TILLAGE AND CROPPING SYSTEMS

Tillage and Poultry Litter Application Effects on Cotton Growth and Yield

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ABSTRACT

Although use of no-tillage in cotton (*Gossypium hirsutum* L.) pro duction in the southeast USA has dramatically increased recently, reports of reduced seedling emergence, poor plant establishment, re duced growth, delayed maturity, and low yields still constrain adop tion. The objective of this study was to evaluate the effect of tillage systems on growth and yield of cotton grown in rotation with a winter rye (*Secale cereale* L.) cover crop with poultry litter and ammonium nitrate fertilizer application in north Alabama. Results from 1996 to 2001 are reported in this paper. Treatment factors were three tillage systems, two cropping systems, two N sources, and four N levels. Winter rye cover cropping increased surface residue cover by up to 35, 70, and 100% in conventional tillage, mulch tillage, and no-tillage systems, respectively. Despite initial differences in rate of seedling emergence, final seedling establishment averaged 10 seedlings m^{-1} in all treatments. At the rate of 100 kg N ha^{-1}, the effect of poultry lit ter on cotton growth and yield parameters was generally lower or similar to that of ammonium nitrate at the rate of 100 kg N ha^{-1}. However, at 200 kg N ha^{-1}, poultry litter improved cotton growth and lint yield compared with ammonium nitrate at 100 kg N ha^{-1} or poultry litter at 100 kg N ha^{-1}. Cotton lint yields averaged over all treatments ranged from 1128 to 1405 kg ha^{-1} over the study period. With adequate N fertility from poultry litter, no-tillage and mulch tillage systems with winter rye cover cropping are ideal for cotton production in the southeast USA.

ADOPTION OF NO-TILLAGE cotton production in the southern U.S. states has increased from about 254 000 ha in 1998 to 784 000 ha in 2002 (CTIC, 2002). Conservation tillage cotton acreage nearly tripled in Alabama and Georgia during this period. A survey by the National Cotton Council of America reported that 57% of the total cotton hectarage in the southeast USA was under no-tillage, which resulted in an average sav ings of $50.03/ha ($20.13/acre) for fuel and labor com pared with conventional tillage (Natl. Cotton Counc. of Am., 2003).

Problems that have been reported with no-tillage cot ton include soil compaction, poor seedling emergence, poor plant establishment, stunted growth, and reduced yields (Reddy et al., 1994; Schertz and Kemper, 1994; Raper et al., 2000; Schwab et al., 2002). There are a number of factors that make no-tillage perform differ ently on cotton compared with other crops such as wheat

(*Triticum* spp.), corn (*Zea mays* L.), and soybean [*Gly cine max* (L.) Merr.], which generally have had success with no-tillage. Cotton does not produce enough resi dues to supply the C necessary to increase soil organic matter and improve soil tilth in the seed zone (Reeves, 1997). In addition, cotton residues do not last long after harvest to protect the soil from erosion and reduce loss of soil moisture from evaporation. Therefore, without additional residues to supplement cotton residues, soils under no-tillage cotton may develop a crust at the sur face and a compacted layer in the top 5 to 10 cm.

The inclusion of winter cover crops in no-tillage cot ton production systems can provide crop residues to make conservation tillage cotton production systems comply with the standards set by the Natural Resource Conservation Service (Bauer and Busscher, 1996; Dan iel et al., 1999). The benefits of additional residues from the cover crops include improving soil water retention, increasing soil organic matter, and reducing soil erosion (Schertz and Kemper, 1994; Bradley, 1993; Nyakatawa et al., 2001). Winter cover crops may also reduce nitrate leaching to the groundwater by picking up excess nutri ents remaining from the summer cotton crop (Brandi-Dohrn et al., 1997; Logsdon et al., 2002). The attributes that make winter rye a superior cover crop over legumes include vigorous growth, winter hardiness, early spring growth, herbicide sensitivity, and mulch persistence (Brown et al., 1985). Rye is a better cover crop than wheat in the Tennessee Valley due to better allelopathic weed control and more growth with a later planting date (Reeves, personal communication, 2004).

Crop rotations of different genus or species improve soil fertility, reduce erosion, reduce the buildup of pests, and increase net profits. Corn, which is an important crop for the southeast USA, can be grown as a summer crop in rotation with cotton to break the life cycles of ma jor cotton insect pests and diseases. Corn also supplies ad ditional residues to increase soil organic matter in conser vation tillage cotton production systems (Reeves, 1997). Cotton, corn, and winter rye, which are dicot, monocot, and monocot respectively, have root systems that com pliment each other in nutrient uptake when grown in rotation, thereby making them more efficient in using soil nutrients. This may reduce the buildup of excess nutrients such as P, which is associated with application of poultry litter based on N content.

Application of poultry litter as a source of N and P has been shown to increase yields of crops such as corn and pastures (Sims, 1986; Ma et al., 1999). Furthermore, our studies have shown that poultry litter improves soil chemical properties compared with inorganic sources of N such as ammonium nitrate (Nyakatawa et al., 2001).

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Table 1. List of treatments used in the cotton study, Belle Mina, AL, 1996 to 2001.

Treatment no.	Tillage system	Cropping system		N source	N rate
		Summer	Winter		
					kg ha^{-1}
1	Conventional till	cotton	rye	none	0
2	Conventional till	cotton	cotton	ammonium nitrate	100
3	No-till	cotton	cotton	ammonium nitrate	100
4	Conventional till	cotton	rye	ammonium Nitrate	100
5	Conventional till	cotton	rye	poultry litter	100
6	Mulch till	cotton	rye	ammonium nitrate	100
7	Mulch till	cotton	rye	poultry litter	100
8	No-till	cotton	rye	ammonium nitrate	100
9	No-till	cotton	rye	poultry litter	100
10	No-till	cotton	cotton	none	0
11	No-till	cotton	rye	poultry litter	200
12	None	fallow	fallow	none	0

The southeast USA produced in excess of 3 billion broilers in the year 2001 (USDA Natl. Agric. Stat. Serv., 2002), generating in excess of 2.5 billion kg of litter. Therefore, application of poultry litter to cotton will provide an environmentally sustainable way of disposing of the large quantities of waste in this region.

The objective of this study was to evaluate the effect of tillage systems on growth and yield of cotton grown in rotation with a winter rye cover crop with poultry litter and ammonium nitrate fertilizer application in north Alabama.

MATERIALS AND METHODS

Study Location

A field study was conducted at the Alabama Agricultural Experiment Station, Belle Mina, AL (34°41′N, 86°52′W) on a Decatur silt loam soil (clayey, kaolinitic thermic, Typic Paleudults) from 1996 to 2001.

Treatments and Experimental Design

Treatments consisted of three tillage systems: conventional tillage, mulch till, and no-tillage; two cropping systems: cotton in summer and fallow in winter and cotton in summer and rye in winter; three N levels: 0, 100, and 200 kg N ha^{-1}; and two N sources: ammonium nitrate and poultry litter. Ammonium nitrate was used at one N rate (100 kg N ha^{-1}), which is the recommended rate for cotton in the Tennessee Valley region (Table 1). The experimental design was an incomplete factorial treatment arrangement in a randomized complete block design with four replications. Plot size was 8 m wide and 9 m long, which resulted in eight rows of cotton spaced 1 m apart.

Conventional tillage was done using a moldboard plow in November and disking in April, followed by a field cultivator to prepare a smooth seedbed. In mulch tillage, a Lely rotary cultivator (Lely USA, Inc., Naples, FL) was used to destroy and partially incorporate crop residues to a depth of 5 to 7 cm before planting. No-tillage included planting into untilled soil using a Tye (Glascock Equipment and Sales, Veedersburg, IN) no-till planter. During the season, a row cultivator was used for controlling weeds in the conventional tillage system while spot applications of glyphosate [isopropylamine salt of N-(phosphonomethyl) glycine] were used to control weeds in the no-tillage and mulch tillage systems.

Amounts of poultry litter to supply 100 and 200 kg N ha^{-1} were calculated for application each year based on the N content of the poultry litter. The N content of the poultry litter, which ranged from 27 to 35 g kg^{-1}, was determined by digestion of 0.5-g samples using the Kjeldahl wet digestion method (Bremner and Mulvaney, 1982) followed by N analysis using the Kjeltec 1026 N Analyzer (Tecator, Hoganas, Sweden). A 60% adjustment factor was used to compensate for the N availability from poultry litter during the first year (Keeling et al., 1995). The litter was broadcast by hand and incorporated to a depth of 5 to 8 cm by preplant cultivation in conventional tillage and mulch tillage systems, whereas in the no-tillage system, it was not incorporated. The ammonium nitrate and poultry litter were applied to the plots 1 d before cotton planting. Before planting, the experimental plots received a blanket application of a 336 kg ha^{-1} of a 0–20–20 fertilizer each year from 1996 to 1999, 112 kg ha^{-1} of a 0–0–60 fertilizer in 2000, and 224 kg ha^{-1} of 5–20–20 fertilizer in 2001 and 2002 to minimize the effects of P and K applied through poultry litter.

Cropping Scheme and Planting Methods

The cropping scheme, varieties, planting dates, and seeding rates, for the cotton, corn, and winter rye crops are presented in Table 2. The winter rye cover crop, variety 'Oklon', was planted in fall and killed with glyphosate herbicide about 7 d after flowering in spring of 1997, 1998, 2000, and 2001. The time between killing of winter rye and cotton planting was about 4 wk in each year (Table 2). A no-tillage grain drill was used to plant the rye cover crop at 60 kg ha^{-1}. The cover crop did not receive any fertilizer to enable it to "scavenge" residual soil nutrients and incorporate them as aboveground biomass during the winter season (when they are susceptible to runoff or leaching losses).

A herbicide mixture of pendimethalin [N-(1-ethylpropyl)-3,4-dimethyl-2-6,-dinitrobenzenamine] at 2.3 L ha^{-1}, fluometuron [1,1- dimethyl-3-(α,α,α-trifluoro-m-tolyl) urea] at 3.5 L ha^{-1}, and paraquat (1,1′-dimethyl-4,4′-bipyridinium ion) at 1.7 L ha^{-1} was sprayed on all plots before planting for weed

Table 2. Cropping scheme, varieties, planting dates, seeding rates, and harvest dates of cotton, winter rye, and corn crops, Belle Mina, AL, 1996 to 2001.

Season	Year	Crop	Variety	Planting date	Seeding rate	Harvest date
Fall	1996	winter rye	Oklon	4 Dec. 1996	60 kg ha^{-1}	
Spring	1997	winter rye				8 Apr. 1997
Summer	1997	cotton	DPL 33B	8 May 1997	16 kg ha^{-1}	4 Nov. 1997
Fall	1997	winter rye	Oklon	24 Nov. 1997	60 kg ha^{-1}	
Spring	1998	winter rye				6 Apr. 1998
Summer	1998	cotton	DPL 33B	5 May 1998	16 kg ha^{-1}	30 Sept. 1998
Summer	1999	corn	Dekalb 687	29 Mar. 1999	75 000 plants ha^{-1}	13 Sept. 1999
Fall	1999	winter rye	Oklon	Nov. 1999	60 kg ha^{-1}	
Spring	2000	winter rye				7 Apr. 2000
Summer	2000	cotton	Stoneville 4892B	19 May 2000	16 kg ha^{-1}	4 Oct. 2000
Fall	2000	winter rye	Oklon	Nov. 2000	60 kg ha^{-1}	
Spring	2001	winter rye				12 Apr. 2001
Summer	2001	cotton	Stoneville 4892B	30 Apr. 2001	16 kg ha^{-1}	16 Oct. 2001

control. In addition, all plots received a band application of 5.6 kg ha^{-1} aldicarb [2-methyl-2-(methylthio)-propionaldehyde *O*-(methylcarbamoyl)oxime] for the early-season control of thrips (*Frankliniella* spp. Karny). The growth regulator mepiquate chloride (1,1-dimethyl-piperidinium chloride), at 0.8 kg ha^{-1}, was applied to all cotton plots to reduce vegetative growth at about 2.5 mo after planting. The cotton was defoliated with a mixture of ethephon [(2-chroroethyl) phosphoric acid] and cyclanilide [1-(2,4-dichlorophenylaminocarbononly) cyclopropane carboxylic acid] at 2.3 L ha^{-1} and *S,S,S*-tributyl phosphorotrithioate at 0.6 kg ha^{-1} 2 wk before the first harvest.

Data Collection

Immediately after cotton seeding in each year, surface residue cover was measured in all plots using the Camline transect method (Reddy et al., 1994). During the first 4 d of cotton seedling emergence, soil temperature, volumetric soil water content, and seedling counts were determined daily in each plot. Soil temperature and volumetric soil water in the top 7 cm of soil were determined around midday by taking an average of four readings randomly from each plot, one block at a time, using Weksler soil thermometers (Weksler Instrument Corp., Freeport, NY) and the Delta T soil water probe (Delta-T Devices, Cambridge, England), respectively.

Cotton data collected were days to squaring, days to flowering, days to maturity, plant height, leaf area index, canopy cover, surface root biomass, number of squares per plant, number of bolls per plant at harvest, leaf N concentration, shoot biomass, and seed cotton yield. Aboveground biomass data were collected for winter rye. Data on plant height, number of squares per plant, and number of bolls per plant of cotton were taken on three randomly selected plants from each of the central four rows of each plot. Leaf area index was measured from the central four rows of each plot using the AccuPAR linear ceptometer (Decagon Devices, Pullman, WA).

Canopy cover was determined by measuring the width of the crop canopy of each row from the four central rows on each plot using a ruler and expressing the figure as a percentage of the row width. Shoot and root biomass were determined by sampling plants with their roots intact from 0.5-m^2 quadrats from each plot. Roots in the top 10 cm of the soil were extracted by removing soil from both sides of the row and lifting the intact plants from the base with a garden fork. The roots were cut from the shoots and washed in water to remove the soil. The shoot and root samples were oven-dried to constant weight at 65°C for 72 h. Data for plant height, leaf area index, canopy cover, surface root biomass (top 10 cm of the soil), leaf N concentration, and shoot biomass were taken at 50% flowering.

Leaf N concentration was determined by sampling a total of 15 fully developed leaves just below the growing tip on main branches of three plants in the central four rows. The leaves were washed in 0.3% v/v detergent solution and then rinsed with distilled water to remove dust and any other surface contaminants. After rinsing, the leaves were dried in a laboratory oven at 65°C for 72 h, after which they were ground to pass through a 2-mm sieve using a Wiley mill (A.H. Thomas Co., Philadelphia, PA). Total N concentration of the samples was determined by digesting 0.1 g of plant material with 5-mL mixture of 350 mL of concentrated H_2SO_4, 420 mL of 30% H_2O_2, 0.42 g of Se powder, and 14 g of $LiSO_4$ (Bremner and Mulvaney, 1982), followed by analysis using an automated Kjeltec 1026 Analyzer (Tecator, Hoganas, Sweden).

Seed cotton yield was determined by mechanically harvesting open cotton bolls in the central four rows of each plot. The seed cotton was weighed and sent to a nearby gin where the percentage cotton lint (ginning percentage) was determined. Lint yield data for the treatments were determined by multiplying the seed cotton yield by a ginning percentage of 40%. Weather data were taken from an automatic weather station at the Experiment Station.

Data Analysis

The data were statistically analyzed using General Linear Model procedures of the Statistical Analysis System (Version 8e; SAS Inst., 2001). Due to the incomplete factorial treatment arrangement used in the study, Treatments 2, 3, 4, and 8 were analyzed separately to evaluate tillage × cropping system interaction. Similarly, Treatments 4, 5, 6, 7, 8, and 9 were analyzed separately to evaluate tillage × N source interaction. Treatment means for main of effect tillage, main effect of cropping systems, and tillage × N source interaction were compared using the least significant difference (LSD) mean separation procedure. Duncan's multiple range test was used to statistically separate the full set of treatment means, which were used to make specific treatment mean comparisons. Correlation analysis was used to determine the association of surface residue cover to cotton growth and yield parameters.

RESULTS AND DISCUSSION

Weather Data

Total monthly rainfall data at the experimental site during 1996 to 2002 are presented in Table 3. Critical months for cotton growth are May (planting and seedling establishment), June (squaring and flowering), July (flowering and boll setting), and August (boll development and maturity). A monthly rainfall mean for 70 yr

Table 3. Total monthly rainfall during the experiment, Belle Mina, AL, 1996 to 2002.

Month	Year								
	1996	1997	1998	1999	2000	2001	2002	Mean	70-yr mean
	mm								
Jan.	214.5	174.6	217.5	328.2	27.0	182.4	146.1	168.4	153.0
Feb.	74.1	129.9	194.4	93.6	78.0	147	70.5	95.0	146.1
Mar.	213	101.1	128.7	152.4	164.1	172.5	165.3	160.3	183.0
Apr.	163.5	120.9	129.6	115.2	257.4	115.8	45.9	150.4	129.9
May	49.5	108.3	73.2	140.7	21.9	191.7	307.5	202.5	122.9
June	99.6	195.0	54.0	195.6	123.0	262.5	26.4	90.7	122.4
July	128.4	50.7	158.7	109.2	22.2	128.4	135.9	117.8	111.0
Aug.	141.6	120.6	54.3	5.7	79.5	104.7	49.8	67.1	132.9
Sept.	242.1	175.5	25.8	16.8	51.3	166.5	159.3	136.2	104.1
Oct.	76.8	228.9	41.1	36.9	0.6	114.3	95.7	89.4	108.9
Nov.	131.7	69.3	85.5	146.4	208.2	93.0	116.7	119.5	89.7
Dec.	136.5	127.5	249.6	89.7	132.3	190.8	185.7	170.1	158.4
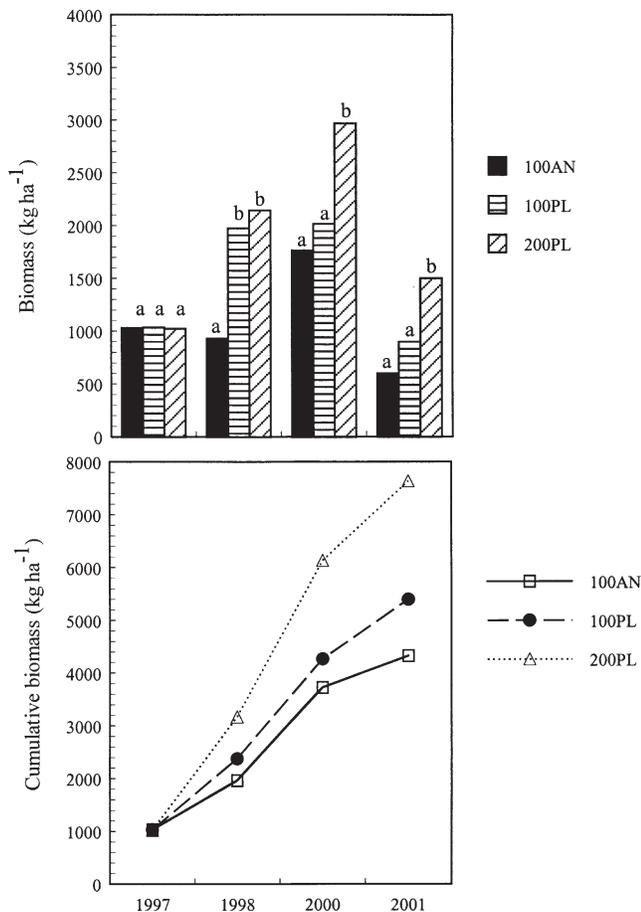
Fig. 1. Yearly and cumulative biomass yields of winter rye cover crop as influenced by ammonium nitrate (AN) and poultry litter (PL) N sources applied to cotton, Belle Mina AL, 1997 to 2001. (Means of yearly biomass for N treatments with the same letter are not significantly different at the 5% level.)

before the initiation of the study is presented for comparison. The years 1998, 2000, and 2001 had poor rainfall distribution for cotton. The years 1998 and 2000 were characterized by droughts in May or June and/or July while the year 2001 had excess rainfall over the same period.

Winter Rye and Surface Residue Cover

In 1998, winter rye biomass yield in plots that had received 100 and 200 kg N ha^{-1} in the form of poultry litter under cotton was 112 and 130% greater than that in plots that received 100 kg N ha^{-1} in the form of ammonium nitrate, respectively. Similar figures in 2000 were 14 and 68% greater, and those in 2001 were 50 and 150% greater, respectively (Fig. 1). Cumulative winter rye cover crop biomass yields due to application of 100 kg N ha^{-1} in the form of ammonium nitrate, 100 kg N ha^{-1} in the form of poultry litter, and 200 kg N ha^{-1} in the form of poultry litter treatments were 4329, 5402, and 7638 kg ha^{-1}, respectively (Fig. 1). The above data show that poultry litter application to cotton has more residual positive effects on the amount of biomass produced by the winter rye cover crop compared with ammonium nitrate when used at the same rate of 100 kg N ha^{-1}. The significance of these results is that since the winter rye cover crop is grown without additional fertilizer, it can scavenge residual N from the poultry litter, which would otherwise be susceptible to leaching during the winter and spring. The winter rye cover crop may also reduce sediment loss of P from the plots by tying P in plant biomass during the winter when there is no cotton.

There was a significant ($P < 0.001$) year × tillage × cropping system interaction on surface residue cover estimated immediately after cotton planting (Table 4). Surface residue cover immediately after cotton planting in conventional tillage with winter rye cover cropping was 20 and 13% in 1997 and 1998, respectively, compared with 1% in conventional tillage with winter fallow (Table 5). Similar values for 2000 and 2001 were 36 and 34%, respectively, in conventional tillage with winter rye cover cropping compared with an average of 5% in conventional tillage with winter fallow cropping. It was observed that crop residues from the rotational corn crop of 1999 were still present in all the plots, especially in no-tillage plots in 2000 and 2001. This explains the increase in surface residue cover from 1% in 1997 and 1998 to an average of 5% in 2000 and 2001 under conventional tillage with winter fallow cropping and the 80% increase in surface residue cover under conventional tillage with winter rye cover cropping during the same period. Similarly, residue coverage in no-tillage with winter fallow cropping increased from 8 and 34% in 1997 and 1998, respectively, to a mean of 88% in 2000 and 2001, respectively (Table 5), due to carryover residue from the corn crop. In mulch till plots where the crop residues were partially incorporated, there was

Table 4. Mean square values showing the effect of year, tillage, cropping systems, and their interactions (Treatments 2, 3, 4, and 8) on surface residue cover (SRC) and cotton growth and yield parameters, Belle Mina, AL, 1996 to 2001.

Source of variation	SRC (%)	Seedlings counts	Height (cm)	Leaf area index	Bolls per plant	Yield (kg ha^{-1})
			mean square			
Year	2 959***	14***	3040***	7***	62*	306 953***
Tillage	63 353***	<1	24	<1	47	163 409*
Cropping	14 499***	<1	30	4**	152**	28 148
Year × tillage	792***	<1	210*	<1	19	80 682
Year × cropping	1 137***	2.4	66	<1	24	21 283
Tillage × cropping	2 139***	3.7	<1	2*	143**	53 214
Year × tillage × cropping	2 317***	0.8	131	<1	8	17 972

* Significant at the 0.05 probability level.
** Significant at the 0.01 probability level.
*** Significant at the 0.001 probability level.

no significant increase in surface residue cover in 2000 and 2001 after the rotational corn crop of 1999. However, mean surface residue cover for mulch tillage were not compared with those of conventional till and no-tillage due to unbalanced treatment factors.

Halvorson et al. (2002) also found that surface crop residues increased with time under no-tillage with corn rotations due to carryovers from year to year, but their findings were in a drier, cooler climate in Colorado. It is interesting that we found similar results in a thermic humid regime. In a corn study in southern Ontario, Beyaert et al. (2002) recorded 6 to 12% surface residue cover in conventional tillage and 78 to 88% surface residue cover in no-tillage. In each of the 4 yr of our study, surface residue cover under mulch tillage with winter rye cropping, no-tillage with winter fallow cropping, and no-tillage with winter rye cropping was significantly greater than that under conventional tillage with winter fallow cropping.

The additional residues from corn in 1999 made conventional tillage with winter rye cover cropping marginally qualify as a conservation tillage system in 2000 and 2001, meeting the Conservation Tillage Information Center (CTIC, 1994) definition of a minimum of 30% soil residue cover required after planting (Table 5). According to Moldenhauer et al. (1983), a minimum of 20% soil surface cover is required for a substantial reduction in soil erosion. In our study, this percentage of soil surface cover was achieved in mulch tillage with winter rye cropping and no-tillage with winter rye cropping in all the years, whereas in conventional tillage with winter rye cover cropping, it was achieved in 1997, 2000, and 2001 (Table 5). In 1997, this result was due to very good winter rye cover crop growth, whereas in 2000 and 2001, it was largely attributed to carryover residue from the rotational corn crop of 1999. Peterson et al. (1998) reported that using corn in no-tillage systems increases the amount of total C remaining in crop residue form.

There was a significant ($P < 0.05$) tillage × N source interaction on surface residue cover immediately after cotton planting (Table 6). In conventional tillage system, where crop residues were incorporated into the soil, application of 100 kg N ha^{-1} in the form of poultry litter increased surface residue cover to 30% compared with 23% for 100 kg N ha^{-1} in the form of ammonium nitrate (data not shown). However, in mulch tillage and no-tillage systems, where crop residues were either partially incorporated into the soil (mulch tillage) or not incorporated at all (no-tillage), there was no improvement in surface residue cover due to application of poultry litter compared with ammonium nitrate. This was expected since a greater proportion of the soil surface would already be covered with crop residues under mulch tillage and no-tillage systems and should not be taken to imply that application of poultry litter did not increase the amount of residues left on the soil surface in mulch tillage and no-tillage system.

Our results suggest that surface application of poultry litter instead of ammonium nitrate can offer further protection to the soil against erosion in a conventional tillage system. Although there was no increase in surface residue cover due to poultry litter application in mulch tillage and no-tillage systems, previous research has shown that poultry litter significantly reduced soil erosion in mulch tillage and no-tillage systems (Nyakatawa et al., 2001). Surface residue cover significantly correlated with number of cotton bolls per plant ($r = 0.36$ to 0.49), biomass yield ($r = 0.35$ to 0.52), and lint yield ($r = 0.30$ to 0.33).

Cotton Seedling Emergence and Establishment

Inadequate cotton seedling emergence and establishment and consequently variable crop stands have been blamed for poor adoption of conservation tillage in cot-

Table 5. Surface residue cover (SRC) measured immediately after cotton planting in conventional till, mulch tillage, and no-tillage systems under cotton followed by winter fallow (WF) and cotton followed by winter rye (WR) cropping systems, Belle Mina, AL, 1997 to 2001.

Year	Conventional till		No-tillage		Mulch tillage
	WF	WR	WF	WR	WR
			SRC, %		
1997	1a†A‡	20cA	8bB	100dB	65§
1998	1aA	13bA	34cB	91dB	51
2000	5aA	36bA	87cB	100bB	69
2001	6aA	34bA	88cB	99dB	69

† Means for WF and WR cropping system under conventional till and no-tillage systems in each year followed by the same lowercase letter are not significantly different from each other at the 5% level.
‡ Means for conventional tillage and no-tillage systems under WF or WR cropping systems in each year followed by the same uppercase letter are not significantly different from each other at the 5% level.
§ Means for mulch tillage system were not included in the treatment interaction analysis and are given here for information purposes.

Table 6. Mean square values showing the effect of year, tillage, N source, and their interactions (Treatments 4, 5, 6, 7, 8, and 9) on surface residue cover (SRC) and cotton growth and yield parameters, Belle Mina, AL, 1996 to 2001.

Source of variation	SRC (%)	Seedlings counts	Height (cm)	Leaf area index	Bolls per plant	Yield (kg ha^{-1})
				mean square		
Year	2 083***	26*	3156***	18***	3	366 975***
Tillage	37 696***	4	111	5***	28	55 688*
N source	109	2	3075***	23***	576***	113 679*
Year × tillage	224	4*	382***	<1	66**	29 003
Year × N source	16	2	422**	5***	38	67 175*
Tillage × N source	608*	4	186	<1	100**	123 024**
Year × tillage × N source	92	1	93	<1	6	15 224

* Significant at the 0.05 probability level.
** Significant at the 0.01 probability level.
*** Significant at the 0.001 probability level.

Table 7. Cotton seedling counts per meter of row in conventional till, mulch tillage, and no-tillage systems under cotton, Belle Mina, AL, 1997 to 2001.

Year	Tillage systems		
	Conventional tillage	No-tillage	Mulch tillage
	seedling counts per meter of row		
1997	10c†	10c	10‡
1998	8a	8a	7
2000	9b	9b	9
2001	10c	10c	11

† Means for year under conventional tillage or no-tillage system followed by the same letter are not significantly different from each other at the 5% level.

‡ Means for mulch tillage system were not included in the treatment interaction analysis and are given here for information purposes.

ton production for the southeastern USA (Schertz and Kemper, 1994). There was a significant ($P < 0.05$) year × tillage system interaction on cotton seedling counts (Table 6). Cotton seedling counts under conventional tillage averaged over cover cropping systems and N treatments were similar to those under no-tillage and mulch tillage systems in each year of study (Table 7). In 1998 and 2000, which received below-average rainfall during seedling emergence, cotton seedling counts were significantly lower than those in 1997 and 2001 irrespective of the tillage system. A similar trend was observed under mulch tillage system (Table 7). In addition, daily monitoring of cotton seedling emergence showed that the rate of emergence in no-tillage system was significantly greater than that in conventional tillage. Also, in plots which received 100 kg N ha^{-1} in the form of poultry litter and 200 kg N ha^{-1} in the form of poultry litter, rate of seedling emergence was significantly greater than that in plots that did not receive N and in plots that received 100 kg N ha^{-1} in the form of ammonium nitrate in all years. This was attributed to higher volumetric soil moisture content in the top 7 to 10 cm of the soil (Nyakatawa and Reddy, 2000). The optimum number for cotton seedling establishment is about 10 plants m^{-1}. Our results show that final cotton seedling counts were in this optimum range in 1997 and 2001. In 1998 and 2000, when soil moisture was most limiting during seedling emergence, surface residue cover was positively correlated ($r = 0.38$ and $r = 0.20$) with final cotton seedling counts, which in turn were positively correlated to leaf area index, number of bolls per plant, biomass, and lint yield of cotton (data not shown).

## Cotton Growth and Yield Parameters

Plant Height

There was a significant ($P < 0.05$) year × tillage system and year × N source ($P < 0.01$) interaction on cotton plant height (Tables 4 and 6). In 1997, cotton plant height under no-tillage was 10 cm greater than that under conventional tillage (Fig. 2). This can be attributed to the fact that no-tillage improved cotton growth by conserving soil moisture during the drought period of July 1997. Cotton plant height for plants that received 100 kg N ha^{-1} in the form of ammonium nitrate was 20, 12, and 15 cm greater than plants in plots that
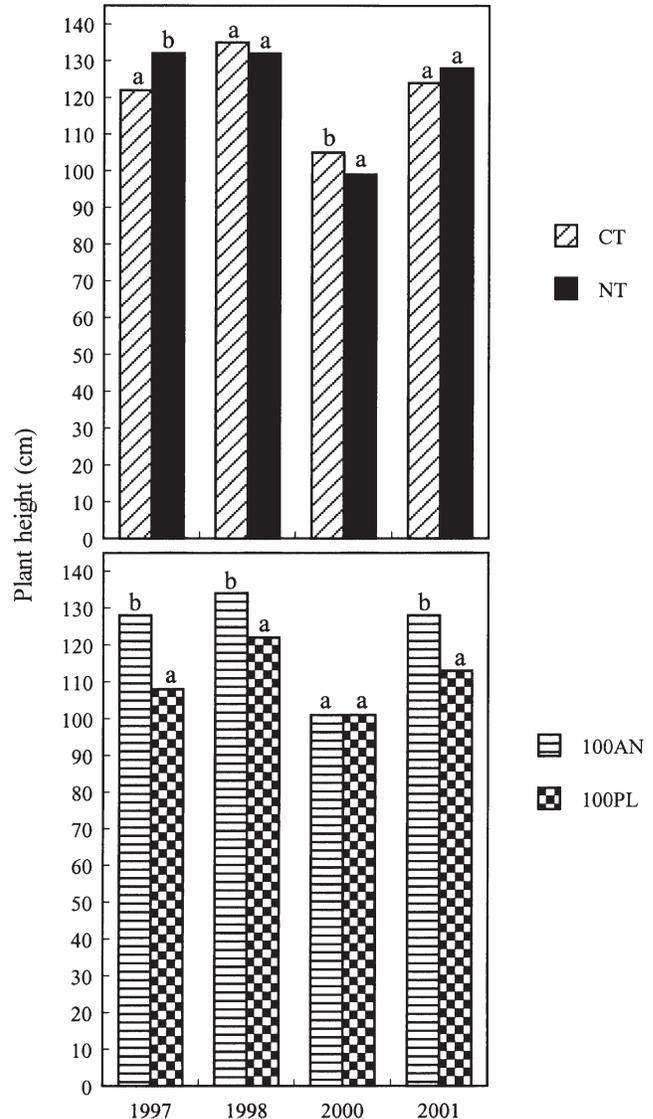
Fig. 2. Cotton plant height as influenced by conventional tillage (CT) and no-tillage (NT) systems and 100 kg N ha^{-1} in the form of ammonium nitrate (100AN) or poultry litter (100PL), Belle Mina AL, 1997 to 2001. (Means of tillage systems and N treatments for each year with the same letter are not significantly different at the 5% level.)

received 100 kg N ha^{-1} in the form of poultry litter in 1997, 1998, and 2001, respectively (Fig. 2). However, in 2000, there were no differences in plant height between plants that received 100 kg N ha^{-1} in the form of ammonium nitrate and those that received 100 kg N ha^{-1} in the form of poultry litter, which may indicate that poultry litter was able to compensate for the lower nutrient availability by conserving soil moisture during the dry spells of May and July.

Although the interaction between tillage system and N treatments for plant height was not significant, incorporation of crop residues in conventional tillage plots results in rapid immobilization of available inorganic N (Sinha et al., 1977; Green et al., 1995). Application of inorganic N in the form of ammonium nitrate can offset the effects N immobilization, whereas more time is
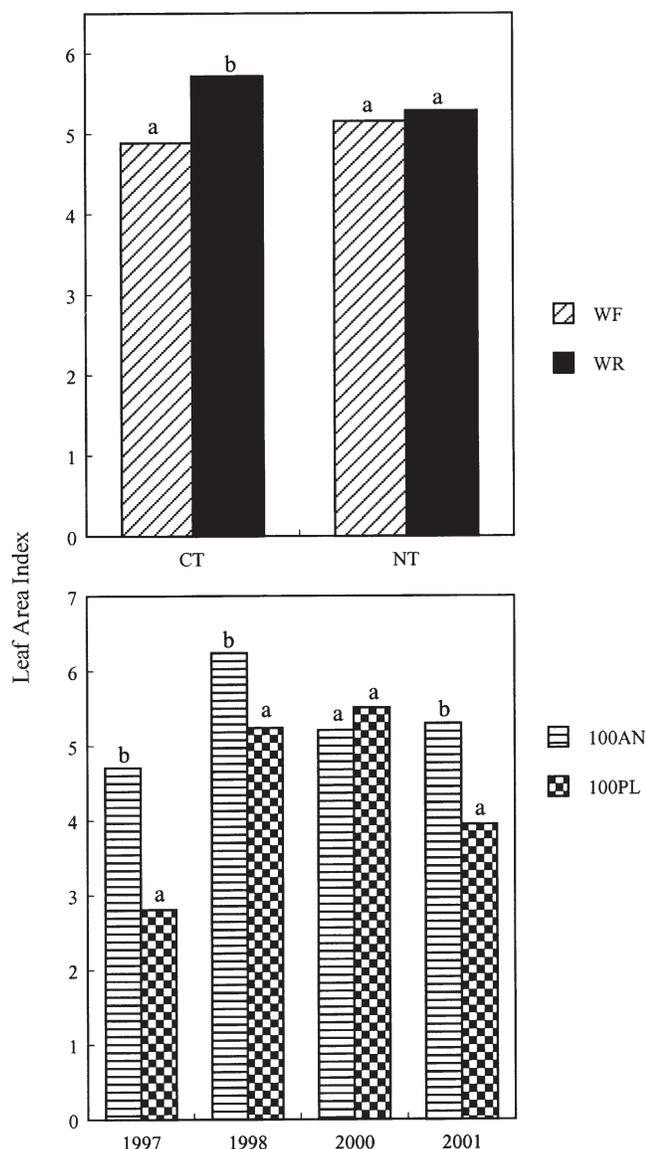
Fig. 3. Leaf area index of cotton as influenced by cotton followed by winter fallow (WF) and cotton followed by winter rye (WR) cropping systems in conventional tillage (CT) and no-tillage (NT) systems and as influenced by 100 kg N ha^{-1} in the form of ammonium nitrate (100AN) or poultry litter (100PL), Belle Mina AL, 1997 to 2001. (Means of WF and WR cropping systems within a tillage system and means of N treatments for each year with the same letter are not significantly different at the 5% level.)

needed for the N to be released when N is applied in the form of poultry litter. Plant height significantly correlated with number of bolls per plant ($r = 0.62$ to 0.75), biomass yield ($r = 0.60$ to 0.88), and lint yield ($r = 0.62$ to 0.99) over the 4-yr period, indicating that plant height is a good indicator of cotton productivity.

Leaf Area Index

There was a significant ($P < 0.05$) tillage $\times$ cropping system and year $\times$ N source ($P < 0.001$) interaction on cotton leaf area index at full bloom (Tables 4 and 6). In conventional tillage plots, cotton leaf area index was 5.80 with winter rye cover cropping compared with 4.80 without winter rye cover cropping (Fig. 3). However,

in no-tillage system with winter rye cover cropping, cotton leaf area index was 5.30, which was only 0.2 units higher compared with winter fallow cropping (Fig. 3). Cotton following winter rye had higher leaf area index compared with cotton after winter fallow, but the differences were not significant. Also, cotton leaf area index for cotton winter rye cropping system under conventional tillage was 0.5 units higher ($P < 0.05$) than that under no-tillage system. In the lower Mississippi River Valley, Pettigrew and Jones (2001) reported 17 to 42% lower cotton leaf area index in no-tillage compared with conventional tillage early in the season, but similar figures were recorded later in the season. Leaf area index for plants that received 100 kg N ha^{-1} in the form of ammonium nitrate was 1.90, 1.00, and 1.40 units greater than those for plants which received 100 kg N ha^{-1} in the form of poultry litter in 1997, 1998, and 2001, respectively (Fig. 3). Leaf area index is a good indicator of plant growth and soil conditions for plant productivity, and it positively correlated with number of bolls per plant ($r = 0.61$ to 0.67), biomass yield ($r = 0.60$ to 0.87), and lint yield ($r = 0.49$ to 0.95) of cotton.

Number of Bolls per Plant

There was significant tillage $\times$ cropping system ($P < 0.01$), tillage $\times$ N source ($P < 0.01$), and year $\times$ tillage ($P < 0.01$) interaction on number of cotton bolls per plant (Tables 4 and 6). In no-tillage system, winter rye cover cropping increased the number of cotton bolls per plant by 7 compared with cotton winter fallow cropping, which had 21 bolls per plant (Fig. 4). However, in conventional tillage, winter rye cover cropping did not have a significant effect on number of bolls per plant. Without rye cover cropping, no-tillage had a slightly lower number of bolls per plant compared with conventional tillage. These results are in agreement with those of Pettigrew and Jones (2001), who found 8% fewer bolls in no-tillage compared with conventional tillage. However, with rye cover cropping, no-tillage had, on average, six more bolls per plant compared with conventional tillage (Fig. 4), showing that rye cover cropping was essential to the reproductive development of cotton under no-tillage system.

In mulch tillage and no-tillage plots, plants that received 100 kg N ha^{-1} in the form of ammonium nitrate had nine and eight more ($P < 0.05$) bolls per plant compared with plants that received 100 kg N ha^{-1} in the form of poultry litter, respectively (Fig. 4). These results are consistent with that for plant height and leaf area index, which showed that the 100 kg N ha^{-1} in the form of ammonium nitrate performed better than the same rate of N in the form of poultry litter. No-tillage system had four and two more bolls per plant compared with conventional tillage system in 1997 and 2001, respectively (Fig. 4). Number of bolls per plant positively correlated with cotton biomass yield ($r = 0.41$ to 0.65) and lint yield ($r = 0.57$ to 0.71).

Lint Yield

There was significant year $\times$ N source ($P < 0.05$) and tillage $\times$ N source ($P < 0.01$) interaction on cotton lint
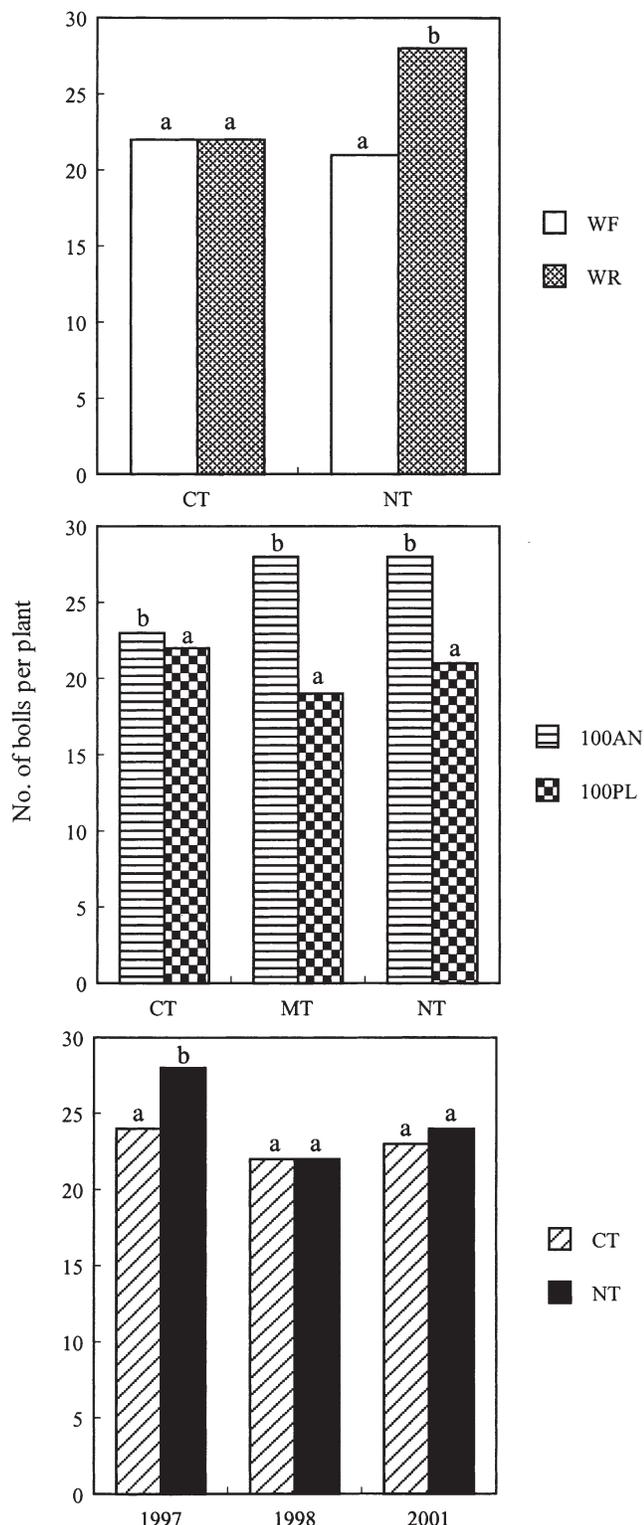
Fig. 4. Number of cotton bolls per plant as influenced by cotton followed by winter fallow (WF) and cotton followed by winter rye (WR) cropping systems in conventional tillage (CT) and no-tillage (NT) systems; 100 kg N ha⁻¹ in the form of ammonium nitrate (100AN) or poultry litter (100PL) treatments in CT, mulch tillage (MT), and NT; and CT and NT systems in 1997, 1998, and 2001, Belle Mina AL. (Means of WF and WR cropping systems within a tillage system, means of N treatments within a tillage system, and means of tillage systems for each year with the same letter are not significantly different at the 5% level.)

Table 8. Cotton lint yield as influenced by N sources under conventional tillage, mulch tillage, and no-tillage systems and years, Belle Mina, AL, 1997 to 2001.

	N sources	
	100 kg N ha⁻¹ ammonium nitrate	100 kg N ha⁻¹ poultry litter
	lint yield, kg ha⁻¹	
Tillage systems		
Conventional tillage	1246a†A‡	1321bA
Mulch tillage	1330bB	1183aA
No-tillage	1405bB	1271bA
Years		
1997	1296bB	1162aA
1998	1536cB	1354bA
2000	1332bA	1335aA
2001	1143aA	1181aA

† Means for tillage systems or years within a N source (in columns) followed by the same lowercase letter are not significantly different from each other at the 5% level.

‡ Means for N sources within a tillage system and year (in rows) followed by the same uppercase letter are not significantly different from each other at the 5% level.

yield (Table 6). In 1998, cotton lint yield in plots that received 100 kg N ha⁻¹ in the form of ammonium nitrate averaged 1536 kg ha⁻¹, which was 19, 15, and 34% greater than lint yields in 1997, 2000, and 2001, respectively (Table 8). In plots that received 100 kg N ha⁻¹ in the form of poultry litter, the highest lint yield was 1354 kg ha⁻¹ in 1998, which was 17 and 15% ($P < 0.05$) greater than lint yields in 1997 and 2001. This variation in yield responses in each year can be explained in terms of rainfall distribution during the months of May, June, and August. Table 9 shows that cotton lint yield in plots that received 100 kg N ha⁻¹ in the form of ammonium nitrate was negatively correlated to total rainfall with r values of -0.41 ($P < 0.004$), -0.59 ($P < 0.001$), and -0.49 ($P < 0.001$) in the months of May, June, and August, respectively. Similar correlation figures for cotton lint yield in plots that received 100 kg N ha⁻¹ in the form of poultry litter were $r = -0.34$ ($P < 0.01$), $r = -0.40$ ($P < 0.05$), and $r = -0.42$ ($P < 0.002$) in the months of May, June, and August, respectively (Table 9). These results clearly show that excess rainfall in the months of May, June, and July negatively impacted cotton lint yields.

Table 9. Pearson correlation coefficients between total rainfall in May, June, July, and August and cotton yield and growth parameters, Belle Mina, AL, 1997 to 2001.

	May rainfall	June rainfall	July rainfall	August rainfall
	100 kg N ha⁻¹ ammonium nitrate			
Seedling counts m⁻²	0.42**	0.56***	−0.08NS	0.39**
Height (cm)	0.52***	0.07NS	0.67***	0.03NS
Leaf area index	−0.10NS	−0.44***	0.50***	−0.60***
Bolls/plant	0.01NS	0.11NS	−0.24NS	0.21NS
Lint yield (kg ha⁻¹)	−0.41**	−0.59***	0.16NS	−0.49***
	100 kg N ha⁻¹ poultry litter			
Seedling counts m⁻²	0.30*	0.52***	−0.25NS	0.51***
Height (cm)	0.18NS	−0.16NS	0.51***	−0.25NS
Leaf area index	−0.61***	−0.57***	0.10NS	−0.74***
Bolls/plant	0.03NS	−0.04NS	0.18NS	0.01NS
Lint yield (kg ha⁻¹)	−0.34**	−0.40**	0.05NS	−0.42**

* Significant at the 0.05 probability level.
** Significant at the 0.01 probability level.
*** Significant at the 0.001 probability level.

Table 10. Treatment means for cotton yield in 1997, 1998, 2000, and 2001, Belle Mina, AL.

Year	1	2	3	4	5	6	7	8	9	10	11	Mean
							Treatments†					
					cotton lint yield, kg ha^{-1}							
1997	845a‡	1225bc	1448cd	1117abc	1227bc	1300bcd	1001ab	1472cd	1258bcd	992ab	1607d	1227B§
1998	1019a	1436bc	1576cd	1506bcd	1425bc	1499bcd	1348b	1604cd	1290b	1055a	1695d	1405C
2000	499a	1412c	1322c	1322c	1403c	1354c	1289c	1322c	1313c	648b	1602d	1226B
2001	745a	1310cd	1210bc	1040b	1226bc	1169bc	1093bc	1223bc	1226bc	683a	1485d	1128A
Mean	777a	1346cde	1389de	1246bc	1320cde	1330cde	1183b	1483e	1272bde	845a	1597f	1246

† Treatment descriptions: 1. conventional till, cotton followed by winter rye, 0 kg N ha^{-1}; 2. conventional till, cotton followed by fallow, 100 kg N ha^{-1} from ammonium nitrate (AN); 3. no-till, cotton followed by fallow, 100 kg N ha^{-1} from AN; 4. conventional till, cotton followed by winter rye, 100 kg N ha^{-1} from AN; 5. conventional till, cotton followed by winter rye, 100 kg N ha^{-1} from poultry litter (PL); 6. mulch-till, cotton followed by winter rye, 100 kg N ha^{-1} from AN; 7. mulch-till, cotton followed by winter rye, 100 kg N ha^{-1} from PL; 8. no-till, cotton followed by winter rye, 100 kg N ha^{-1} from AN; 9. no-till, cotton followed by winter rye, 100 kg N ha^{-1} from PL; 10. no-till, cotton followed by fallow, 0 kg N ha^{-1}; 11. no-till, cotton followed by winter rye, 200 kg N ha^{-1} from PL.

‡ Treatment means for each year (in rows) followed by the same letter are not significantly different from each other at the 5% level.

§ Means for years averaged over treatments (in last column) followed by the same letter are not significantly different from each other at the 5% level.

The year 1998 had less than 100 mm of rainfall in May and June and more than 150 mm in July; hence, it had the highest lint yields. The year 2000 had less than 100 mm in May but had more than 100 mm in June and less than 100 mm in July, which reduced yields. The excessive rainfall in June may have caused nitrate leaching, which could also have reduced lint yields. The worst year in terms of excess rainfall was 2001, which had 192, 263, 128, and 105 mm in May, June, July, and August, respectively. As a result, 2001 had the lowest cotton lint yield of about 1100 kg ha^{-1} irrespective of the N source.

There were no significant differences in cotton lint yield between 100 kg N ha^{-1} ammonium nitrate and 100 kg N ha^{-1} poultry litter treatments in plots under conventional tillage system (Table 8). However, for mulch tillage and no-tillage systems, plants in plots that received 100 kg N ha^{-1} ammonium nitrate had 12 and 11% higher lint yield compared with those in plots that received 100 kg N ha^{-1} poultry litter, respectively. In plots that received 100 kg N ha^{-1} in the form of ammonium nitrate, cotton lint yield in mulch tillage and no-tillage systems was 7 and 13% greater than that in conventional tillage (Table 8). However, in plots that received 100 kg N ha^{-1} in the form of poultry litter, cotton lint yield in conventional tillage system was 12% greater ($P < 0.05$) than that under mulch tillage system and 4% greater than that under no-tillage system. These results can be attributed to the fact that soil incorporation of poultry litter under conventional tillage speeds up mineralization whereas in mulch tillage and no-tillage systems, poultry litter mineralization is slower. In no-tillage with winter rye cropping (Treatment 8), cotton lint yields averaged about 100 kg ha^{-1} greater than those in no-tillage with winter fallow cropping (Treatment 3) during the same period. Compared with conventional tillage with winter fallow cropping (Treatment 2), lint yields in no-tillage with winter rye cropping averaged 137 kg ha^{-1} higher during the study period.

The key to increasing cotton lint yields is using conservation tillage (mulch tillage or no-tillage) with adequate N fertility and soil moisture during the critical growth stages of cotton growth and development; namely, seedling emergence, squaring, flowering, and boll development to maturity (Table 8). These critical stages include the months of May, June, July, and August. The benefits of conservation tillage are mainly a result of keeping crop residues on the soil surface, which improves the plant environment by holding additional moisture (Nyakatawa and Reddy, 2000). This will further improve soil organic matter and reduce soil erosion (Nyakatawa et al., 2001).

Breaking up and incorporation of crop residues during tillage, such as in conventional tillage, leaves little or no residues on the surface. Therefore, the benefits of cover cropping such as reduction in surface evaporation of water and erosion control are diminished. In addition, crop residue incorporation results in immobilization of inorganic N, which affects early plant growth. Tillage promotes the oxidation of crop residues and soil organic matter, which are important in soil moisture conservation. Therefore, for the benefits of cover cropping to be realized, crop residues need to be left intact on the soil surface to reduce soil moisture evaporation and also to slow down the rate of decomposition. Without winter rye cover cropping, no-tillage with 100 kg N ha^{-1} (Treatment 3) gave similar or slightly lower yields compared with conventional tillage (Treatment 2) with the same N rate of 100 kg N ha^{-1} (Table 10). Similar results were reported by Pettigrew and Jones (2001) and Raper et al. (2000).

Nitrogen application in the form of ammonium nitrate or poultry litter significantly increased cotton lint yield in conventional tillage except for the 100 kg N ha^{-1} in the form of poultry litter treatment in 1997. In mulch tillage plots where poultry litter was incorporated into the soil, there were no significant differences in cotton lint yields between the 100 kg N ha^{-1} in the form of ammonium nitrate and the 100 kg N ha^{-1} in the form of poultry litter treatments in all years (data not shown). With 200 kg N ha^{-1} of poultry litter and cotton winter rye cover cropping (Treatment 11), cotton lint yields under no-tillage were up to 28% (or 351 kg ha^{-1}) greater than those under conventional tillage with 100 kg N ha^{-1} of ammonium nitrate and winter rye cover cropping. However, with 100 kg N ha^{-1} of poultry litter, no-tillage did not do better than conventional tillage with 100 kg N ha^{-1} in the form of ammonium nitrate, which further supports the need for adequate N fertilization in no-tillage.

SUMMARY

Mulch tillage and no-tillage systems did not have adverse effects on cotton seedling emergence and establishment compared with conventional tillage, contrary to previous reports. Generally, cotton growth parameters in plots that received the same rate of N in the form of ammonium nitrate were better than those that received poultry litter. However, during drought years, no-tillage compensated for reduced availability of N from poultry litter by conserving soil moisture. In the no-tillage system, winter rye cover cropping significantly increased number of cotton bolls compared with winter fallow cropping. The use of no-tillage without a cover crop in cotton production may not give significant benefits. Rainfall distribution in the months of May, June, July, and August had significant effect on cotton lint yields. Similarly to what was observed with cotton growth parameters, application of poultry litter at the rate of 100 kg N ha^{-1} generally gave lower or similar cotton lint yield compared with ammonium nitrate at the same rate, whereas at 200 kg N ha^{-1}, lint yields were significantly greater than those at 100 kg N ha^{-1}, irrespective of the N source.

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