Cotton Nitrogen Management in a High-Residue Conservation System: Source, Rate, Method, and Timing

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More than 70% of cotton (*Gossypium hirsutum* L.) grown in the Tennessee Valley of northern Alabama is produced using conservation tillage systems with cereal cover crops. The resulting decreased N efficiency requires development of new N fertilizer recommendations. We conducted a replicated 3-yr field study on a Decatur silt loam (fine, kaolinitic, thermic Rhodic Paleudult) to determine the effects of N source ($NHNO_3$ [AN] and urea–NH_4NO_3 [320 g N kg^{-1}, UAN]), N rates (0, 45, 90, 135, and 180 kg N ha^{-1}), N application timing (all at-planting or 50:50 split between planting and first match head square), and N application method (banded or broadcast) on cotton grown in high-residue rye (*Secale cereale* L.) conservation systems. Generally, 67 to 80% more N was needed than average conventional N rate recommendations to reach optimal yields if N was split applied, while N applied at-planting had yield responses with 169% of the recommended N rate. Urea–NH_4NO_3 applications resulted in greater yields when banded at-planting (1045 kg lint ha^{-1}), while AN was more effective when broadcast applied at-planting or in split applications (1002 and 996 kg lint ha^{-1}, respectively). Chlorophyll meter readings, petiole NO_3, and leaf N were not useful predictors of cotton N deficiency or yield. The most efficient practice is to apply 88% more N (126 kg N ha^{-1} total) than the mean conventional N cotton recommendation as a broadcast split application using AN. We speculate that N requirements may be decreased with time as C and N pools reach a new equilibrium.

Abbreviations: AN, ammonium nitrate; HVI, high-volume instrumentation; UAN, urea–ammonium nitrate.

Of the 218,370 ha of cotton grown in Alabama, 94,226 ha is located in the Tennessee Valley region of northern Alabama (Conservation Technology Information Center, 2006, available through NRCS offices). Continuous conventional cotton production for >100 yr (Raper et al., 1998) has caused soil degradation, erosion, and loss of organic matter in these soils (Schwab et al., 2002). Due to these farming practices, this highly productive limestone valley had the highest loss of soil in Alabama (>35.8 t soil ha^{-1} yr^{-1}; Yoo et al., 1989).

Since the late 1990s, following an aggressive research and education program, growers have largely converted to conservation tillage. No-till cotton production systems are currently used by >70% of farmers in the Tennessee Valley region of Alabama (Conservation Technology Information Center, 2006, available through NRCS offices), with many utilizing high-residue (>4500 kg residue ha^{-1}) cereal cover crops. The conservation system recommended for cotton in the region involves the use of a rye cover crop (Raper et al., 2000; Schwab et al., 2002). Integration of cover crop residue into production systems, however, increases microbial activity and alters the amount and seasonality of available inorganic N, affecting N use efficiency (Jackson, 2000).

Two common N sources, urea–NH_4NO_3 liquid (32% N, UAN) and NH_4NO_3 (34% N, AN) are commonly used in cotton cropping systems. Urea–NH_4NO_3 liquid is generally cheaper at US$292 t^{-1} (US$0.91 kg^{-1} N) (Limestone Farmers Cooperative, personal communication, 2006), easy to handle and apply, does not require special equipment, and herbicides can be mixed with it during application. Ammonium nitrate is more expensive at US$364 t^{-1} (US$1.07 kg^{-1} N) (Limestone Farmers Cooperative, personal communication, 2006), has become a security concern, and is very hygroscopic. Several researchers have reported that AN is more efficient than UAN in conservation tillage systems with surface residue, as UAN may be more susceptible to N losses as NH_3 (Touchton and Hargrove, 1982; Touchton and Martin, 1983; Fenn and Hossner, 1985; Reeves et al., 1993).

Nitrogen application method also influences N use efficiency. Banding UAN often results in higher yields and N uptake in no-till corn (*Zea mays* L.) compared with broadcast treatments (Touchton and Hargrove, 1982; Dinnes et

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al., 2003). Broadcast N applications are more vulnerable to denitrification and leaching in soils that are wetter for periods of time, as no-till soils are (Doran, 1980). A study by Bell et al. (1998), however, showed that banded and broadcast N–P–K fertilizer resulted in similar cotton yields, while Howard et al. (2001) reported that broadcasting AN was a satisfactory application method for no-till cotton production on loess soils in western Tennessee.

Timing of N application can also affect N use efficiency. Nitrogen demand peaks at mid-bloom through boll set for cotton production, with leaf N concentrations decreasing as the season progresses (Mullins and Burmester, 1990; Mitchell, 1996). Mitchell (1996) stated that only half of the N application should be applied at-planting, with the remainder before first bloom. A study by Ebelhar et al. (1996) showed a significant increase in cotton yield when N was 50:50 split between planting and pinhead square formation; however, research by Howard et al. (2001) showed that splitting UAN, 50% at-planting and 50% 6 wk later, resulted in higher yields in only one of 8 yr.

Currently, the base N rate recommended by the Alabama Cooperative Extension System for silt loam soils in the limestone valleys of northern Alabama is 67 ± 33 kg N ha^{-1} (Adams and Mitchell, 2000). Nitrogen rates for conservation-tilled cotton may need to be increased, as recommendations were developed for conventional practices. On a silt soil, Howard et al. (2001) found that 101 kg N ha^{-1} was needed to maximize no-till cotton yields following corn stover. Several researchers have shown that applying 25% more N or 25 to 30 kg N ha^{-1} at-planting is beneficial to cash crops following small grain cover crops to reduce early-season deficiency (Reeves et al., 1986; Touchton et al., 1986; Harris, 2002). Hutchinson et al. (1995) reported that 34% more N (118 kg N ha^{-1} total) was needed for cotton when a winter wheat (*Triticum aestivum* L.) cover crop was used compared with volunteer native vegetation on a fallow winter field; however, a study by Bauer et al. (1993) on a loamy sand indicated that cotton lint yield reached a plateau at 56 kg N ha^{-1} even if rye was introduced into the system as a winter cover crop.

The objectives of this study were to update conventional N recommendations for farmers utilizing high-residue cereal cover crops in the Tennessee Valley region—specifically, to find the N source, N application method, and N application timing with the corresponding N rate to increase cotton yield efficiency. Petiole NO_3–N and leaf N concentrations were used to test cotton N status as an indication of cotton plant N assimilation.

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 (34°41′00″ N, 86°53′02″ W, elevation 157 m), with planting of a rye cover crop using a conventional grain drill. The soil series was a historically tilled Decatur silt loam under cotton production. The yearly experimental design was a randomized complete block, with treatments applied in a factorial arrangement of N source (UAN and AN), time of N application (at-planting and split 50% at-planting and 50% at first match head square), method of N application (broadcast and banded), and N rate (45, 90, 135, and 180 kg N ha^{-1}). Treatments were applied to the same plot each year and were replicated four times. Nitrogen source, N application timing, N application method, and N rate were fixed effects, while replication served as a random effect. A 0-N control was also included. 'Elbon' rye and SureGrow 125 BG/RR (2000 and 2001) and SureGrow 215 BG/RR (2002) cotton were used.

Phosphorous, K, and lime applied before planting the fall crop were based on Auburn University test recommendations (Adams and Mitchell, 2000). Compaction can become a problem for this soil; thus, each year plots were noninversion deep tilled to a 46-cm depth using a Paratill bent-leg subsoiler (Bigham Brothers, Lubbock, TX) immediately following the planting of the rye cover crop in early November. Equipment used was guided with a Trimble AgGPS Autopilot automatic steering system (Trimble, Sunnyvale, CA), with centimeter-level precision. This ensured that equipment-induced compaction was kept away from the cotton row and allowed band applications of N to be placed in the same location each time it was applied. Rye was killed at anthesis using the labeled rate of glyphosate [*N*-(phosphonomethyl) glycine, 1.12 kg isopropylamine salt ha^{-1}]. A roller/crimper was then used to roll down the cover crop in the same direction as the cotton was 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 seeds m^{-1}. All cotton production practices were followed as outlined by the Alabama Cooperative Extension System. In 2002, an additional 296 mL ha^{-1} of mepiquat (1,1-dimethylpiperidinium) chloride was applied to those cotton plots that had received a total N rate of 135 kg N ha^{-1} or more, in addition to 296 mL ha^{-1} that was applied 2 wk earlier to all treatments.

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. Banded applications of both N sources were positioned about 30 to 35 cm from the row and covered about 10 cm of soil surface. The second application of the 50:50 split N was applied at match head square. Before termination, rye was sampled by harvesting the aboveground biomass from two 0.25-m^2 sections per plot for both UAN and AN treatments broadcast in a split application, at all four N rates, along with the 0-N control in 2001 and 2002 (total plots sampled = 36). Rye samples in 2000 were randomly taken across the entire plot area, since no prior cotton N treatments were yet established. Residue was dried at 55°C and weighed to determine dry matter. Total C and N were determined by dry combustion using a Fisons 1500 NCS N/C analyzer (Fisons Instruments, Beverly, MA) (Jones, 2001).

At cotton mid-flower, leaf chlorophyll from 25 of the uppermost fully expanded leaves in each plot was measured with a Minolta 502 SPAD chlorophyll meter (Spectrum, Plainfield, IL). Petioles were separated from leaf blades and analyzed for NO_3–N using an ion selective electrode combination (University of Arkansas, 1991), while leaf blades were analyzed for N using the combustion technique (Jones, 2001). To account for alley border effects, 76 cm was cut off each end of the plots using a rotary mower before harvest. The center two rows were harvested with a spindle picker equipped with a sacking unit. The harvested cotton was subsampled and ginning percentage was determined using a 10-saw microgin before being sent to the USDA classing office for high-volume instrumentation (HVI) analysis.

Data were analyzed using general linear models (PROC GLM) and means were separated using Fisher's protected LSD using SAS (SAS Institute, 2001). A significance level of $P \leq 0.10$ was established

Table 1. Effect of N application timing × N application method × N source on cotton lint yield for a high-residue conservation system located in the Tennessee Valley of Alabama, averaged across N rates and years (0-N check = 621 kg lint ha^{-1}).

N timing	Broadcast N method		Banded N method	
	NH_4NO_3	Urea–NH_4NO_3	NH_4NO_3	Urea–NH_4NO_3
	kg lint ha^{-1}			
At-planting	1002†	919	901	1045
Split‡	996	932	899	917

† Compare treatment averaged across years, LSD(0.10) = 55 kg lint ha^{-1}.

‡ 50% at-planting, 50% at first square.

a priori. The model was tested across years in a split-plot design using procedures described by McIntosh (1983), where N treatments served as main plots and years as subplots of each N treatment. Regression equations were established utilizing simple linear regression (PROC REG) for variables containing a significant N rate interaction. Independent variables and interactions significant by year are presented separately by year; other data are averaged across years.

RESULTS AND DISCUSSION

Lint Yield

A three-way N source × N application timing × N application method interaction indicated that AN broadcast at-planting, AN broadcast with split applications, and UAN banded at-planting provided maximum yields (1002, 996, and 1045 kg lint ha^{-1}, respectively; LSD[0.10] = 55 kg lint ha^{-1}), when averaged across N rates and years (Table 1). Lint yields with AN were higher than UAN when broadcast in both split and at-planting applications. When applied in a band at-planting, however, UAN had higher yields than AN (1045 vs. 901 kg lint ha^{-1}, respectively). Source effects can be related to the amount of urea fertilizers touching rye cover crop residue. Urea-containing fertilizers, such as UAN, have high NH_3 volatilization potential due to urease enzyme activity when they are surface applied to residues (Torello and Wehner, 1983). Touchton and Hargrove (1982) reported that banded UAN had higher efficiency than broadcast applications when using urea-containing fertilizers. Ammonium nitrate sources yielded higher when broadcast applied compared with banded applications, since AN is not impacted by urease. Broadcast applications of AN probably supplied more N closer to young cotton plants than when banded ~35 cm (1/3 row width). Supplying N close to the root zone increases early growth (Touchton et al., 1986).

Nitrogen application timing was only important for banded UAN applications, where at-planting applications resulted in higher lint yields than split applications (1045 vs. 917 kg lint ha^{-1}, respectively). Recommending single vs. split N applications is opposite to traditional extension recommendations; however, Howard et al. (2001) reported that splitting UAN (50% at-planting and 50% 6 wk later) resulted in higher cotton yields in only one of 8 yr, while Mullins et al. (2003) saw no difference in splitting applications when using AN, similar to our results.

A N application timing × N application method × N rate × year interaction indicated varying N application rates to reach maximum cotton lint yields (Table 2). Yearly variation was caused by two main effects. Primarily, rainfall dispersion and differences in accumulation of growing degrees caused varying yield responses to the same N treatments (Fig. 1). Another cause of yearly variation was the cumulative effects of additions of the N treatment to the same plot each year coupled with additions of varying yields of high-residue biomass.

In 2000 (the first year in conservation tillage following a history of conventionally tilled cotton), all treatments had linear responses to N rates except split broadcast applications, which had a quadratic response, where 112 kg N ha^{-1} provided maximum yield. A rate of 112 kg N ha^{-1} is 67% higher than the mean recommended extension rate of 67 kg N ha^{-1}, while linear responses still had a yield response with 169% of the mean recommended rate (180 kg N ha^{-1}) (Adams and Mitchell, 2000). Split broadcast N treatments had lower N requirements but yielded 102 and 120 kg lint ha^{-1} less than N treatments applied broadcast at-planting and banded at-planting, respectively. Indicating lower fertilizer efficiency, split banded treat-

Table 2. Regression equations and economic returns for N application timing × N application method × N rate × year interaction on cotton lint yield for a high-residue conservation system located in the Tennessee Valley of Alabama, averaged across N sources.

N timing	Broadcast N method						Banded N method					
	Equation†	R^2	$P > F$	Peak‡	Yield§	Economic return¶	Equation	R^2	$P > F$	Peak	Yield	Economic return
				kg N ha^{-1}	kg lint ha^{-1}	US$				kg N ha^{-1}	kg lint ha^{-1}	US$
						2000						
At-planting	$660 + 1.97N$	0.62	0.0072	180	1015	2.81	$666 + 2.04N$	0.64	0.0052	180	1033	2.91
Split††	$625 + 5.16N - 0.023N^2$	0.79	0.0043	112	913	3.67	$662 + 1.02N$	0.33	0.0827	180	846	1.46
						2001						
At-planting	$669 + 7.49N - 0.031N^2$	0.85	0.0013	121	1121	5.33	$702 + 2.65N$	0.61	0.0074	180	1179	3.78
Split	$686 + 7.83N - 0.031N^2$	0.85	0.0014	126	1181	5.61	$638 + 8.10N - 0.033N^2$	0.96	<0.0001	123	1135	5.77
						2002						
At-planting	$659 + 2.30N$	0.86	0.0001	180	1073	3.28	$679 + 2.69N$	0.59	0.0094	180	1163	3.84
Split	$640 + 6.22N - 0.027N^2$	0.75	0.0082	115	998	4.44	$616 + 5.76N - 0.025N^2$	0.90	0.0003	115	947	4.11

† Highest order that was significant.

‡ Peak N rate for quadratic equations and highest N rate applied for linear equations.

§ Optimum yield at peak N rate.

¶ US$ lint value/US$ N cost = [(Yield – 0-N check)/Peak N rate](US$1.17 kg^{-1} lint/US$0.82 kg^{-1} N).

†† 50% at-planting, 50% at first square.

ments had half the yield response per kilogram of N of broadcast and banded at-planting applications (1.02, 1.97, and 2.04, respectively).

Quadratic responses were observed in 2001 with the exception of banded at-planting applications, which had a linear response (Table 2). Quadratic optimum fertilizer projections were 81 to 88% (121–126 kg total N ha^{-1}) more than mean recommended rates. Optimum N rate projections for 2002 were similar to 2000, with split broadcast applications requiring 72% (115 kg total N ha^{-1}) more N than mean extension recommendations while both at-planting treatments had linear N rate responses.

In all 3 yr, broadcast split applications had the highest lint production/N applied ratios (8.2, 9.4, and 8.7 kg lint kg^{-1} N applied for 2000, 2001, and 2002, respectively). Similarly, broadcast split applications had the highest economic return (price of cotton lint produced per N cost) in 2000 and 2002, while banded split applications were highest in 2001 (Table 2), based on 10-yr average prices of cotton lint and N (US\$0.82 kg^{-1} N and US\$1.17 kg^{-1} lint) (USDA Economic Research Service, 2007). Treatments with the lowest lint produced per kilogram N applied and the lowest economic return were split banded, at-planting banded, and at-planting broadcast for 2000, 2001, and 2002, respectively (Table 2). Generally, N rate recommendations agree with previous research stating that split N applications have higher efficiency and higher economic returns than at-planting applications (Ebelhar et al., 1996; Mitchell, 1996) and >40% more N than conventional N rate recommendations may be necessary with these treatments for high-residue cover crop systems to reach the highest lint yield/N applied ratios (Hutchinson et al., 1995; Harris, 2002).

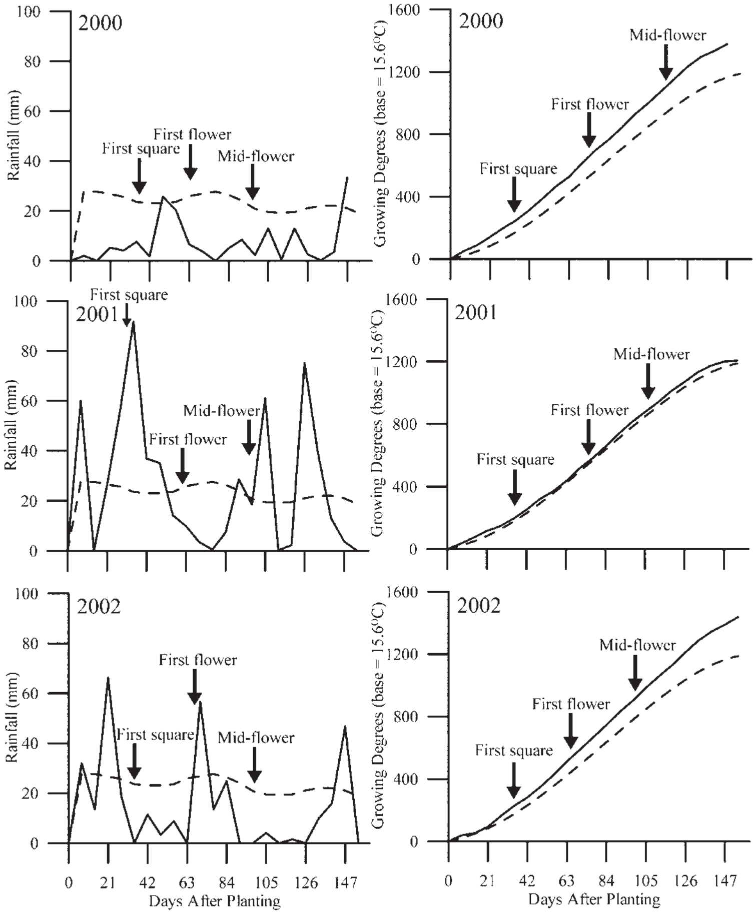

Fig. 1. Precipitation and cumulative growing degree heat unit (base = 15.6°C) weather patterns from planting of cotton crop to harvest for the Tennessee Valley of Alabama in 2000, 2001, and 2002: yearly pattern (solid line) and 30-yr average (broken line).

Lint Quality

Lint quality was not greatly impacted by N variables, similar to research conducted by Mullins et al. (2003). All treatments had micronaire values in the premium (37–42 units) or base range (43–49 units) of the scale in relationship to market value, with a mean value of 45 units (USDA, 1999). Fiber length and uniformity from HVI samples were also not affected by treatments (27 mm and 83%, respectively). Fiber strength readings were impacted, as at-planting treatments had weaker lint than treatments applied in split applications (261 vs. 264 kN m kg^{-1}, respectively; LSD[0.10] = 1.8 kN m kg^{-1}), averaged across N application timing, N application method, N rates, and years, although all values were within the average range (255–275 kN m kg^{-1}) (USDA, 1999).

Cotton Nitrogen Status Measurements at Mid-flower

Leaf N concentration, petiole NO_3 concentration, and chlorophyll meter measurements were used to indicate N deficiency in cotton plants at mid-bloom, when cotton plants have the highest N requirements (Mullins and Burmester, 1990; Mitchell, 1996). Prediction of possible lint yield was hampered by yearly experimental variation even though statistically significant models were established (Table 3). For instance, petiole NO_3 concentrations that resulted in the highest yields in 2000 and 2001 were lower than optimum concentrations in 2002 (3031, 2499, and 8785 mg NO_3–N kg^{-1}, respectively),

Table 3. Regression of lint yield on mid-flower leaf N, petiole NO_3 content, and chlorophyll meter reading N sufficiency tests for 3 yr during a high-residue conservation system study located in the Tennessee Valley of Alabama, averaged across all N treatments.

Year	Equation†	R^2	N peak‡
			kg N ha^{-1}
	Leaf N (g N kg^{-1} tissue) × lint yield		
2000	NS§	NS	NS
2001	$-5009 + 348.7N - 4.956N^2$	0.82	35.2
2002	$325.6 + 13.12N$	0.19	52.0
	Petiole nitrate (mg NO_3–N kg^{-1} tissue) × lint yield		
2000	$375.96 + 0.4243N - 0.00007N^2$	0.62	3031
2001	$473.61 + 0.5998N - 0.00012N^2$	0.48	2499
2002	$562.70 + 0.1051N - 0.000006N^2$	0.56	8758
	Chlorophyll meter reading × lint yield		
2000	$-802.1 + 35.94N$	0.44	48.6
2001	$-1346.0 + 57.00N$	0.57	45.8
2002	$-16057 + 742.79N - 8.1004N^2$	0.54	45.8

† Highest order that was significant.

‡ Concentration that gives highest lint yield in this study. Value is peak for quadratic models and highest treatment mean for linear model.

§ No significant model was found.

Table 4. Effect of N application timing × N application method × year on cotton leaf N concentrations at mid-flower for a high-residue conservation system located in the Tennessee Valley of Alabama, averaged across N source and N rate (0-N check = 31.6, 26.5, and 44.3 g N kg^{-1} for 2000, 2001, and 2002, respectively).

N timing	N application method	
	Broadcast	Banded
	g N kg^{-1}	
	2000	
At-planting	38.3†	39.1
Split‡	40.2	38.5
	2001	
At-planting	32.8	32.5
Split	32.7	32.5
	2002	
At-planting	43.2	40.7
Split	44.3	45.6

† Compare same treatment in different years, LSD(0.10) = 2.1 g N kg^{-1}; compare any treatment within any year, LSD(0.10) = 2.1 g N kg^{-1}.

‡ 50% at-planting, 50% at first square.

making establishment of deficiency thresholds impossible. Therefore, the remainder of this discussion will focus on long-term deficiency thresholds established by previous research. Nitrogen status measurement data were beneficial for establishing soil N availability and the resulting plant assimilation from various treatments at mid-bloom.

Numerous studies have established that cotton plants with 30.0 to 43.0 g N kg^{-1} in their uppermost fully expanded leaf at mid-bloom have sufficient N available and yield is not limited (Mills and Jones, 1996). In our study, leaf N at mid-flower was higher with AN than UAN (39.2 vs. 37.4 g N kg^{-1}, LSD[0.10] = 0.9 g N kg^{-1}), averaged across N application timing, N application method, N rates, and years. Higher leaf concentrations suggest that AN treatments had more available soil N during the mid-flower growth stage than sources containing urea, possibly due to volatilization due to urease from crop residue. A N application timing × N application method × year interaction indicated that leaf N concentrations were lower in 2001 than 2000 or 2002 (Table 4), averaged across N source and N rate. We suspect that dry weather coupled with excess growing degrees (Fig. 1) led to lower cotton plant residues in 2000 and 2002, which may have contributed to higher N concentrations (dilution effect). All fertilizer treatments were within or higher than accepted leaf N concentrations at mid-bloom; however, split broadcast treatments in 2000 were higher than at-planting treatments and split banded treatments in 2002 were higher than at-planting banded treatments (Table 4). Our research agreed with other research in the southern United States that excessive leaf N concentrations from overapplication of N did not negatively impact cotton lint yield, possibly due to the plant's ability to increase vegetative biomass (Bell et al., 2003).

Table 5. Effect of N source × N application method × year on cotton petiole NO$_3$ concentrations at mid-flower for a high-residue conservation system located in the Tennessee Valley of Alabama, averaged across N application timing and N rate (0-N check = 380, 329, and 1081 mg NO$_3$–N kg^{-1} for 2000, 2001, and 2002, respectively).

N source	N application method	
	Broadcast	Banded
	mg NO$_3$–N kg^{-1}	
	2000	
NH_4NO_3	1833†	1863
Urea–NH_4NO_3	1494	1282
	2001	
NH_4NO_3	1826	1527
Urea–NH_4NO_3	1195	1265
	2002	
NH_4NO_3	7583	5863
Urea–NH_4NO_3	5534	5908

† Compare same treatment in different years, LSD(0.10) = 456 NO$_3$–N kg^{-1}; compare any treatment within any year, LSD(0.10) = 480 NO$_3$–N kg^{-1}.

A petiole NO$_3$–N source × N application method × year interaction indicated that 2002 petiole NO$_3$ concentrations were higher than 2000 or 2001 (Table 5), averaged across N application timing and N rate. We believe petiole NO$_3$ concentrations were impacted by weather in all 3 yr (Fig. 1), as leaf N at mid-bloom showed sufficient plant N status while petiole NO$_3$ concentrations indicated deficient N status (<5000 mg NO$_3$–N kg^{-1}) for all treatments in 2000 and 2001 (Campbell, 2000). Generally, AN treatments had higher leaf N concentrations than UAN treatments (Table 5), suggesting a higher concentration of soil N available for plant uptake. A N source × N application timing × N rate × year interaction was significant; however, variation was too high to provide significant regression equations. High variation corresponds to field studies conducted by Touchton et al. (1981), which concluded that Alabama's growing conditions are too variable to make petiole NO$_3$ testing a practical method for predicting the N status of unirrigated cotton.

Chlorophyll meter readings were similar to the responses observed with tissue leaf N but did not correlate well with lint yield and will not be discussed in detail. Generally, broadcast AN and banded UAN resulted in the highest chlorophyll meter readings and readings increased linearly as N rates increased (data not shown).

Cover Crop Biomass

Rye biomass varied with year and cotton fertilizer treatments. There were no N treatments established before cover crop burn-down in 2000, but random samples across replications averaged 4450 kg residue ha^{-1}. Rye biomass totaled 6504 kg ha^{-1} in 2001 and 2240 kg ha^{-1} in 2002 (LSD[0.10] = 227 kg biomass ha^{-1}), averaged across cotton N treatments. Biomass in 2002 was probably lower than previous years due to low concentrations of soil available N. A companion study to this project indicated similar biomass production on unfertilized rye treatments while 34 kg N ha^{-1} applied to the cover crop produced 4480 kg rye biomass ha^{-1}, similar to 2000 and 2001 yields in this study (Reiter, 2003). High rye residue production without fertilization was evidence that N was assimilated into biomass that might otherwise have been lost from the agronomic system over winter by leaching or denitrification. High cotton yields coupled with ample rainfall (Fig. 1) in 2001 depleted soil N that would have been available for the 2002 rye catch cover crop. Generally, as cotton N rate increased, rye biomass production also increased the following winter, averaged across other cotton fertilizer treatments and years (Table

6). Beneficial use of residual cotton fertilizer as well as mineralization of organic N sources probably provided the necessary N for biomass production.

Carbon/nitrogen ratios for rye residue at termination were significantly affected by cotton N source × N rate (Table 6), averaged across other N treatments and years. Ammonium nitrate C/N ratios were not impacted by cotton N rate, while UAN had the lowest C/N ratio when 180 kg N ha^{-1} was applied. As C/N ratios decrease with added cotton N fertilizer, organic N will mineralize at faster rates and higher concentrations of N from cover crops will be available for cotton crop use in the future. A study by Wagger (1989) had similar conclusions and indicated that rye with lower C/N ratios mineralized more biomass N that was then available for crop uptake.

CONCLUSIONS

Leaf N, chlorophyll meter readings. and petiole NO_3 status did not correlate well with lint yields during these immoderate growing seasons, which included 2 yr of drought and 1 yr 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, N application timing, and N application method. The data suggest, however, that generally 67 to 169% more N (45–113 kg N ha^{-1}) than the mean conventional N rate recommendations may initially be needed for cotton grown in high-residue (>4500 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 with time in high-residue systems as soil C and N pools reach new equilibria. At-planting applications offered superior lint yield compared with split applications; however, split applications generally had more lint produced per kilogram of N applied and a higher economic return than at-planting applications and had higher plant N status measurements. Ammonium nitrate applications resulted in greater yields when broadcast, while the efficiency of UAN applications were increased when banded. For producers wishing to have maximum cotton yields in the initial stages of high-residue cover crop farming systems, we recommend applying 180 kg N ha^{-1} in banded applications using UAN at-planting. Alternatively, if N efficiency and return of lint per kilogram of applied N is the main goal, we recommend applying 126 kg N ha^{-1} as AN in broadcast applications split between planting and first match head square.

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Table 6. Cotton N rate (45, 90, 135, and 180 kg N ha^{-1}) main effect, averaged across N source and years, on the following rye cover crop (0-N check = 4146 kg biomass ha^{-1}) and effect of cotton N source × N rate, averaged across years, on biomass C/N ratio (0-N check = 22.9) for a high-residue conservation system located in the Tennessee Valley of Alabama.

Parameter	45 kg N ha^{-1}	90 kg N ha^{-1}	135 kg N ha^{-1}	180 kg N ha^{-1}
		Cotton N rate effect†		
Biomass produced, kg ha^{-1}	3893	4015	4447	4978
		C/N ratio‡		
NH_4NO_3	24.8	23.0	23.4	22.9
Urea–NH_4NO_3	23.3	25.6	22.3	20.0

† Compare treatment averaged across years, LSD(0.10) = 443 kg biomass ha^{-1}.

‡ Compare treatment averaged across years, LSD(0.10) = 2.2.

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