EFFECT OF SOIL NITROGEN RATES ON RESIDUAL SOIL N, PLANT GROWTH PARAMETERS, YIELD, AND QUALITY: AN ECONOMIC ANALYSIS

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Abstract

Supplemental nitrogen and irrigation water are critical agricultural inputs for cotton production in the Texas High Plains region. A multi-year field study was conducted to examine the effect of soil nitrogen (residual nitrogen plus applied nitrogen) on cotton agronomic growth parameters, yield, and fiber quality attributes under a drip irrigation production system. Fixed-rate nitrogen application experimental plots consisted of five annual augmented nitrogen fertility levels (0, 50, 100, 150, and 200 lb/acre) with five replications. Each year, soil to a 24-in. depth in each experimental plot was sampled for residual nitrogen analysis prior to planting or before treatment deployment. Rates of applied N exceeding 100 lb/acre resulted in higher residual nitrogen detection during the following season. Rates of N application exceeding 100 lb/acre resulted in higher lint yield, but micronaire values were significantly reduced. In this study, we examined the effect of augmented soil N and residual N in cotton production in the Texas High Plains. Specifically, we estimated the marginal product value of nitrogen and water inputs in Texas High Plains cotton production.

Introduction

Nitrogen fertility and irrigation water are the primary constraints in cotton production in the Texas High Plains. Because Texas High Plains cotton production is a low-input system, increasing production costs, limited productivity, and low cotton price are becoming increasing challenges for our cotton producers. On the other hand, nitrogen deficiency negatively impacts cotton plant growth and reproduction, causing reduced plant height, fewer fruiting branches, fewer bolls, and ultimately lower yields. However, the use of excess nitrogen fertility beyond the crop demand can have negative impacts on lint yields and fiber quality. The excessive use of nitrogen also tends to produce excessive vegetative growth and harvest delays, increasing pest pressure, and increased concern for groundwater pollution due to nitrate contamination. The objective of this study was to conduct an economic analysis of the impact of nitrogen fertilizer on cotton lint yield and fiber quality.

Materials and Methods

The study was conducted on a 5-acre sub-surface drip irrigated field at the Texas A&M AgriLife Research farm near Plainview, Texas. Five nitrogen application rates (0, 50, 100, 150, 200 lb/acre) had been deployed to the same experimental units consistently for six consecutive years since 2009. Soil residual nitrogen was monitored annually by taking two 24-inch core samples from each plot. The 0-12 inch portions of each core were combined to form a single, composite soil sample, and likewise, the 12-24 inch portions were combined, resulting in two samples per experimental plot. Samples were sent to Ward Laboratories, Kearny, Nebraska for analysis. Regionally well-adapted cultivars were used in this study over the duration of the study: FM960B2R was planted on May 20, 2009 and May 27, 2010, DP104B2RF on June 14, 2011, and FM9063B2RF on May 17, 2012, May 23, 2013, and June 16, 2014. The experiment consisted of a randomized block design with five treatments and five replications (Fig. 1). The five treatments included side-dress applications of nitrogen fertilizer at rates of 0, 50, 100, 150, and 200 lb N/acre. Cotton was planted (56,000 seeds/acre) in 30-inch spaced rows and was irrigated with a subsurface drip irrigation system.

0	50	200	50	200
100	100	0	100	50
200	150	50	150	0
50	200	100	200	100
150	0	150	0	150

Figure 1. Helms Farm nitrogen study experimental plot layout following a five-treatment x five-replication randomized block design. Annually, each of the 25 plots received one of the five nitrogen augmentation treatments including 0, 50, 100, 150, or 200 lb N/acre, Hale Co., TX.

Figure 2. A) Annual pre-season soil sampling of 25 sub-surface drip irrigated cotton plots; B) Annually near the time of first bloom, each plot received the same side-dressed nitrogen application treatment rate; C) Differential cotton plant growth responses are often visually apparent between plots receiving high and low N application rates, Hale Co., TX.

Several plant growth parameters including plant height, root length, leaf surface area, and chlorophyll content were measured throughout the growing season annually. In order to determine the level of residual nitrogen, soil samples were taken from the experimental plots prior to the deployment of nitrogen fertility treatments. Fertility treatments were applied when plants began squaring with a soil applicator ground rig. Hand-harvested yield samples were obtained from each plot. Fiber samples were analyzed for lint quality parameters at the Cotton Incorporated Fiber Testing Laboratory.

Economic analysis consisted of developing a lint yield function based upon the numerous variable inputs. The classical production function of a farm producing cotton lint (Y) with the available X inputs, Y= f(X), was used. The input variables included N application, residual soil nitrate N, rainfall, irrigation, and planting date. Rainfall and irrigation were further categorized into two groups, pre-plant and post-plant (during the growing season). The purpose of categorizing the time period was to examine the effect of each of these factors on two different sets of time (pre-plant versus during the growing season). This will allow for an effective management of crop inputs, especially the more economic allocation of the irrigation water.

The cotton lint production function can be further illustrated as, lint yield= f (total N, pre-plant water, post-plant water, planting time). Different parameters were estimated using the following ordinary least squares (OLS) regression: $Y = \alpha 1 + \alpha 2X1 + \alpha 3X2 + \alpha 4X3 + \alpha 5X4 + \alpha 6X5 + \varepsilon$, whereY = cotton lint yield (lb/acre)

X1 = Total N available to the crop (lb/acre)
X2 = Pre-plant water (mm) (irrigation plus rainfall)
X3 = Post-plant water (mm) (irrigation plus rainfall)

X4 = Total N * Pre-plant water
X5= Total N *Post-plant water
ε is the least square regression residual

Binary logistic model was used to analyze the effect of the variable inputs on fiber quality parameter, micronaire. The probability function for the model is: P (Y_i = 1) = $P_i = \frac{1}{1+exp^{-z}}$

This can be operationalized as,

$$Logit\ \ P(Y_i^*) = \beta_0 + \sum_{i=1}^{n} \beta_i X_i + \varepsilon_i \qquad \text{Logit}\ (Y_i^* = \text{j}) = \gamma\ '\ \text{X} + \varepsilon_i$$

where j = grade, dummy (1 if premium quality, 0 otherwise).
(micronaire value in the range of 3.5 – 4.9 units were considered as premium quality)

The estimated model has the following functional form: $Prob\ (grade = j\ ) = \ \alpha 1 + \alpha 2X1 + \alpha 3X2 + \alpha 4X3 + \alpha 5X4 + \alpha 6X5 + \alpha 7X6 + \varepsilon$

Where,
X1 = Pre-plant water (mm)
X2= Post-plant water (mm)
X3 = Residual N (lb/acre)
X4= Applied N (lb/acre)
X5= Planting time dummy (1 if May planting, 0 otherwise).
ε is the least square regression residual

Results and Discussion

In general, soil residual N levels were significantly higher in plots that received the two highest annual application rates of N fertilizer versus plots receiving lower-rate N applications or no N augmentation (Fig. 3). Averaged over the six-year study period, soil residual N levels were lowest in zero and 50 lb N/acre plots, although the 50 lb N/acre plots had numerically higher residual N than in zero N plots. The highest N augmentation plots (200 lb N/acre) had the significantly highest average residual N; the year-to-year residual N was always the highest amount in this treatment, at least numerically. The two second highest N augmentation plots (100 and 150 lb/acre) resulted in significantly higher amounts of soil residual N compared to that in zero and 50 lb/acre plots.

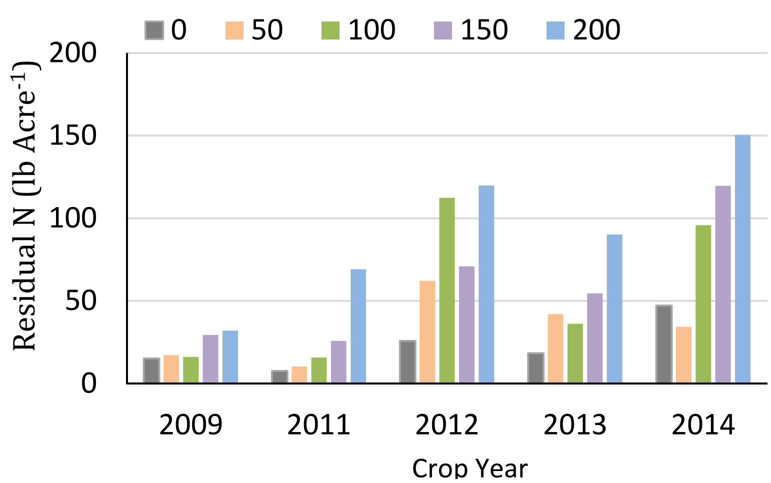

Figure 3. Effect of prior year's N application (0, 50, 100, 150, and 200 lb per acre) on residual N accumulations. In some cases, residual N carry-over resulted over more than one season's N augmentation.

As expected, zero N plots consistently produced the lowest lint yield compared to that in N-augmented plots (Fig. 4). Overall, 150 and 200 lb/acre plots produced the highest lint yield, followed by 100, 50, and zero N plots. Yield increased curvilinearly with each additional 50 lb N added, with the numerically highest average yield occurring in augmented 150 lb N/acre treatment, but the yield numerically decreased beyond 150 lb N/acre with additional N. Consistent numerical decline in yield beyond 150 lb N/acre in most years suggests that N application beyond 150 lb/acre may be unfavorable for cotton yield. Yield advantages because of optimal N application have been attributed to larger bolls at greater number of fruiting sites (Boquet and Breitenbeck, 2000; Moore, 1999).

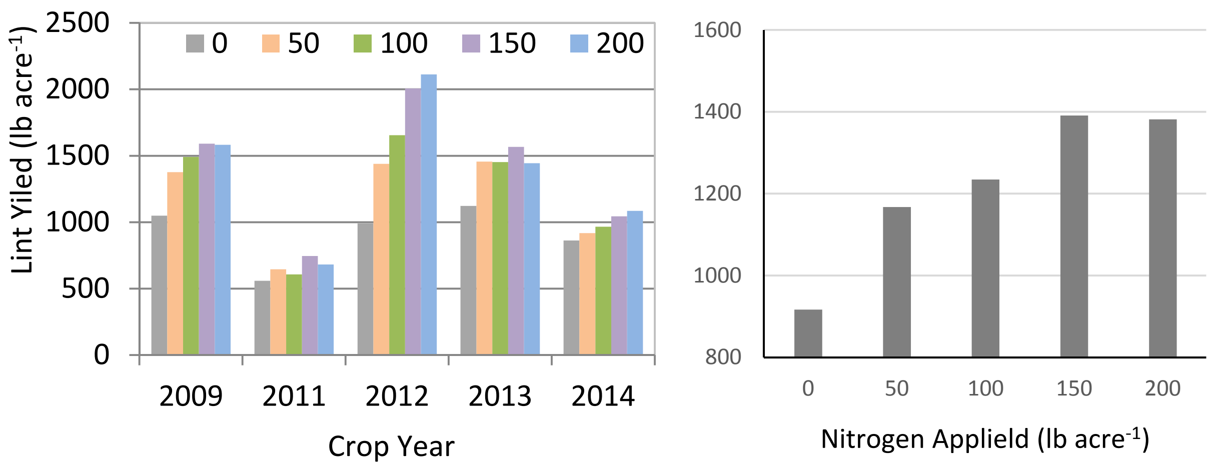

Figure 4. Effect of nitrogen application rates on cotton lint yield, Hale Co., TX, 2009-2014.

Lint maturity, measured in terms of micronaire values, also varied with N treatments (Fig. 5). Averaged over five years, micronaire values were similar and at the base range (3.5-3.6) across the three lower N levels, whereas the two highest N levels resulted in micronaire values in a discount range (<3.5).

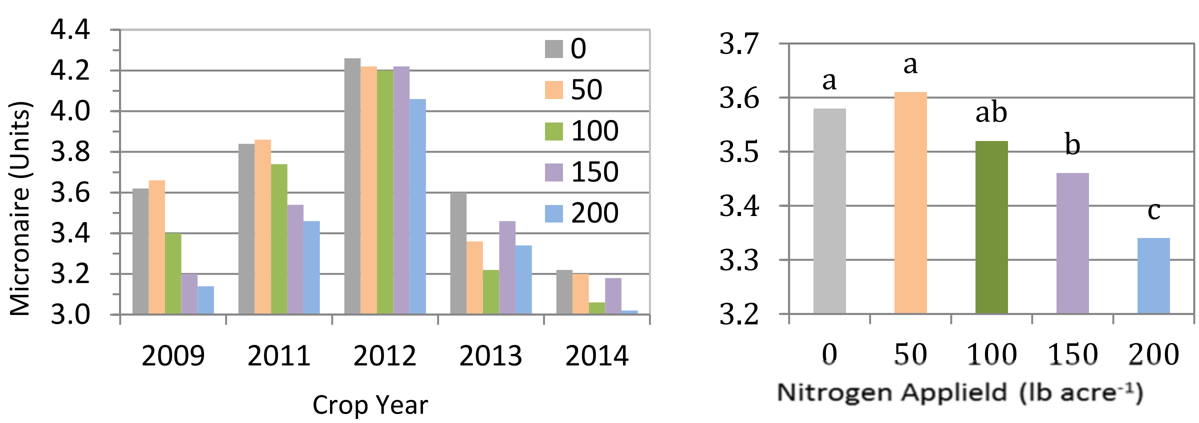

Figure 5. Effect of nitrogen application rates on cotton lint micronaire, Hale Co., TX, 2009-2014.

The yield response estimation results for the OLS with different N and irrigation application are summarized in Table 1. The N was applied on the third week of July. Pre-season irrigation was generally applied 1-3 weeks before planting, whereas post-irrigation was applied throughout the growing season on a regular basis. Pre-plant rainfall was recorded from 3 months prior to planting and post-plant rainfall was recorded during the growing season. Pre-plant water is the sum of pre-plant irrigation and pre-plant rainfall, whereas post-plant water is the sum of post-plant irrigation and post-plant rainfall. The rainfall after crop cut-out, although included in the post-plant water, likely did not contribute toward fruit maturity and lint.

Table 1: Simple statistics of variables used in the analysis, 209-2014, Hale Co., Texas.

Variable	Description	Mean	Std Error	Minimum	Maximum
Applied N	0, 50, 100, 150, 200 (lbs N acre^{-1})	100.00	71.00	0	200.00
Residual NO_3-N	Residual nitrogen (lbs acre^{-1})	64.75	80.73	5.00	481.00
Total nitrogen	Applied nitrogen+ residual nitrogen	164.75	126.92	6.00	631.00
Pre-plant water	Pre-plant rainfall + pre-plant irrigation (inch)	10.40	2.80	6.93	13.41
Post-plant water	Post-plant rainfall + post-plant irrigation (inch)	19.77	8.57	12.60	24.47
Yield)	Lint Yield (lbs acre-1	1218.10	473.33	406.21	2744.59
Micronaire	measure of fiber fineness & maturity (Units)	3.56	0.45	2.56	4.52
Planting date	Dummy (Early planting 1, 0 Otherwise)	0.66	0.13	0	1.00

Parameter estimates for the lint yield model are presented in Table 2. Coefficients total N (applied N plus residual N), pre-plant water, and total N x pre-water interaction showed a positive effect on lint yield, whereas post-plant water, total N x post-plant water, and pre-water x post-water interactions showed negative relationships. Nevertheless, all parameters, except the constant term, were significant in the model. The marginal effect of pre-plant water was found to be higher than post-plant water. Neupane (2010) noted a similar relationship in prior year data from the same study. Total water available to plants (rainfall and irrigation) at different stages showed varied the impact on lint yield. Post-plant water, if irrigated late or rainfall occurs around crop cut-out, may contribute to undesirable vegetative growth at the cost of cotton boll growth and maturity. Neupane (2010) reported the marginal effect of residual NO_3 on lint higher than the variable N. Boquet (2005) reported that increasing N from 90 to 157 kg ha^{-1} did not result in increased lint yield in irrigated or rain-fed cotton.

Table 2. Parameter estimates for the lint yield model using OLS.

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	66.17	155.89	0.42	0.672
Total N	1.25	0.18	6.78	<.0001
Pre-water	176.14	18.23	9.66	<.0001
Post water	-40.03	12.38	-3.23	0.0016
Total N* Pre-water	0.52	0.11	4.81	<.0001
Total N* Post water	-0.13	0.07	-1.79	0.0767
Pre-water *Post water	-12.44	2.81	-4.42	<.0001

The model gave a reasonably acceptable fit with R-square of 0.73. Observed values were fitted around 0 between 600 to -600 which indicated that OLS model behaved well with equal variance of error term and reasonable linear relationship (Figure 6).

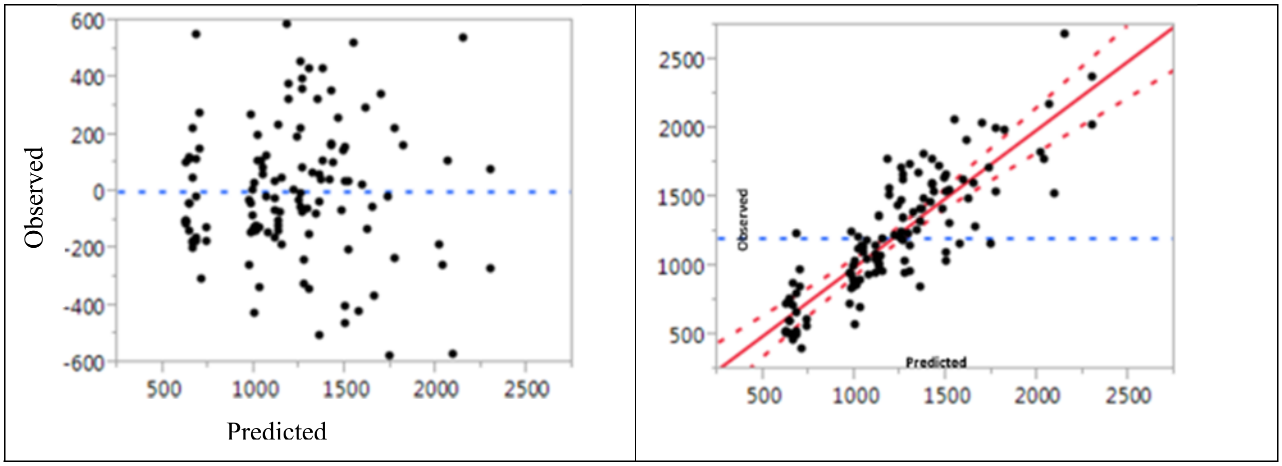

Figure 6. Residual analysis of the lint yield model (left) and observed versus predicted lint yield (right).

Table 3: Parameter estimates for micronaire using binary logistic model

Term	Estimate	Std Error	Wald $\chi 2$	Prob>|t|	Odds Ratio
Intercept	3008.80	1253.90	5.76	0.0164	
Pre-plant water	2.15	0.55	15.28	<.0001	0.12
Post-plant water	-1.02	0.21	24.77	<.0001	2.78
Residual N	0.01	0.01	3.50	0.0614	1.00
Applied N	-0.02	0.01	14.53	<.0001	1.02
Planting date	0.15	0.06	5.78	0.0162	0.86

Binary logistic model was used to analyze the effects of variable inputs on micronaire quality. The coefficient was estimated from regression and results were interpreted in terms of change in the odds ratio. The marginal effects of increased inputs on the odds ratio was calculated and compared with the standard value (1.0). If the marginal effect is higher than 1, an increase in the input causes the production of a premium micronaire quality for the lint. Similarly, a value less than 1 will increase the chance of the fiber being in a lower grade. Rainfall and irrigation water received during the different crop stages showed different relationships with micronaire quality. Pre-plant irrigation and pre-plant rainfall showed a positive relationship on premium quality lint production, whereas post-plant water resulted in negative relationships regarding micronaire values. Residual N and early planting showed positive relationships and N application rate had a numerical negative relationship, but they were all significant (Table 3). Neupane (2010) reported a positive linear relationship between micronaire and water/N fertility level.

Acknowledgments

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References

Boquet, D. J. 2005. Cotton in ultra-narrow row spacing: Planting density and nitrogen fertilizer rate. *Agronomy Journal.* 97:279-287.

Boquet, D. J., G. A. Breitenbeck. 2000. Nitrogen rate effect on partitioning and dry matter of cotton. *Crop Science*. 40: 1685-1693.

Moore, S. H. 1999. Nitrogen effect on position of harvestable bolls in cotton. *Journal of Plant Nutrition*. 22: 901-909.
Neupane, D. 2010. The impacts of water and nitrogen use on cotton lint yield and quality: An econometric analysis MS thesis, Texas Tech University.