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MANAGING NITROGEN FOR COTTON IN A HIGH-RESIDUE CONSERVATION TILLAGE SYSTEM

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Abstract

Over 70% of the cotton (*Gossypium hirsutum* L.) in the Tennessee Valley of northern Alabama is currently raised using conservation tillage techniques. High-residue small grain cover crops are becoming a common tool in these systems, but N immobilization may occurr causing previous N recommendations to be obsolete. A replicated 3-year field study was initiated in 1999 in the Tennessee Valley of Alabama on a Decatur silt loam (clayey, kaolinitic, thermic Rhodic Paleudult) to test a factorial arrangement of N source (ammonium nitrate and urea-ammonium nitrate), N rates (0, 40, 80, 120, 160 lb N/A), N application timing (all at-planting and 50-50 split between at-planting and first square), and N application method (banded or broadcast) for cotton grown in a high-residue rye (*Secale cereale* L.) conservation system. Preliminary results suggest that 120 lb N/A may be needed to optimize yields (781 lb lint/A in 2000, 1026 lb lint/A in 2001, and 875 lb lint/A in 2002). Generally, highest yields were obtained when N was applied at-planting (803 lb lint/A in 2000, 957 lb lint/A in 2001, and 863 lb lint/A in 2002). Ammonium nitrate applications resulted in greater yields when broadcast at-planting while UAN applications resulted in greater yields when banded, regardless of application timing. At current prices for AN and UAN, the preliminary data suggest the most efficient and economical practice for cotton grown in high-residue conservation systems would be to apply 120 lb N/A as UAN in a banded application at-planting.

Introduction

The Tennessee Valley region of North Alabama is predominantly a monoculture cotton production system that plants nearly 250,000 A/year. Historically, N recommendations for these systems were developed using conventional tillage. Most of these recommendations were based upon N and C degraded soils as a result of tillage for extensive periods of time (Martens, 2001). Alabama Cooperative Extension Service currently recommends a range of 30 to 90 pounds of N per acre (lb N/A) for cotton production systems in the Tennessee River Limestone Valley of North Alabama, with 60 lb N/A used as an average (Mitchell et al., 1991; Monks and Patterson, 1996). Continuous cotton production, which has little crop residue, has caused soil degradation, erosion, and loss of organic matter in these soils (Schwab et al., 2002). If the soil continues to be degraded at the conventionally tilled rate, cotton production systems would be seriously jeopardized in the future.

Approximately 70% of the farmers in the Tennessee Valley region of Alabama currently use conservation tillage in cotton (Patterson, personal communication, 2002). The main two methods they use are planting into the old cotton stubble, or planting into a cereal cover crop. Planting into the cotton stalks is easier for plant establishment, but may increase compaction problems and reduces lint yield (Burmester et al., 1993; Raper et al., 2000; Schwab et al., 2002). Producers in the Tennessee Valley are increasingly using more high-residue cereal cover crops (>4,000 lb residue/A).

Bauer and Bradow (1993) state that rye offers many benefits as a cover, as it is easy to kill with herbicides, easy to establish, and provides intensive ground cover, even if planted late (Brown et al., 1985). Raper et al. (2000) also found that a rye cover crop was the most critical factor in increasing yields of conservation tillage cotton on this soil type.

Integration of cover crop residue into production systems increases microbial activity and alters the amount and seasonality of available inorganic N, affecting N use efficiency (Jackson, 2000). Two common N sources, urea-ammonium nitrate liquid 32% N (UAN) and ammonium nitrate 34% N (AN) are used in cotton cropping systems. Urea-ammonium nitrate liquid 32% N is generally cheaper at $120/ton ($0.188/lb N) (Limestone Farmers Cooperative, personal communication, 2002), easy to handle and apply, does not require special equipment, and herbicides can be mixed with it during application. It has a few disadvantages as it can scorch plant foliage, salt out at low temperatures, and may become bulky to store (Alabama Certified Crop Advisor Program, 2002). Ammonium nitrate works well as a top-dressing but is more expensive at $195/ton ($0.287/lb N) (Limestone Farmers Cooperative, personal communication, 2002) and very hygroscopic so it may cause caking problems or present an explosion hazard. Research by Touchton and Hargrove (1982) showed that AN is more efficient than UAN in conservation tillage systems, as UAN may be more susceptible to the urease enzyme concentrated in crop residue, causing more N loss as ammonia to the atmosphere (Bovis and Touchton, 1998).

Nitrogen application method also influences crop N use efficiency. Touchton and Hargrove (1982) showed that banding UAN resulted in higher yields and N uptake in no-till corn (*Zea mays* L.), when compared to broadcast treatments. Another study by Johnston and Fowler (1991) found that dribble banded UAN resulted in higher yields than broadcast UAN in no-till wheat (*Triticum aestivum* L.). However, a study by Bell et al. (1998) showed that banded and broadcast N-P-K fertilizer resulted in similar cotton yields.

Nitrogen application timing also affects cotton N use efficiency. The peak time that N is needed is mid-bloom through boll set (Monks and Patterson, 1996). Mullins and Burmester (1990) found that most nutrient accumulation occurs 63 to 98 days after planting, with leaf N concentrations decreasing as the season progresses. Monks and Patterson (1996) stated that only half of N should be applied at-planting, with the remainder prior to first bloom. A study by Ebelhar et al. (1996) showed a significant increase in cotton yield when N was 50-50 split at-planting and pinhead square formation. However, research by Howard et al. (2001) showed that splitting UAN, 50% at planting and 50% six weeks later, resulted in higher yields in only one of eight years.

It is likely that high-residue conservation tillage techniques will initially require higher N rates due to immobilization of N and loss from ammonia (NH_3) volatilization. Monks and Patterson (1996) expect total fertilizer N rates to be increased from 60 lb/A to 90 lb/A in the Tennessee Valley, but no research has been conducted to verify this rate. The objective of this research is to determine the most efficient combination of N rate, method, application timing, and source for high-residue conservation tillage cotton systems in the Tennessee Valley in northern Alabama.

Materials and Methods

This experiment was initiated in November of 1999 at the Tennessee Valley Research and Extension Center of the Alabama Agricultural Experiment Station, in Belle Mina, AL with the planting of a rye cover crop. The soil type was a Decatur silt loam (clayey, kaolinitic, thermic Rhodic Paleudult), the major type in the region. The experiment design was a factorial arrangement of two N sources (UAN and AN), two N application times (at-planting and 50% at-planting/50% at first square), two N application methods (broadcast and banded), and four N rates (40, 80, 120, and 160 lb N/A) in a randomized complete block of 4 replications. A 0-N control was also included. The varieties used were 'Elbon[1]' Rye and 'SureGrow 125 (2000 and 2001) and 215 (2002) BG/RR[1]' cotton.

Phosphorous, potassium, and lime were applied prior to planting the fall crop based on Auburn University test recommendations. Compaction can become a problem for this soil (Schwab et al., 2002), thus, each year plots were non-inversion deep-tilled to the 18-inch depth using a Paratill®[1] bent-leg subsoiler (Bigham Brothers Inc., Lubbock, TX 79452) immediately following the planting of the rye cover crop, in early November. Equipment used in this experiment was guided using a Trimble AgGPS Autopilot®[1] automatic steering system (Trimble, Sunnyvale, CA 94088), with centimeter level precision. This insures that the equipment compaction is kept off the cotton row. This guidance system allows the banded application of N to be placed in the same location each time it is applied. The rye was terminated in mid-April using glyphosate at the labeled rate. A roller/crimper was then used to roll down the cover crop (Ashford et al., 2000). Cotton was planted in early May using a 4-row unit vacuum planter set on 40-inch rows at a rate of 5 seed per foot. All cotton production practices were followed as outlined by the Alabama Cooperative Extension Service.

Initial N applications were made immediately following planting of cotton using a drop spreader equipped for broadcast or banded applications for AN and a sprayer rig for UAN. The second application of the 50-50 split N was applied at first match head square formation. To account for the border effect of alleys, 2.5 feet were cut off each end of the plot using a rotary mower before harvest. The center two rows were harvested with a spindle picker equipped with a sacking unit.

Prior to termination, rye biomass was sampled by collecting two 0.25 m^2 per plot. The residue was dried at 131^0F (55^0C) until all moisture was removed and weighed to determine dry matter/A. Approximately 30 g of subsample was ground through a 1 mm screen on a rotary mill. Total C and N by dry combustion using a Fisons 1500 NCS®[1] nitrogen/carbon analyzer (Fisons Instruments, Beverly, MA 01915) was determined on subsamples. At first square, leaf chlorophyll from 25 of the upper most expanded leaves in each plot were read with a Minolta 502 SPAD®[1] chlorophyll meter (Spectrum, Plainfield, IL 60544). Nitrogen concentrations from the leaf blade/petiole combination were then determined by dry combustion. Chlorophyll meter readings from 25 of the upper-most expanded leaves were taken again when the cotton is at 1st flower and mid-bloom. Petioles were separated from leaf blades and analyzed for NO_3-N using an ion selective electrode combination, while leaf blades were again analyzed for N using the combustion technique. The harvested cotton was subsampled and ginning percentage was determined before being sent to the USDA classing office[1] (USDA, Pelham, AL 35124) for high volume instrumentation (HVI) analysis.

Data was analyzed with General Linear Model procedures (GLM) and means were separated using Fisher's protected least significant differences (LSD) using the SAS statistical package®[1] (SAS Institute, 2001). A significance level of $\underline{P \leq 0.10}$ was established *a priori*. Only leaf N at 1st bloom and cotton yield data from the 2000, 2001, and 2002 seasons are presented in this paper.

Results

2000 Season

Cotton Yield. In 2000, lint yield ranged from 547 lb/A (0-N check plots) to 1043 lb/A. A significant interaction occurred between N timing × N rate × N application method (Table 1). All N rates significantly increased yield over the 0-N check. When N was broadcast at-planting, highest yield was obtained with the 160 lb N/A application (960 lb lint/A), and rates of 40-120 lb N/A were similar in yield. When N was banded at-planting, highest yields (946 lb lint/A) were obtained with the 120 lb N/A rate, with a trend for reduced yields at the 160 lb N/A rate. Too much N will harm cotton as the plants grow excess vegetation, which reduces fruit load and lint yield (Gerik et al., 1994). When N was split applied, regardless of application method (broadcast or banded), there was no response to N application rate other than a yield increase over the 0-N control. However, yields were generally greater for broadcast applications than for banded applications when N was split applied.

Leaf Nitrogen at 1st Flower. At first flower, N source and N rate significantly affected leaf N concentration. Ammonium nitrate applications had higher leaf N (3.88%) than did UAN (3.78%). The 40 lb N/A rate had lower leaf N% (3.64%) than the other three rates (3.86%, 3.87%, and 3.96, for 80, 120, and 160 lb N/A respectively), as expected. Although significantly different, they were all within the sufficiency level of 3.50 to 4.50% N at first bloom (Jones et al., 1991). All treatments were in the sufficiency level except the 0-N check plots (3.16%) and UAN broadcast application of 40 lb N/A at-planting (3.34%). These plots yielded 547 and 762 lb lint/A, respectively.

2001 Season

Cotton Yield. In 2001, cotton lint yield ranged from 572 lb/A (0-N check) to 1135 lb/A. There were several significant interactions in this crop season. There was a N source × N method interaction (Table 2). Ammonium nitrate applications resulted in greater yield (1014 lb/A) when broadcast, but UAN applications yielded higher when banded (1006 lb lint/A). Rain may affect urea efficiency (Bovis and Touchton, 1998). No rain fell after fertilization in 2000, but within 12 hours of application in 2001, 0.38 inches fell after the at-planting and 0.92 inches after first square applications. It is expected that the banded UAN performed better than when broadcast as the N was more concentrated near the cotton root system (Touchton and Hargrove, 1982).

There was an application timing × N rate × application method interaction in 2001 (Table 3) . Nitrogen rate did not affect yield when broadcast at-planting, except when compared to 0-N check plots (572 lb lint/A). Broadcast split applications at 80 lb N/A and greater yielded higher than the 40 lb N/A rate. Banded at-planting N increased yields with 120 lb N/A (1029 lb lint/A) over 80 lb N/A (839 lb lint/A).

There was also a N source × N method × N application timing interaction (Table 4). Urea-ammonium nitrate liquid banded at-planting (1053 lb lint/A) out performed AN banded at planting (840 lb lint/A), but AN broadcast at-planting (1035 lb lint/A) out performed the UAN broadcast at-planting (913 lb lint/A). When N was split, there was no yield response; yields were equivalent regardless of N source and method.

Leaf Nitrogen at 1st Flower. A N source × N method interaction revealed broadcast AN (3.43%) increased leaf N compared to banded AN (3.33%). Ammonium nitrate broadcast also resulted in greater leaf N concentrations (3.43%) than when UAN was broadcast (3.26%). There was a linear response to N rate when N was applied at-planting (Table 5). Split applications resulted in an increase in leaf N from the 40 lb N/A (2.92%) to the 80 lb N/A (3.54%), but no increase after that. There was also a N application timing × N source × N rate interaction (Table 6). At-planting, AN rates of 120 (3.60%) and 160 lb N/A (3.81%) had greater leaf N than lower rates. Urea-ammonium nitrate source resulted in a linear response to N rate when applied at-planting. The highest N rates (120 and 160 lb N/A) were generally the only plots without a N deficiency, regardless of source. There was also a N source × N method × N rate interaction (Table 7). Broadcast AN resulted in a linear response to N rate, while banded AN resulted in increased leaf N only with N rates greater than 80 lb/A. The reason for the greater leaf N concentrations for UAN applications of 40 lb N/A is unclear, but may be related to reduced plant size and a concentration effect.

2002 Season

Cotton Yield. Cotton lint yields in 2002 ranged from 544 (0-N check plots) to 1209 lb/A (UAN, split, broadcast with 160 lb N/A), across all treated plots. There were many significant interactions. Averaged over all other treatments, at-planting applications (863 lb lint/A) yielded more than split N applications (809 lb lint/A). No yield response was found above 80 lb N/A (821 lb lint/A), over all treatments. Yields were better when AN was broadcast applied compared to band application (866 vs.782 lb lint/A, respectively), while UAN yielded higher with banded applications (895 banded vs. 798 lb lint/A broadcast). An N application time x N rate interaction showed at-planting applications maximized yields when a rate of 160 lb N/acre was applied (987 lb lint/A), while split applications maximized yields at 80 lb N/acre (860 lb lint/A). The same yield was obtained with 120 lb N/A applied at-planting as the 80 lb N/A split applied. Urea-ammonium nitrate applied all at-planting resulted in higher yields than AN applied with split applications. Regardless of N source, at-planting banded applications yielded higher than broadcasted split-applications. In 2002, application of 160 lb N/A banded as UAN at-planting generally provided highest yields, although under some treatments 80 lb N/A was sufficient.

Leaf Nitrogen at 1st Flower. Although there were several significant interactions, all treatments had a sufficient amount of leaf N at first bloom. The lowest leaf N level was 4.30% (80 lb N at-planting AN banded) while the highest was 5.12% (80 lb N split UAN banded). Dry weather and lower plant residue may have contributed to higher N concentrations. The N source × N method × N rate interaction (Table 8) showed that AN required less N to achieve higher concentrations than UAN when broadcast, while UAN had more uptake when banded. Splitting N gave the highest N concentration according to the N time × N method × N rate interaction (Table 9). If split, it did not matter if the N was banded or broadcast, and only 80 lbs N/A was needed. If applied at-planting, more N was needed to achieve higher levels if banded (120 lb N/A) than if broadcast (80 lb N/A) (4.87% and 4.90%). An N source × N timing × N rate interaction (Table 10) showed that UAN had equal efficiency if applied at-planting or split. Ammonium nitrate required more N to achieve maximum concentrations when applied at-planting (120 lbs N/A at 4.88%) compared to split applications (80 lbs N/A at 5.03%). Splitting N required less N and gave greater efficiency, regardless of source.

Conclusions

Lint yield and leaf N at 1st bloom suggest that 120 lb N/A may initially be needed for cotton grown in high-residue (>4,000 lb residue/A) conservation systems in the Tennessee Valley. We speculate that N requirements may not be as high for systems with less residue and that N requirements may be reduced over time in high residue systems as soil C and N pools reach new equilibriums. Nitrogen applied at-planting resulted in greater or equivalent lint yields (803 lb lint/A in 2000; 957 lb lint/A in 2001; and 863 lb lint/A in 2002) for both sources (UAN and AN) compared to split applications (739 lb lint/A in 2000; 962 lb lint/A in 2001; and 809 lb lint/A in 2002). Ammonium nitrate applications resulted in greater yields when broadcast compared to banding, while efficiency of UAN application was increased when banded. Using 120 lb N/A, at a cost of $0.19/lb N for UAN ($22.80/A) and $0.28/lb N for AN ($33.60/A), producers can save $10.80/A by using UAN rather than AN. Applying all N at-planting saves trips across the field, reducing operating costs and compaction. Banding all UAN at-planting may help producers maximize cotton yield and profit in high-residue conservation systems in the Tennessee Valley.

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[1] Reference to trade or company name is for specific information and does not imply approval or recommendation of the company by the USDA or Auburn University to the exclusion of others that may be suitable.

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Table 1. Effect of N application timing, method, and N rate (lb/A) on cotton lint yield (lb/A) for a high-residue conservation system in the Tennessee Valley of Alabama in 2000.

	Broadcast N Rate (lb N/A)				**Banded N Rate (lb N/A)**			
Application timing	**40**	**80**	**120**	**160**	**40**	**80**	**120**	**160**
	lb/A							
At-planting	767	733	725	960	717	739	946	839
Split†	700	812	790	791	663	742	663	750

$LSD_{0.10}$ = 132 lb/A
0-N check = 547 lb/A
† Split = 50% N at-planting, 50% N at 1st square.

Table 2. Effect of N source and N method on cotton lint yield (lb/A) for a high-residue conservation system located in the Tennessee Valley of Alabama in 2001.

	N application method	
N Source	Banded	Broadcast
	----lb/A----	
AN	877	1014
UAN	1006	944

$LSD_{0.10}$ = 56 lb/A
0-N check = 572 lb/A

Table 3. Effect of N application timing, N method, and N rate on cotton lint yield (lb/A) for a high-residue conservation system located in the Tennessee Valley of Alabama in 2001.

	Broadcast N rate (lb N/A)				Banded N rate (lb N/A)			
Application timing	40	80	120	160	40	80	120	160
	----lb/A----							
At-planting	912	985	1006	980	819	839	1029	1129
Split†	896	1004	1026	1020	838	958	1042	913

$LSD_{0.10}$ = 112 lb/A
0-N check = 572 lb/A
† Split = 50% N at-planting, 50% N at 1st square.

Table 4. Effect of N application time, N method, and N source on cotton lint yield (lb/A) for a high-residue conservation system located in the Tennessee Valley of Alabama in 2001.

	Broadcast N method (lb N/A)		Banded N method (lb N/A)	
Application timing	AN	UAN	AN	UAN
	----lb/A----			
At-planting	1035	913	840	1053
Split†	995	976	912	964

$LSD_{0.10}$ = 80 lb/A
0-N check = 572 lb/A
† Split = 50% N at-planting, 50% N at 1st square.

Table 5. Nitrogen leaf percentage at the first bloom cotton stage for application timing and N rate in a high-residue conservation system located in the Tennessee Valley of Alabama in 2001.

	N rate (lb N/A)			
Application timing	40	80	120	160
	----%----			
At-planting	2.95†	3.06†	3.50	3.69
Split‡	2.92†	3.54	3.55	3.63

$LSD_{0.10}$ = 0.110% N
0-N check = 2.65% N
† Insufficient leaf N at first bloom.
‡ Split = 50% N at-planting, 50% N at 1st square.

Table 6. Nitrogen leaf percentage at the first bloom cotton stage for application timing, N source, and N rate in a high-residue conservation system located in the Tennessee Valley of Alabama in 2001.

Application timing	**AN rate (lb N/A)**				**UAN rate (lb N/A)**			
	40	**80**	**120**	**160**	**40**	**80**	**120**	**160**
	%							
At-planting	3.02†	2.96†	3.60	3.81	2.88†	3.15†	3.39†	3.57
Split‡	2.93†	3.47†	3.53	3.72	2.91†	3.24†	3.57	3.54

$LSD_{0.10}$ = 0.155% N
0-N check = 2.65% N
† Insufficient leaf N at first bloom.
‡ Split = 50% N at-planting, 50% N at 1st square.

Table 7. Nitrogen leaf percentage at the first bloom cotton stage for N source, N application method, and N rate in a high-residue conservation system located in the Tennessee Valley of Alabama in 2001.

Source	**Broadcast N rate (lb N/A)**				**Banded N rate (lb N/A)**			
	40	**80**	**120**	**160**	**40**	**80**	**120**	**160**
	%							
AN	3.00†	3.37†	3.52	3.83	2.94†	3.06†	3.62	3.70
UAN	3.93	2.93†	3.50	3.42†	3.87	3.21†	3.46†	3.69

$LSD_{0.10}$ = 0.155% N
0-N check = 2.65% N
† Insufficient leaf N at first bloom.

Table 8. Nitrogen leaf percentage at the first bloom cotton stage for N source, N method, and N rate in a high-residue conservation system located in the Tennessee Valley of Alabama in 2002.

Source	**Banded N rate (lb N/A)**				**Broadcast N rate (lb N/A)**			
	40	**80**	**120**	**160**	**40**	**80**	**120**	**160**
	%							
AN	4.79	4.67	4.92	4.94	4.91	4.96	5.00	4.97
UAN	4.88	5.03	4.96	4.87	4.73	4.95	4.95	4.99

$LSD_{0.10}$ = 0.069% N
0-N check = 4.43% N

Table 9. Nitrogen leaf percentage at the first bloom cotton stage for N time, method, and N rate in a high-residue conservation system located in the Tennessee Valley of Alabama in 2002.

Time	**Banded N rate (lb N/A)**				**Broadcast N rate (lb N/A)**			
	40	**80**	**120**	**160**	**40**	**80**	**120**	**160**
	%							
At-planting	4.79	4.62	4.87	4.83	4.73	4.90	4.94	4.92
Split	4.88	5.07	5.02	4.99	4.91	5.01	5.00	5.04

$LSD_{0.10}$ = 0.069% N
0-N check = 4.43% N

Table 10. Nitrogen leaf percentage at the first bloom cotton stage for N source, N time, and N rate in a high-residue conservation system located in the Tennessee Valley of Alabama in 2002.

Source	**At-planting N rate (lb N/A)**				**Split N rate (lb N/A)**			
	40	**80**	**120**	**160**	**40**	**80**	**120**	**160**
	%							
AN	4.81	4.60	4.88	4.85	4.89	5.03	5.06	5.06
UAN	4.71	4.93	4.94	4.90	4.90	5.05	4.96	4.96

$LSD_{0.10}$ = 0.069% N
0-N check = 4.43% N