The *Journal of Cotton Science* 3:109-115 (1999)
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ECONOMICS AND MARKETING

Economics of Broadcast and Injected Nitrogen on No-Till Cotton Produced at Three Locations in Tennessee

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INTERPRETIVE SUMMARY

Although several researchers have studied N sources and application methods for conventional-tillage cotton systems, less research has dealt with N sources and application methods in no-till production systems. Economically optimal N rates for alternative application methods have not been identified for no-tillage cotton systems. The objectives of this research were to (i) determine if no-till cotton yields respond differently to injected and broadcast N, (ii) determine if no-till cotton yields respond differently across locations with different soil types and surface residues, and (iii) identify economically optimal N rates, yields, and net revenues for no-till cotton at three locations in Tennessee.

No-till cotton lint yields were obtained for broadcast and injected N rates of 0, 30, 60, 90, and 120 lb A^{-1} on Loring, Lexington, and Memphis silt loam soils at three Univ. of Tennessee experiment stations; Milan for 1994 through 1997, the West Tennessee station at Jackson for 1996 and 1997, and the Ames Plantation, for 1996 and 1997. Surface residues were killed native winter vegetation at Milan, killed winter wheat at Jackson, and corn stover at Ames Plantation. The cultivar was D&PL 50 in 1994 through 1996 and D&PL 5409 in 1997. Plots were four rows wide and 30 ft long, with row widths of 38 in. at Jackson and 40 in. at Milan and Ames Plantation.

The data were used to estimate yield response functions for broadcast and injected N at each location and to test for significant differences in the response function among application methods and locations. The functions for Jackson and Ames Plantation included a weather variable, while the functions for Milan included a weather variable and a variable to account for boll weevil damage.

The broadcast and injected yield response functions were not significantly different from one another, but the functions were significantly different across location. Therefore, the functions estimated from pooling the broadcast and injected data at each location were used to represent yield response to applied N regardless of the application method. The weather variable was significant in explaining cotton lint yields at each location. An increase of one growing degree day above 60 °F between pinhead and bloom was estimated to increase cotton lint yield by 1.74 lb A^{-1} at Milan, 3.13 at Jackson, and 1.39 at Ames Plantation. The boll-weevil-damage variable for Milan was estimated to reduce cotton lint yield by 18.14 lb A^{-1} for a one-weevil increase in the average number of boll weevils caught per pheremone trap during early-to-mid June. The functions estimated from pooling the broadcast and injected data at each location were used to identify economically optimal N rates, yields, and net revenues above N costs.

Economically optimal N rates were 100 lb A^{-1} at Milan, 82 at Jackson, and 96 at Ames Plantation. These rates were higher than the 80 lb A^{-1} maximum currently recommended for cotton production in Tennessee.

Optimal lint yield was 1,153 lb A^{-1} at Milan, which produced an optimal net revenue above N cost of \$751.02 A^{-1}. Comparable per-acre numbers for the other two sites were 1,348 lb (\$886.15) at Jackson and 997 lb (\$647.79) at Ames Plantation.

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Only 3 % (\$3.97 A^{-1}) of the net revenue difference between Milan and Jackson, and only 1 % (\$2.97 A^{-1}) of the net revenue difference between Ames Plantation and Jackson came from the difference in N cost. Most of the net revenue difference between the Lexington soil at Jackson and the Loring soil at Milan or the Memphis soil at Ames Plantation came from higher optimal lint yields at Jackson than at the other two sites.

ABSTRACT

Nitrogen sources and application methods in no-till cotton production have received little attention by researchers. The objectives of this study were to (i) determine if no-till cotton yields respond differently to injected and broadcast N, (ii) determine if no-till cotton yields respond differently across locations, and (iii) identify economically optimal N rates, yields, and net revenues. Yields were obtained for broadcast and injected N rates of 0, 34, 67, 101, and 134 kg ha^{-1} on Loring (killed native winter vegetation), Lexington (killed winter wheat), and Memphis (corn stover) silt loam soils at Milan, TN (1994 through 1997), Jackson, TN (1996 and 1997), and Ames Plantation, TN (1996 and 1997), respectively. Quadratic yield response functions were estimated and tested for significant differences among application methods and locations. The broadcast and injected functions were not significantly different, but significant differences were found across locations. Economically optimal N rates were 112, 92, and 107 kg ha^{-1} at Milan, Jackson, and Ames Plantation. These rates were 24, 2, and 19 % higher than the 90 kg ha^{-1} maximum currently recommended for cotton production in Tennessee. Optimal yields were 1,291, 1,510, and 1,117 kg ha^{-1}, and optimal net revenues above N costs were \$1,955.80, \$2,189.72, and \$1,600.73 ha^{-1}, respectively. Only 3 % (\$9.80 ha^{-1}) of the net revenue difference between Milan and Jackson came from the difference in N cost, while this percentage was only 1 % (\$7.35 ha^{-1}) when Ames Plantation and Jackson were compared. The remainder of the net revenue difference came from differences in optimal lint yields.

Nitrogen sources and application methods have been studied for conventional-tillage cotton systems by several researchers (Overton and Long, 1969; Maples and Keough, 1971; Howard and Hoskinson, 1986, 1990; Hutchinson et al., 1995; McConnell et al., 1995; Ebelhar and Welch, 1996; Ebelhar et al., 1996; Moore, 1998). Less research has dealt with N sources and application methods in no-till production systems (Howard and Gwathmey, 1997; Hutchinson et al., 1995; Thompson and Varco, 1996; Thompson et al., 1997).

Economically optimal N rates for alternative application methods have not been identified for no-till cotton production systems. The objectives of this research were to (i) determine if no-till cotton yields respond differently to injected and broadcast N, (ii) determine if no-till cotton yields respond differently across locations with different soil types and surface residues, and (iii) identify economically optimal N rates, yields, and net revenues for no-till cotton at three locations in Tennessee.

MATERIALS AND METHODS

No-till cotton lint yield data for five N rates were obtained from three Univ. of Tennessee experiment stations. They were at Milan (on Loring silt loam soil with killed native winter vegetation), Jackson (on Lexington silt loam with killed winter wheat), and Ames Plantation (Memphis silt loam with corn stover).

The experiments were initiated at Milan in 1994 and at Jackson and Ames Plantation in 1996. All three experiments ended in 1997. The experiment design was a randomized complete block with five replications. Nitrogen rates of 0, 34, 67, 101, and 134 kg ha^{-1} were either broadcast (ammonium nitrate) or injected (urea-ammonium nitrate) after planting in mid-May.

Before planting, each treatment received 15 kg ha^{-1} P (triple superphosphate) and 55 kg ha^{-1} K (KCl). The cultivars used were D&PL 50 in 1994 through 1996 and D&PL 5409 in 1997. Plots were four rows wide and 9.1 m long, with row widths of 0.97 m at Jackson and 1.02 m at Milan and Ames Plantation.

The data were used to estimate quadratic yield response functions for each location and application method. The response functions took the form:

$$Y_{ij} = a_{ij} + b_{ij}N + c_{ij}N^2 + d_{ij}DD60PB_j + u_{ij}$$
$$i = 1 \text{ and } 2, j = 1, 2, \text{ and } 3 \qquad [1]$$

where i is an index with a 1 indicating N was broadcast ammonium nitrate and a 2 indicating N was injected urea-ammonium nitrate; j is an index with a 1 indicating Milan, a 2 indicating Jackson, and a 3 indicating Ames Plantation; Y is total cotton lint yield from first and second harvests in kg ha^{-1}; N is the N application rate in kg ha^{-1}; DD60PB is growing degree days above 16 °C from pinhead to bloom; a, b, c, and d are the parameters to be estimated by regression; and u is a random error term.

The signs of b_{ij} and c_{ij} were hypothesized to be positive and negative, respectively. These hypothesized signs correspond with economic theory which hypothesizes that yield response to a production input increases at a decreasing rate (diminishing marginal physical product). The sign of d_{ij} was hypothesized to be positive, suggesting that favorable temperatures for crop growth between pinhead and bloom produce higher yields. Additional weather variables dealing with temperature and precipitation were considered, but excluded because of high correlation among themselves and too few years of data for Jackson and Ames Plantation. The DD60PB variable was used because it appeared to be the best proxy for weather related variation in the cotton lint yields in this experiment.

The data were pooled across years to estimate the response functions for each location and to account for the effect of weather each year through DD60PB. Inclusion of DD60PB allowed more accurate estimation of the parameters for N and N^2 because more of the variation across years and locations was explained. Also, pooling the data across years allowed the estimation of an average yield response function for each application method and location. These response functions could be used by farmers and researchers to estimate optimal N rates and yields for expected or average weather conditions.

The broadcast and injected yield response functions for each location and the yield response functions across locations were tested for significant differences using *F*-tests (Chow tests) (Kennedy, 1992, p. 108–109). The economically optimal level of N for a yield response function was found by setting the slope of the yield response function (first derivative with respect to N or marginal physical product) equal to the ratio of N price to cotton lint price and solving for N. The economically optimal level of N was substituted into the yield response function, which was then solved for the optimal yield. Optimal net revenues above N costs were then calculated and compared. Other costs were the same among treatments; therefore, calculating differences in net revenues above N costs was the same as calculating differences in net revenues above variable or total costs.

In computing these optima, a price of \$0.49 kg^{-1} of N for broadcast ammonium nitrate (Billy Jack Hopper, Madison Farmers' Cooperative, Jackson, TN, Personal Communication, 18 March 1999) and the 1993 through 1997 Tennessee mean annual cotton lint price of \$1.48 kg^{-1} (Tennessee Agricultural Statistics Service, 1998) were used.

Another possible source of yield variation across years and locations was insect damage. Attempts were made to account for this yield variation by including a variable for boll weevil population (BW). Unfortunately, too few years of yield data were collected at Jackson and Ames Plantation to include both DD60PB and BW in the functions. At Milan, however, 4 yr of data allowed the inclusion of both variables. Therefore, the Milan yield response functions were re-estimated as follows:

$$Y_{i1} = a_{i1} + b_{i1}\mathrm{N} + c_{i1}\mathrm{N}^2 + d_{i1}\,\mathrm{DD60PB}_1 + e_{i1}\mathrm{BW}_1 + u_{i1},\ i = 1 \text{ and } 2 \qquad [2]$$

where BW is the number of boll weevils caught per pheremone trap during the week ending the second Friday in June for 1994 through 1996 and the third Friday in June for 1997 in the county where the respective experiment station resides (C. Jones, 1998, personal communication). These data gave an indication of the size of the boll weevil population that potentially caused yield loss. Higher boll weevil populations were likely to cause more yield damage; therefore, the sign of e_{i1} was hypothesized to be negative. All other variables and coefficients in Eq [2] were as defined in Eq [1].

RESULTS AND DISCUSSION

Cotton yield response functions (Eq [1]) estimated for broadcast and injected N for each location are presented in Table 1. The response functions for each location estimated from pooling the broadcast and injected data are also presented. The *F*-tests suggest that the coefficients for the

Table 1. Estimated cotton lint yield response functions for broadcast, injected, and pooled models by location, and *F*-tests to detect differences across application methods.

Location & method	Intercept	N†	N^2	DD60PB	R^2	*F*-test‡	No. Obs.§
Milan							
Broadcast	-172.58 (-1.29) ¶	10.49** (7.62)	-0.049** (-4.97)	1.88** (7.08)	0.65		100
Injected	-17.73 (-0.15)	8.62** (6.98)	-0.033** (-3.69)	1.56** (6.52)	0.68		100
Pooled#	-95.15 (-1.06)	9.55** (10.35)	-0.041** (-6.17)	1.72** (9.65)	0.66	0.80	200
Jackson							
Broadcast	-487.74** (-2.77)	8.73** (6.03)	-0.043** (-4.22)	3.42** (9.49)	0.78		48
Injected	-576.73** (-3.07)	7.88** (5.14)	-0.043** (-3.97)	3.59** (9.36)	0.73		48
Pooled#	-528.64** (-4.03)	8.23** (7.65)	-0.043** (-5.57)	3.50** (13.03)	0.74	1.98	96
Ames							
Broadcast	252.89 (1.22)	5.26** (4.45)	-0.020* (-2.41)	1.38** (2.77)	0.60		50
Injected	133.85 (0.61)	4.80** (3.88)	-0.024** (-2.71)	1.72** (3.28)	0.46		49
Pooled#	189.98 (1.25)	5.04** (5.83)	-0.022** (-3.60)	1.56** (4.26)	0.52	1.48	99

* Significance at $P = 0.05$.

** Significance at $P = 0.01$.

† The dependent variable is cotton lint yield (kg ha^{-1}). The explanatory variables are: N = fertilizer nitrogen (kg ha^{-1}); N^2 = fertilizer nitrogen squared; and DD60PB = growing degree days above 16 °C from pinhead to bloom.

‡ F-statistic to test whether the coefficients of the Broadcast and Injected models are the same(Kennedy, 1992).

§ The number of observations equals the number of N rates times the number of replicationstimes the number of years (5x5x4 for Milan and 5x5x2 for Jackson and Ames Plantation).Yields from four plots were lost at Jackson and one plot at Ames Plantation from factorsoutside the control of the researchers.

¶ Student t-statistics are in parentheses.

\# The Pooled model combines data from the Broadcast and Injected models.

Table 2. Estimated cotton lint yield response functions pooled across locations and application methods, and *F*-tests to detect differences across locations.

Pooled models	Intercept	N†	N^2	DD60PB	R^2	*F*-test‡	No. Obs.§
Milan-Jackson	-69.90 (-0.69)¶	9.23** (9.39)	-0.042** (-5.99)	1.94** (9.55)	0.50	65.71**	296
Milan-Ames	45.63 (0.68)	8.06** (11.33)	-0.035** (-6.81)	1.57** (11.32)	0.61	7.71**	299
Jackson-Ames	-780.60** (-8.29)	6.72** (8.11)	-0.033** (-5.58)	3.98** (19.24)	0.72	22.96**	196

** Significant at $P = 0.01$

† The dependent variable is cotton lint yield (kg ha^{-1}). The explanatory variables are: N = fertilizer nitrogen (kg ha^{-1}); N^2 = fertilizer nitrogen squared; and DD60PB = growing degree days above 16 °C from pinhead to bloom.

‡ *F*-statistic to test the null hypothesis that the coefficients of the pooled models from Table 1 are the same across locations (Kennedy, 1992). Significant *F*-statistics indicate rejection of the null hypothesis.

§ The number of observations equals the number of N rates times the number of replications times the number of application methods times the number of years at the first location plus the same for the second location ($5 \times 5 \times 2 \times 4 + 5 \times 5 \times 2 \times 2$ for Milan-Jackson and Milan-Ames and $5 \times 5 \times 2 \times 2 \times 5 \times 5 \times 2 \times 2$ for Jackson-Ames). Yields from four plots at Jackson and one plot at Ames Plantation were lost from factors outside the control of the researchers.

¶ Student *t*-statistics are in parentheses.

broadcast and injected yield response functions within locations were not significantly different from one another. Furthermore, the *F*-tests in Table 2, which compared the injection-broadcast pooled models in Table 1, clearly rejected the null hypothesis that the yield response functions were the same across locations. Therefore, pooling of data across locations was rejected as an option, and the yield response functions estimated from pooling data across application methods in Table 1 were used to represent yield response to N at each location.

As expected, the coefficients for N and N^2 had positive and negative signs, respectively, and were significantly different from zero in all equations, suggesting that lint yields increased at a decreasing rate as fertilizer N increased. The coefficients for DD60PB also were significant and had the hypothesized positive sign. The pooled response functions in Table 1 indicated that an additional growing degree day between pinhead and bloom would add 1.72 kg ha^{-1} to cotton lint yield at Milan, 3.50 at Jackson, and 1.56 at Ames Plantation.

Table 3 presents the yield response functions for Milan, which included BW (Eq [2]). The signs of the coefficients for BW were negative as expected, and the coefficients were significantly different from zero at $\alpha = 0.05$, except in the broadcast-N equation. Also, the R^2s increased

Table 3. Estimated cotton lint yield response functions for broadcast, injected, and pooled models for Milan, and *F*-tests to detect differences across application methods.

Location & method	Intercept	N†	N^2	DD60PB	BW	R^2	*F*-test‡	No. Obs.§
Broadcast	-166.34 (-1.24)¶	10.49** (7.63)	-0.049** (-4.97)	2.04** (6.75)	-13.77 (-1.08)	0.65		100
Injected	-5.55 (-0.05)	8.62** (7.15)	-0.033** (-3.78)	1.86** (7.03)	-26.86* (-2.41)	0.70		100
Pooled#	-85.94 (-0.97)	9.55** (10.48)	-0.041** (-6.25)	1.95** (9.74)	-20.32* (-2.41)	0.67	0.98	200

* Significant at $P = 0.05$.

** Significant at $P = 0.01$.

† The dependent variable is cotton lint yield (kg ha^{-1}). The explanatory variables are: N = fertilizer nitrogen (kg ha^{-1}); N^2 = fertilizer nitrogen squared; DD60PB = growing degree days above 16 °C from pinhead to bloom; and BW = number of boll weevils caught per pheremone trap during the week ending the second Friday in June for 1994 through 1996 and the third Friday in June for 1997 in the county in which the respective experiment station resides.

‡ *F*-statistic to test whether the coefficients of the broadcast and Injected models are the same (Kennedy, 1992).

§ The number of observations equals the number of N rates times the number of replications times the number of years (5 × 5 × 4).

¶ Student *t*-statistics are in parentheses.

\# The pooled model combines data from the broadcast and injected models.

Table 4. Economically optimal N rates, yields, and net revenues, and differences in optimal N costs, revenues, and net revenues for Milan and Ames Plantation, compared with Jackson.

Location	N rate (kg ha^{-1})	Yield (kg ha^{-1})	Net revenue† ($ ha^{-1})	Difference in N cost‡ ($ ha^{-1})	Difference in revenue‡ ($ ha^{-1})	Difference in net revenue§ ($ ha^{-1})
Milan	112	1,291	1,855.80	9.90	-324.12	-333.92
Jackson	92	1,510	2189.72	- - -	- - -	- - -
Ames	107	1,117	1,600.73	7.35	-581.64	-588.99

† Net revenue is total revenue (yield times cotton lint price) minus the cost of N (N rate times Nprice). The cotton lint price was the 1993–1997 Tennessee mean annual cotton lint price of $1.48 kg^{-1} (Tennessee Agricultural Statistics Service, 1998) and the N price was the March 1999 ammonium nitrate price of $0.49 kg^{-1} of N (Billy Jack Hopper, Madison Farmers' Cooperative,Jackson, TN, personal communication, 18 March 1999).

‡ The difference in N cost is the N cost (N rate times N price) for Milan or Ames Plantation minus the N cost for Jackson. The difference in revenue is total revenue (yield times cotton lint price) for Milan or Ames Plantation minus total revenue for Jackson.

§ The difference in net revenue is calculated by subtracting the difference in N cost from the difference in revenue across the row or by subtracting the net revenue for Milan or Ames Plantation from the net revenue for Jackson.

slightly for the injected and pooled response functions. Again, the *F*-test failed to reject the hypothesis that the coefficients of the injected and broadcast yield response functions were the same. The BW coefficient in the pooled model indicated that yield would decrease about 20 kg ha^{-1} if the number of boll weevils per trap increased by one during early-to-mid June.

The coefficient for DD60PB in the pooled function increased from 1.72 kg ha^{-1} to 1.95 kg ha^{-1} after BW was included as an explanatory variable. This finding suggests that the exclusion of BW from Eq [1] may have biased the coefficients for DD60PB in Table 1 (Kennedy, 1997). Nonetheless, after rounding, the N and N^2 coefficients for Milan were the same (Tables 1 and 3), suggesting that the addition of BW into the yield response function did not change the optimal amount of N to apply and the exclusion of BW from the pooled Milan model in Table 1 did not significantly bias the N and N^2 coefficients.

A similar statement cannot be made for the cases of Jackson and Ames Plantation because sufficient data were not available to test this hypothesis. Nevertheless, assuming a similar result for Jackson and Ames Plantation, and with the caveat that the unbiasedness of the N and N^2 coefficients at those locations has not been shown, the pooled functions in Table 1 for Jackson and Ames Plantation and the pooled function for Milan in Table 3 were used to calculate the optimal N rates and yields presented below. Because no difference was found in the effectiveness of broadcasting and injecting N and broadcasting N is less expensive than injecting it (Roberts et al., 1995), broadcasting was assumed to be the method of application in computing these optima.

The lowest economically optimal N rate of 92 kg ha^{-1} and the highest optimal cotton lint yield of 1,510 kg ha^{-1} were found on the Lexington soil at Jackson (Table 4). The Loring soil at Milan produced an optimal yield that was 15 % lower (1,291 kg ha^{-1}) than at Jackson. This lower yield required 22 % more N (112 kg ha^{-1}), which was the highest optimal N rate of the three locations. The Memphis soil at Ames Plantation produced the lowest economically optimal cotton lint yield of 1,117 kg ha^{-1} with an optimal N rate of 107 kg ha^{-1}. The economically optimal yield was 26 % lower and the optimal N rate was 16 % higher than at Jackson.

The optimal N rates at all three sites were higher than 90 kg ha^{-1} currently recommended for cotton production in Tennessee (Extension Plant and Soil Science, 1998). The rate at Milan was 22 kg ha^{-1} (24 %) above the recommended rate, that at Jackson was 2 kg ha^{-1} (2 %) above it, and that at Ames Plantation exceeded it by 17 kg ha^{-1} (19 %).

Table 4 shows the estimated optimal net revenue above N cost for each location. Net revenue above N cost was highest at Jackson, where \$333.92 ha^{-1} more net revenue was earned than at Milan and \$588.99 ha^{-1} more net revenue was earned than at Ames Plantation.

Most of this higher net revenue came from higher yields at Jackson, which caused gross revenue to be \$324.12 ha^{-1} higher than at Milan and \$581.64 ha^{-1} higher than at Ames Plantation. A lower optimal N rate, and hence, a lower N cost at Jackson contributed only \$9.80 ha^{-1} to its higher net revenue compared with Milan and \$7.35 ha^{-1} compared with Ames Plantation.

CONCLUSIONS

At three locations with different soil types and surface residues, no-till cotton lint yield response to applied N was not affected differently by injecting or broadcasting N. However, significant differences in yield response were found across locations. The lowest economically optimal N rate and the highest optimal yield were found at Jackson on the Lexington soil with a killed winter wheat surface residue. The highest optimal N rate was found at Milan on the Loring soil with a killed native winter vegetation surface residue, while the lowest optimal yield was found at Ames Plantation on the Memphis soil with corn stover as the surface residue.

Net revenue was highest at Jackson and lowest at Ames Plantation. The higher optimal net revenue at Jackson was affected mostly by a higher optimal yield than at Milan and Ames Plantation, while the a lower optimal N rate contributed relatively little to the higher net revenue at Jackson.

ACKNOWLEDGEMENTS

This research was supported by The University of Tennessee Agricultural Experiment Station. The authors acknowledge the contributions of Chip Jones, Ron Seward, Gordon Percell, Jim Larson, and Justin Gersman for their contributions to this work.

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