THE ECONOMICS OF PRECISION AGRICULTURAL PRACTICES IN COTTON PRODUCTION

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Abstract

Spatial optimal nitrogen fertilizer application levels and associated net revenues in irrigated cotton production were derived. 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 toward the enhancement of agriculture's productivity over the past several decades. Currently, production agriculture is facing significant challenges such as escalating costs of production, shortage of irrigation water, and increased public concern about the impacts of agricultural production on the environment. As world trade liberalization continues, agricultural producers will increasingly continue to compete to produce high quality products at low prices for the world market, while attempting to use production practices that are profitable and benign to the environment. Traditionally, optimal fertilizer input use in agriculture has assumed spatial and temporal field homogeneity with respect to soil fertility, 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) state 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.

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 and environmental implications of precision farming practices with respect to nitrogen use in irrigated cotton production in the Southern High Plains of Texas (SHPT). The SHPT is a semiarid region located in the northwestern part of the state, which encompasses about 22 million acres (35,000 square miles) in 42 counties. Cotton is the most important crop produced in the area 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.

Reprinted from the *Proceedings of the Beltwide Cotton Conference*
Volume 1:369-374 (2000)
National Cotton Council, Memphis TN

Materials and Methods

Contemporary studies (Segarra, et al., 1989; Carter, et al., 1974; Onken and Sunderman, 1972; Yu, et al., 1999) have shown that both nitrogen or phosphorus fertilizer applications and residual fertility have positive impacts on crop yields. This manuscript combines new technologies to address the impacts of nitrogen fertilizer application and residual spatially on irrigated cotton production under different levels of initial soil fertility.

The primary source of data is from an experiment conducted at the Texas Agricultural Experiment Station at Lamesa, Texas in 1998. At the beginning of the experiment, 104 locations within the field were chosen. At each location, the nitrogen residual level in the top soil at a depth of 0 to 90 centimeters was measured. Using MapInfo, a desktop mapping software that can provide a mapping technique for calculating and displaying the trends of data which vary continuously over geographic space (Vertical Mapper Manual), the 104 locations and their nitrogen residual levels are shown in Figure 1. As depicted in that figure, the nitrogen residual levels in the top soil at a depth of 0 to 90 centimeters ranged from 25.94 to 263.86 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 (50% ET or 75% ET) and nitrogen fertilizer, which was applied at three different rates (0, 80, or 120 pounds per acre). Other production inputs, including pesticides, were applied at the same rate across the whole field. Total nitrogen available to the crop at each of the 104 locations, which is equal to the sum of applied nitrogen and nitrogen residual in the top 0 to 90 centimeters of soil, was obtained and expressed in Figure 2 using the MapInfo. It ranged from 60.15 pounds per acre to 343.86 pounds per acre.

At the end of the season, a cotton stripper equipped with sensors and a Global Position System (GPS) was used. Then, data were downloaded into a computer and analyzed by MapInfo. Cotton lint yields associated with the 104 locations were obtained. Figure 3 shows the cotton lint yield map for the field. As depicted in Figure 3, cotton lint yield in this field ranged from 392.64 pounds per acre to 1086.66 pounds per acre.

Using the above data, a site-specific production function was estimated to depict the relationship between cotton lint yield, and nitrogen fertilizer availability and other site-specific characteristics. Following the estimated function, two scenarios -- conventional whole-field farming practices and precision farming practices, were assumed in the analysis.

According to the assumption of precision farming, optimal nitrogen application rates for each location were derived. In order to achieve maximum profit at each location, optimal input use can be obtained by equating the value of marginal product of nitrogen (VMP_N) to input price, assuming perfect competition in both product and factor markets. This can also be expressed as equating the marginal physical product of nitrogen (MPP_N) to the ratio of input price to product price:

$$MPP_N = P_N / P_C \,, \tag{1}$$

where MPP_N is the marginal physical product of nitrogen; P_N is the price of nitrogen in dollars per pound; and P_C is the price of cotton in dollars per pound (Beattie and Taylor, 1993). By using equation (1), optimal nitrogen application rates for each of the 104 locations and their predicted yields were calculated. Using the prices of nitrogen and cotton, the profit associated with the 104 locations and the whole field were derived.

According to the assumption of conventional farming practices, the whole field is treated equally. Optimal nitrogen application rates, which are the same across the whole field can be obtained also by using the equation (1). Predicted yields and profits can be obtained using the same approach discussed above.

Using MapInfo, figures depicting optimal nitrogen fertilizer application rates and associated net revenues within the field under the assumption of precision farming practices were produced. Also, figures were used to express the amounts of nitrogen fertilizer over or under application, by comparing precision farming practices and whole-field farming, and precision farming practices and the experiment.

Results

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

$$\begin{aligned} Y = {} & \underset{(10.50)}{432.5003} + \underset{(8.38)}{4.6362}*NT*W - \underset{(-5.12)}{0.0062}*NT^2 \\ & + \underset{(2.07)}{16.7507}*PR*W - \underset{(-2.17)}{0.0895}*NT*PR*W. \end{aligned} \tag{2}$$

$$R^2 = 0.4712$$

Where, Y is the cotton lint yield in lbs./acre; NT is the total nitrogen available to the crop (lbs./acre), which equals applied nitrogen plus residual nitrogen in the soil; W is the available water to the crop in either 50% or 75% ET; PR represents the phosphorus residual in the soil at the beginning of the season (lbs./acre). The values in parenthesis below the estimated parameters in equation (2) represent the associated *t*-values, where the intercept, NT*W, and NT^2 were significant above the 0.0001 level; and the interaction terms PR*W and NT*PR*W were significant above the 0.05 level. From the function estimated, it can be seen that there are significant interaction effects between nitrogen and water, and phosphorus and water, and among nitrogen, phosphorus, and water in explaining cotton yield variability. The R^2 value indicates that 47.12% of the variation in cotton yield was explained by the independent variables included.

(1) Environmental Implications

Assuming a cotton price of $0.60/pound and a nitrogen price of $0.30/pound, the optimal level of nitrogen for each of 104 locations in the field can be derived. It should be noted that the optimal level of nitrogen at each location depends on the water application level and initial phosphorus residual level in the soil because of the interaction effects in the estimated yield function. By deducting the amount of nitrogen residual available at the beginning of the season, the optimal nitrogen application rates were derived for each of the 104 locations within the field. Using MapInfo, the optimal levels of spatial nitrogen application rates within the field are shown in Figure 4. As depicted in Figure 4, the result is almost opposite to Figure 1. The slight differences can be explained by the interaction effects among water, phosphorus, and nitrogen. At those locations, such as 17B, which has a high nitrogen residual level at the beginning of the season, no additional nitrogen fertilizer would be required. At those locations with a low nitrogen residual level at the beginning of the season, such as 18A, additional nitrogen fertilizer should be applied to obtain the maximum profit.

Assuming whole field farming practices, the optimal level of nitrogen for the whole field is 146.96 pounds per acre, using the same prices for cotton and nitrogen fertilizer. After deducting the average nitrogen residual in the soil of 111.09 pounds per acre, the average nitrogen application rate under conventional farming practices is 35.87 pounds per acre.

When comparing the optimal nitrogen application amount under the precision farming practices (Figure 4) with conventional farming practices, the over- or under-application of nitrogen fertilizer in this field can be seen in Figure 5. It was found that nitrogen fertilizer over-application accounts for 45.83% of the whole field. The average amount of over-applied nitrogen fertilizer in these portions of the field is 26.67 pounds per acre. These additional amounts of nitrogen fertilizer could cause both environmental damage and reduced profits. In some parts of the field, nitrogen fertilizer application was not high enough, reducing crop yield and producers' profits. These portions of the field make up 54.17% of the whole field. The average under-application nitrogen fertilizer amount is 39.86 pounds per acre. Overall, it can be found that the average optimal nitrogen application level was 35.87 pounds per acre under whole-field farming practices, compared to the average 45.24 pounds per acre under precision farming practices. Although there is a 26.12% increase of nitrogen use under precision farming practices, the applied nitrogen fertilizer would be efficiently used, which increases crop yields and producers' profits and reduce additional environmental damages.

When comparing optimal nitrogen application amounts under precision farming practices against the experiment, under which three different levels of nitrogen fertilizer (0, 80, or 120 pounds/acre) were applied randomly, the over- or under-application of nitrogen fertilizer in this field can be seen in Figure 6. Given this, it was found that nitrogen fertilizer over-application makes up 57.29% of the whole field. The average amount of over-applied nitrogen fertilizer in these areas of the field was 68.03 pounds per acre. The under-application areas of the field account for 36.46% of the whole field. The average under-application nitrogen fertilizer amount was 46.99 pounds per acre. Also there was 6.25% of the field in which the amount applied is exactly the amount of nitrogen fertilizer needed. Overall, it was found that the average optimal nitrogen application level was 45.24 pounds per acre, comparing this level to the average 67.08 pounds per acre of nitrogen that was applied in the field, represents a 48.28% decrease of nitrogen application because of precision farming practices. Also, it is important to highlight that nitrogen fertilizer is more efficiently used under precision farming practices.

(2) Economic Implications

Cotton lint yields were also derived for the two scenarios. It was found that the average yield would be improved from 741.35 pounds per acre under conventional whole-field farming practices to an average yield of 758.29 pounds per acre under precision farming practices. In the experiment, the average cotton yield was only 729.42 pounds per acre. That is, cotton lint yield would be increased by 3.75%, when comparing precision farming practices to the experiment. Comparing to conventional farming practices, precision farming practices can increase yield by 2.29%.

By assuming a cotton price of $0.60/pound and a nitrogen price of $0.30/pound, the net revenue above nitrogen fertilizer cost associated with precision farming practices were calculated and are depicted in Figure 7. As shown in that figure, spatial net revenue levels ranged from $355.88 per acre to $577.41 per acre. Toward the west side of the field, net revenue is much higher than in the inside. This is a direct result of higher levels of irrigation water being applied on that location. Comparing this to the conventional farming practices, which resulted in net revenue above nitrogen fertilizer cost of $434.05 per acre, precision farming practices increase net revenue by 1.69%. Comparing these results to those of the experiment, which resulted in $418.41 per acre, precision farming practices increase net revenue by 5.49%.

A summary comparison of the overall results associated with precision farming practices, conventional farming practices, and the experiment is depicted in Table 1.

Conclusions and Disucssion

The objective of this study was to evaluate the economic and environmental implications of precision farming practices with respect to nitrogen use in cotton production. This analysis revealed that precision spatial utilization of nitrogen fertilizer, as compared to whole field farming practices, would result in a 2.29% yield increase on a per acre basis. The associated increase in net revenues above nitrogen fertilizer cost was found to be 1.69% on a per acre basis. Comparing precision farming practices and the random nitrogen application experiment, precision farming practices increased cotton yield by 3.75% and net revenues above nitrogen fertilizer cost by 5.47%. Most importantly, this study revealed that nitrogen fertilizer could be used more efficiently, implying higher yields and net revenue, and lower potential environmental damage under precision farming practices, as compared to conventional farming practices and the experiment.

As implied from the above conclusions, the net revenues associated with precision farming practices do not show much increase. This can be partially explained by the fact that the whole field does not show much variability in initial soil nitrogen residual levels. Future studies should be conducted to evaluate the relationship between this variability and net revenue. Also, because of information limitations, this study did not consider the costs associated with adoption of precision farming practices. Future studies should incorporate these costs.

Acknowledgements

The authors would like to acknowledge funding for this research from the Precision Agriculture Initiative, TAES-Lubbock, Texas A&M University and the cotton economics line item at Texas Tech University. We would also like to thank Sukant Misra, Phillip Johnson, and Kal Chakraborty for their contributions. Texas Tech University, Department of Agricultural and Applied Economics Cotton Economics Research Report CER-00-3.

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Table 1. Comparison of the Experiment, Conventional Farming, and Precision Farming Practices in Irrigated Cotton Production at Lamesa, Texas 1998.

	Experiment	Conventional Farming	Precision Farming
Average Nitrogen Applied (lbs./a.)	67.08	35.87	45.24
Average Yield (lbs./a.)	729.42	741.35	758.29
Average Net Revenue above Nitrogen Cost ($/acre)	418.41	434.05	441.40

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).

Figure 1. NO_3-N Residual Map from 0 to 90 Centimeters of Soil Depth, Lamesa, Texas 1998.

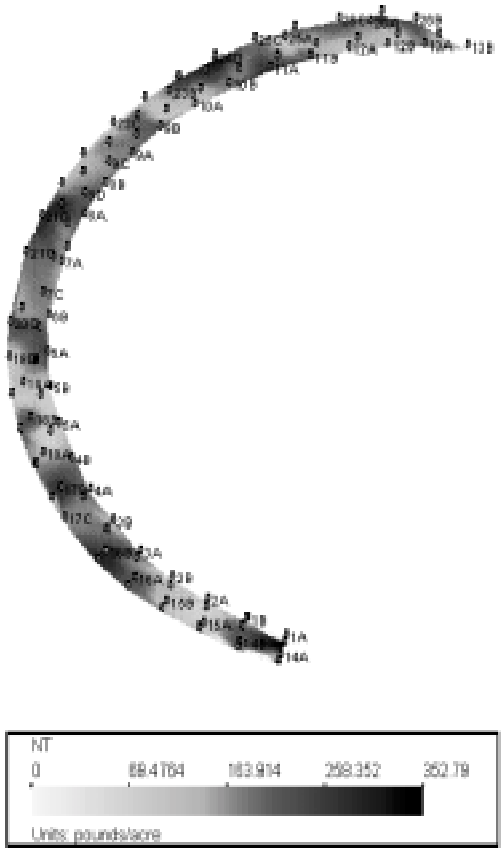

Figure 2. Total Nitrogen Available Map, Lamesa, Texas 1998.

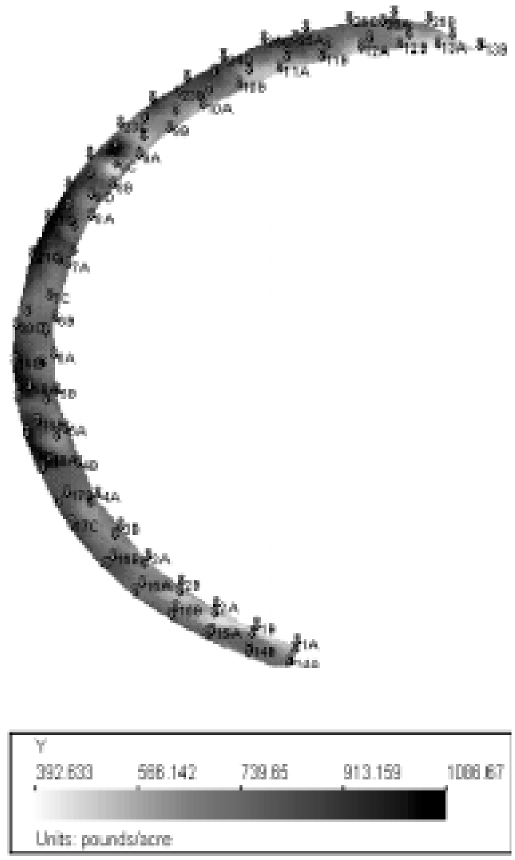

Figure 3. Spatial Cotton Yield Map, Lamesa, Texas 1998.

Figure 4. Optimal Levels of Spatial Nitrogen Application Map, Lamesa, Texas 1998.

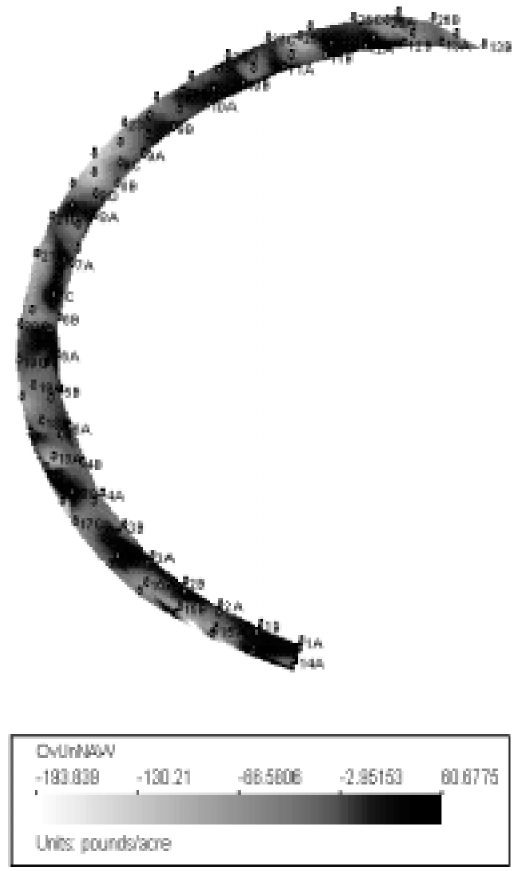

Figure 5. Nitrogen Over or Under Application Map, Comparing Precision Farming Practices and Traditional Farming Practices, Lamesa, Texas, 1998.

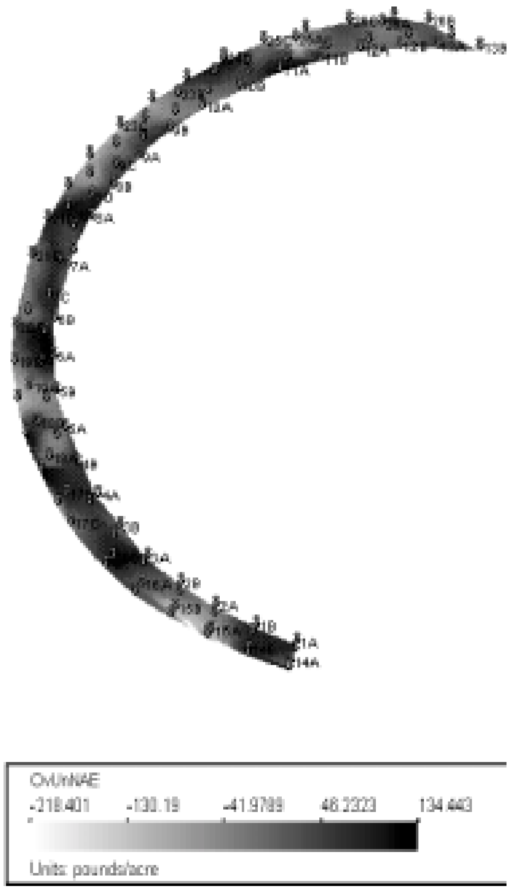

Figure 6. Nitrogen Over or Under Application Map, Comparing Precision Farming Practices and Experiment, Lamesa, Texas 1998.

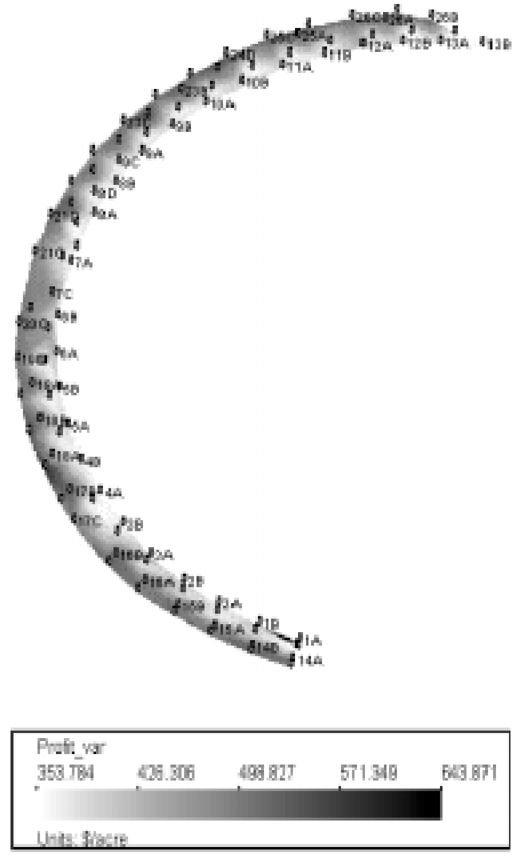

Figure 7. Spatial Net Revenue to Nitrogen Use, Lamesa, Texas 1998.