Nitrogen Management for Conservation-Tilled Cotton Following a Rye Cover Crop

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Abstract: Over 70% of the more than 100,000 ha of cotton (*Gossypium hirsutum* L.) in the Tennessee Valley of northern Alabama, USA, is currently produced using conservation tillage systems with cereal cover crops. Decreased N efficiency, as a result of N immobilisation and/or ammonia (NH_3) volatilisation in these high-residue systems, requires development of new N fertiliser recommendations. We conducted a replicated 3-year field study (2000-2002) on a Decatur silt loam (clayey, kaolinitic, thermic Rhodic Paleudult) to test a factorial arrangement of N source [ammonium nitrate (AN) and urea-ammonium nitrate 32% (UAN)], N rates (0, 45, 90, 134, and 179 kg N ha^{-1}), N application timing (all at-planting and 50-50 split between at-planting and first match head square), and N application method (banded or broadcast) for cotton grown in a high-residue rye (*Secale cereale* L.) conservation system. Lint yield and leaf chlorophyll meter readings were used to evaluate N management practices. Chlorophyll meter readings did not correlate with cotton yields during these growing seasons. Optimal yields were obtained with 134 kg N ha^{-1} in 2000 and 2001 (875 kg lint ha^{-1} and 1150 kg lint ha^{-1}) and 179 kg N ha^{-1} in 2002 (895 kg lint ha^{-1}). Generally, highest yields were obtained when N was applied at-planting (900 kg lint ha^{-1}, 1073 kg lint ha^{-1}, and 969 kg lint ha^{-1} for 2000, 2001, and 2002, averaged over N rates, sources, and application methods). Urea-ammonium nitrate applications resulted in greater yields when banded, regardless of application timing, while AN was more effective when broadcast applied. Given current prices for UAN and AN, the most efficient and economical practice for cotton grown in high-residue conservation systems on these soils would be to apply 134 kg N ha^{-1} as UAN in a banded at-planting application.

Key words: N timing, N application method, N source, UAN, ammonium nitrate, leaf chlorophyll, crop residue

INTRODUCTION

The Tennessee Valley region of northern Alabama, USA, is predominantly a monoculture cotton production system that plants nearly 100,000 ha year^{-1}. Continuous cotton production systems produce little crop residue, which has led to soil degradation, erosion, and loss of soil organic matter (Schwab *et al*., 2002). Historically, N recommendations for this region were developed based on conventional tillage practices. Most recommendations were based upon N and C degraded soils as a result of tillage for extensive periods of time (Martens, 2001). The Alabama Cooperative Extension Service currently recommends a range of 34 to 101 kg N ha^{-1} for cotton production systems in this region, with 67 kg N ha^{-1} used as an average (Mitchell *et al*., 1991).

Approximately 70% of the farmers in the Tennessee Valley region of Alabama currently use conservation tillage in cotton (Mike Patterson, Alabama Cooperative Extension Service, personal communication, 2002). The main two methods employed are planting into previous crop cotton stubble, or planting into a cereal cover crop. Planting into cotton stalks is easier for plant establishment, but may increase compaction problems and reduce lint yields (Raper *et al*., 2000; Schwab *et al*., 2002). Producers in the Tennessee Valley are increasingly using more high-residue cereal cover crops (>4,500 kg residue ha^{-1}). 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. Raper *et* *al*. (2000) 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 thereby affecting N use efficiency (Jackson, 2000). Two common N sources, urea-ammonium nitrate liquid 32% N (UAN) and ammonium nitrate 34% N (AN) are commonly used in cotton cropping systems. Urea-ammonium nitrate is cheaper at \$109 mt^{-1} (\$0.42 kg N^{-1}) (Limestone Farmers Cooperative, personal communication, 2002), easy to handle and apply, does not require special equipment, and can be mixed with herbicides during application. Ammonium nitrate works well as a top-dressing, but is more expensive at \$177 mt^{-1} (\$0.62 kg N^{-1}) (Limestone Farmers Cooperative, personal communication, 2002), is very hygroscopic (cause caking problems), and can be explosive. 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 (NH_3) to the atmosphere.

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 fertiliser resulted in similar cotton yields.

Nitrogen use efficiency is also affected by N application timing. The peak time for required N is mid-bloom through boll set. Extension recommendations state that only half of the recommended N should be applied at-planting, with the remainder applied prior to first bloom for greatest N efficiency (Monks and Patterson, 1996). 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.

Handheld chlorophyll meters have shown good correlation with petiole nitrate and leaf N status in cotton plants, but not well with lint yield (Wood *et al*., 1992). This technology is still useful for rapid determination of cotton N status in the field. Meters have a range of 0.0 to 99.9 (unitless measurement). Since peak bloom requires more N demand by cotton, chlorophyll meter readings should be taken at the early flowering stage to allow sufficient time for applied N to be taken up by the plant (Feibo *et al*., 1998).

It is likely that high-residue conservation tillage techniques will initially require higher N rates due to immobilisation of N and loss from NH_3 volatilisation. Monks and Patterson (1996) expect total fertiliser N rates to be increased from 67 kg N ha^{-1} to 101 kg N ha^{-1} in the Tennessee Valley, but no research has been conducted to verify these predictions. The objective of this research was 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 1999 at the Tennessee Valley Research and Extension Center of the Alabama Agricultural Experiment Station, in Belle Mina, Alabama, USA (34^{O}41'00"N, 86^{O}53'02"W, elevation 157 m) 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 experimental 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 (45, 90, 134, and 179 kg N ha^{-1}) in a randomized complete block of four replications. A 0-N control was also included. The varieties used were 'Elbon'[1] Rye and 'SureGrow 125 BG/RR'[1] (2000 and 2001) and 'SureGrow 215 BG/RR'[1] (2002) 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, thus, each year plots were non-inversion deep-tilled to a 46-cm 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 was guided with a Trimble AgGPS Autopilot®[1] automatic steering system (Trimble, Sunnyvale, CA 94088), with centimeter level precision. This insured that equipment-induced compaction was kept away from the cotton row and allowed band applications of N to occur in the same location each time it was applied. Rye was terminated in mid-April using glyphosate at the labeled rate. A roller/crimper was then used to roll down the cover crop in the same direction as cotton was to be planted (Ashford and Reeves, 2003). Cotton was planted in early May using a four-row unit vacuum planter set on 102-cm rows at a rate of 16 seed m^{-1}. 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 match-head square formation. To account for alley border effects, 76 cm were cut off each end of plots 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. Total C and N was determined by dry combustion using a Fisons 1500 NCS®[1] nitrogen/carbon analyser (Fisons Instruments, Beverly, MA 01915). At first square, leaf chlorophyll from 25 of the uppermost expanded leaves in each plot were measured with a Minolta 502 SPAD®[1] (Soil-Plant Analysis Development) chlorophyll meter (Spectrum, Plainfield, IL 60544). Nitrogen concentrations from the leaf blade/petiole combination were determined by dry combustion. Chlorophyll meter readings were repeated at 1st flower and mid-bloom. Petioles were separated from leaf blades and analysed for NO_3-N using an ion selective electrode combination, while leaf blades were again analysed 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 analysed 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 $P \leq 0.10$ was established *a priori*. Only chlorophyll meter readings at 1st bloom and cotton yield data from the 2000, 2001, and 2002 seasons are presented.

RESULTS

2000 season

In 2000, lint yield ranged from 613 kg lint ha^{-1} (0-N check plots) to 1168 kg lint ha^{-1}. A significant interaction occurred between N timing × N rate × N application method (Table 1). When N was broadcast at-planting, the highest yield was obtained with the 179 kg N ha^{-1} application (1075 kg lint ha^{-1}) and rates of 45-134 kg N ha^{-1} were similar in yield. When N was banded at-planting, the highest yields (1060 kg lint ha^{-1}) were obtained with the 134 kg N ha^{-1} rate, with a trend for reduced yields at the 179 kg N ha^{-1} rate. Too much N results in excessive vegetative growth, which can reduce 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.

Chlorophyll meter readings at first bloom showed at-planting applications had slightly lower readings than split applications (42.4 vs. 43.7), averaged over all other treatments. Wood *et al*. (1992) reported

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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.

a reading of 49 at first bloom was required for maximum economic yield. This suggests that N was not optimal at first bloom in our study, however, varietal and environmental differences in chlorophyll meter readings are common, and we cannot say with certainty that N was limiting. A N application timing × N rate × N method interaction for meter readings (Table 1) indicated that for broadcast at-planting applications, only 90 kg N ha^{-1} was needed for the highest leaf chlorophyll reading, while 179 kg N ha^{-1} was needed for the highest lint yield. For banded at-planting applications, there was not a significant difference in chlorophyll meter readings, but 134 kg N ha^{-1} was needed for highest yields. A N application timing × N method × N source interaction indicated that AN applied broadcast at-planting had higher readings than AN banded at-planting (43.7 vs. 41.0), while lint yield was not significantly different between AN application methods at planting.

Table 1. Effect of N application timing, N rate (kg N ha^{-1}), and N application method on cotton lint yield (kg lint ha^{-1}) and chlorophyll meter readings [values in ( )]for a high-residue conservation tillage system in the Tennessee Valley Region of Alabama in 2000.

	Broadcast N Rate (kg N ha^{-1})				**Banded N Rate (kg N ha^{-1})**			
Application timing	**45**	**90**	**134**	**179**	**45**	**90**	**134**	**179**
	kg lint ha^{-1} (chlorophyll meter reading)							
At-planting	859 (41.5)	821 (43.6)	812 (43.9)	1075 (44.0)	803 (41.2)	828 (42.7)	1060 (41.5)	940 (41.5)
Split†	784 (44.2)	909 (42.3)	885 (44.4)	886 (44.9)	743 (42.0)	831 (43.8)	743 (43.7)	840 (44.2)

$LSD_{0.10}$ = 148 kg lint ha^{-1} (1.8)
0-N check = 613 kg lint ha^{-1} (37.8)
† Split = 50% N at-planting, 50% N at 1st square.

2001 season

In 2001, cotton lint yield ranged from 641 kg lint ha^{-1} (0-N check) to 1271 kg lint ha^{-1}. There were several significant interactions in this season. There was a N source × N method interaction; AN applications resulted in greater yield (1136 kg lint ha^{-1}) when broadcast, but UAN applications yielded higher when banded (1127 kg lint ha^{-1}). No rain fell after fertilisation in 2000, but within 12 h of application in 2001, 9.7 mm fell after the at-planting application and 23.4 mm after first square applications. Rainfall after UAN application may affect urea efficiency (Bovis and Touchton, 1998). It is suspected that banded UAN performed better than when broadcast because more N was concentrated near cotton roots. Banded UAN exposed less of the urea to urease concentrated in the rye cover crop residue thereby reducing N loss as NH_3 and increasing N efficiency (Touchton and Hargrove, 1982). There was a N source × N rate × N application method interaction (Table 2) in 2001. For both broadcast AN and banded UAN yields peaked at 90 kg N ha^{-1} (1206 and 1138 kg N ha^{-1}, respectively). If UAN was broadcast at-planting, 134 kg N ha^{-1} was needed for maximum yield (1126 kg lint ha^{-1}). There was also a N source × N method × N application timing interaction. Urea-ammonium nitrate banded at-planting (1179 kg lint ha^{-1}) out performed AN banded at planting (941 kg lint ha^{-1}), but AN broadcast at-planting (1159 kg lint ha^{-1}) out performed UAN broadcast at-planting (1023 kg lint ha^{-1}). When N was split, there was no response; yields were equivalent regardless of N source and method.

On average, 2001 lint yields were higher than 2000 and 2002, however, chlorophyll meter readings were lowest in 2001. In 2001, averaged over other treatments, leaf chlorophyll meter readings were higher with split applications (37.6) compared to at-planting applications (36.5), but lint yields were not different between application methods. Meter readings for N rate also showed varying results, with 45 kg N ha^{-1} having the lowest readings (35.8) and a linear response to N rates (179 kg N ha^{-1} with a reading of 38.2). A N source × N rate × N method interaction (Table 2) for meter readings indicated readings peaked with broadcast AN (38.1) and banded UAN (38.2) applications at 179 kg N ha^{-1}, but cotton yield was maximised at 90 kg N ha^{-1}.

Table 2. Effect of N source, N rate (kg N ha^{-1}), and N method on cotton lint yield (kg lint ha^{-1}) and chlorophyll meter readings [values in ( )] for a high-residue conservation tillage system in the Tennessee Valley Region of Alabama in 2001.

	Broadcast N Rate (kg N ha^{-1})				**Banded N Rate (kg N ha^{-1})**			
Source	**45**	**90**	**134**	**179**	**45**	**90**	**134**	**179**
	kg lint ha^{-1} (chlorophyll meter reading)							
AN	1061 (36.1)	1206 (37.2)	1151 (36.9)	1131 (38.1)	904 (35.6)	875 (36.0)	1126 (37.6)	1042 (38.7)
UAN	964 (36.0)	1021 (36.1)	1126 (38.0)	1112 (37.9)	953 (35.4)	1138 (37.2)	1195 (37.5)	1243 (38.2)

$LSD_{0.10}$ = 125 kg lint ha^{-1} (0.8)
0-N check = 641 kg lint ha^{-1} (34.3)

2002 season

Cotton lint yields in 2002 ranged from 609 kg lint ha^{-1} (0-N check plots) to 1354 kg lint ha^{-1}. Averaged over all other treatments, at-planting applications (967 kg lint ha^{-1}) yielded more than split N applications (906 kg lint ha^{-1}). Yields were higher when AN was broadcast applied compared to band application (970 vs. 876 kg lint ha^{-1}, respectively), while UAN yielded higher with banded applications (1002 banded vs. 894 kg lint ha^{-1} broadcast). An N application time x N rate interaction showed at-planting applications maximized yields when 179 kg N ha^{-1} was applied (1105 kg lint ha^{-1}), while split applications maximized yields at a lower yield potential with 90 kg N ha^{-1} (963 kg lint ha^{-1}). 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 179 kg N ha^{-1} banded as UAN at-planting generally provided highest yields, although under some treatments 90 kg N ha^{-1} was sufficient.

In 2002, chlorophyll meter readings did not show the same interactions and results as lint yield to treatments. Although not significant for lint yield, a N application method × N source × N rate interaction for chlorophyll meter readings suggested needing 90 kg N ha^{-1} if AN was broadcast (38.2), but lint yield trended towards requiring 179 kg N ha^{-1} for maximum yield.

CONCLUSIONS

Chlorophyll meter readings did not correlate with lint yields during these immoderate growing seasons, which included two years of drought and one year of slightly above normal rainfall (338 and 184 mm below normal during the growing season for 2000 and 2002, respectively, and 58 mm above normal for 2001). Nitrogen required for maximum lint yield varied due to yearly variations in environmental conditions, N source, application timing and method. However, data suggests that generally, 134 kg N ha^{-1} may initially be needed for cotton grown in high-residue (>4,500 kg residue ha^{-1}) 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 (899 kg lint ha^{-1} in 2000; 1072 kg lint ha^{-1} in 2001; and 967 kg lint ha^{-1} in 2002) for both sources (UAN and AN) compared to split applications (828 kg lint ha^{-1} in 2000; 1077 kg lint ha^{-1} in 2001; and 906 kg lint ha^{-1} in 2002). Ammonium nitrate applications resulted in greater yields when broadcast compared to banding, while efficiency of UAN application was increased when banded. Using 134 kg N ha^{-1}, at a cost of \$0.42 kg N^{-1} for UAN (\$56.28 ha^{-1}) and \$0.62 kg N^{-1} for AN (\$83.08 ha^{-1}), producers can save \$26.80 ha^{-1} 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 Region of Alabama, USA.

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