Lint Yield and Fiber Quality of Cotton Fertilized with Broiler Litter

H. Tewolde,* K. R. Sistani, D. E. Rowe, A. Adeli, and J. R. Johnson

ABSTRACT

Poultry litter is generated in large quantities in the same southeastern U.S. states where cotton (*Gossypium hirsutum* L.) is a dominant field crop, but is rarely used as a primary cotton fertilizer partly because of lack of adequate management recommendations. This research was conducted to determine adequate rates of broiler litter and whether supplementation with inorganic N would be necessary for optimum cotton lint yield and fiber quality. The research was conducted from 2002 to 2004 on two commercial farms representing conventional-till (CT) and no-till (NT) systems. The treatments consisted of an unfertilized control, a farm standard (STD) fertilized with inorganic fertilizers, and broiler litter of 2.2, 4.5, and 6.7 Mg ha^{-1} in an incomplete factorial combination with 0, 34, or 67 kg ha^{-1} N as urea–ammonium nitrate solution (UAN). Litter without supplemental UAN–N increased yield by 23 to 110 kg lint ha^{-1} for every 1.0 Mg ha^{-1} litter under both CT and NT. The often-recommended litter rate of 4.5 Mg ha^{-1} was not adequate to increase yield to be equivalent to that of the STD that received 101 to 135 kg ha^{-1} as UAN. It was necessary to supplement this or the other litter rates with 34 or 67 kg ha^{-1} UAN–N to support yield equal to or greater than the yield of the STD. The most consistently well-performing treatment under both tillage systems in all years was the 4.5 Mg ha^{-1} litter supplemented with 67 kg ha^{-1} UAN–N. Lint yield was highly correlated (r^2 = 0.83–0.97) with applied total plant-available N (N_{TPA}) under both systems. Fiber quality, fiber length and micronaire in particular, also responded to N_{TPA}, but the responses were smaller than lint yield. Litter when adequately supplemented with UAN–N did not adversely affect fiber quality. These results show broiler litter as much as 4.5 Mg ha^{-1} should be supplemented with inorganic N fertilizers when used as a primary cotton fertilizer and when the expected yield is ≈1700 kg ha^{-1} under CT and ≈1500 kg ha^{-1} under NT.

Poultry litter, which is a mixture of manure, bedding material, feathers, and spilled feed and water, is rich in N, P, K, and other essential plant nutrients but is often viewed as a waste. The vast majority of the litter generated by the U.S. poultry industry is usually land-applied within short distances of poultry production houses on pastures and hayfields as a fertilizer. This practice is likely to be regulated and restricted because repeated litter application to the same soil for an extended period usually leads to environmentally unacceptable overload of soil nutrients, particularly P. Some poultry production regions are considering alternatives including application to new sites such as forest (Lynch and Tjaden, 2004).

Cotton production in the southeastern USA can ease the enormous burden placed on pastures nearby poultry houses because cotton is one of the most dominant field crops in the same states that also produce the majority of U.S. poultry. In 2003, nearly 81% of the land area planted to cotton in the USA was located in six states—Georgia, Arkansas, Alabama, Mississippi, North Carolina, and Texas (USDA-NASS, 2004a)—which also produced >65% of the broiler chickens (USDA-NASS, 2004b). These six states in 2002 generated ≈8.2×10^9 kg litter from broiler chickens alone containing ≈2.45×10^8 kg N assuming each bird generated 1.46 kg litter with 30 g N kg^{-1} litter (Sharpe et al., 2004; van der Watt et al., 1994). In 2003, these six states applied nearly 3.20×10^8 kg N, 1.45×10^8 kg phosphate, and 1.86×10^8 kg potash to cotton (USDA-NASS, 2004a), presumably all from conventional fertilizers. This implies that cotton alone has the capacity to utilize a large fraction of the litter generated in the region.

Yet, poultry litter is used very little as a primary cotton fertilizer in the same region where both poultry and cotton are dominant agricultural enterprises. This in part is due to the lack of well-established recommendations for poultry litter use in cotton production under different tillage methods, cropping systems, and soil types. When used, the recommended litter application rate for cotton is 4.5 Mg ha^{-1}, a rate which appears to be largely convenience-based rather than research-based but may have also been chosen to lessen the buildup of soil P if repeatedly applied. Broiler litter as low as 2.2 Mg ha^{-1} may be adequate when applied repeatedly for as many as 20 yr under certain production conditions (Sistani et al., 2004), but such low rates without supplemental N fertilization to fields with no history of litter application is probably too low for many cotton production systems in the southeastern USA (Millhollon et al., 2001; Danforth et al., 1993).

The lack of adequate recommendations for using poultry litter as a cotton fertilizer may in part be due to the difficulty and complexity associated with managing litter as a fertilizer. Litter supplies nearly all essential plant nutrients (Tewolde et al., 2005a, 2005b) of which N is the most important but also the most difficult to manage because it exists in both organic and inorganic forms. The organic fraction of litter-N becomes plant available only after mineralization by microbial action. At the time of litter application, it is difficult to predict how much of this organic N becomes plant available during the grow-

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Abbreviations: +b, yellowness index; CT, conventional-till; L_0N_0, $L_{2.2}N_0$, $L_{2.2}N_{34}$, $L_{2.2}N_{67}$, $L_{4.5}N^0$, $L_{4.5}N_{34}$, $L_{4.5}N_{67}$, $L_{6.7}N_0$, $L_{6.7}N^{34}$, L = litter, N = N as urea–ammonium nitrate and a subscript represents applied litter (Mg ha^{-1}) or N (kg ha^{-1}); L_L, linear effect of litter; N_L, linear effect of N as urea–ammonium nitrate; NT, no-till; N_{TPA}, applied total plant-available N; Rd, reflectance; STD, farm standard fertilization; UAN, urea–ammonium nitrate solution; UAN–N, UAN–nitrogen; UR, length uniformity ratio.

ing season. Equally difficult is predicting how much of the litter-N that is vulnerable to volatilization is actually lost during handling and application and before incorporation. Furthermore, litter as a fertilizer is often improperly managed not only because of its complex nature but also because the undertaking of litter management as a fertilizer is often underappreciated and has a low priority next to other farming operations.

The development of best management practices for litter fertilization has further been complicated by considerable changes in cotton tillage practices from conventional-till (CT) to no-till (NT). As much as 38% of the cotton production in the Mississippi Delta is produced under NT (Martin and Cooke, 2004). Use of poultry litter under NT implies litter is applied on the surface and not incorporated, a practice that exposes the litter and its nutrients to risks of loss in runoff water, volatilization, and wind erosion. Vories et al. (2001) found nutrients from litter applied to cotton could be lost in runoff water particularly shortly after application when the incorporation is not effective. The magnitude of nutrient loss due to runoff or volatilization and whether surface-applied unincorporated litter is an effective application method under NT or reduced-till cotton production systems is not well understood. Nyakatawa et al. (2001) reported surface application of poultry litter to be beneficial for soil moisture conservation but did not compare the fate of nutrients of incorporated and nonincorporated litter.

The objective of this research was to determine adequate rates of broiler litter and whether supplementation with inorganic N would be necessary for optimum lint yield and fiber quality of cotton. The research was part of a larger program with an overall goal of developing best management practices for using poultry litter as a primary fertilizer for optimum cotton production in the southeastern USA.

MATERIALS AND METHODS

The research was conducted on two commercial farms representing CT at Cruger (33.30° N, 90.23° W, 32.9 m altitude) and NT at Coffeeville (33.97° N, 89.68° W, 71.2 m altitiude), MS, in 2002, 2003, and 2004. The soil under the CT was a Dubbs silt loam (fine-silty, mixed, active, thermic Typic Hapludalfs) and the soil under the NT was an Ariel silt loam (coarse-silty, mixed, thermic Fluventic Dystrochrepts). Cotton was grown continuously for 25 yr under the CT at Cruger and for 4 yr under the NT at Coffeeville before initiating this research. At each location, response of cotton to fresh broiler litter rates of 2.2, 4.5, and 6.7 Mg ha^{-1} was tested in an incomplete-factorial combination with 0, 34, or 67 kg ha^{-1} N as UAN. The combinations included $L_{2.2}N_0$, $L_{2.2}N_{34}$, $L_{2.2}N_{67}$, $L_{4.5}N_0$, $L_{4.5}N_{34}$, $L_{4.5}N_{67}$, $L_{6.7}N_0$, and $L_{6.7}N_{34}$ where L = litter, N = UAN–N, and a subscript represents litter (Mg ha^{-1}) or UAN–N (kg ha^{-1}) rate. The supplemental UAN–N rates in 2004 under the CT were 0, 67, and 135 kg N ha^{-1}. An unfertilized control (L_0N_0) and a farm standard fertilization (STD) were also included as treatments to make a total of 10 treatments. Nitrogen, P, and K fertilizers at both locations were applied to the STD at the same rate as adjacent fields as practiced by the respective farm (Table 1). The STD received no fertilizers other than inorganic N, P, and K fertilizers in any of the 3 yr.

The 10 treatment combinations were tested in a randomized complete block design with four replications. Each plot consisted of four 119-m-long and 1.02-m-wide rows under the CT and eight 73-m long and 0.97-m wide rows under the NT. Each plot received the same treatment each of the 3 yr under each tillage system.

Litter was broadcast-applied within 10 d before planting under the CT and within 25 d before or after planting under the NT (Table 2). The application was accomplished using a commercial fertilizer spreader equipped with ground speed sensing radar, electronic scale (±4.5 kg resolution), and rate-control computer system (Barrons & Brothers, Gainsville, GA). The amount of litter applied to each plot was recorded as a difference between scale readings at the beginning and end of spreading to a specific plot. Applied litter was soil-incorporated within 1 d of application to a depth of approximately 0.1 m using a rolling cultivator under the CT at Cruger but was left on the surface without incorporation under the NT at Coffeeville. The litter used for both locations was obtained from a commercial broiler chicken producer in southern Mississippi in 2002 and from another broiler chicken producer in central Mississippi in 2003 and 2004. Chemical analysis of the litter applied to each location is shown in Table 2. The litter as applied to the plots was fresh or briefly stacked, not composted, on concrete structures on the poultry farm.

Each year, UAN solution (32% N) was applied between square and first flower stage as a sidedress using a commercial liquid fertilizer applicator equipped with coulters that opened slits about 0.15 to 0.20 m away from the row center. The UAN solution was injected into the slit to a depth of approximately 0.10 m. Phosphorus as triple superphosphate (0–46–0) and K as KCl (0–0–60) were applied to the STD as a broadcast by hand before planting.

Cotton was planted and managed according to each farm's standard practice including row spacing, cultivars, tillage, and

Table 1. Crop management and chemical properties of soil taken before planting from the farm standard treatment to a depth of 0 to 0.15 m under CT (Cruger, MS) and NT (Coffeeville, MS) systems where broiler litter was tested as a fertilizer for cotton.

Tillage	Row spacing	Date planted	Date defoliated	Cultivar	Soil pH	Soil organic matter	Soil P†	Soil K†	Applied N‡	Applied P‡	Applied K‡	Date litter applied	Date N applied
	m					%	mg kg^{-1}		kg ha^{-1}				
Conventional-till	1.02	19 Apr. 2002	3 Sept. 2002	ST BXN 49B	5.6	1.53	40.4	233	135	0	140	16 Apr. 2002	23 May 2002
		16 Apr. 2003	5 Sept. 2003	ST 4892 BG/RR	6.0	1.57	63.2	264	135	20	98	15 Apr. 2003	23 June 2003
		19 Apr. 2004	13 Sept. 2004	ST 4892 BG/RR	5.9	1.66	78.6	295	135	0	93	9 Apr. 2004	8 June 2004
No-Till	0.97	21 May 2002	4 Oct. 2002	SG 501 BG/RR	5.7	1.53	8.1	49	101	29	56	29 Apr. 2002	19 June 2002
		2 May 2003	30 Sept. 2003	DP 555 BG/RR	6.3	1.50	22.8	48	118	20	75	27 May 2003	24 June 2003
		28 Apr. 2004	18 Oct. 2004	DP 555 BG/RR	6.3	1.58	28.7	58	118	0	112	7 May 2004	9 June 2004

† Phosphorus and K concentrations were determined based on Mehlich-3 extraction and analyzed by inductively coupled argon plasma spectrophotometer (ICP).
‡ Rates of inorganic N, P, and K applied to the farm standard treatment.

Table 2. Chemical property of broiler litter used for research under conventional (Cruger, MS) and NT (Coffeeville, MS) systems between 2002 and 2004.

Tillage	Year	moisture	C	N	P	K	Ca	Mg	Fe	Cu	Mn	Zn
		%		g kg^{-1}					mg kg^{-1}			
Conventional-till	2002	34.2	25.1	23.6	16.9	24.8	23.6	4.55	996	276	270	294
	2003	39.1	23.2	26.3	10.3	25.0	13.0	5.10	660	606	391	322
	2004	26.1	29.6	26.0	11.8	28.9	17.4	5.71	783	612	436	363
No-till	2002	22.9	25.9	33.5	18.9	30.7	24.7	6.80	1150	751	698	533
	2003	28.0	23.7	28.1	12.7	29.2	17.1	5.80	997	668	479	373
	2004	26.5	24.8	31.3	12.8	29.1	17.1	5.75	768	627	463	371

pest control (Table 1). At Cruger, the plots were prepared each year in October by subsoiling to a depth of ≈0.36 m and hipping the previous year's bed without breaking it. This was followed by rehipping in March. The final operation was applying and incorporating the litter, firming and smoothing the bed, and planting all of which took place within 1 d in April (Table 1). Plots at Coffeeville were not cultivated during the year but were overseeded with wheat (*Triticum aestivum* L.) as a cover crop by surface broadcasting the seed immediately before defoliating the previous crop. The wheat stand was killed with glyphosate [*N*-(phosphonomethyl) glycine] ≈10 d before planting each spring and the cotton was planted with a NT planter. The average end-of-season plant stand was ≈11 plants m^{-2} at Cruger and ≈10 plants m^{-2} at Coffeeville.

Lint yield was determined by picking the entire length of the middle two or four rows of each plot. Cotton in 2003 and 2004 was picked with a two-row picker retrofitted with a self-weighing (0.02 kg resolution) basket with gates at the bottom that allowed the dumping and transfer of weighed cotton to the main holding basket of the picker. In 2002, the cotton was picked with a one-row picker that also was equipped with a self-weighing basket. Approximately 1.0-kg samples were taken from each plot to determine the lint turnout. The samples were ginned on a bench-top 10-saw gin and lint turnout was calculated as follows: Lint Turnout = 100 × lint weight/(weight of lint + seed + trash). This lint turnout was used to convert the seed cotton yield to lint yield. Subsamples from the ginned samples were used to measure fiber quality including fiber length, strength, micronaire, elongation, and length uniformity using high volume instrumentation (StarLab, Knoxville, TN).

Daily maximum and minimum air temperatures and rainfall were recorded at each location with a self-recording weather station. Temperature and rain were recorded every 1 h and the maximum and minimum temperatures within a day extracted from this record. Missing data due to instrument failure, particularly at Cruger, were filled with data from a standard weather station within 16 km of each location.

Litter and supplemental N effects were tested by subjecting the data to analysis of variance using the MIXED model analysis of SAS (Littell et al., 2002). Preliminary analysis of variance was performed for a randomized complete block design with a factorial treatment structure for litter and N factors. Additional analysis was performed using a trend to describe the litter and UAN–N treatment structure as a response surface model where the full model had three slope parameters that included litter linear (L_L), UAN–N linear (N_L), and their interactions ($L_L \times N_L$). The significance of the linear effects of litter (L_L) and UAN–N (N_L) were tested by omitting the $L_L \times N_L$ interaction term from the full model when the interaction was not significant. The association between lint yield and lint turnout with N_{TPA} was tested by regression analysis up to the third degree. Applied total plant-available N was estimated by summing litter-N and UAN–N assuming 50% of the total litter N and 100% of the UAN becomes plant available during the cotton-growing season. All declared differences are significant at $P \leq 0.05$ unless stated otherwise.

RESULTS AND DISCUSSION

Weather

The weather pattern within each season was similar at both locations though Coffeeville had slightly cooler minimum and maximum temperatures than Cruger. Minimum and maximum temperatures averaged across July and August in 2002 were 21.8 and 33.5°C under the CT at Cruger, and 21.4 and 33.0°C under the NT at Coffeeville. Minimum temperature averaged across May, June, July, and August was 20.4°C and 20.1°C under the CT and 19.0 and 19.4°C under the NT in 2003 and 2004, respectively. The corresponding maximum temperature was 31.5 and 30.8°C under the CT, and 30.8 and 30.7°C under the NT in 2003 and 2004, respectively.

The NT plots at Coffeeville received more rain than the CT plots at Cruger in the first 2 yr. Rain summed across May, June, July and August under the NT was 589, 596, and 717 mm in 2002, 2003, and 2004 respectively compared with 313, 421, and 726 mm under the CT. The CT cotton at Cruger received supplemental irrigation as needed using an overhead center pivot as part of the farm's irrigation system. The NT cotton at Coffeeville was not irrigated.

Lint Yield and Turnout

Conventional-Till

The unfertilized control (L_0N_0) under the CT produced 1478, 928, and 728 kg ha^{-1} lint in 2002, 2003, and 2004, respectively (Table 3). This large yield decline of the L_0N_0 treatment across years should largely be due to N removal in the harvested crop without replacement. Litter without supplemental inorganic N increased lint yield over the untreated control in each of the 3 yr. The increase was proportional to the rate of litter up to the maximum rate of 6.7 Mg ha^{-1}. Fitting a first-order response surface model showed a linear yield response to increasing litter rate in each of the 3 yr. Lint yield increased by 23.2, 85.0, and 100.0 kg ha^{-1} for every 1.0 Mg ha^{-1} applied litter in 2002, 2003, and 2004 respectively when yield was regressed on applied litter without supplemental UAN–N. The lack of significant interaction between the L_L and N_L terms in 2002 and 2003 shows that yield linearly increased with increasing litter application at all levels of supplemental UAN–N. The

Table 3. Lint yield and fiber quality of cotton grown with broiler litter ± supplemental urea ammonium nitrate solution (UAN) under CT (Cruger, MS) during 2002 to 2004.

UAN–N	Broiler litter	Lint yield	Lint turnout	Fiber length	UR	Fiber strength	Elongation	Micronaire	Rd†	+b‡
kg ha^{-1}	Mg ha^{-1}	kg ha^{-1}	%	mm	%	kN m kg^{-1}	%			
				2002 (Cultivar: ST BXN 49B)						
0	0	1478	38.9	28.5	82.7	265	7.65	4.95	78.1	8.3
	2.2	1567	39.5	28.8	82.9	267	7.75	4.80	77.8	7.8
	4.5	1595	39.1	27.9	83.0	271	7.63	4.80	77.8	8.6
	6.7	1643	38.4	29.1	83.5	268	7.80	4.78	77.5	7.2
34	2.2	1617	38.9	29.0	83.0	272	7.80	4.83	78.6	8.4
	4.5	1701	38.7	28.8	82.8	269	7.80	4.85	77.7	8.5
	6.7	1693	38.1	28.5	83.0	268	7.85	4.93	76.8	8.3
67	2.2	1678	38.8	28.8	83.4	270	8.05	4.93	76.6	7.6
	4.5	1718	38.5	28.6	82.9	275	7.95	4.88	78.0	7.3
135	0	1670	38.1	28.5	83.0	264	7.90	4.93	77.8	7.1
Avg.		1636	38.7	28.7	83.0	269	7.82	4.87	77.7	7.9
P > *F*	L_L§	0.0012	0.0655	0.7054	0.5347	0.8289	0.7909	0.1833	0.5994	0.7930
	N_L§	0.0002	0.0145	0.7481	0.6494	0.8029	0.1070	0.8688	0.6526	0.1990
	$L_L \times N_L$	0.4021	0.5867	0.6465	0.5431	0.3465	0.3106	0.2836	0.8826	0.6576
				2003 (Cultivar: ST4892 BG/RR)						
0	0	928	44.7	27.0	82.8	261	8.15	5.13	62.1	7.5
	2.2	1120	44.6	26.9	82.4	277	8.55	5.18	62.6	8.1
	4.5	1355	44.4	26.9	82.2	266	8.40	5.15	62.5	7.5
	6.7	1484	43.4	27.2	82.7	259	7.93	4.88	60.1	7.6
34	2.2	1446	44.0	27.3	82.8	257	8.25	4.95	62.6	7.5
	4.5	1636	44.0	27.5	82.5	259	8.10	4.98	60.7	7.9
	6.7	1670	43.0	27.5	82.1	256	8.00	4.78	62.6	7.8
67	2.2	1667	43.3	27.6	82.8	256	7.85	4.88	61.5	7.6
	4.5	1725	43.1	28.1	82.8	261	8.10	4.90	61.6	7.4
135	0	1771	43.2	27.4	82.8	258	8.05	5.03	60.7	7.7
Avg.		1480	43.7	27.4	82.6	261	8.14	4.97	61.6	7.7
P > *F*	L_L	0.0018	0.0033	0.9069	0.3775	0.7475	0.4905	0.1021	0.3192	0.7593
	N_L	0.0002	0.0002	0.0710	0.6239	0.3689	0.2545	0.1901	0.1908	0.9092
	$L_L \times N_L$	0.4616	0.4857	0.0013	0.8263	0.6036	0.7719	0.2397	0.3193	0.6685
				2004 (Cultivar: ST4892 BG/RR)						
0	0	728	42.7	26.9	82.6	257	7.68	5.53	68.0	8.4
	2.2	1045	42.6	26.9	82.9	265	8.00	5.28	66.5	8.6
	4.5	1198	41.8	27.7	82.9	260	7.90	5.23	68.5	8.5
	6.7	1424	41.5	27.5	83.2	262	8.05	5.28	66.0	8.9
67	2.2	1413	41.0	27.8	83.4	261	7.90	5.28	68.0	8.9
	4.5	1628	41.3	27.8	83.6	266	8.25	5.35	67.0	8.7
	6.7	1566	41.0	27.9	83.3	263	8.10	5.25	65.4	8.9
135	0	1601	41.1	28.0	83.6	267	8.10	5.18	65.9	9.2
	2.2	1605	41.0	28.3	83.7	268	8.13	5.25	67.4	8.9
	4.5	1574	40.2	27.9	83.4	270	8.15	5.05	67.8	9.1
Avg.		1378	41.3	27.8	83.3	264	8.06	5.24	66.9	8.8
P > *F*	L_L	0.0015	0.0160	0.0119	0.0908	0.6407	0.1233	0.0925	0.3354	0.0860
	N_L	0.0004	0.0035	0.0013	0.0016	0.1092	0.0816	0.0621	0.3870	0.0016
	$L_L \times N_L$	0.0317	0.9038	0.0658	0.1783	0.9866	0.6067	0.5782	0.3930	0.1983

† Rd = reflectance.
‡ +b = yellowness index.
§ L_L = Litter linear effect, N_L = UAN–N linear effect.

significant $L_L \times N_L$ interaction in 2004 shows that the yield increase (slope) in response to applied litter was greater with no supplemental UAN–N than with 67 or 135 kg ha^{-1} UAN–N. Lint yield in 2004 increased linearly with increasing litter rate when no supplemental UAN–N was applied. There was no yield benefit of applied litter when 135 kg ha^{-1} UAN–N was applied apparently because the 135 kg ha^{-1} UAN–N is an adequate amount for lint yield.

Litter application of 2.2 or 4.5 Mg ha^{-1} without supplemental N was insufficient to produce lint yield equal to the yield of the STD in all 3 yr (Table 3). Litter alone at 4.5 Mg ha^{-1} produced 75, 416, and 403 kg ha^{-1} less lint than the STD in 2002, 2003, and 2004, respectively. Increasing the litter rate to 6.7 Mg ha^{-1} resulted in equivalent lint yield as the STD in 2002 when the soil was not responsive to fertilization. But, this treatment ($L_{6.7}N_0$) produced 287 and 177 kg ha^{-1} less lint than the STD in 2003 and 2004, respectively, suggesting litter as much as 6.7 Mg ha^{-1} may not be adequate for optimum production under the CT.

Supplementing litter with UAN–N was necessary to produce lint yield equivalent to or greater than the yield of the STD (Table 3). Supplementing 4.5 Mg ha^{-1} litter with 67 kg ha^{-1} UAN–N was the best combination, consistently producing essentially the same lint yield as the STD each of the 3 yr. Supplementing the 4.5 Mg ha^{-1} litter with 34 kg ha^{-1} UAN–N produced as much lint yield as the STD in 2002 when the soil was less responsive but produced 135 kg ha^{-1} less lint than the STD in 2003. The $L_{6.7}N_{34}$ treatment also produced as much lint yield as the STD in 2002 but produced 101 kg ha^{-1} less lint than the STD in 2003. Other treatment combinations such as $L_{2.2}N_{34}$ and $L_{2.2}N_{67}$ usually were less effective than $L_{4.5}N_{67}$ and $L_{6.7}N_{34}$. These results suggest 4.5 Mg ha^{-1} litter supplemented with 67 kg ha^{-1} UAN–N may be the most effective treatment combination for lint yield under the CT.

Lint turnout, which is the weight of lint as a percentage of the weight of machine-picked seed cotton, differed greatly across years probably due to cultivar differences. When averaged across treatments, lint turnout was 38.7% in 2002 compared with 43.7% in 2003 and 41.3% in 2004 (Table 3). Turnout was linearly ($P < 0.10$) affected by both litter and UAN–N with no $L_L \times N_L$ interaction (Table 3). Turnout decreased with increasing litter or UAN–N application, although the rate of change was small. The absence of a significant $L_L \times N_L$ interaction suggests that the rate of decrease (slope) in turnout with increasing litter rate is the same at all levels of supplemental UAN–N. In general, treatments that received a combination of the higher rates of litter and UAN–N had the smallest lint turnout. Treatments that received inadequate N such as the low litter rates and the untreated control had the largest turnout. The STD treatment usually had the smallest turnout. These results are similar to other findings that show inverse relationships between lint turnout and rates of applied N in Upland and Pima cotton (*Gossypium barbadense* L.) (Fritschi et al., 2003; Tewolde and Fernandez, 2003).

No-Till

Lint yield of the unfertilized control (L_0N_0) under the NT was 867, 724, and 748 kg ha^{-1} in 2002, 2003, and 2004, respectively (Table 4). As in the CT, litter without supplemental inorganic N under the NT increased lint yield in proportion to the litter rate up to the maximum of 6.7 Mg ha^{-1}. Lint yield under this tillage increased by 54.2, 110.3, and 68.7 kg ha^{-1} for every 1.0 Mg ha^{-1} applied litter in 2002, 2003, and 2004, respectively when yield was regressed on applied litter without supplemen-

Table 4. Lint yield and fiber quality of cotton grown with broiler litter ± supplemental urea ammonium nitrate solution (UAN) under NT (Coffeeville, MS) during 2002 to 2004.

UAN–N	Broiler litter	Lint yield	Lint turnout	Fiber length	UR	Fiber strength	Elongation	Micronaire	Rd†	+b‡
kg ha^{-1}	Mg ha^{-1}	kg ha^{-1}	%	mm	%	kN m kg^{-1}	%			
				2002 (Cultivar: SG 501 BG/RR)						
0	0	867	40.4	26.5	83.2	292	8.63	5.6	71.2	7.4
	2.2	1079	40.4	26.4	83.1	289	8.75	5.5	71.7	5.0
	4.5	1088	40.5	26.5	82.7	297	8.70	5.5	71.5	7.2
	6.7	1269	40.9	26.6	83.1	299	8.62	5.4	71.4	7.1
34	2.2	1143	40.3	26.4	83.5	294	8.68	5.6	72.7	7.1
	4.5	1250	39.9	26.5	83.2	294	8.55	5.4	72.9	6.9
	6.7	1243	40.4	26.5	83.4	283	8.70	5.5	73.0	6.6
67	2.2	1255	39.2	26.5	83.0	295	8.80	5.6	72.5	7.5
	4.5	1393	39.8	27.0	83.5	297	8.60	5.5	72.7	7.9
101	0	1282	39.8	26.7	83.4	292	8.40	5.4	71.9	7.7
Avg.		1187	40.2	26.6	83.2	293	8.64	5.5	72.1	7.0
P > *F*	L_L§	0.0033	0.0534	0.1986	0.8876	0.7549	0.4478	0.0132	0.6237	0.7909
	N_L§	0.0016	0.2885	0.1456	0.6539	0.8129	0.0917	0.0161	0.3872	0.2698
	$L_L \times N_L$	0.8605	0.0472	0.9376	0.5676	0.6383	0.2494	0.1007	0.0667	0.9554
				2003 (Cultivar: DP 555 BG/RR)						
0	0	724	44.0	26.7	80.8	260	7.20	4.4	71.4	6.9
	2.2	977	44.5	27.0	81.0	258	7.20	4.5	70.0	6.8
	4.5	1182	44.2	27.0	80.8	262	7.15	4.6	71.4	6.8
	6.7	1405	44.6	26.7	80.6	255	7.25	4.5	70.6	7.2
34	2.2	1052	44.3	26.9	80.4	268	7.28	4.6	70.0	6.9
	4.5	1290	44.2	26.9	80.6	263	7.35	4.6	68.4	7.0
	6.7	1440	44.6	27.3	80.9	276	7.43	4.7	70.1	6.9
67	2.2	1199	43.9	26.9	80.5	258	7.18	4.5	70.2	6.8
	4.5	1565	44.3	27.1	80.6	246	7.20	4.7	71.5	6.9
118	0	1278	44.3	27.6	80.7	243	6.95	4.5	71.0	7.1
Avg.		1211	44.3	27.0	80.7	259	7.22	4.6	70.4	6.9
P > *F*	L_L	<0.0001	0.0895	0.5849	0.9853	0.8678	0.5508	0.1227	0.9121	0.4169
	N_L	<0.0001	0.5828	0.0458	0.7526	0.2119	0.0543	0.5679	0.8480	0.3430
	$L_L \times N_L$	0.9507	0.3811	0.5671	0.8310	0.5172	0.0776	0.4932	0.6902	0.3180
				2004 (Cultivar: DP 555 BG/RR)						
0	0	748	44.7	27.4	81.5	260	7.0	4.6	60.0	6.8
	2.2	1007	44.3	27.3	81.7	251	6.9	4.5	61.7	6.6
	4.5	1042	44.7	27.8	81.8	260	7.1	4.6	60.6	7.2
	6.7	1252	44.5	27.8	81.9	256	7.0	4.7	60.3	6.9
34	2.2	975	44.7	27.7	82.1	244	7.1	4.6	60.0	7.0
	4.5	1336	44.4	28.0	82.2	252	7.0	4.7	61.2	6.9
	6.7	1212	44.7	28.1	82.2	253	6.9	4.7	59.5	7.4
67	2.2	1250	45.2	27.8	81.9	256	7.1	4.7	59.7	6.7
	4.5	1401	45.2	27.9	82.5	247	7.1	4.7	61.3	7.1
118	0	1295	44.8	28.1	82.1	255	7.2	4.5	61.6	6.9
Avg.		1152	44.7	27.8	82.0	253	7.0	4.6	60.6	6.9
P > *F*	L_L	0.0008	0.4477	0.5849	0.2672	0.8943	0.9469	0.2821	0.9055	0.2974
	N_L	0.0002	0.5738	0.0458	0.1852	0.9661	0.0526	0.6945	0.5176	0.6376
	$L_L \times N_L$	0.9164	0.2180	0.5671	0.2866	0.3279	0.3654	0.1739	0.7468	0.7498

† Rd = reflectance.
‡ +b = yellowness index.
§ L_L = Litter linear effect, N_L = UAN–N linear effect.

tal UAN–N. The response surface model analysis showed a linear yield response to increasing litter rate with no significant $L_L \times N_L$ interaction in each of the 3 yr.

Litter application of 2.2 or 4.5 Mg ha^{-1} without supplemental N under the NT, as in the CT, was insufficient to produce lint yield equal to the yield of the STD (Table 4). The $L_{4.5}N_0$ treatment under the NT produced 194, 96, and 253 kg ha^{-1} less lint than the STD in 2002, 2003, and 2004, respectively. As in the CT, supplementing litter with UAN–N was necessary with the $L_{4.5}N_{67}$ treatment consistently producing the best yield each of the 3 yr. The $L_{4.5}N_{67}$ treatment exceeded the yield of the STD by 111, 287, and 106 kg ha^{-1} lint in 2002, 2003, and 2004, respectively, suggesting the UAN–N rate of the STD under the NT may not have been adequate. Supplementing the 4.5 Mg ha^{-1} litter with 34 kg ha^{-1} UAN–N did not seem to be as effective as supplementing with 67 kg ha^{-1} UAN–N. The $L_{4.5}N_{34}$ treatment produced equivalent lint yield as the STD but produced less lint than the $L_{4.5}N_{67}$ treatment each of the 3 yr. The $L_{6.7}N_{34}$ treatment also was not as effective as the $L_{4.5}N_{67}$ treatment yielding 150, 125, and 176 kg ha^{-1} less lint than the $L_{4.5}N_{67}$ treatment in 2002, 2003, and 2004, respectively. Other litter and UAN–N combinations were much less effective than the $L_{4.5}N_{67}$ treatment suggesting 4.5 Mg ha^{-1} litter supplemented with 67 kg ha^{-1} UAN–N was the most effective combination under the NT as it was under the CT.

Loss of nutrients to volatilization and runoff is often a concern when litter is surface-applied as broadcast without incorporation. Our results show applying broiler litter on the soil surface without incorporation is an effective method of fertilizing NT cotton. The NT lint yield in this research increased in direct proportion to the amount of applied litter suggesting that a substantial fraction of the litter-supplied nutrients are used by cotton (Table 4). Although they did not provide data, Mitchell and Tu (2005) believe the availability of N from broiler litter when applied to soils under conservation tillage parallel that of soil under CT. Nitrogen available as NH_3 or NH_4^+ at the time of application and shortly after application is the most likely form of N to be lost by volatilization from nonincorporated litter. Depending on weather conditions and litter, as little as 3% or as much as 24% of the total litter-supplied N can be lost as NH_3 during a season with the greatest loss occurring within the 1st week of application (Sharpe et al., 2004). We did not measure the loss of litter-derived ammonia in this research but there are indications that the loss of yield advantage due to lack of soil incorporation of applied litter under NT production systems to be ≈10% (Tewolde et al., 2005c).

Lint turnout under the NT differed by year with an average across treatments of 40.2% in 2002 compared with 44.3% in 2003 and 44.7% in 2004 (Table 4). As in the CT, the different turnout in 2002 compared with 2003 and 2004 may be due to cultivar differences. The test was planted to the cultivar SG 501 BG/RR in 2002 and to DP 555 BG/RR in 2003 and 2004. Litter affected turnout significantly ($P < 0.10$) in 2002 and 2003 but the trends were less obvious under NT than under CT (Table 4). Nitrogen did not significantly affect turnout under the NT in any of the 3 yr.

Relationship of Lint Yield and Turnout with Applied Plant-Available Nitrogen

Lint yield was significantly correlated (r^2 = 0.83–0.97) with applied N_{TPA} each of the 3 yr under both tillage systems when the N_{TPA} was calculated as a sum of applied UAN–N and litter-supplied N assuming 50% of the analytically determined total litter-N becomes plant available during the growing season (Fig. 1). Lint yield under the NT was a direct function of N_{TPA} with 3.2, 5.2, and 4.3 kg ha^{-1} lint yield benefit for every 1.0 kg ha^{-1} N_{TPA} in 2002, 2003, and 2004, respectively. The relationship between lint yield and N_{TPA} under the CT was nonlinear with much stronger quadratic response in 2004 than in the other years. Yield response to N_{TPA} under the CT was much smaller in 2002 than in 2003 and 2004 probably because of greater residual N in 2002 than in the other 2 yr. This is indicated in the lint yield trend across the 3 yr of the L_0N_0 and other treatments that received inadequate N. Lint yield of the L_0N_0 treatment that received no fertilization declined from 1478 kg ha^{-1} in 2002, to 928 kg ha^{-1} in 2003, to 728 kg ha^{-1} in 2004 (Table 3), suggesting a gradual depletion of N and probably other nutrients during the 3-yr period. The yield of $L_{2.2}N_0$ and $L_{4.5}N_0$ treatments also showed a clear decline across the 3 yr. Unlike the L_0N_0 and other N-deficient treatments, lint yield of the STD treatment that received adequate N fertilization remained relatively stable across the 3 yr (1670, 1771, and 1601 kg ha^{-1} in 2002, 2003, and 2004 respectively). This suggests the STD treatment maintained similar residual N and other nutrient status across the 3 yr, while the unfertilized and other inadequately fertilized treatments progressively depleted the initial high residual N during the 3-yr period.

Lint turnout was also significantly correlated with N_{TPA} each year (r^2 = 0.59–0.91) under the CT, with turnout linearly decreasing with increasing N_{TPA} in all 3 yr (Fig. 1). Correlations between turnout and N_{TPA} under the NT were not significant in all 3 yr, but the N_{TPA} by year interaction was significant ($P = 0.0871$). Lint turnout under NT showed a tendency to decrease with increasing N_{TPA} in 2002; but there was not such a trend in the other 2 yr, a response that may be indicative of differences in cultivar responsiveness to N. The cultivar used under the NT in 2003 and 2004 was DP 555 BG/RR that had a large turnout of >44% suggesting it is a small-seeded cultivar. The average 100-delinted-seed weight of this cultivar under the STD treatment was 6.56 g in 2003 and 6.27 g in 2004 compared with 8.53 g of SG 501 BG/RR in 2002. This may be indicative that the lint turnout of small-seeded cultivars is less responsive to N than large-seeded cultivars.

The amount of litter-N that mineralized and became plant available in this research was estimated to be ≈50% of the total litter-N. This estimation was based on preliminary regression and correlation analysis of lint yield with N_{TPA} calculated as the sum of applied UAN–N and litter-N assuming 30, 40, 50, 55, 60, 70, or 80% of the analytically determined total litter-N becomes plant

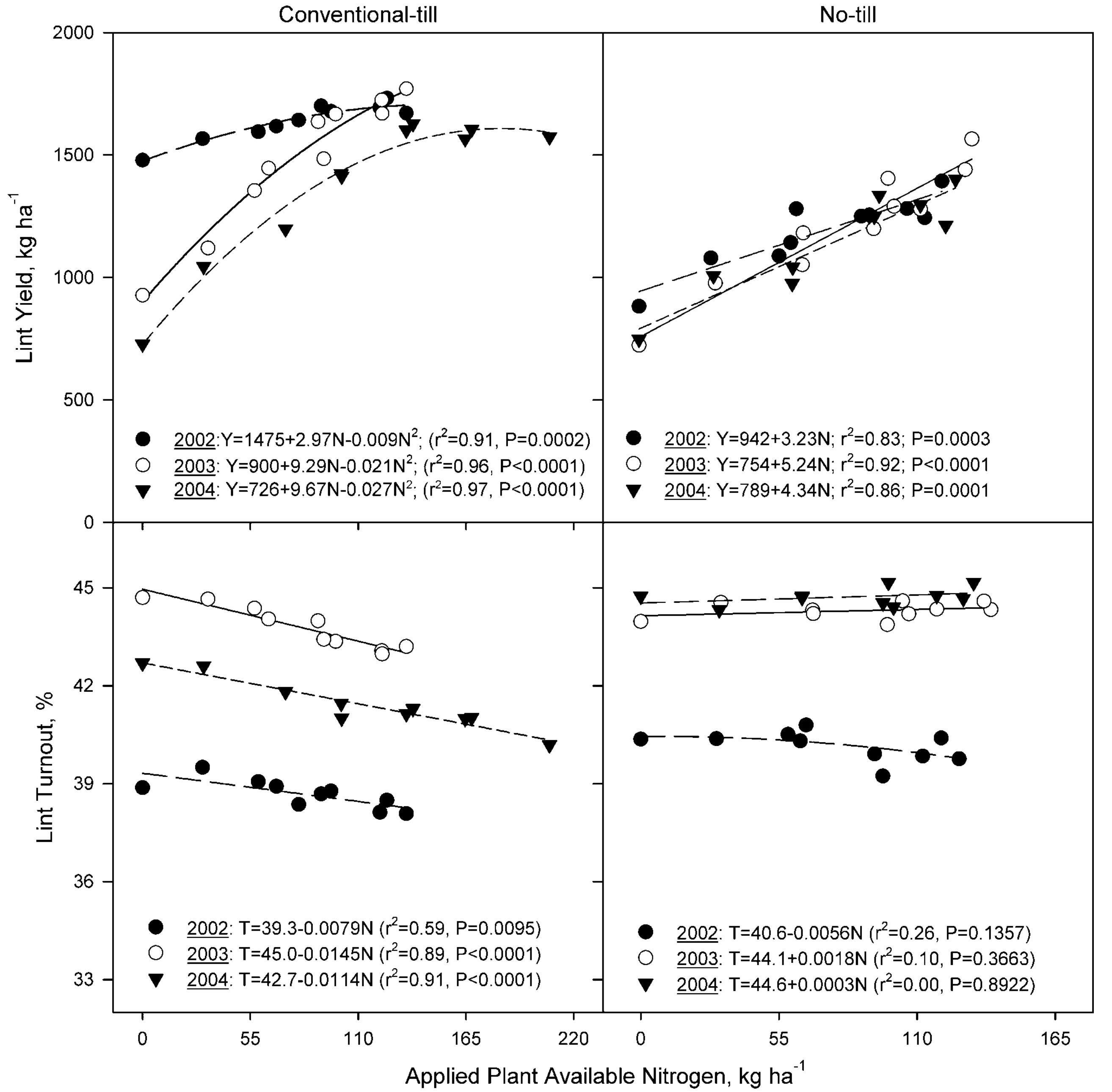

Fig. 1. Mean lint yield (Y) and lint turnout (T) of cotton as a function of total plant available N applied in broiler litter and urea–ammonium nitrate solution for 3 yr under CT (Cruger, MS) and NT (Coffeeville, MS) systems. Applied plant-available N was estimated as a sum of 100% UAN–N and 50% of litter N. Fitted lines are best-fit curves.

available in the first season. In general, lint yield was more strongly correlated with N_{TPA} (quadratic fit under the CT and linear fit under the NT) when the N_{TPA} was calculated based on 50% litter-N availability than on higher or lower percentage availability. No N mineralization rate has been established for litter applied to cotton, but our estimation of ≈50% of the amount of litter-N becoming plant available in the first season approximates incubation studies that show 42 to 64% of fresh poultry litter-N mineralized in 120 d under idealized incubation conditions (Preusch et al., 2002). In a more recent research, fertilizing corn (*Zea mays* L.) with poultry litter, assuming 67% of the litter-N becomes plant available during the growing season, significantly reduced grain yield relative to standard inorganic N fertilization (Warren et al., 2006). The researchers attributed this yield reduction to an overestimation of the N availability factor (67%) and subsequent underapplication of litter. Their results suggest corn grain yield would have been greater had the researchers applied litter based on <67% litter-N availability factor.

Fiber Quality

Fiber quality that includes micronaire, fiber length, strength, length uniformity ratio, color and other quality characteristics is an important component of cotton marketing worldwide. Upland cotton base quality standards that result in no discounts include fiber length of 26.7 to 27.2 mm; micronaire of 3.5, 3.6, and 4.3 to 4.9; strength of 260 to 279 kN m kg^{-1}; and uniformity ratio of 80.5 to 81.4% (USDA-AMS, 2006). Management practices employed to grow the cotton affect many of these quality characteristics. Litter treatments with or without supplemental UAN–N in this research affected some fiber quality characteristics.

Fiber Length

Fiber length was significantly affected by litter and UAN–N only in the last year of the research under the CT (Table 3). All treatments under this tillage produced fibers that met the base length standard of 26.7 to 27.2 mm each of the 3 yr. However, treatments that received litter and UAN–N favorable for lint yield seem to increase fiber length above the inadequately fertilized treatments. The often-recommended litter rate of 4.5 Mg ha^{-1} produced among the shortest fibers every year under the CT despite producing fibers that meet the base length standard. When supplemented with 67 kg ha^{-1} UAN–N, however, the 4.5 Mg ha^{-1} litter rate resulted in fibers that were among the longest. For example, in 2003, fiber length of the $L_{4.5}N_0$ treatment was 26.9 mm compared with 28.1 mm for the $L_{4.5}N_{67}$ treatment that produced the longest fibers (Table 3). Under the NT, UAN–N significantly affected fiber length in 2003 and 2004 (Table 4), but litter did not affect fiber length in any of the 3 yr under this tillage.

Regression of fiber length on N_{TPA} under the CT showed a significant association between N_{TPA} and fiber length in 2003 and 2004, with fiber length linearly increasing with increasing N_{TPA} (Fig. 2). There was no association between fiber length and N_{TPA} in 2002 when the soil was not as responsive to applied N as in the other 2 yr. Fiber length under the NT was also significantly ($P < 0.10$) associated with N_{TPA} in 2002 and 2004 (Fig. 2). The association in 2003 was weaker.

These results show litter and UAN–N fertilizations favorable for lint yield are also favorable for fiber length. The results also show that imposed fertilization deficiency, regardless of the severity, did not reduce fiber length below the base range at either location with the exception of 1 yr under the NT when the cultivar SG 501 BG/RR was used. Even cotton that did not receive any fertilization for three consecutive years in both tillage systems produced fibers that met the base length standard for the most part. This implies moderate nutrient deficiencies under typical cotton production systems in the southeastern USA may not reduce fiber length below the base range but the opportunity to increase the length to receive better prices may be missed.

Micronaire

Micronaire, which is measured as the resistance of a unit fiber mass to air flow, measures fiber fineness and indicates the degree of fiber maturity. In general, micronaire under the CT was high in each of the 3 yr with an average across treatments of 4.87, 4.97, and 5.24 in 2002, 2003, and 2004, respectively (Table 3). All treatments in 2004 under this tillage produced fibers with micronaire >5.0 placing the cotton beyond the base range and into the discount range. In 2003 under the CT, only the STD treatment and treatments that were severely underfertilized produced fibers with >5.0 micronaire. All of the litter-fertilized treatments in 2002 with or without supplemental UAN–N had micronaire between 4.78 and 4.95 falling within the base range. Micronaire of all treatments under the NT in 2002, when the cultivar was SG 501 BG/RR, exceeded 5.0 falling into the discount range (Table 4). None of the treatments exceeded the base range in 2003 and 2004 under the NT, when the cultivar was DP 555 BG/RR, with an average across treatments of 4.6 in 2003 and 4.7 in 2004.

Micronaire was not significantly affected by litter or UAN–N in any of the 3 yr under the CT and in 2003 and 2004 under the NT (Table 3 and 4). However, regressing micronaire on N_{TPA} showed a general trend for micronaire to decrease with increasing amount of applied N_{TPA} under the CT (Fig. 2). The response of micronaire to N_{TPA} under the NT was inconsistent. The declining trend of micronaire with increasing N fertilization is similar to other previous findings. For example, Ebelhar et al. (1996) showed that micronaire of Upland cotton cv. DES-119 decreased as N rate increased between 101 and 202 kg N ha^{-1}. Hearn (1976) also reported heavy N application (225 vs. 34 kg N ha^{-1}) decreased micronaire of two Upland cultivars, Acala 1517 BRI and Deltapine 16, with greater decrease in Deltapine 16 than in Acala 1517. However, there are reports that show increasing micronaire with increasing N fertilization. For example, Tewolde and Fernandez (2003) showed that increasing N rate resulted in a small but a highly significant linear increase of micronaire in Pima cotton.

Fiber Strength

Fiber strength was not significantly affected by litter or UAN–N in any of the 3 yr in either tillage system. However, fiber strength of some treatment combinations regardless of the fertilization level fell below the base standard at both locations (Table 3 and 4). Under the CT, fiber strength of six treatments in 2003 and one treatment in 2004 fell below the base standard of 260 to 279 kN m kg^{-1} (USDA-AMS, 2006). Under the NT, mean fiber strength of five treatments in 2003 and eight treatments in 2004 were below the base standard. Usually treatments that received adequate fertilization for yield and the other fiber qualities were among the ones that had below-standard fiber strength. All treatments in 2002 under both tillage systems produced fibers that met the base standard in strength. Fiber strength in this year, under the NT in particular where all treatments had unacceptable micronaire, exceeded the base range into the premium range of ≥289 kN m kg^{-1}. The cultivars used under both tillage systems in 2002 were different than the ones used in 2003 and 2004 (Table 1).

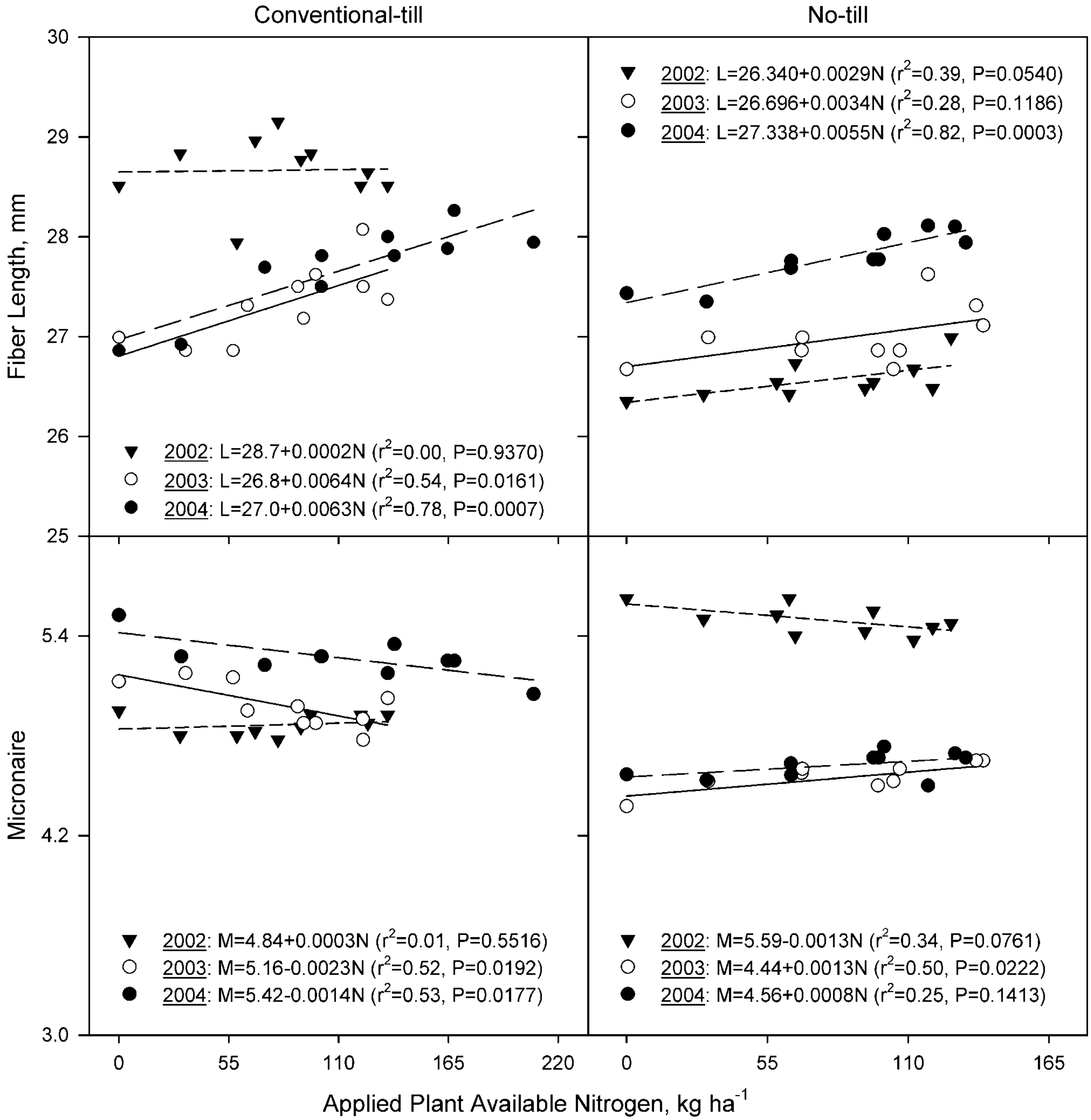

Fig. 2. Fiber length (L) and micronaire (M) of cotton as a function of total plant-available N applied as broiler litter and urea–ammonium nitrate solution for 3 yr under CT (Cruger, MS) and NT (Coffeeville, MS) systems. Applied plant-available N was estimated as a sum of 100% UAN–N and 50% of litter-N. Fitted lines are best-fit curves.

Length Uniformity Ratio

Length uniformity ratio (UR) was not significantly affected by litter or UAN–N in 2002 and 2003 under the CT and in any of the 3 yr under the NT (Table 3 and 4). Both litter and UAN–N significantly affected UR in 2004 under the CT. Unlike fiber strength, all treatments in all year–locations produced cotton with UR that meet marketing standards without discounts. Despite producing acceptable UR and despite the lack of treatment effects in most years, results from both tillage systems indicate that greater N fertilization may improve UR. Length uniformity ratio in both tillage systems in 2004 significantly and linearly increased with increasing N_{TPA} suggesting UR benefits from better N fertilization. The fitted lines were UR = 82.7+0.0045 × N_{TPA} (r^2 = 0.67, P = 0.0037) under the CT, and UR = 81.6 + 0.0054 × N_{TPA} (r^2 = 0.72, P = 0.002) under the NT. Relationships between applied N_{TPA} and UR in other years were not strong.

Fiber Elongation

Fiber elongation, which is the degree of fiber extension (%) at the point of break while force is applied to fibers when measuring strength, was not significantly affected by treatments in any of the 3 yr under the CT. Under the NT, litter did not significantly affect elongation but N appeared to affect elongation significantly ($P < 0.10$) each of the 3 yr. Elongation under the CT significantly increased with increasing applied N_{TPA} in 2003 and 2004 suggesting that adequate N fertilization may be beneficial for fiber elongation. Similar to these results, Tewolde and Fernandez (2003) reported that fiber elongation of Pima cotton increased with increasing applied N up to a maximum of 269 kg N ha^{-1}. Fiber elongation that affects the frequency of yarn breakage during spinning (Waters et al., 1966) may be related to the degree of secondary wall deposition (Ramey, 1986). In our research, micronaire, which is related with the degree of fiber maturity, was highly ($r^2 = 0.89$) and positively correlated with fiber elongation when data from all 3 yr and both tillage systems were analyzed together.

CONCLUSIONS

Poultry litter at 4.5 Mg ha^{-1} is an often recommended rate for cotton in the southeastern USA, but adequacy of this rate for typical cotton production in the region is not well supported by research. The results of our research show broiler litter as much as 6.7 Mg ha^{-1} as the primary fertilizer may not be adequate for optimum cotton production. However, when supplemented with 67 kg N ha^{-1} inorganic N fertilizers, 4.5 Mg ha^{-1} fresh broiler litter may be adequate to produce lint yield equivalent to that of conventional fertilization where the yield expectations may be ≈1700 kg ha^{-1} under CT and ≈1500 kg ha^{-1} under NT systems. An added benefit of applying litter supplemented with inorganic N fertilizers is that it minimizes the buildup of excess soil P and, therefore, is an environmentally preferred practice. Applying litter to supply the full N need of cotton leads to applying P in excess of the crop's ability to absorb and use because litter is a disproportionately rich source of P. Litter when adequately supplemented with UAN–N may not particularly adversely affect fiber quality. Only litter treatments with or without supplemental inorganic N that do not provide adequate N for lint yield may negatively affect fiber quality, fiber length in particular.

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