Fertilizer Nitrogen Requirements for Cotton Production as Affected by Tillage and Traffic

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Reprinted from the *Soil Science Society of America Journal*
Volume 58, no. 5, September–October 1994
677 South Segoe Rd., Madison, WI 53711 USA

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ABSTRACT

Soil compaction and its associated problems have led to interest in investigating the interactive effects of traffic and tillage systems on fertilizer N requirement for cotton (*Gossypium hirsutum* L.). In 1987, a study was initiated on a thermic Typic Hapludult soil complex with a cropping system of wheat (*Triticum aestivum* L.)-cotton double cropped. The experimental design was a split-split plot with four replications. Main plots were two traffic treatments (conventional and no-traffic), subplots were four tillage systems for cotton (surface tillage without subsoiling [surface-only], surface tillage and annual in-row subsoiling [subsoiling], surface tillage with one-time-only complete disruption of the tillage pan [complete], or no surface tillage and in-row subsoiling [strip-till]), and sub-subplots were four N rates (0, 45, 90, and 135 kg N ha^{-1}). In addition, application of ^{15}N-labeled NH_4NO_3 was made to microplots inside each tillage-traffic-90 kg N ha^{-1} plot. In 1990 and 1991, increasing N application increased cotton biomass and decreased lint percentage. In the dry year of 1990, no-traffic decreased seed cotton yield from 1500 to 1360 kg ha^{-1}, while tillage had no significant effects on cotton yield components. Above-normal rainfall in 1991 resulted in the strip-till with no-traffic treatment having the highest seed cotton yield (2749 kg ha^{-1}) and the greatest fertilizer N uptake efficiency (35%). Results indicate that the detrimental effects of traffic on N uptake efficiency may be reduced with conservation tillage systems and that higher fertilizer N application rates may not be needed for conservation tillage practices such as strip-till in Coastal Plain soils.

Soil compaction and the formation of tillage pans has been recognized as a problem for crop production in the sandy Coastal Plain soils of the Southeast (Håkansson et al., 1988; McConnell and Frizzell, 1989; Reeves et al., 1992), including limitations for cotton production (Touchton and Reeves, 1988; McConnell and Frizzell, 1989). There are a number of methods aimed at alleviating soil compaction, including deep plowing, subsoiling, chiseling, and crop rotation (Bowen, 1981). but some form of deep tillage is most commonly used.

Methods of alleviating soil compaction also have been Incorporated into conservation tillage systems. Strip tillage for example, is a conservation tillage system that combines deep tillage with limited disturbance of surface residues by performing in-row subsoiling at planting. Because of its ability to both relieve subsoil compaction and maintain crop residues on the soil surface, strip-till is a good choice for cotton production in the sandy soils of the Southeast (Touchton and Reeves, 1988).

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Published in Soil Sci. Soc. Am. J. 58:1416–1423 (1994).

Controlled traffic has also been studied as a means of preventing soil compaction and the formation of hardpans. with a beneficial effect being reported for cotton production (Dumas et al., 1973; Williford, 1982). Research on controlled traffic, however, has focused on conventional tillage systems. There is a need to investigate the interactions of conservation cropping systems with traffic, as recent research indicates these systems may withstand the effects of traffic better than conventional tillage systems (Reeves et al., 1992).

Part of the effects of both tillage systems and soil compaction on crop production may derive from their influence on N dynamics in the plant-soil system. Conservation tillage has been reported to increase N leaching (Tyler and Thomas, 1977), N denitrification (Olson et al., 1979; Gilliam and Hoyt, 1987). and N immobilization (Gilliam and Hoyt, 1987). Soil compaction decreases plant N uptake (Castillo et al., 1982; Garcia et al., 1988), increases N losses through denitrification (Bakken et al., 1987; Torbert and Wood, 1992), and affects N application efficiency (Jenkinson et al., 1985).

The interaction of tillage systems and soil compaction caused by traffic on N requirements for cotton has not been studied. The objective of this experiment was to determine the effect of traffic and tillage systems, including a strip-till system, on yield and N requirement for cotton production.

MATERIALS AND METHODS

A field study was initiated in June 1987 at the Alabama Agricultural Experiment Station, E.V. Smith Research Center, Shorter. AL (32°24'N, 85°54'W), in cooperation with the USDA-ARS National Soil Dynamics Laboratory This study utilized a wide-frame tractive vehicle (WFTV) designed to allow 6.1-m-wide, untrafficked research plots. A detailed description of the vehicle and its capabilities has been published by Monroe and Bun (1989) and Reeves et al. (1992). The WFTV allows implementation of various tillage systems in a no-traffic environment.

Cotton, McNair 220, was grown in a double-cropping system with Coker 9733 wheat. The development of early-maturing cotton and wheat cultivars has made wheat-cotton double cropping a feasible alternative in the southeastern USA (Baker. 1987). Figure 1 depicts a time line indicating the approximate times for farm operations. treatment applications, and data

Abbreviations: WFTV, wide-frame tractive vehicle; CEC, cation-exchange capacity; ANOVA, analysis of variance; LSD, least significant difference.

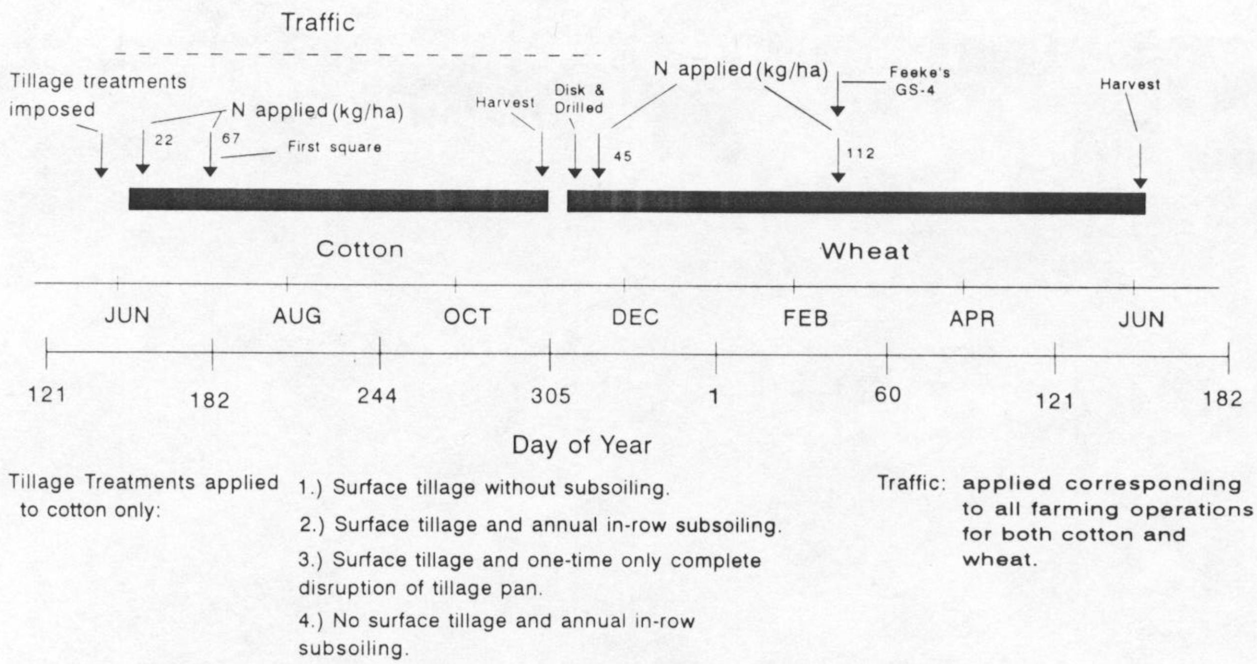

Fig. 1. Time frame for operations and data collection in cotton–wheat double-cropping experiment.

collection in the study. The soil is a Cahaba-Wickham-Bassfield sandy loam complex. The Cahaba soil is a fine-loamy. siliceous, thermic Typic Hapludult. The Wickham soil is a fine-loamy. mixed, thermic Typic Hapludult. The Bassfield soil is a coarse-loamy, siliceous, thermic Typic Hapludult. Average CEC and organic matter content for the test site were 6.31 $cmol_c$ kg^{-1} and 11.9 g kg^{-1}, respectively. Physical characteristics of the soils are presented in Table 1. As commonly found in these soils, the site had a well-developed g- to 15-cm-thick hardpan from 20 to 30 cm deep. To reduce variation, a uniform hardpan was formed at a depth of 20 cm by running a motor grader repeatedly in plowed furrows incrementally across the experiment site. Recommended cultural practices for insect and weed control were used on all plots throughout the growing season for both crops.

The experimental design was a split plot with four replications. Main plots (6.1 m wide and 182.9 m long) were: (i) conventional traffic and (ii) no traffic. Main plots were split into subplots (37 m long) of tillage systems applied to cotton: (i) complete surface tillage without subsoiling (surface-only), (ii) complete surface tillage and annual in-row subsoiling to 40-cm depth (subsoil), (iii) complete surface tillage with one-time-only complete disruption of the tillage pan (complete). and (iv) no surface tillage but planted with in-row subsoiling (strip-till). Complete surface tillage consisted of disking, chisel plowing (20-cm depth), disking, and field cultivation. The one-time-only complete disruption of the tillage pan was accomplished by subsoiling to a 50-cm depth on 25-cm centers, using a V-ripper in November 1987. The one-time-only complete disruption of the hardpan was included to examine the effect of recompaction of the subsoil, with and without traffic. The strip-tilled cotton was planted into wheat stubble with an in-row subsoiler planter. Subplot tillage treatments were imposed on cotton only, with the complete complement of tillage treatments first Imposed during the 1988 growing season.

All operations were performed with the WFTV. On the conventionally trafficked plots, a 4440 John Deere tractor[1] (4.6 t with 470 by 970 mm tires inflated to an average pressure of 125 kPa) was driven through the plots to simulate traffic that would have been applied with each operation. Traffic patterns followed those expected with four-row equipment, with random patterns used to simulate preparation and planting operations for wheat and uniform patterns used for operations performed during the cotton growing season.

Cotton was planted in eight 76-cm rows, at 222000 seed ha^{-1} as close to 1 June as possible. After the cotton was harvested, all plots were disked and planted to wheat with a 3-m-wide drill with 10-cm drill spacing.

In 1990 and 1991, research was conducted to evaluate N dynamics in this tillage-traffic study. The tillage subplots were split into sub-subplots (8.7 m long) of four N rates (0, 45, 90, and 135 kg N ha^{-1}), creating a split-split plot design. Nitrogen was applied as NH_4NO_3 at 22 kg N ha^{-1} at planting and the remaining fertilizer was applied at first square. In addition, in three of the replications, ^{15}N-depleted NH_4NO_3 was applied to a 2.4 by 3 m microplot inside each tillage-traffic treatment for the 90 kg N ha^{-1} treatment plots only. An additional 0.3-m^2 microplot (made by pressing a 59.5-cm metal cylinder into the ground) was used for application of ^{15}N-enriched NH_4NO_3 containing 2.0 atom % ^{15}N, inside the same tillage-traffic-90 kg N ha^{-1} plots. The microplots were rotated to a new location within the sub-subplots each year.

Table 1. Physical characteristics of soils in this study.†

Soil Series	Soil Subgroup	Surface texture‡	Soil depth	Sand	Silt	Clay	Rock fragments
			cm	g kg^{-1}			
Bassfield	Typic Hapludult	sl	0–18	67.3	23.6	9.1	43
			18–107	66.0	19.1	14.9	44
			107–203	80.8	16.2	3.0	57
Cahaba	Typic Hapludult	sl	0–23	67.3	23.6	9.1	14
			23–135	55.5	17.5	27.0	58
			135–203	91.2	1.6	7.2	30
Wickham	Typic Hapludult	sl	0–15	67.3	23.6	9.1	30
			15–127	55.5	17.5	27.0	27

† From soil survey data (Williams et al., 1990).
‡ sl = sandy loam.

[1] Trade names and products are mentioned solely for information. No endorsement by the USDA is implied.

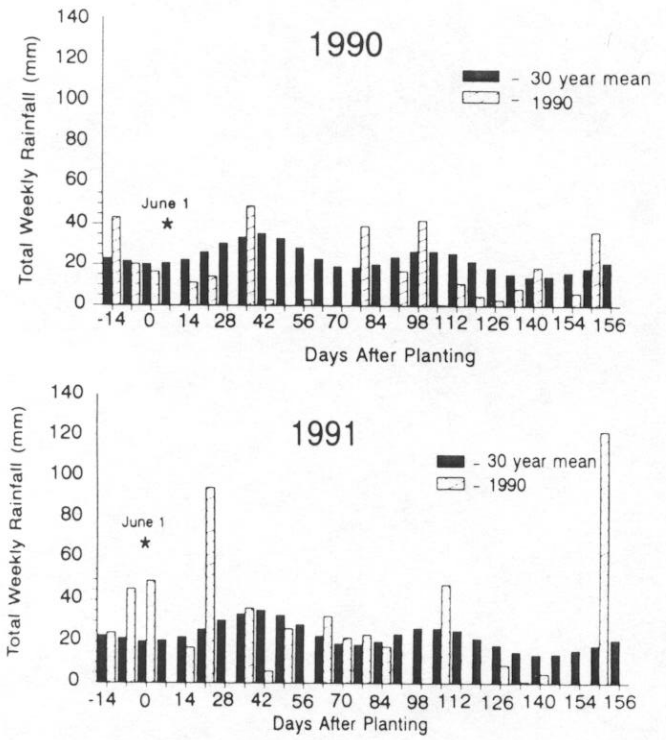

Fig. 2. Total weekly rainfall during 1990 and 1991 growing seasons in relation to 30-yr mean rainfall.

Fertilizer contribution values were calculated from the average values of ^{15}N-enriched and ^{15}N-depleted microplots. Data for the 1990 and 1991 growing seasons only are reported here.

Cotton was hand picked for yield on approximately 1 November of each year. Cotton yield was measured from 12 m of row. and stalk samples were taken from 3 m of row. Stalk and cotton samples were collected from 3 m of row within the microplots installed in the 90 kg N ha^{-1} sub-subplots. The cotton and stalk samples were dried at 65°C (until weight loss was complete) and cotton samples were ginned to separate seed from lint.

Soil cores were collected from within both microplots to a depth of 90 cm. Cores were sectioned into 0- to 15-, 15- to 30-, 30- to 60-, and 60- to 90-cm increments and frozen immediately for transport to the laboratory The total N content of both plant and soil samples was determined using a permanganate-reduced Fe modification of a semimicro-Kjeldahl method (Bremner and Mulvaney, 1982). Distillates were concentrated for isotope-ratio analyses, which were performed as described by Mulvaney et al. (1990), using an automated mass spectrometer (Nuclide Model 3-60-RMS, Measurement and Analysis Systems, Bellefonte, PA).

Soil bulk density. used in calculationof fertilizer N recovery, was determined for each plot from intact soil cores collected to a depth of 90 cm. Soil bulk density and soil strength data from this experiment were reported by Raper et al. (1992). The term *fertilizer* N is used to reflect N added to the plant-soil system through fertilizer application. The term *total fertilizer* N recovery is used to reflect fertilizer N recovered in the total plant-soil system. The term *plant fertilizer N uptake efficiency* is used to reflect differences in plant use of applied fertilizer N and was calculated by ^{15}N in plant/^{15}N applied. Data was analyzed using ANOVA procedures and means were separated using a protected LSD at the 0.10 probability level (SAS Institute, 1982). The term *trend* is used to designate appreciable nonsignificant treatment effects with probability levels >0.10. In addition, regression analysis was performed for treatment effects with significant N application rate interactions at the 0.10 probability level.

RESULTS AND DISCUSSION

Cotton Yield Components

Data for the 1990 and 1991 growing seasons only are repotted. Weather conditions were exceptional during both the 1990 and the 1991 cotton growing seasons. The 1990 growing season had the lowest rainfall total in 100 yr, while 1991 had the highest rainfall totals (Fig. 2). The conditions produced drastically different growing conditions in which to evaluate cotton production as it is affected by traffic and tillage.

During the 1990 growing season, cotton plants were under water stress throughout most of the growing season (Fig. 2, 23-cm total rainfall during growing season). In this year, both cotton stalk and total biomass significantly increased with increasing fertilizer N application rate (averaged across all tillage and traffic treatments) (Table 2). Regression analyses indicated that application of 135 kg N ha^{-1} increased total cotton biomass from 2483 to 3110 kg ha^{-1} compared with 0 kg N ha^{-1} application (R^2 = 0.15, equation not shown). Lint percentage was also affected by N rate, decreasing with increasing fertilizer N application (data not shown). Similar reductions in the lint percentage due to increased N levels have been repotted by Perkins and Douglas (1965). Nitrogen availability does not restrict growth of lint as much as other yield components because there is very little N in cotton lint. Thus, lint production may not be limited under conditions where N availability would otherwise limit plant growth and seed mass. In this year, the increase in biomass with increasing N application was counter to the decrease in the lint percentage. Consequently, no significant difference was observed for lint production with regard to N rate (Table 2).

In 1990, significant traffic x N rate and traffic x tillage x N rate interactions were observed for lint percentage (Table 2). However, differences were small and considered to b-e of no practical importance. In addition, no significant interactions between N application and tillage or traffic treatments were observed for other yield components. This indicates that the beneficial response of cotton to fertilizer N was limited under the extremely dry growing conditions.

In 1990, traffic had a positive effect on cotton production. While total cotton biomass was not significantly affected by traffic, both seed and lint production were lower in the no-traffic treatment than under conventional traffic (Tables 2 and 3), with 1500 vs. 1360 kg seed cotton ha^{-1} production for traffic and no-traffic. respectively. Cotton seed production was higher with traffic (855 kg ha-') than with no-traffic (793 kg ha-‘). It is believed that cotton plants grown under the traffic treatment became water stressed earlier in the growing season, producing smaller plants. As a result, the smaller plants were able to partition more resources into the production of seed and lint as the drought conditions continued

Table 2. Probability of greater F values for the effect of tillage system (Ti), traffic (T), N application rate (N), and their interactions on measured parameters.†

Parameter	Ti	T	N	Ti × T	Ti × N	T × N	Ti × T × N
	$P > F$						
				1990			
Dry matter							
Lint	0.3408	0.0047	0.6302	0.9642	0.4790	0.6440	0.7639
Seed	0.3116	0.0793	0.6541	0.8605	0.6316	0.8256	0.8955
Stalk	0.2284	0.7220	0.0001	0.5749	0.4303	0.8396	0.9676
Seed cotton	0.3194	0.0102	0.7645	0.9200	0.5706	0.7477	0.8513
Total biomass	0.2646	0.3684	0.0008	0.6934	0.2252	0.7635	0.9509
Lint %	0.7343	0.2915	0.0001	0.8171	0.1028	0.0829	0.0190
N uptake‡							
Seed	0.5717	0.5571	0.0512	0.9933	0.5037	0.8738	0.3025
Stalk	0.1365	0.6531	0.0001	0.3825	0.7650	0.9916	0.8583
Total plant	0.3236	0.6985	0.0001	0.8097	0.4228	0.8943	0.5195
				1991			
Dry Matter							
Lint	0.0149	0.0512	0.0001	0.2018	0.0312	0.4421	0.7098
Seed	0.0011	0.0051	0.0001	0.1767	0.0230	0.2531	0.4000
Stalk	0.0007	0.4606	0.0001	0.3057	0.7445	0.0645	0.1874
Seed cotton	0.0031	0.0123	0.0001	0.2000	0.0217	0.3094	0.5177
Total biomass	0.0001	0.1096	0.0001	0.1468	0.2523	0.0722	0.2474
Lint %	0.2047	0.0465	0.0634	0.0828	0.3872	0.6241	0.4640
N uptake‡							
Seed	0.0024	0.0026	0.0001	0.0310	0.0181	0.1851	0.5877
Stalk	0.1939	0.0359	0.0001	0.6285	0.4725	0.1761	0.9380
Total plant	0.0020	0.0044	0.0001	0.0324	0.0579	0.0631	0.7619

† Probability of greater F value indicates level of significance (Gomez and Gomez, 1984).
‡ Total N uptake in plant components.

compared with the larger plants in the no-traffic treatment, which would be consistent with no significant differences in total plant biomass between traffic treatments. Similar results have been repotted for other crops under severe environmental conditions (Voorhees et al., 1985). For example, Voorhees et al. (1985) found that wheat yield was reduced in nontracked soil under dry growing conditions. In this year. drought conditions overwhelmed differences between tillage treatments, resulting in no significant tillage effects or interactions between tillage and traffic observed for yield components (Table 2).

In 1991, above-normal rainfall occurred during the cotton growing season (Fig. 2, 35-cm total rainfall during growing season). In this year, N application significantly affected cotton seed, stalk, lint, and total biomass production (Table 2). There was a significant tillage x N rate interaction for both cotton seed and lint production and a traffic x N rate interaction for cotton stalk and total biomass (Table 2).

In surface-only and strip-till treatments, a quadratic response to N application for seed and lint production was observed, with the response to N being greater in the strip-till treatment (Table 4 and Fig. 3). This indicated that N limited production at the lower rates of N application for these two tillage treatments, but that strip-tilled cotton better utilized N applied as fertilizer, most likely due to better soil moisture conditions (data not shown).

As in 1990, the cotton lint percentage for 1991 decreased with increasing fertilizer N application, with a decrease from 40.9 to 40.1% for 0 and 135 kg N ha^{-1}, respectively. In this year, however, the increased growth in response to N application resulted in higher lint yield even though the percentage of dry matter going to lint was reduced. In addition, a significant traffic x tillage interaction was observed for lint percentage in 1991, with traffic increasing the lint percentage in the surface-only and strip-till treatments; the effect was much greater in the surface-only tillage treatment (Table 5).

In 1991, tillage system affected cotton yield components. In this year, strip-till significantly increased seed, seed cotton, stalk, and total biomass compared with the other tillage treatments (Tables 2 and 6). Lint yield was also higher in the strip-till treatment than complete and subsoil tillage treatments. but was not significantly different than in the surface-only tillage treatment. This was due to a higher lint percentage for the surface-only tillage than the strip-till treatment (Table 5) and partially offset the beneficial effect of strip-till on cotton yield.

Table 3. Effect of traffic on yield components of cotton, 1990 and 1991.

Component	Yield	
	No traffic	Traffic
	kg ha^{-1}	
	1990	
Stalk	1777 a†	1740 a
Seed	793 a	855 b
Lint	567 a	646 b
Biomass	3138 a	3241 a
	1991	
Stalk	2548 a	2429 a
Seed	1572 a	1355 b
Lint	1036 a	945 b
Biomass	5155 a	4729 a

† Values represent means of four replicates. Values within a row followed by the same letter do not differ significantly (0.10 level).

Table 4. Predictive equations and R^2 values for regression analyses of cotton yield and N uptake in 1991 on N application rate.

Parameters	Equation†	R^2	$P > F$
	Yield		
Seed			
Surface-only	$Y = 1121.6 + 3.763\ N - 0.0116\ N^2$	0.22	0.0262
Strip-till	$Y = 1255.3 + 8.320\ N - 0.0544\ N^2$	0.38	0.0011
Complete	NS		0.2267
Subsoil	NS		0.4319
Lint			
Surface-only	$Y = 790.8 + 2.257\ N - 0.0073\ N^2$	0.24	0.0200
Strip-till	$Y = 854.1 + 5.551\ N - 0.0392\ N^2$	0.33	0.0028
Complete	NS		0.3784
Subsoil	NS		0.4373
Stalk			
Traffic	$Y = 1811.2 + 5.933\ N$	0.21	0.0001
No-traffic	$Y = 2096.3 + 2.951\ N$	0.07	0.0334
Biomass			
Traffic	$Y = 3667.4 + 10.202\ N - 0.0107\ N^2$	0.22	0.0005
No-traffic	$Y = 4171.8 + 15.571\ N - 0.0905\ N^2$	0.14	0.0121
	Total N uptake		
Seed			
Surface-only	$Y = 73.11 + 0.200\ N$	0.33	0.0007
Strip-till	$Y = 75.06 + 0.683\ N - 0.0042\ N^2$	0.58	0.0001
Complete	$Y = 74.78 + 0.383\ N - 0.0026\ N^2$	0.24	0.0199
Subsoil	$Y = 72.72 + 0.138\ N$	0.24	0.0049
Total Plant			
Surface-only	$Y = 93.62 + 0.429\ N$	0.53	0.0001
Strip-till	$Y = 95.23 + 0.952\ N - 0.0037\ N^2$	0.77	0.0001
Complete	$Y = 95.57 + 0.637\ N - 0.0031\ N^2$	0.51	0.0001
Subsoil	$Y = 99.17 + 0.3345\ N$	0.48	0.0001
Traffic	$Y = 88.66 + 0.432\ N$	0.58	0.0001
No-Traffic	$Y = 103.12 + 0.746\ N - 0.0034\ N^2$	0.59	0.0001

† N = N fertilizer application rate (kg N ha^{-1}); NS = not significant.

Strip-till produced more total dry matter, but surface-only produced a higher proportion of the dry matter as lint, resulting in no significant difference between these two treatments for lint yield,

In 1991, unlike 1990, traffic reduced seed cotton yield compared with no-traffic, with 2301 vs. 2607 kg seed cotton ha^{-1} for traffic and no-traffic, respectively. In this year, significant increases were observed in both lint

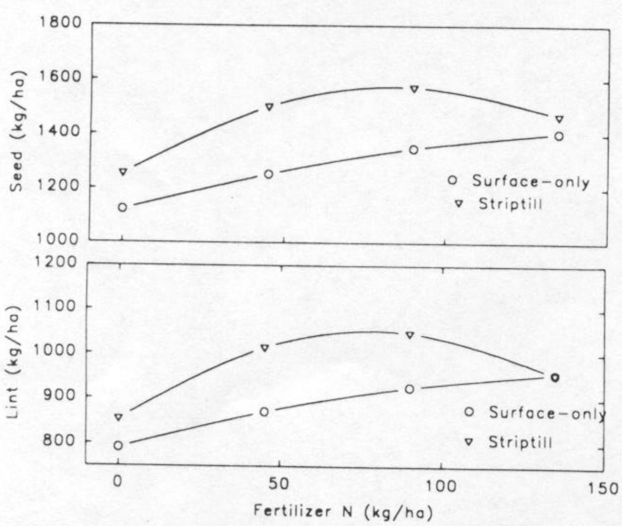

Fig. 3. Effect of tillage system and N application rate on cotton seed and lint dry weight, 1991. Cotton tillage systems were: surface-only = surface tillage without subsoiling; strip-till = no surface tillage but planted with annual in-row subsoiling.

Table 5. Traffice and tillage system effect on cotton lint percentage, 1991.†

Tillage‡	Lint: No traffic	Lint: Traffic
	%	%
Complete	40.3	40.4
Strip-till	39.0	41.1
Subsoil	39.7	40.9
Surface-only	39.9	42.0
LSD(0.10-any two means) = 2.7		
LSD(0.10-within traffic) = 1.3		

† Values represent means of four replicates.
‡ Cotton tillage: complete = complete surface tillage with one-time only complete disruption of tillage pan; strip-till = no surface tillage but planted with in-row subsoiling; subsoil = complete surface tillage and annual in-row subsoiling; surface-only = complete surface tillage without subsoiling.

and seed yield with the no-traffic treatment, with a similar trend for total biomass (Table 2), while a N rate x traffic interaction was observed for stalk and total biomass production. Regression analyses of these yield components indicated a greater response to N application with the no-traffic treatment than-with traffic up to a rate of 120 kg N ha^{-1} (Table 4, Fig. 4), suggesting that the fertilizer N requirement may be greater for cotton grown in soils compacted by traffic.

It is speculated that strip-till resulted in a positive plant response (due to water conservation with the residue mulch cover) resulting in better utilization of available N and thus an increase in seed production, while traffic-induced soil compaction produced a restriction on N uptake and thus a reduction in stalk and dry matter production (but plant N redistribution resulted in no seed reduction). However, the poor correlations between yields and N application for tillage and traffic treatments (as indicated by low R^2 values, Table 4) indicate that factors other than N availability contributed to differences in the yield observed with these cotton production systems.

In addition, a nonsignificant trend for a traffic x tillage interaction was observed for several yield components. with $P \leq 0.20$ for seed cotton yield, $P \leq 0.18$ for seed, and $P \leq 0.15$ for total biomass. The interaction trend was for the strip-till treatment to withstand the effects of traffic better than surface-tilled treatments (complete, surface-only, and subsoil).

Nitrogen Uptake

Fertilizer N application significantly increased total plant N uptake in 1990 (Table 2). with regression analyses

Table 6. Effect of tillage system† on yield components of cotton. 1991.

	Yield: Complete	Strip-till	Subsoil	Surface-only
	kg ha^{-1}			
Stalk	2240 b‡	2873 a	2513 b	2331 b
Seed	1409 b	1625 a	1380 b	1437 b
Lint	952 b	1085 a	934 b	992 ab
Biomass	4601 b	5583 a	4827 b	4760 b

† Cotton tillage: complete = complete surface tillage with one-time only complete disruption of tillage pan; strip-till = no surface tillage but planted with in-row subsoiling; subsoil = complete surface tillage and annual in-row subsoiling; surface-only = complete surface tillage without subsoiling.
‡ Values represent means of four replicates. Values within a row followed by the same letter do not differ significantly (0.10 level).

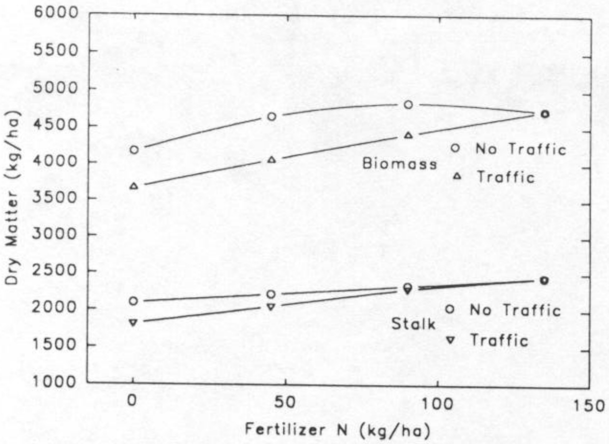

Fig. 4. Effect of traffic on stalk and total biomass dry weight at harvest in 1991.

Table 7. Probability of greater *F* values for the effect of tillage system, traffic, and their interaction on fertilizer N contribution of cotton plant components as measured by ^{15}N analysis.†

Fertilizer N	Tillage (Ti)	Traffic (T)	Ti × T
		$P > F$	
		1990	
Total plant	0.7270	0.6330	0.5253
Seed	0.1021	0.1230	0.2734
Stalk	0.9072	0.9886	0.6870
Remaining in soil	0.5954	0.2907	0.5755
Total recovered	0.8412	0.3219	0.3686
		1991	
Total plant	0.0951	0.0299	0.5413
Seed	0.0370	0.0478	0.1883
Stalk	0.4752	0.0519	0.4564
Remaining in soil	0.9547	0.7992	0.4831
Total recovered	0.5781	0.3358	0.4453

† Values represent means of three replicates. Fertilizer N application rate of 90 kg N ha^{-1}.

indicating that 135 kg N ha^{-1} application would result in 85.9 kg plant N ha^{-1}, compared with 63.7 kg plant N ha^{-1} for 0 kg N ha^{-1} applied (R^2 = 0.30). However, the dry growing season of 1990 resulted in extremely limited fertilizer N uptake by the cotton plants, with an average fertilizer N uptake of 24 kg N ha^{-1} or 27% of applied fertilizer for the 90 kg N ha^{-1} application rate (^{15}N data). In this year, most of the difference in plant N accumulation was observed in the stalks. The rate of fertilizer N application had very little effect on seed N content in this year, with only the 135 kg N ha^{-1} rate having significantly higher N content in the seed (50 kg ha^{-1}) compared with no fertilizer N application (45 kg ha^{-1}).

In 1990, no significant tillage treatment effects were observed for N uptake by cotton plant components (Table 2). Likewise, in this year, no significant tillage treatment effects were observed for fertilizer N uptake calculated by ^{15}N analysis (Table 7). However, a nonsignificant trend ($P \leq 0.102$) was observed for strip-till to increase fertilizer N uptake in the seed compared with the other tillage treatments (Tables 7 and 8). These results are most likely a result of redistribution of N in the plant to provide adequate N for seed production. In addition, since no difference in total dry matter was observed, these results indicate that even under very dry conditions, strip-tilled cotton better utilized fertilizer N.

In 1990, traffic had no significant effect on either fertilizer contribution (^{15}N data) or total plant N uptake (Tables 2 and 7. respectively). While no differences were observed for stalk fertilizer N, a trend ($P \leq 0.12$) was observed for higher fertilizer in the seed in the no-traffic treatment, with 12.6 and 13.6 kg ha^{-1} fertilizer N in the seed for traffic and no-traffic, respectively.

In 1991, higher rainfall during the growing season resulted in a significant effect for N application on cotton seed, stalk, and total plant N uptake (Table 2). In addition, a tillage X N rate interaction was observed for total plant N and for seed N, but no significant difference in stalk N uptake was observed (Table 2). In this year, strip-till resulted in increased seed and total plant N uptake compared with the other tillage treatments. Unlike the yield response for seed and biomass, a significant regression line was found for all of the tillage treatments for N uptake when regressed across N application rates (Table 4), indicating that reduced yield response observed in the subsoil and complete tillage treatments was not a result of N availability.

Results from the regression analyses indicated that plant N uptake was similar at the 0 kg N ha^{-1} rate for all tillage treatments, but increased with more N fertilization in strip-till than in the other tillage treatments (Fig. 5). Similar results were observed from fertilizer N contribution (^{15}N data), with fertilizer N in the seed and total plant being significantly increased using strip-till than the other tillage treatments (Table 8). This indicated that, even though higher N immobilization is expected with conservation tillage (Kitur et al., 1984; Rice and Smith, 1984). the strip-till treatment with surface residues made better utilization of fertilizer N.

No-traffic resulted in increased levels of fertilizer N contributing to total plant N uptake in 1991 (^{15}N data) (Table 9). In this year, fertilizer N uptake was higher in both seed and stalk as a result of no-traffic. In addition, a significant traffic x N application rate interaction for

Table 8. Effect of tillage system† on fate of fertilizer N applied at 90 kg N ha^{-1} in cotton calculated from ^{15}N data, 1990 and 1991.†

	N fertilizer uptake			
	Complete	Strip-till	Subsoil	Surface-only
	kg ha^{-1}			
	1990			
Stalk	12.4 a‡	12.0 a	12.1 a	13.2 a
Seed	10.3 a	14.0 a	11.2 a	11.2 a
Total plant	22.7 a	26.0 a	23.3 a	24.5 a
Remaining in soil	29.0 a	21.0 a	29.6 a	29.2 a
Total recovered	51.7 a	47.0 a	52.9 a	53.6 a
	1991			
Stalk	7.5 a	9.1 a	8.1 a	7.0 a
Seed	15.0 b	19.4 a	15.6 b	16.4 b
Total plant	22.5 b	28.5 a	23.6 b	23.4 b
Remaining in soil	24.9 a	24.6 a	29.6 a	26.9 a
Total recovered	47.4 a	53.1 a	53.2 a	50.3 a

† Values represent means of three replicates. Values within a row followed by the same letter do not differ significantly (0.10 level).
‡ Cotton tillage: complete = complete surface tillage with one-time only complete disruption of tillage pan; strip-till = no surface tillage but planted with in-row subsoiling; subsoil = complete surface tillage and annual in-row subsoiling; surface-only = complete surface tillage without subsoiling.

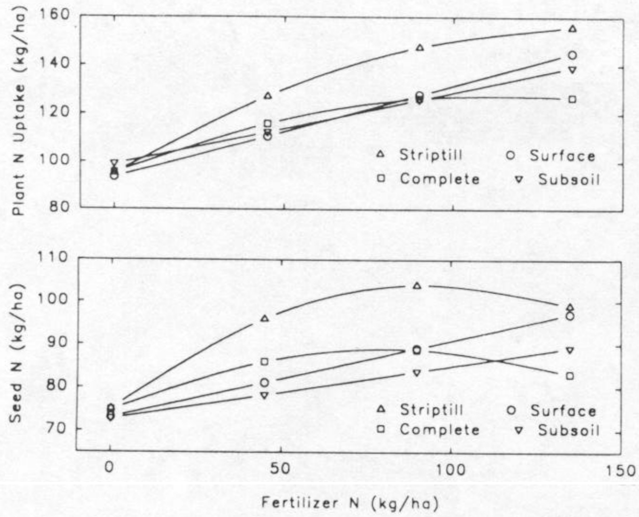

Fig. 5. Effect of tillage system and N application rate on cotton seed N uptake and total plant N uptake in 1991. Cotton tillage systems were: surface-only = surface tillage without subsoiling; subsoil = surface tillage and annual in-row subsoiling; complete = surface tillage with one-time only complete disruption of tillage pan; strip-till = no surface tillage but planted with annual in-row subsoiling.

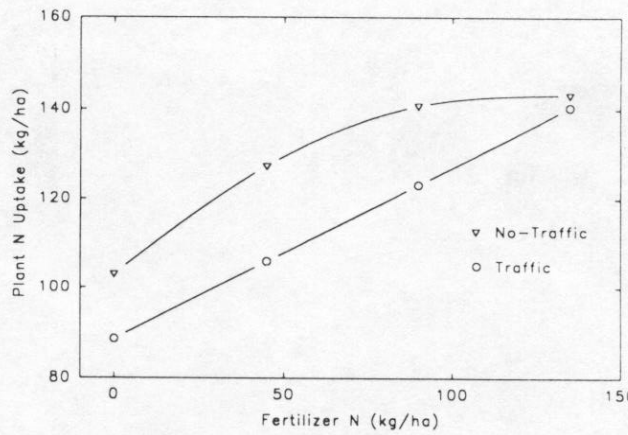

Fig. 6. Effect of traffic on total plant N uptake at harvest in 1991.

total N uptake was observed, with similar trends in both seed and stalk (Table 2). Regression analysis indicated that traffic reduced N uptake compared with no-traffic at every N application rate, including the 0 kg N ha^{-1} rate (Table 4, Fig. 6). This suggests (as evidenced in penetrometer data, Raper et al., 1992) that physical restraints on plant rooting were responsible for N uptake reductions in the traffic treatments.

A significant traffic X tillage interaction occurred for cotton N uptake, similar to the trends observed for yield components of cotton (Table 2). The detrimental effect of traffic on N uptake was much reduced in the strip-till treatment compared with the other tillage treatments (Table 10), with a plant fertilizer N uptake efficiency in the strip-till of 28.4%. compared with 20.7% for surface-only in the traffic treatment (calculated from ^{15}N in plant/^{15}N applied, Table 8). These results are consistent with penetrometer and soil bulk density data, indicating that soil strength measurements for strip-tillage plots were reduced compared with the other tillage treatments (Raper et al., 1992). This effect is most likely a result of both a reduction in the number of traffic trips needed for strip-till as well as an increase in the bearing capacity (Reeves et al., 1992) of soil when conservation tillage practices are used. This indicates that the detrimental effect of traffic on N efficiency may be reduced if conservation tillage practices are used on these sandy Coastal Plain soils.

Total N in the top 15 cm of soil was increased in the strip-till treatment compared with the other tillage treatments in both years, with strip-till having 1714 kg N ha^{-1} in 1990 and 1380 kg N ha^{-1} in 1991, compared with 1342 kg N ha^{-1} in 1990 and 1021 kg N ha^{-1} in 1991 in the surface-only tillage treatment. This was most likely due to higher levels of N immobilization in the strip-till plots, as commonly reported for conservation tillage practices (Gilliam and Hoyt, 1987).

While tillage and traffic treatments resulted in changes in plant and soil levels of N, no significant difference was observed for fertilizer N remaining in the soil down to 90 cm or in total fertilizer N recovery (plant + soil fertilizer N, ^{15}N data) in either 1990 or 1991 (Table 7). Similar results were reported by Carter and Rennie (1985) for spring wheat grown in a ^{15}N study. with no differences in fertilizer N recovery in the plant-soil system due to tillage. In addition, while plant N uptake in

Table 9. Effect of traffic on fate of fertilizer N applied at 90 kg N ha^{-1} in cotton calculated from ^{15}N data, 1990 and 1991.

	N fertilizer uptake	
	No traffic	Traffic
	kg ha^{-1}	
	1990	
Stalk	12.1 a†	11.3 a
Seed	12.4 a	12.4 a
Total plant	24.6 a	23.7 a
Remaining in soil	30.8 a	23.5 a
Total recovered	55.4 a	47.2 a
	1991	
Stalk	9.3 a	6.6 b
Seed	18.2 a	15.0 b
Total plant	27.5 a	21.6 b
Remaining in soil	26.4 a	26.6 a
Total recovered	53.8 a	48.1 a

† Values represent means of three replicates. Values within a row followed by the same letter do not differ significantly (0.10 level).

Table 10. Traffic and tillage system effect on total plant N uptake, 1991.†

	Total N uptake	
Tillage‡	No traffic	Traffic
	kg ha^{-1}	
Complete	120.5	112.1
Strip-till	133.7	129.4
Subsoil	128.4	110.1
Surface-only	132.0	106.7
LSD (0.10-any two means) = 21.2		
LSD (0.10-within traffic) = 10.8		

† Values represent means of four replicates.
‡ Cotton tillage: complete = complete surface tillage with one-time only complete disruption of tillage pan; strip-till = no surface tillage but planted with in-row subsoiling; subsoil = complete surface tillage and annual in-row subsoiling; surface-only = complete surface tillage without subsoiling.

both seed and stalk was increased with increased N application in the wet 1991 year compared with 1990, only marginal increases in plant N could be attributed to fertilizer N application at the 90 kg N ha^{-1} application rate (^{15}N data, Table 8). This is an indication that most of the yield and N uptake response to tillage and traffic was due to changes in native soil N and not to dynamics of N fertilizer application.

CONCLUSIONS

Results from this study indicate that the effect of tillage and traffic on cotton production is variable depending on the moisture condition during the growing season. While no-traffic reduced seed cotton yield under extremely dry growing conditions, it increased N uptake and seed cotton yield when moisture conditions were adequate. In addition, results indicate that the detrimental effect of traffic on plant N uptake efficiency may be reduced with conservation tillage systems on sandy soils. The results from both fertilizer N rate application and ^{15}N data indicated that most of the N uptake response to tillage and traffic was due to changes in native soil N and not to the dynamics of fertilizer N. As a result. these data indicate that higher fertilizer N application rates may not be required for conservation tillage practices such as strip-till on Coastal Plain soils.

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