17.77%
22a	60.22	2519.45	902.33	93.92	2500.34	888.22	81.51	0.76%	1.59%	15.22%
23a	82.58	2519.61	901.55	90.95	2507.13	890.31	81.51	0.50%	1.26%	11.59%
24a	45.97	2517.58	899.68	95.80	2479.60	881.82	81.51	1.53%	2.03%	17.54%
25a	80.12	2579.21	902.27	97.80	2580.54	912.94	81.51	-0.05%	-1.17%	19.99%
26a	80.12	2579.21	922.34	97.80	2580.54	912.94	81.51	-0.05%	1.03%	19.99%
27a	42.10	2576.11	922.34	102.83	2527.39	896.56	81.51	1.93%	2.88%	26.16%
28a	113.80	2573.75	924.77	93.34	2551.61	904.02	81.51	0.87%	2.30%	14.51%
29a	36.71	2197.66	918.05	52.12	2096.87	763.81	81.51	4.81%	20.19%	-36.06%
30a	59.92	2200.75	776.38	49.05	2066.32	754.39	81.51	6.51%	2.92%	-39.83%
31a	35.20	2197.33	775.21	52.32	2097.68	764.06	81.51	4.75%	1.46%	-35.81%
32a	34.29	2197.13	776.43	52.44	2098.10	764.19	81.51	4.72%	1.60%	-35.66%
33a	79.91	2257.71	776.45	56.23	2121.35	771.35	81.51	6.43%	0.66%	-31.02%
34a	73.22	2258.06	797.23	57.11	2137.57	776.36	81.51	5.64%	2.69%	-29.93%
35a	90.64	2256.52	797.89	54.81	2089.49	761.53	81.51	7.99%	4.77%	-32.76%
36a	62.79	2257.99	796.00	58.49	2157.19	782.41	81.51	4.67%	1.74%	-28.24%
37a	88.22	2404.54	798.76	76.18	2342.58	839.57	81.51	2.65%	-4.86%	-6.54%
38a	134.85	2391.71	854.98	70.00	2194.18	793.81	81.51	9.00%	7.71%	-14.12%
39a	132.43	2392.74	847.66	70.32	2205.23	797.22	81.51	8.50%	6.33%	-13.72%
40a	130.47	2393.55	848.14	70.58	2213.95	799.91	81.51	8.11%	6.03%	-13.40%
41a	69.94	2250.58	848.52	56.26	2131.50	774.49	81.51	5.59%	9.56%	-30.97%
42a	67.68	2250.58	795.05	56.56	2136.08	775.90	81.51	5.36%	2.47%	-30.60%
43a	142.15	2232.31	795.25	46.70	1816.26	677.28	81.51	22.91%	17.42%	-42.71%
44a	116.87	2242.73	784.01	50.05	1963.95	722.82	81.51	14.19%	8.46%	-38.60%
45a	63.50	2376.55	846.05	75.67	2328.15	835.12	81.51	2.08%	1.31%	-7.17%
46a	70.09	2376.72	845.54	74.80	2324.03	833.85	81.51	2.27%	1.40%	-8.24%
47a	98.49	2374.09	842.43	71.03	2274.98	818.73	81.51	4.36%	2.89%	-12.85%
48a	126.79	2366.02	837.91	67.28	2175.61	788.09	81.51	8.75%	6.32%	-17.45%
Whole-Field	**72.72**	**2430.66**	**866.36**	**81.51**						
AVERAGE		**2439.56**	**871.91**	**81.50**	**2346.22**	**840.69**	**81.51**	**4.50%**	**4.01%**	**-0.01%**
VARIANCE		**21838.47**	**3296.12**	**425.98**	**53150.53**	**5053.35**	**0.00**			

(YIELDwf), optimal nitrogen application for whole-field farming (NAwf), net present value of returns above nitrogen and water costs percentage increases when using precision farming over whole-field farming (NREV CH), yield percentage increases when using precision farming over whole-field farming (YIELD CH), and nitrogen application percentage increases when using precision farming over whole-field farming (NA CH). The initial residual nitrogen in Table 1 corresponds to those shown spatially in the cotton field map in Figure 1.

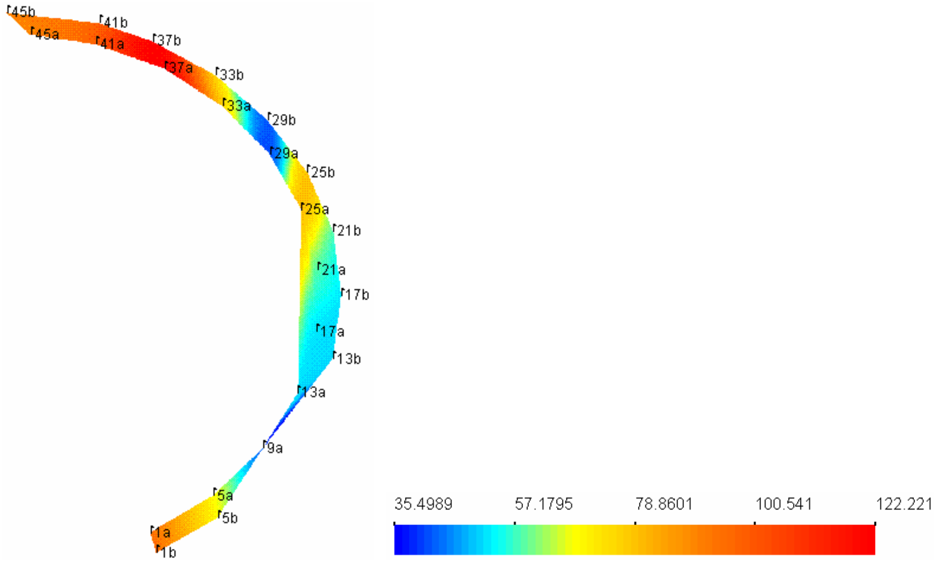

Figure 1. NO3-N Pre-Season Residual Map in lbs/acre from 0 to 12 Inches of Soil Depth, Lamesa, Texas.

In this figure, the red area in the northern portion of the field indicates locations with the highest residual nitrogen in the soil from 0 to 12 inches. This field was a research plot irrigated under a center pivot; therefore, the shape of the field is a portion of a plot (50 acres). As shown in Table 1, location 17a has an associated residual nitrogen level of 41.59 lbs per acre, which can be found in Figure 1 in the center portion of the field, whereas location 37a is shown to have 88.22 lbs per acre of residual nitrogen, which is in the northern portion of the field. The red areas indicate locations with the most residual nitrogen before the experiment, while the blue areas represent locations within the cotton field with the least residual nitrogen.

The optimal levels of nitrogen applied to maximize NPVR for precision farming are illustrated in Figure 2. It is clearly more likely to be profitable to fertilize the center and southern portions of the field (red zones) heavier than the northern locations (blue zones). The optimal nitrogen application map in Figure 2 mirrors the spatial yield map in Figure 3. The optimal levels of spatial nitrogen to apply are shown in Table 1. For example, at location 5a, NPVR will be maximized if 26.34% more nitrogen is applied than the optimal application recommendation under whole-field farming practices. Also, location 35a is shown to use 32.76% less nitrogen application than under optimal whole-field farming practices to maximize NPVR. A blanket nitrogen application of 81.51 lbs per acre is shown to be optimal for whole-field farming practices. Overall, for the whole-field, precision farming is shown to use 0.01% less nitrogen on the average than under whole-field farming, thus it becomes critical to observe individual location needs.

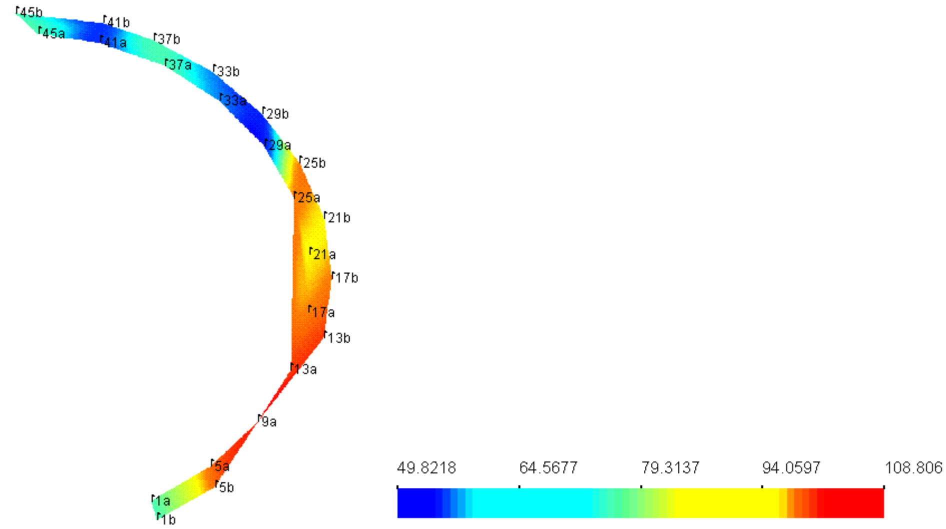

Figure 2. Optimal Levels of Spatial Nitrogen Application (lbs/acre) Map for Precision Farming Practices on a Per-Year Basis for a Ten-Year Planning Horizon, Lamesa, Texas.

The spatial yield map for precision farming is illustrated in Figure 3. The red areas in the northern portion of the field, where residual nitrogen concentrations are highest, yield the lowest. This same phenomenon holds true for whole-field farming yields in Figure 4.

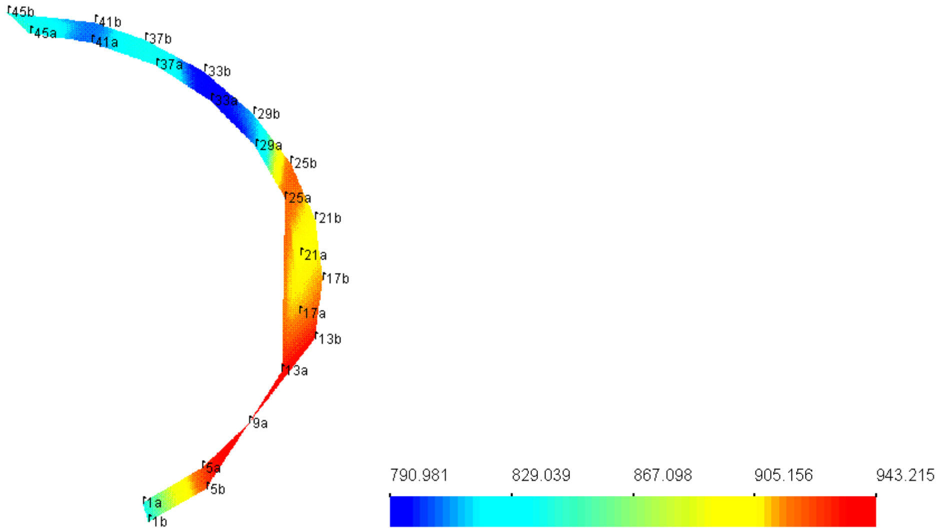

Figure 3. Spatial Cotton Yield Map (lbs/acre) for Precision Farming Practices, Lamesa, TX.

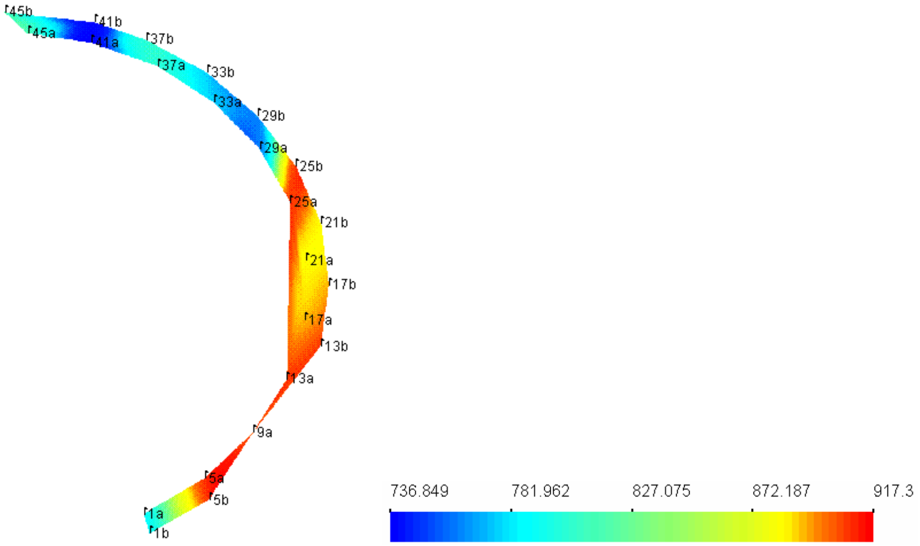

Figure 4. Spatial Cotton Yield Map in lbs/acre for Whole-Field Farming Practices, Lamesa, Texas.

For example, location 25a is shown to yield 1.17% less under precision farming practices, in contrast to location 29a, which is shown to yield 20.19% more under precision farming practices as compared to whole-field farming practices. Overall, the naïve whole-field farming scenario estimated lower yields than precision farming, but higher than actual whole-field farming on the average. The actual whole-field farming yield was shown to be 4.01% lower when compared with precision farming management practices.

The optimal levels of spatial NPVR for precision farming are illustrated in Figure 5. Notice that this figure closely resembles the corresponding spatial cotton yield map in Figure 3. This same trend holds for Figure 6 under whole-field farming management practices. Individual locations, such as location 3a, have the potential to increase NPVR by 39.92% if the optimal nitrogen application is observed under precision farming practices. Thus, it is crucial to observe individual location potential as well as the average potential of the field as a whole. The NPVR estimates for the ten-year planning horizon are more optimistic under the naïve whole-field farming scenario than under the actual whole-field farming scenario. However, under the precision farming scenario, NPVR is shown to increase by 4.50% on the average across the field as compared to the actual whole-field farming scenario.

The spatial pdf's for cotton NPVR and cotton yields, respectively are illustrated in Figures 7 and 8. Figure 7 indicates that there is less spatial variability in precision farming NPVR than with whole-field farming NPVR. Precision farming is also shown to have a greater probability of higher and mid-level NPVR. There is a greater probability of lower NPVR under the whole-field farming scenario, indicating more downside variability when whole-field farming practices are employed. The dashed line in Figure 7 indicates a higher NPVR on the average for precision farming than with whole-field farming (solid line). Figure 8 indicates less spatial yield variability under precision farming practices with less downside variability and more upside potential. On the average, cotton yields are shown to be higher under precision farming practices as compared to whole-field farming practices. Figure 9 shows the cumulative density function for both precision and whole-field farming NPVR. The spatial cdf for precision farming (dashed line) clearly dominates the spatial cdf for whole-field farming (solid line), indicating that more NPVR would be expected from precision farming practices than from whole-field farming practices.

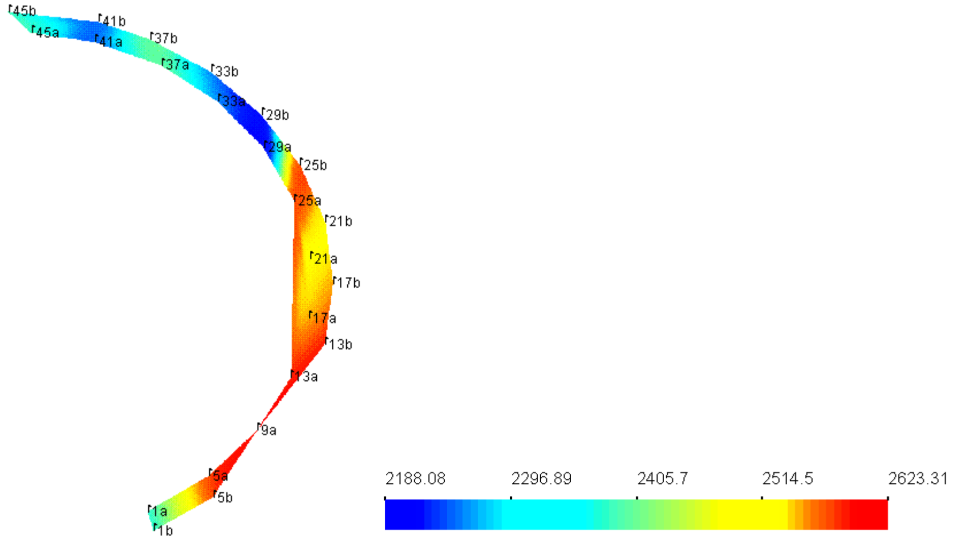

Figure 5. Spatial Net Revenue Above Nitrogen and Water Costs for a Ten-Year Optimization Model for Precision Farming Practices, Lamesa, Texas.

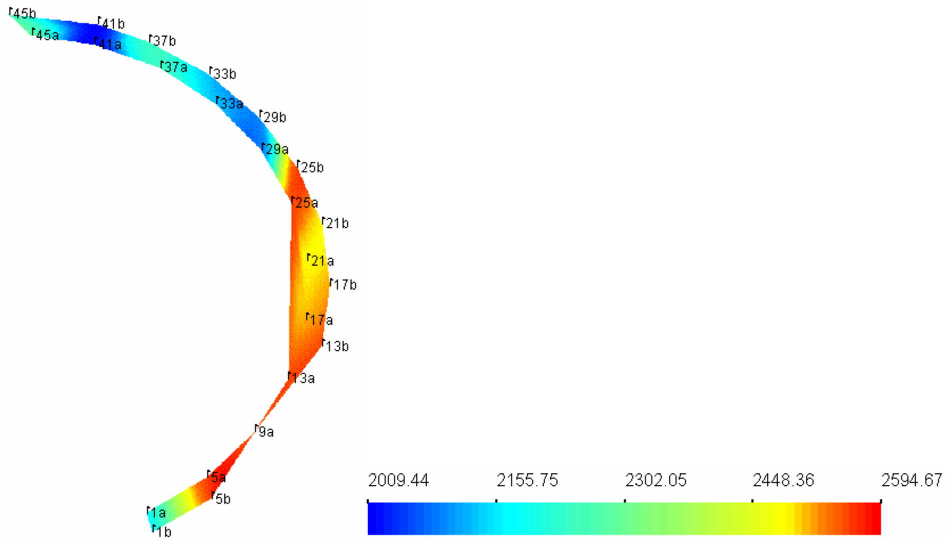

Figure 6. Spatial Net Revenue Above Nitrogen and Water Costs for a Ten-Year Optimization Model for Whole-Field Farming Practices, Lamesa, Texas.

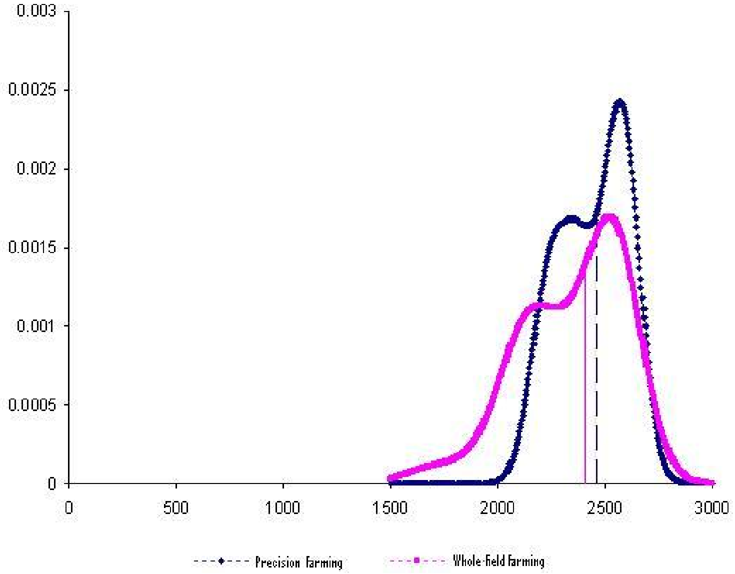

Figure 7. Probability Density Function for Cotton Net Revenues Above Nitrogen and Water Costs.

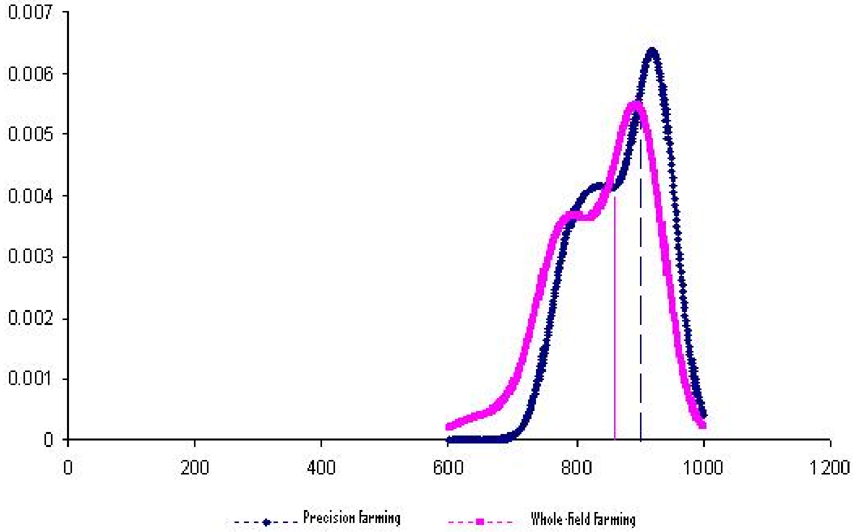

Figure 8. Probability Density Function for Cotton Yields.

In this experiment, yield and NPVR on average increased by 4.01% and 4.50%, respectively, when using precision farming practices. Nitrogen application was virtually the same with 0.01% less nitrogen application on the average under precision farming practices. Variability associated with yield and NPVR is clearly smaller under precision farming practices. There is more downside variability with whole-field farming for both yields and NPVR. Therefore, precision farming clearly dominates whole-field farming in terms of average yield and NPVR as well as decreases variability.

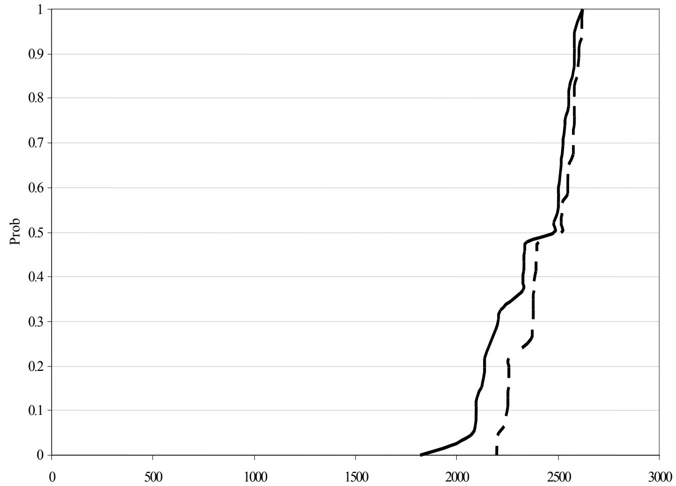

Figure 9. Cumulative Density Function for Cotton Net Revenues Above Nitrogen and Water Costs. (- - - Precision Farming ― Whole-Field Farming)

SUMMARY AND DISCUSSION

Both yields and NPVR increased on the average when precision farming practices were employed. On the average, yield was shown to increase by 4.01%, while NPVR were shown to increase by 4.05% as compared to whole-field farming. The optimal level of spatial nitrogen application was slightly lower in the precision farming scenario, by 0.01%. The naïve whole-field farming scenario overestimated both yield and NPVR. Finally, precision farming had less yield and NPVR variability as compared to whole-field farming.

This study suggests that nitrogen fertilizer can be used more efficiently to maximize NPVR under precision farming. Precision farming increased yield and NPVR on the average. The naïve whole-field farming scenario consistently overestimated yield and NPVR in cotton.

Optimal nitrogen application was not significantly different in cotton when using precision farming technology as compared to whole-field farming. The spatial NPVR cdf for precision farming clearly dominated the whole-field farming cdf. Therefore, precision farming is shown to be more profitable than whole-field farming based on net revenues above nitrogen and water costs. As mentioned earlier, the purpose of determining the difference in NPVR when using precision farming practices was to determine the maximum amount a producer could spend to implement precision farming practices. Knowing that precision farming will cost more than whole-field farming to implement, this study determines the magnitude a producer could afford to pay for the implementation of this new technology.

Several agricultural consulting groups in the Southern High Plains of Texas were contacted to determine the additional costs of implementing precision farming practices above whole-field farming. A wide range of responses left no real confidence in the values obtained. Yield monitors could cost $4000-$7000; with soil sampling estimated at $3-$7 per acre. GIS software is estimated at $3000. Service costs including yield monitoring, crop scouting, GPS receiver and, possibly a satellite signal subscription, and variable rate fertilizer application in the range of $2.50-$ 14.50 above whole-field farming costs on a per acre basis. (Cowan 2000). The cotton study increased NPVR by $9.33 per acre when precision farming was employed, covering all variable costs and contributing towards the fixed investment costs of implementing this new technology. This is the amount that producers can justify spending on precision agriculture in dollar terms. This is the figure to compare with costs of implementation in an area considering precision agriculture.

Overall, this study suggests that precision farming overall would be more profitable than whole-field farming. With the current cost of implementation of this technology, precision farming is expected to be more profitable today than whole-field farming is in the SHPT. This is very optimistic for precision farming as only one input was optimized. The results could reasonably be expected to improve even more if other inputs, such as phosphorus or water were to be considered. Future studies should address the specific costs of implementing this technology, as well as including more variable inputs. Also, a thorough risk analysis would be beneficial in future explorations.

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