Precision Farming in Irrigated Corn Production: An Economic Perspective

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Introduction

Agriculture in Texas is a large industry from which the economy thrives. For instance, in Texas, agriculture is the second-largest industry, contributing $80 billion dollars to the state's economy annually, as well as producing 16% of the gross state product. Almost 80% of the land in Texas is used in some form of agricultural production activity. The agricultural industry also employs 20% of the state's residents (TDA press release, 2001). Thus, the viability of agriculture on the livelihood of the Texas economy is critical.

There are several commodities that lead the state's agricultural industry in importance in terms of production and generation of revenues, among these include corn. Cotton and feed grains are among Texas' top five exports (TDA press release, 2001). Therefore, due to the importance of agricultural production in Texas, specifically corn production; the focus of this study will address this commodity.

The Southern High Plains of Texas (SHPT) is the region that will be emphasized 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, is located in the northwestern portion of the state.

Texas corn production ranks number ten in the United States in terms of production with 216.6 million bushels produced annually. Average yield per acre is just over one hundred bushels. Texas corn contributes about 5% to the annual agricultural cash receipts in Texas in addition to corn grown for silage. Approximately 65 to 85% of this production comes from irrigated fields. Corn yields have increased since the early 1900's (TAEX corn, 2001).

Currently, production agriculture is facing challenges such as increasing cost of production, shortage of irrigation water, and increased public concern for the impacts of agricultural production on the environment. To survive in the world market, producers must produce high quality products at low prices while employing environmentally friendly practices. Increased uses of fertilizers, pesticides, and other chemicals have contributed toward the enhancement of agriculture's productivity in recent decades. Today, technology adoption is seen as the key to increasing agriculture's productivity as available resources decline. Precision agriculture technology is one technological advance that may have the potential to increase productivity. Therefore, precision agriculture is the focus of this study in analyzing the economics of the Texas High Plains' commodity production.

General Problem

Traditional whole-field farming practices assume spatial and temporal field homogeneity, with optimal levels of input use not accounting for inherent differences within fields (Weiss, 1996). However, fields are not homogeneous, indicating that many field characteristics, such as nitrogen, sand, clay, and silt levels vary within the field. In general, optimal input use under traditional whole-field farming optimizes for average characteristics, for example, average residual nitrogen 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 input 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. All locations do not have the same yield potential, thus it appears that a uniform application may not necessarily result in optimal yields or profitability (Onken and Sunderman, 1972).

The differences within fields are 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.

Specific Problem

Potential advantages of precision farming may include higher average yield, lower farm input costs, and environmental benefits from applying fewer inputs (English et al., 2000). 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.

Objectives

The overall objective of this study is to evaluate the profitability of precision farming and evaluate optimal decision rules for corn production 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 corn yields;

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

3. To assess the short-run and long-run economic implications of precision farming management practices.

Methods and Procedures

This section is composed of the following sub-sections: (1) the optimization model, (2) data considerations for corn, (3) estimation of production and input carry-over functions, and (4) economic evaluation of whole-field farming versus precision farming.

Optimization Model

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 corn. 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 corn experiment is shown in equations (1) through (4):

$$\text{Max NPV} = \overset{n}{\underset{t=0}{?}} (PC_t{*}Y_t(XT_t) - PX_t{*}XA_t){*}(1+r)^{-t}) \qquad (1)$$

subject to:

$$XT_t = XA_t + XR_t, \qquad (2)$$

$$XR_{t+1} = f_t(XA_t, XR_t) \qquad (3)$$

$$XR_0 = XR(0), \qquad (4)$$

$$\text{and } XA_t, XR_t, XT_t \geq 0 \text{ for all t}$$

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 corn in year t; Y_t is the corn yield function in year t; PX_t is the price of the input in year t; XA_t is the amount of input applied in year t; r is the discount rate; XT_t is the total amount of input available for crop growth in year t; XR_t is the residual amount of input already available in the soil in year t; and XR_0 is the initial residual amount of input available in the soil at the beginning of the planning horizon.

Equation (1) is the objective function, or performance measure of the optimization model. Equation (2) is the equality constraint that sums the amount of input applied and residual input to obtain the total amount of input available for crop growth in any given year. This equation is used in the objective function to calculate corn yield. Equation (3) is the equation that updates residual input annually, which is necessary for equation (2). This equation is also called the equation of motion because it updates the input residual at time t+1 depending on residual input at time t and input application at time t. Equation (4) is the initial input residual condition, which represents the residual level at the beginning of the planning horizon. Non-negativity constraints are also specified for input application, residual, and total amount of input. The corn model was formulated as a ten-year dynamic model.

Data Considerations for Corn

The experiment was conducted in 2000 and 2001 in Halfway, Texas at the Texas A&M University Agricultural Research and Extension Center. The fields consisted of Pullman clay loam and Olton loam soils with moderately slow permeability and were irrigated with a low energy precision application (LEPA) system. In the experiment, 93 locations were analyzed. Water was applied at two levels, 17.185 and 15.26 acre-inches. Nitrogen was applied at three rates, 194.05, 149.58, and 88.93 lb./acre. The soil index, residual nitrogen, pH, organic matter, sulfur, magnesium, calcium, and iron were all measured in ppm in 6-inch increments of the soil profile up to 36 inches. No insecticide was applied in 2000 while Asana, Dimethoate, and Capture insecticides were applied in 2001. Only the drought-tolerant hybrid variety (Pioneer 3223) was used in this experiment.

Estimation of Production and Input Carry-over Functions

The data described in the previous sections was 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, 1982). The carry-over function was 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.

Economic Evaluation of Whole-Field Farming Versus Precision Farming

The economic feasibility of the two management practices was analyzed and compared with respect to input use, net present value of revenue above nitrogen and water costs (NPVR), and yield. The corn experiment was used to derive optimal decision rules for a dynamic ten-year planning horizon.

The optimization model in equations (1) through (4) was used in the corn analysis. Combinations of two water, nitrogen, and corn prices were solved for both precision farming and whole-field farming practices. A 5.0% discount rate was used under a 10-year planning horizon. Under the precision farming scenario, the initial residual nitrogen conditions vary 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 vary across time periods in the planning horizon for a given input and output price combination. However, given that a stable decision rule would be desirable to simplify management implementation, an additional constraint of equating nitrogen input applications across time periods within the planning horizon was introduced. Corn yield, 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, was used to solve the optimization models for both commodities and 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 will allow 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.

Results

The purpose of this section is to present the results and findings of this research. First, the functions estimated and results of the optimization models are discussed. Comparisons between precision farming and conventional whole-field farming results are then drawn in terms of NPVR, yield, and nitrogen application levels. Finally, spatial probability density functions and cumulative density functions are analyzed to evaluate the spatial variability associated with each management practice.

The corn production function was estimated using GLM procedures in SAS (SAS, 1982). Several functional forms were estimated, with the quadratic functional form providing the best fit for the data while maintaining feasible economic interpretation. The corn production function in this specific study is shown in equation (5).

$$Y = 57841.41891 + 29.54678*NT - .00003*NT^2*W - .00083*W*ORG*SI + \quad (5)$$
$$(4.22) \quad (4.55) \quad (-3.61) \quad (-3.44)$$
$$69.194*IRON - 527.966652*CALPER - 625.78723*MGPER$$
$$(2.51) \quad (-3.88) \quad (-3.85)$$
$$+ 0.75938*ORG*SUL - 1124.0942*YEAR$$
$$(3.16) \quad (-3.57) \qquad R^2 = .271$$

Where Y is the corn yield in lbs./acre; NT is total nitrogen available to the crop in lbs./acre; W is the irrigation water level in acre-inches; ORG is the organic matter in ppm; SI is the soil index, where high values indicate areas of high clay content; IRON is the amount of iron in the soil in ppm; CALPER is the percentage of calcium in the soil; MGPER is the percentage of magnesium in the soil; SUL is the amount of sulfur in the soil in ppm, and YEAR represents the year of the experiment, either 2000 or 2001.

The values in parenthesis below equation (5) are t-values, indicating that all variables were significant at the 99% level of probability. The R^2 value indicates that 27.12% of the variation in corn yields was explained by the independent variables included in the regression. The nitrogen carry-over function is shown in equation (6).

$$NR_{t+1} = 301.8831 + 0.016566*NR_t*EC + 0.1385*NA - 0.0242313*W*PH \quad (6)$$
$$(8.25) \quad (4.59) \quad (4.24) \quad (-8.81)$$
$$+ 0.0038502*W*ORG - 6.345*ORG$$
$$(10.21) \quad (-9.15) \qquad R^2 = .751$$

Where the variables are defined as before with the addition of NR_t which was defined as residual nitrogen at the beginning of the growing season from 0 to 24 inches of the soil depth profile in lbs./acre; EC was defined as the measure of electrical conductivity; NA was defined as the amount of nitrogen applied during the season in lbs./acre; and PH was defined as the pH level in the soil. T-values are again listed in parenthesis below the parameter estimates. The R^2 value indicates that 75.1% of the variation in residual nitrogen was explained by the independent variables included in the regression.

The optimization model used to evaluate this experiment is shown in equations (1) through (4), with the addition of the constraint to equate nitrogen application across time periods. The scenario discussed has a water price = $2.68 acre-inch, a corn price = $4.50 bushel, and a nitrogen price = $0.30/lb. under a high level of irrigation water, which is shown in Table 1. The locations shown in Table 1 correspond to those in Figures 1 through 6. Several price scenarios were analyzed, however, only one is discussed in this paper.

Figure 1 shows the initial residual nitrogen level from 0 to 24 inches of soil depth. The map indicates lower levels of residual nitrogen in the center to lower portions of the field. For example, location 52a, had an associated residual nitrogen level of 21.83 lbs./acre at the beginning of the season. In contrast, location 1a, a southern location, had an associated residual nitrogen level of 93.79 lbs./acre.

Figure 2 shows the spatial optimal nitrogen application levels for each location in the field under precision farming practices. This map is virtually a mirror opposite of the initial residual map (Figure 1). Precision farming optimally prescribed more nitrogen application in the residual nitrogen deficient locations. This explains why the yield maps, although mirror opposites of the residual nitrogen maps, are remarkably similar to the nitrogen application maps on a location by location basis. The single spatially optimal nitrogen application level for whole-field farming is 121.30 lbs./acre across the field. Location 49a is shown to use 92.59% less nitrogen under precision farming practices to maximize NPVR, while location 29a is shown to use 113.82% more nitrogen application under precision farming practices when maximizing NPVR. Precision farming maximizes NPVR when 6.39% more nitrogen is applied on the average than under whole-field farming practices. However individual locations may vary dramatically across the field.

Figure 3 shows the spatial corn yield map for precision farming practices. Comparing this map to the initial residual nitrogen map, it is shown that areas where there was little initial residual nitrogen at the beginning of the season ended with the highest yields.

The spatial corn yield map for whole-field farming, Figure 4, is similar to the precision farming yield map, with the pocket of high yielding locations in the center portion of the field. For example, location 49a was shown to decrease yield by 35.71% when precision farming practices were employed as compared to whole-field farming, whereas location 93a was shown to increase yield by 6.71% under precision farming practices. On the average, the naïve whole-field farming scenario estimated lower yields than the precision farming scenario, however, the actual whole-field farming scenario produced 7.41% higher yields than either the naïve or precision farming scenarios.

The optimal levels of spatial NPVR are shown in Figure 5 for precision farming practices. This figure resembles the spatial corn yield map in Figure 3. The same phenomenon holds for whole-field farming in Figure 6, where the center portion of the field is the most profitable in response to the optimal spatial nitrogen application prescription. The locations that were shown to receive the most nitrogen application ultimately had the highest NPVR. The revenues generated from the additional yield outweighed the cost of additional fertilizer. Overall, the naïve whole-field farming scenario predicted lower NPVR than the actual whole-field farming scenario. Precision farming had the highest NPVR, with an 8.15% increase over whole-field farming when precision farming practices were employed.

An interesting result of this specific study is that precision farming is not without NPVR and yield variability. Figure 7 shows the spatial pdf's for precision (dashed line) and whole-field farming (solid line) NPVR. Precision farming has a higher probability of generating the highest and lowest NPVR, while whole-field farming has the highest probability of generating mid-level NPVR. Therefore, it is shown that there is more NPVR variability under precision farming practices in this experiment, with more upside potential and downside variability. Yields for corn, which are lower on average with precision farming, are also more variable than with whole-field farming (Figure 8). There is much downside variability for corn yield under precision farming practices, with a slightly larger probability than whole-field farming of obtaining the highest yields. The spatial cdf's for precision (dashed line) and whole-field farming (solid line) are presented in Figure 9. Overall, precision farming dominates whole-field farming with respect to NPVR. This study is the most favorable to precision farming thus far, however, it also presents the most variability in terms of both yield and NPVR when this new technology is used.

Summary and Conclusions

The overall objective of this study was to evaluate the profitability of precision farming and evaluate optimal decision rules of corn production in the Southern High Plains of Texas. Whole-field farming had 7.41% higher yields than precision farming with less variability. However, precision farming had an average of 8.15% more NPVR as compared to whole-field farming. The optimal level of spatial nitrogen application averaged 6.39% higher under precision farming practices. The naïve whole-field farming scenario underestimated both yield and NPVR in this experiment. The variance for NPVR was lower under the whole-field farming scenario as compared to precision farming.

This study reveals that nitrogen fertilizer can be used more efficiently to maximize NPVR under precision 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 present value of 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, which 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. Therefore, the cost determined in Tennessee of $1.50 to $5.50 per acre, with an average increase of $3.08 per acre could be used as the baseline. However, the general consensus is that the cost of adoption would be higher in the Southern High Plains of Texas. Even doubling this estimate, precision farming is likely to be more profitable. Corn was very responsive to precision farming practices. The study allowed for $33.72 for implementation costs.

This study reveals that precision farming would be overall 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.

Table 1: Comparison of Precision Farming and Whole-Field Farming Scenarios with Water Price=$2.68/acre-inch, Corn Price=$4.50/bu., and Nitrogen Price=$0.30/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	93.79	5463.69	8437.01	8.99	5633.23	10486.56	121.30	-3.01%	-19.54%	-92.59%
2a	44.47	3602.42	5947.69	44.86	3939.59	7875.44	121.30	-8.56%	-24.48%	-63.02%
3a	14.55	4625.56	8176.47	210.08	3687.90	7487.40	121.30	25.43%	9.20%	73.19%
4a	69.54	3796.29	6198.35	36.36	4317.66	8458.32	121.30	-12.08%	-26.72%	-70.02%
5a	20.21	4762.45	8520.61	244.92	3904.41	7821.20	121.30	21.98%	8.94%	101.91%
6a	55.79	3302.51	5567.43	68.21	3400.84	7044.84	121.30	-2.89%	-20.97%	-43.77%
7a	64.68	3055.54	4707.47	8.99	3578.16	7318.21	121.30	-14.61%	-35.67%	-92.59%
8a	61.45	3973.73	6129.17	8.99	4606.13	8903.05	121.30	-13.73%	-31.16%	-92.59%
9a	53.36	4226.20	6924.14	49.31	4537.63	8797.45	121.30	-6.86%	-21.29%	-59.35%
10a	67.92	3740.28	6095.13	32.97	4275.16	8392.80	121.30	-12.51%	-27.38%	-72.82%
11a	20.21	5402.16	9439.53	226.38	4517.01	8765.66	121.30	19.60%	7.69%	86.63%
12a	38.81	5172.79	8927.44	186.00	4442.33	8650.52	121.30	16.44%	3.20%	53.34%
13a	25.07	4774.45	8577.76	254.92	3984.20	7944.22	121.30	19.83%	7.97%	110.16%
14a	39.62	4786.24	8246.14	164.52	4119.96	8153.51	121.30	16.17%	1.14%	35.63%
15a	50.13	4626.69	7701.53	88.96	4502.90	8743.91	121.30	2.75%	-11.92%	-26.66%
16a	25.87	4840.06	8277.83	150.07	4152.27	8203.34	121.30	16.56%	0.91%	23.72%
17a	35.58	4666.62	7796.90	95.97	4406.72	8595.62	121.30	5.90%	-9.29%	-20.88%
18a	19.41	5443.63	9373.98	192.29	4568.05	8844.35	121.30	19.17%	5.99%	58.53%
19a	19.41	5828.77	10075.90	220.09	4935.31	9410.56	121.30	18.10%	7.07%	81.44%
20a	48.51	5266.26	8787.52	113.41	4934.74	9409.69	121.30	6.72%	-6.61%	-6.51%
21a	34.77	5275.11	9144.14	200.84	4500.18	8739.71	121.30	17.22%	4.63%	65.57%
22a	25.07	5446.51	9511.29	227.14	4602.35	8897.23	121.30	18.34%	6.90%	87.25%
23a	31.53	4606.62	8012.78	175.63	3852.78	7741.61	121.30	19.57%	3.50%	44.79%
24a	51.75	3902.50	6555.24	83.01	3829.71	7706.04	121.30	1.90%	-14.93%	-31.56%
25a	46.90	3750.31	6283.37	73.01	3760.91	7599.96	121.30	-0.28%	-17.32%	-39.81%
26a	29.92	4452.78	7655.20	144.50	3814.33	7682.32	121.30	16.74%	-0.35%	19.13%
27a	44.47	4045.58	6704.76	63.38	4156.17	8209.34	121.30	-2.66%	-18.33%	-47.75%
28a	30.73	4701.44	7886.87	104.50	4347.25	8503.93	121.30	8.15%	-7.26%	-13.85%
29a	13.75	5142.14	9162.22	259.37	4268.85	8383.06	121.30	20.46%	9.29%	113.82%
30a	24.26	5521.53	9496.72	193.04	4681.53	9019.30	121.30	17.94%	5.29%	59.14%
31a	25.87	5194.66	8932.47	177.85	4399.35	8584.26	121.30	18.08%	4.06%	46.62%
32a	18.60	4850.79	8644.58	241.58	3972.18	7925.68	121.30	22.12%	9.07%	99.16%
33a	41.24	4478.24	7601.85	121.54	4044.04	8036.48	121.30	10.74%	-5.41%	0.20%
34a	34.77	4503.37	7699.59	136.00	3944.94	7883.68	121.30	14.16%	-2.34%	12.11%
35a	44.47	4032.29	6720.71	72.65	4044.13	8036.61	121.30	-0.29%	-16.37%	-40.11%
36a	37.19	4634.69	7722.53	90.03	4429.43	8630.63	121.30	4.63%	-10.52%	-25.78%
37a	67.92	3666.59	5652.99	8.99	4149.19	8198.58	121.30	-11.63%	-31.05%	-92.59%
38a	52.56	3467.08	5349.96	8.99	3991.57	7955.57	121.30	-13.14%	-32.75%	-92.59%
39a	48.51	4303.11	7222.47	94.84	4104.02	8128.94	121.30	4.85%	-11.15%	-21.81%
40a	50.13	4399.53	7421.92	107.47	4112.60	8142.17	121.30	6.98%	-8.85%	-11.40%
41a	22.64	4858.35	8635.19	236.03	4003.67	7974.23	121.30	21.35%	8.29%	94.58%
42a	42.85	4680.44	7962.85	134.12	4172.53	8234.56	121.30	12.17%	-3.30%	10.57%
43a	29.11	4741.79	8292.25	193.78	3932.13	7863.94	121.30	20.59%	5.45%	59.75%
44a	57.41	2894.90	4460.95	8.99	3525.67	7237.29	121.30	-17.89%	-38.36%	-92.59%
45a	62.26	4002.52	6179.28	8.99	4522.18	8773.63	121.30	-11.49%	-29.57%	-92.59%
46a	41.24	3397.77	5712.78	65.96	3455.03	7128.37	121.30	-1.66%	-19.86%	-45.62%
47a	26.68	4226.21	7172.96	110.04	3791.97	7647.85	121.30	11.45%	-6.21%	-9.29%
48a	80.05	3201.95	4925.32	8.99	3798.86	7658.47	121.30	-15.71%	-35.69%	-92.59%
49a	42.85	3045.25	4712.71	8.99	3585.85	7330.06	121.30	-15.08%	-35.71%	-92.59%
50a	30.73	4708.29	8262.98	199.70	3902.32	7817.98	121.30	20.65%	5.69%	64.64%

Table 1 Continued

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
51a	25.07	5118.04	8712.29	151.18	4418.54	8613.84	121.30	15.83%	1.14%	24.64%
52a	21.83	5338.32	9269.58	207.82	4461.27	8679.71	121.30	19.66%	6.80%	71.33%
53a	27.49	4978.64	8681.63	199.69	4149.64	8199.27	121.30	19.98%	5.88%	64.63%
54a	32.34	4713.97	8256.71	195.93	3920.74	7846.38	121.30	20.23%	5.23%	61.52%
55a	34.77	4639.45	7945.39	145.25	4026.82	8009.93	121.30	15.21%	-0.81%	19.74%
56a	40.43	4297.53	7189.83	87.45	4136.20	8178.55	121.30	3.90%	-12.09%	-27.90%
57a	68.73	3660.34	5636.88	8.99	4167.41	8226.67	121.30	-12.17%	-31.48%	-92.59%
58a	71.15	3313.05	5098.87	8.99	3861.83	7755.55	121.30	-14.21%	-34.26%	-92.59%
59a	29.92	4632.96	7753.68	98.09	4307.92	8443.29	121.30	7.55%	-8.17%	-19.13%
60a	47.71	3670.54	5959.99	23.45	4252.54	8357.91	121.30	-13.69%	-28.69%	-80.67%
61a	15.36	5243.63	9226.42	234.84	4326.45	8471.86	121.30	21.20%	8.91%	93.61%
62a	25.87	5091.92	8844.71	196.38	4257.46	8365.50	121.30	19.60%	5.73%	61.89%
63a	36.39	5346.96	9051.71	148.54	4724.91	9086.18	121.30	13.17%	-0.38%	22.46%
64a	32.34	4862.97	8433.27	181.91	4096.82	8117.84	121.30	18.70%	3.89%	49.97%
65a	33.96	4562.62	7946.11	176.01	3826.14	7700.53	121.30	19.25%	3.19%	45.10%
66a	38.00	4584.63	7884.84	151.89	3954.90	7899.04	121.30	15.92%	-0.18%	25.22%
67a	32.34	4767.86	8250.38	172.65	4026.67	8009.69	121.30	18.41%	3.00%	42.33%
68a	48.51	4243.20	7052.37	75.96	4193.05	8266.20	121.30	1.20%	-14.68%	-37.38%
69a	36.39	5023.39	8439.96	120.35	4547.74	8813.03	121.30	10.46%	-4.23%	-0.78%
70a	55.79	3859.99	6424.33	67.96	3924.11	7851.58	121.30	-1.63%	-18.18%	-43.97%
71a	58.22	3542.16	5708.19	12.49	4292.20	8419.06	121.30	-17.47%	-32.20%	-89.71%
72a	35.58	4616.41	7753.25	105.19	4266.31	8379.14	121.30	8.21%	-7.47%	-13.28%
73a	46.09	4340.05	7389.27	122.29	3925.73	7854.07	121.30	10.55%	-5.92%	0.82%
74a	38.00	4757.99	8259.02	179.34	4025.05	8007.19	121.30	18.21%	3.14%	47.85%
75a	39.62	4682.67	8085.44	164.50	4013.56	7989.48	121.30	16.67%	1.20%	35.61%
76a	48.51	4662.05	7848.99	113.25	4305.40	8439.41	121.30	8.28%	-7.00%	-6.64%
77a	38.00	4321.92	7580.57	178.55	3581.38	7323.18	121.30	20.68%	3.51%	47.20%
78a	40.43	4649.15	8090.12	179.39	3926.68	7855.53	121.30	18.40%	2.99%	47.89%
79a	40.43	4540.19	7814.06	151.90	3910.58	7830.72	121.30	16.10%	-0.21%	25.23%
80a	46.09	4271.62	7279.00	121.94	3833.58	7711.99	121.30	11.43%	-5.61%	0.53%
81a	42.85	4133.11	7004.36	106.14	3798.06	7657.24	121.30	8.82%	-8.53%	-12.50%
82a	38.00	4664.17	7934.48	133.24	4123.95	8159.67	121.30	13.10%	-2.76%	9.85%
83a	46.90	4457.40	7592.02	128.37	3988.52	7950.87	121.30	11.76%	-4.51%	5.83%
84a	63.07	3522.39	5396.43	235.73	4219.00	8306.21	121.30	-16.51%	-35.03%	94.34%
85a	22.64	4854.43	8627.86	235.73	3997.71	7965.04	121.30	21.43%	8.32%	94.34%
86a	16.98	4479.47	8162.79	266.01	3657.31	7440.24	121.30	22.48%	9.71%	119.30%
87a	60.64	4109.56	6852.14	78.20	4114.61	8145.27	121.30	-0.12%	-15.88%	-35.53%
88a	66.30	3708.15	6063.34	38.44	4123.19	8158.49	121.30	-10.07%	-25.68%	-68.31%
89a	36.39	4881.47	8475.94	185.63	4135.69	8177.77	121.30	18.03%	3.65%	53.03%
90a	46.09	4613.31	7883.51	140.77	4081.75	8094.60	121.30	13.02%	-2.61%	16.05%
91a	43.66	4445.98	7620.84	140.05	3889.65	7798.45	121.30	14.30%	-2.28%	15.46%
92a	31.53	4837.62	8332.58	166.15	4104.77	8130.09	121.30	17.85%	2.49%	36.98%
93a	22.64	4907.86	8568.75	198.77	4039.69	8029.76	121.30	21.49%	6.71%	63.86%
WFnaive	**40.66**	**3920.17**	**6736.71**	**121.30**						
AVERAGE		**4467.07**	**7569.77**	**129.05**	**4129.84**	**8168.75**	**121.30**	**8.15%**	**-7.41%**	**6.39%**
VARIANCE		**401454.68**	**1618682.59**	**5442.32**	**119518.44**	**284083.87**	**0.00**			

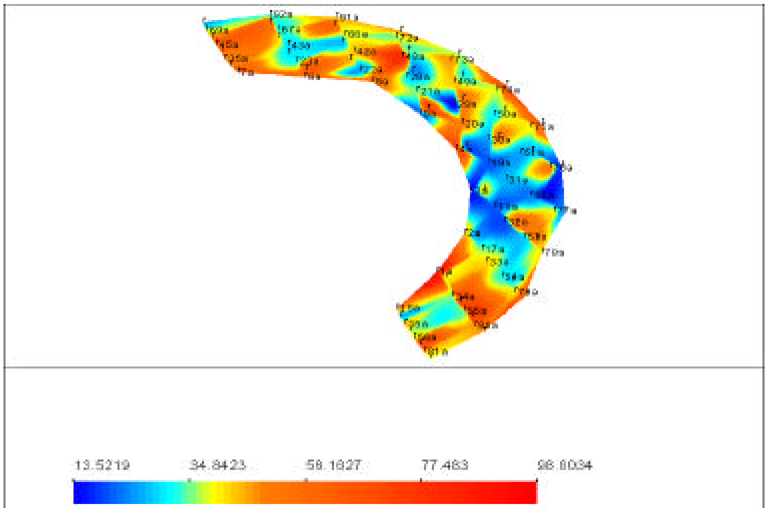

Figure 1: NO3-N Pre-Season Map from 0 to 24 Inches of Soil Depth, Halfway, Texas.

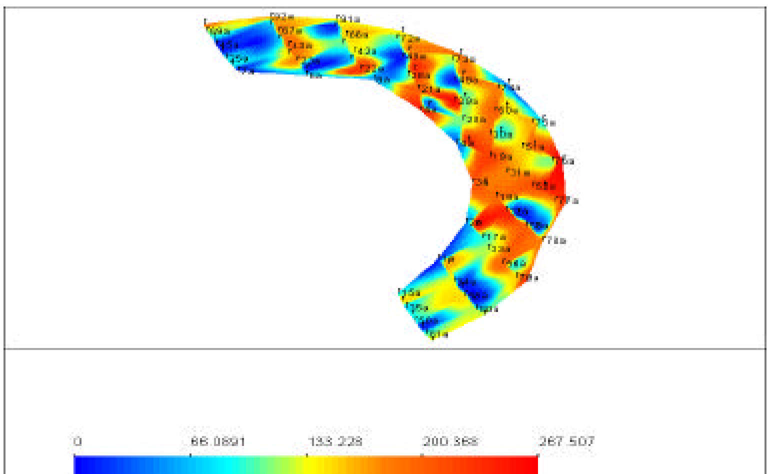

Figure 2: Optimal Levels of Spatial Nitrogen Application Map for Precision Farming Practices on a Per-Year Basis for a Ten-Year Planning Horizon, Halfway, Texas.

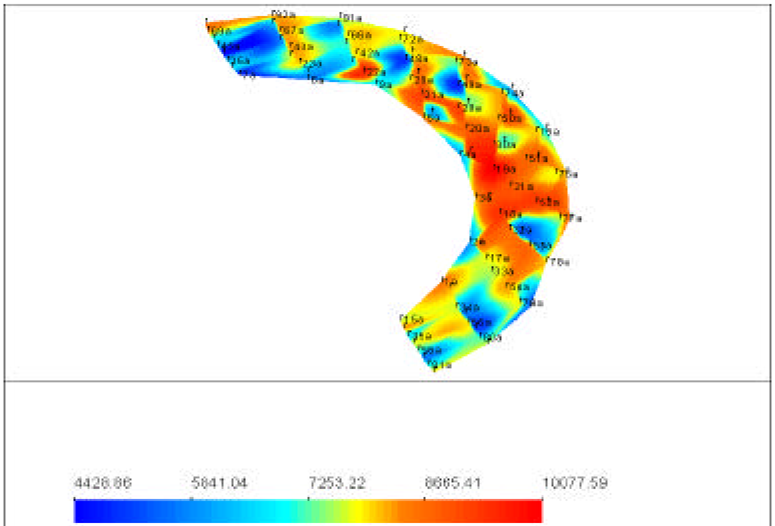

Figure 3: Spatial Corn Yield Map for Precision Farming Practices, Halfway, Texas.

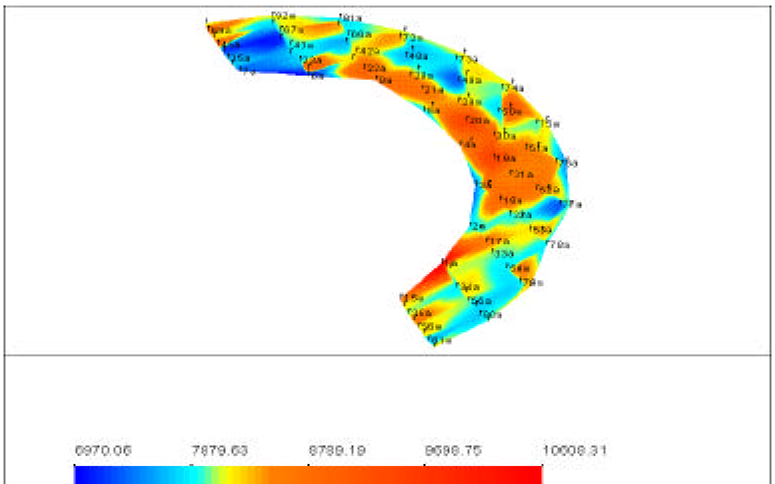

Figure 4: Spatial Corn Yield Map for Whole-Field Farming Practices, Halfway, Texas.

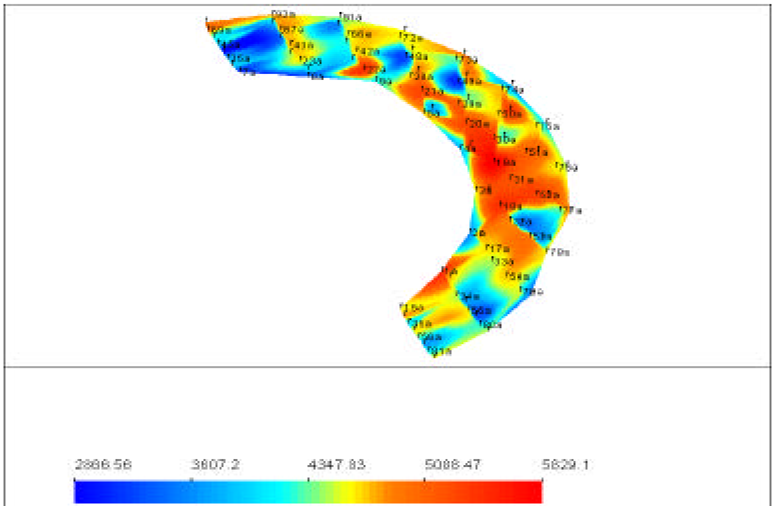

Figure 5: Spatial Net Revenue Above Nitrogen and Water Costs for a Ten-Year Optimization Model for Precision Farming Practices, Halfway, Texas.

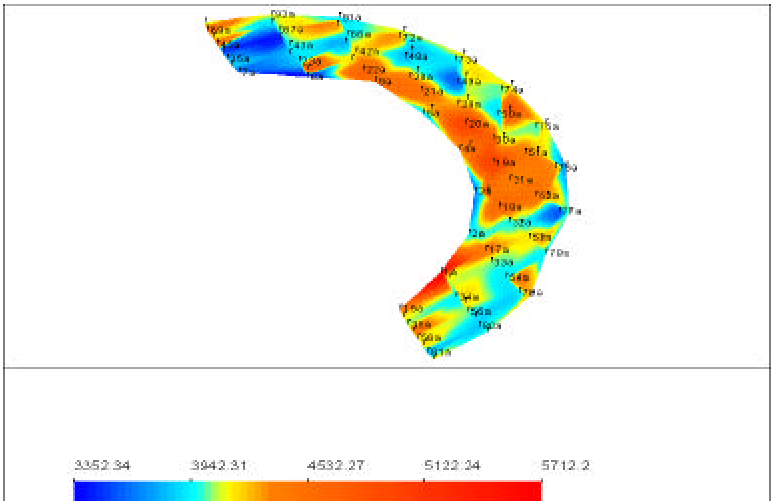

Figure 6: Spatial Net Revenue Above Nitrogen and Water Costs for a Ten-Year Optimization Model for Whole-Field Farming Practices, Halfway, Texas.

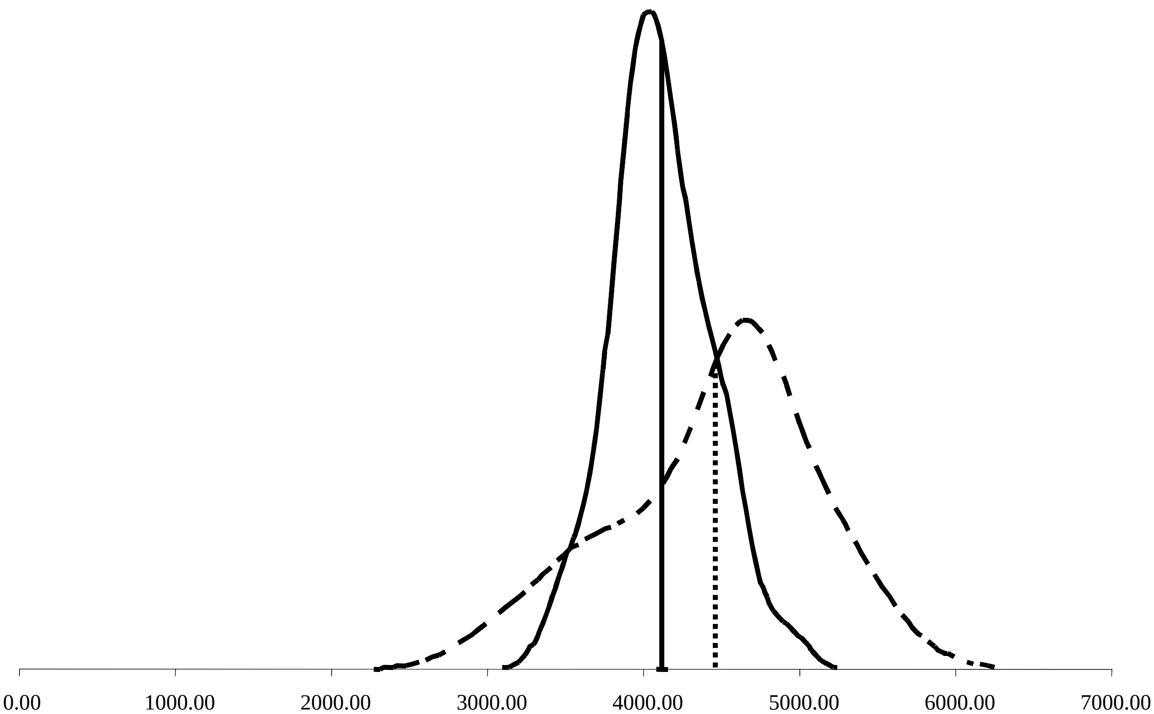

Figure 7. Probability Density Function for Corn Net Revenues Above Nitrogen and Water Costs.

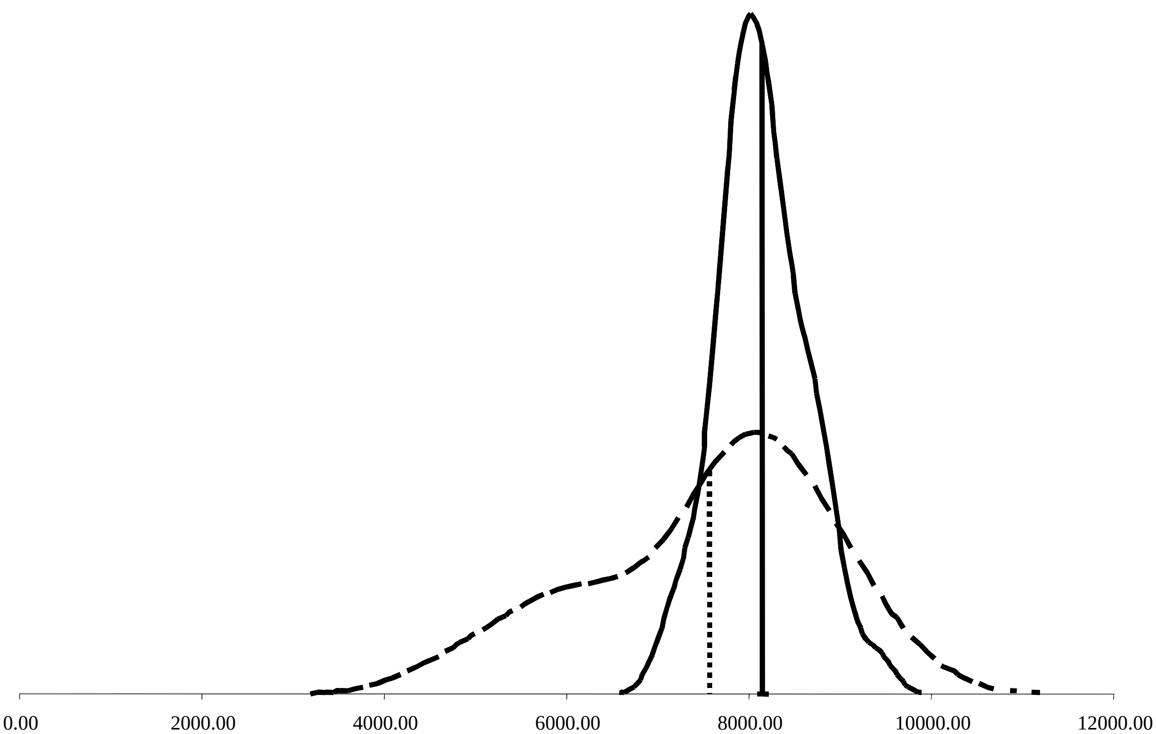

Figure 8. Probability Density Function for Corn Yields.

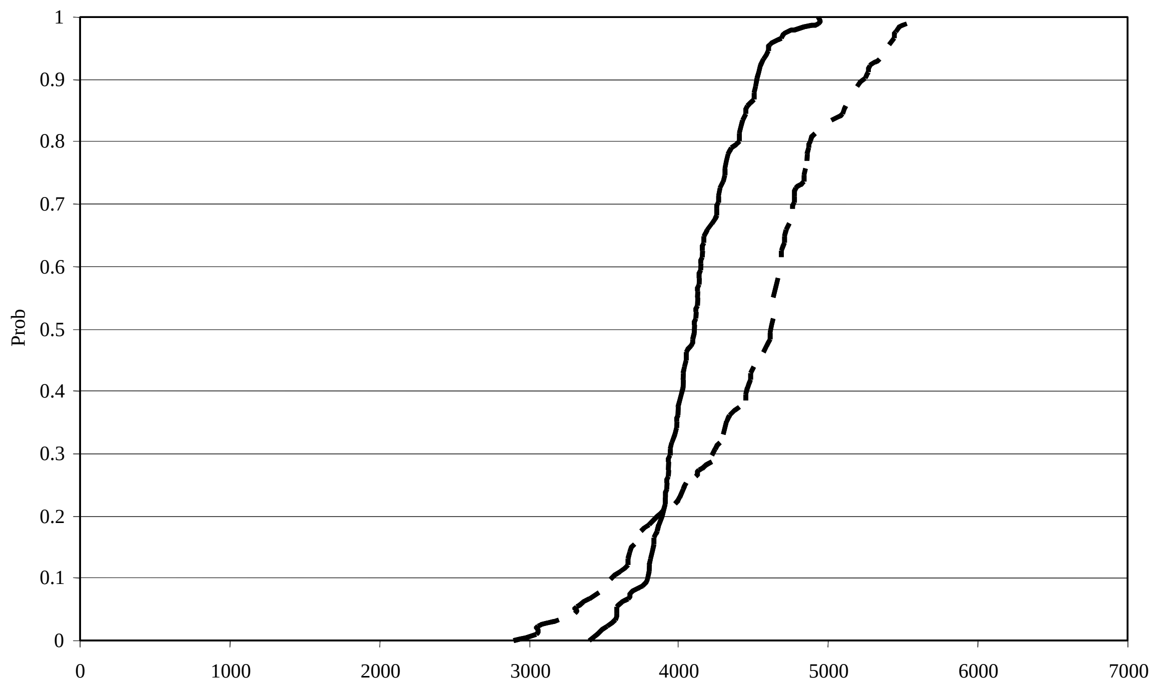

Figure 9. Cumulative Density Function for Corn Net Revenues Above Nitrogen and Water Costs.

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