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CONSERVATION TILLAGE AND POULTRY LITTER MANAGEMENT FOR SUSTAINABLE COTTON PRODUCTION

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Abstract

Use of no-till conservation tillage in cotton (*Gossypium hirsutum*, L.) in the south-east USA cotton belt has been slowed down by reports of reduced seedling emergence, poor plant establishment, reduced plant growth, delayed maturity, and in some cases reduced yields. Our objectives were to evaluate the effects of no-till (NT) and mulch-till (MT) conservation tillage with winter rye (*Secale cereale* L.) cover cropping system (WR) and poultry litter (PL) as a N source on growth parameters and yield of cotton in north Alabama. Winter rye cover cropping increased surface residue cover (SRC) by 20 to 30% in CT and by 80 to 100% in NT system. Cotton seedling establishment was significantly enhanced by NT with WR cover cropping and PL application, especially in years with below average rainfall distribution during seedling emergence. This was attributed to up to 80% soil moisture conservation in the top 7 cm of the soil during seedling emergence. Surface residue cover was significantly correlated to number of 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) over the duration of the study. Winter rye cover cropping did not improve cotton lint and biomass yields in CT system. However, in NT with WR cropping, cotton lint yields were 222, 214, 427, and 365 kg ha^{-1} greater ($P < 0.05$) than those in NT with WF cropping in 1997, 1998, 2000, and 2001 respectively. Similarly, biomass yields were 4229, 3945, 4741, and 4307 kg ha^{-1} greater in NT with WR compared to NT with WF. Poultry litter at 100 kg N ha^{-1} generally gave similar cotton lint yields to ammonium nitrate (AN), except in the first season of the study in 1997 and following the corn (*Zea Mays*, L.) crop of 1999 in 2001. At 200 kg N ha^{-1}of PL, lint yields were significantly greater than those at 100 kg N ha^{-1} irrespective of the N source. Our study shows that without WR and/or application of PL, lint and biomass yield gains from NT alone are not consistent from year to year. Therefore, in order for NT to be successful for cotton production, it has to be used in conjunction with winter rye cover cropping and/or poultry litter at 200 kg N ha^{-1}. These treatments would be appropriate for the southeastern U.S.A. where soil erosion is a problem and the disposal of PL from the large poultry industry poses an environmental problem.

Introduction

Despite the benefits of conservation tillage such as reduced soil erosion, soil moisture conservation, and reduced operational costs, its adoption on cotton farms in the southeast USA region has been slow. This region, which includes the states of Alabama, Florida, Georgia, North Carolina, South Carolina, and Virginia produced over 930 million kilograms of upland seed cotton (about 30% of the total US upland cotton production) in the year 2000 (Cotton Council International, 2002). Most of the land under cotton production in the southeast USA is therefore largely under conventional tillage, which leaves the soil bare in the fall and early spring, thereby making it susceptible to erosion and depletion of soil organic matter (Stevens et al., 1992; Triplett et al., 1996).

Problems which have been found with no-till cotton include poor seedling emergence, poor plant establishment, and stunted growth, and reduced yields (Reddy et al., 1994; Schertz and Kemper, 1994). There are a number of factors which make no-till perform differently on cotton compared to crops such as wheat (*Triticum spp*), corn and soybean (G*lycine max* L.) which generally have had success with no-till. Cotton does not produce enough residues to supply the carbon necessary to increase soil organic matter and improve soil tilth in the seed zone. Therefore, without additional residues to supplement that from cotton leaves which is not only inadequate, but do not last long after harvest, soils under no-till cotton may develop a crust at the surface and a compacted layer in the top 5 to 10 cm.

The inclusion of winter cover crops in no-till cotton 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; Daniel 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 and Reddy, 2000; Nyakatawa et al., 2001). Winter cover crops may also reduce nitrate leaching to the groundwater by picking up excess nutrients from the summer cotton crop (Meisinger et al., 1991; Kelley et al., 1992; Brandi-Dohrn et al., 1997). The attributes which 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).

Use of poultry litter (PL), which improves soil physical and chemical properties such as soil water holding capacity, soil aeration, and soil organic carbon compared to inorganic sources of N such as ammonium nitrate, can reduce the problems associated with use of conservation tillage in cotton. Application of PL to cotton will provide an environmentally friendly way of disposing of the large quantities of waste in the southeast USA region. The objectives of this study were to evaluate the effects of no-till and mulch-till conservation tillage systems with winter rye cover cropping and PL as a source of N, on growth and yield of cotton on a Decatur silt loam soil in north Alabama.

Materials and Methods

Study Location

The field study was carried out at the Alabama Agricultural Experiment Station, Belle Mina, Alabama (34^o 41' N 86^o 52' W) on a Decatur silt loam soil (clayey, kaolinitic thermic, Typic Paleudults) from 1996 to 2001.

Treatments and Experimental Design

The treatments consisted of three tillage systems; conventional till (CT), mulch-till (MT), and no-till (MT); two cropping systems: cotton-winter fallow, (cotton in summer and fallow in winter) and cotton-winter rye sequential cropping, that is cotton in summer and rye (*Secale cereale* L.) in winter; three N levels: 0, 100, and 200 kg N ha^{-1} and two N sources: ammonium nitrate (AN) and poultry litter (PL). Ammonium nitrate was used at one N rate (100 kg N ha^{-1}) only. The experimental design was a Randomized Complete Block Design with 4 replications. Plot size was 8 m wide and 9 m long which resulted in 8 rows of cotton, 1 m apart.

Conventional tillage included moldboard plowing in November and disking in April. A field cultivator was used to prepare a smooth seedbed after disking. Mulch-till (MT) included tillage with a field cultivator before planting to destroy and partially incorporating crop residues to a depth of 5 to 7cm. No-till included planting into un-tilled soil using a no-till planter. During the season, a row cultivator was used for controlling weeds in the CT system, while spot applications of Roundup herbicide were used to control weeds in the NT and MT systems.

The N content for the poultry litter was determined by digesting 0.5 g samples using the Kjeldhal wet digestion method (Bremner and Mulvaney, 1982) and followed by N analysis using the Kjeltec 1026 N Analyzer (Kjeltec, Sweden). The amounts of poultry litter to supply 100 and 200 kg N ha^{-1} were calculated each year based on the N content of the PL. A 60% adjustment factor was used to compensate for the N availability from PL during the first year (Keeling et al., 1995). The poultry litter was broadcast by hand and incorporated to a depth of 5 to 8 cm by pre-plant cultivation in CT and MT systems. In NT system, the PL was surface applied. The AN and PL were applied to the plots 1 d before cotton planting. The experimental plots received a blanket application of a 0-20-20 fertilizer to nullify the effects of P and K applied through PL at the beginning of the study in fall 1996 and in 2000.

Planting Methods and Crop Management

The winter rye cover crop, variety Oklon, was planted in fall and killed by Roundup herbicide (glyphosate) about 7 d after flowering in spring of 1997, 1998, 2000, and 2001. A Tye (Glascock Equipment and Sales, Veedersburg, IN) no-till grain drill was used to plant the rye cover crop at 60 kg ha^{-1}. Cotton variety Deltapine NuCotn 33B was planted in all plots at 16 kg ha^{-1}, using a no-till planter. A herbicide mixture of Prowl (pendimethalin) at 2.3 L ha^{-1}, Cotoran (fluometuron) at 3.5 L ha^{-1}, and Gramoxone extra (paraquat) at 1.7 L ha^{-1} was sprayed on all plots before planting for weed control. In addition, all plots received a band application of 5.6 kg ha^{-1} Temik (aldicarb) for the early season control of thrips. The growth regulator, Pix at 0.8 kg ha^{-1} was applied to cotton to reduce vegetative growth at about 2.5 months after planting. The cotton was defoliated with a mixture of Finish at 2.3 L ha^{-1} and Def at 0.6 kg ha^{-1} two weeks before the first harvest.

Data Collection

Immediately after cotton seeding, surface residue cover (SRC) was measured in all plots using the Camline transect method (Reddy et al., 1994) in each year. During the first 4 d of cotton seedling emergence, soil temperature, volumetric soil water content, and seedling counts were determined daily in each plot in 1997 and 1998. Soil temperature and volumetric soil water in the top 7 cm of the soil were determined around midday by taking an average of four readings randomly taken from each plot, one block at a time, using Weksler soil thermometers (Weksler Instrument Corp., Freeport, N.Y.) and the Delta T soil water probe (Delta-T Devices, Cambridge, England), respectively. Plant data collected were: days to squaring, days to flowering, days to maturity, plant height, leaf area index (LAI), 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.

Data Analysis

The data were statistically analyzed using General Linear Model procedures (Steel and Torrie, 1980) of the Statistical Analysis System (SAS, 1987). Main effects of the treatment factors were determined by contrast analysis procedures. Correlation analysis was used to show the association of volumetric soil water content, soil temperature, and cotton seedling counts to LAI, days to squaring, number of squares per plant, number of bolls per plant, above-ground biomass and lint yield of cotton.

Results and Discussion

Weather Data

Total monthly rainfall data and mean monthly temperatures at the Experimental site during 1996 to 2001 are presented in Table 1. Rainfall totals during the critical months of the cotton growth cycle were those for May (planting and seedling establishment), June (squaring and flowering), July (flowering and boll development), and August (maturity) of 1997, 1998, 2000, and 2001. A mean for the last 70 yrs prior to the initiation of the study is presented for comparison. The years 1998 and 2000 had the worst rainfall distribution for cotton since they were characterized by droughts in May, June, July and or August.

Surface Residue Cover

Surface residue cover (SRC) after cotton planting was significantly ($P < 0.01$) influenced by tillage system and cropping system (Table 2) and tillage and N treatments (Table 3). In conventional till with winter-rye cover cropping (CTWR), SRC was 20% and 13% in 1997 and 1998 respectively, compared to only 1% in conventional till with winter-fallow cropping (CTWF) (Table 2). Similar figures for SRC under CTWR in 2000 and 2001 were 31% compared to 5% and 6%, in CTWF respectively.

It was observed that crop residues from the rotational corn crop of 1999 were still present in all the plots especially in NT plots. This explains the increase in SRC from 1% in 1997 and 1998 to an average of 5% in 2000 and 2001 under CTWF, and the 88% increase in SRC under CTWR. Similarly, SRC in no-till with winter-rye cropping (NTWF) increased from 17% and 34% in 1997 and 1998 to 80% and 81% in 2000 and 2001, respectively (Table 2). In mulch-till (MT) plots where the SRC was partially incorporated, there was no significant increase in SRC in 2000 and 2001 after the rotational corn crop of 1999. In a corn study in southern Ontario, Beyaert et al. (2002) recorded 6 to 12% SRC in CT and 78 to 88% SRC in NT. In each of the four years of our study, SRC under MT, NTWF, and NTWR was significantly greater than that under CTWF and CTWR.

With additional crop residues from the rotational corn crop, CTWR was able to qualify as a conservation tillage according to the definition of the Conservation Tillage Information Center (CTIC, 1994), which requires at least 30% of the soil surface covered by crop residue after planting. Cotton residues do not persist long after harvest to conserve soil moisture, protect the soil from erosion and to supply carbon needed to improve soil organic matter. Therefore, incorporation of the cereals winter rye and corn in cotton production systems is important for soil erosion control and to improve soil organic matter. 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 MT and NTWR in all the years, whereas in CTWR it was achieved in 1997, 2000, and 2001 while it was never achieved in CTWF (Table 2).

In NT plots, application of 100 kg N ha^{-1} in the form of ammonium nitrate (100AN) increased SRC by 20% compared to 0 kg N ha^{-1} in 2000 and 2001 (Table 3). However, in CT and MT plots, there was no significant effect of application of 100AN on SRC (Table 3). In CT plots, application of 100 kg N ha^{-1} in the form of PL (100PL) increased SRC by up to 27% in 2000 and 2001. In NT plots, the 100PL and 200PL N treatments increased SRC by 21% to 50% compared to 0N treatment from during the duration of the study (Table 3). The above results suggest that surface application of PL provides additional benefits of protecting the soil from erosion and moisture conservation when used in place of AN to supply the same amount of N to the crop. The benefits of PL were more visible after the rotational corn crop of 1999.

The effects of the leaving more crop residues on the soil surface after cotton planting had a significant ($P < 0.05$) effect on cotton productivity. Table 4 shows that SRC was significantly correlated to 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) over the duration of the study. This was attributed to the fact that SRC significantly increased volumetric soil moisture content; $r = 0.68$ and 0.60 in 1997 and 1998 respectively (Nyakatawa and Reddy, 2000).

Seedling Emergence and Establishment

Inadequate cotton seedling emergence and establishment, which result in variable crop stands has been raised as a constraint to the adoption of no-till conservation tillage for cotton production in the southeast USA. There have been reports that no-till with cover cropping reduced cotton seedling emergence due to low temperatures, which resulted in reduced yields. Table 2 shows that cotton seedling counts under CTWR, MT, and NTWR were similar to those under CTWF, which is the traditional farmers' practice. In 1998 and 2000, cotton seedling counts in NTWR were significantly greater than those under NTWF (Table 2). In 1998, final cotton seedling counts in 100PL and 200PL treatments were significantly greater than those in the 0N and 100AN treatments (Table 3).

Results from our study indicate that final cotton seedling establishment was significantly enhanced by NT tillage with WR cover cropping and PL application in years with below average rainfall distribution during seedling emergence. In addition, daily monitoring of cotton seedling emergence showed that the rate of emergence in no-till system was greater than that in conventional till, while that in 100PL and 200PL was significantly greater than that in 0N and 100AN treatments 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 rate of cotton seedling establishment is about 10 plants m^{-1}. Our results show that the final counts of cotton seedlings were in this optimum range, hence, contrary to other reports, NTWR had no detrimental effect on cotton seedling emergence and establishment. In 1998 and 2000, when soil moisture was most limiting during seedling emergence, SRC was positively correlated (r = 0.38 and r = 0.20) to final cotton seedling counts, which in turn were positively correlated to LAI, number of bolls per plant, biomass and lint yield of cotton (Table 4).

Lint and Biomass Yield

In CT system, WR cover cropping did not improve cotton lint and biomass yields (Fig. 1). Although not significant, cotton lint yields under CTWR were 160, 119, 338, and 307 kg ha^{-1} lower than those in CTWF in 1997, 1998, 2000, and 2001 respectively (Fig. 1). Cotton biomass yields in CTWR were 3828, 3149, and 1539 lower than those in CTWF in 1997, 2000, and 2001 respectively. On the other hand, in NTWR cropping, cotton lint yields were 222, 214, 427, and 365 kg ha^{-1} greater ($P < 0.05$) than those in NTWF in 1997, 1998, 2000, and 2001 respectively (Fig. 1). Similarly, biomass yields were 4229, 3945, 4741, and 4307 kg ha^{-1} greater in NTWR compared to NTWF respectively (Fig. 1).

The above results correspond closely to those observed with plant height and clearly show that NT enhances the benefits of cover cropping whereas CT offsets the benefits of cover cropping. Breaking up and incorporation of crop residues during tillage leaves little or no residues on the surface (Table 2). 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 and nutrient retention against leaching.

Preliminary data from this study has shown that NT with WR cover cropping improves soil organic matter in the top 0-15 cm of the soil (Nyakatawa et al., 2001). Therefore, for the benefits of cover cropping to be realized, crop residues need to be left intact on the soil surface to reduce evaporation and also to slow down the rate of decomposition. Figure 1 clearly shows that cotton lint and biomass yields under NT without WR cover cropping, were similar or slightly lower than those in CT. Pettigrew and Jones (2001) reported 11% lower lint yield in NT compared to CT. Our results suggest that the use of NT without WR cover cropping may not improve cotton yields.

Average lint yield increases due to application of 100AN and 100PL in CT plots were 354, 428, 886, and 456 kg $ha\text{-}^{1}$ in 1997, 1998, 2000, and 2001 respectively. In 1998 and 2000, there were no significant differences in biomass yield between 100AN and 100PL treatments. However, in 1997 and 2001, biomass yields for the 100AN treatment in CT plots were 5244 and 3038 kg ha^{-1} greater ($P < 0.05$) than that for the 100PL treatment (Fig. 2). This can be attributed to the less available N from PL compared to AN at the start of the study and following the corn crop of 1999. In NT plots cotton lint yields for 100AN and 200PL treatments in 1997 were 467 and 614 kg ha^{-1} significantly greater than that for the 0N control, whereas for 100PL, lint yield was similar to control (Fig. 2). However, in 1998, 2000, and 2001 cotton lint yields for the 100PL treatment was 236, 665, and 542 kg ha^{-1} greater than that for the control. In MT plots where PL was incorporated into the soil, there were no significant differences in cotton lint and biomass yields between 100AN and 100PL treatments in all years (Data not shown). Similarly to what was observed with WR cover cropping, without application of N in the form of AN or PL, yield and biomass gains from NT alone are not consistent from year to year (Fig. 2). Therefore, in order for NT to be successful for cotton production, it has to be used in conjunction with winter rye cover cropping and or poultry litter at 200 kg N ha^{-1} of PL.

Conclusions

Results from our study show that cotton seedling establishment, cotton lint and biomass yields were significantly improved by NT tillage with WR cover cropping and PL application at 200kg kg N ha^{-1}. These benefits were more visible in years with below average rainfall distribution during seedling emergence. In contrary to other reports, NT with WR cover cropping had no detrimental effect on cotton seedling emergence and establishment compared to CT. However, in agreement with research elsewhere, the use of NT without WR or PL in cotton production may not give significant benefits. Averaged over cropping systems and N treatments, cotton lint yields under NT were 24%, 7%, 24%, and 8% greater than that under CT in 1997, 1998, 2000, and 2001, respectively. Winter rye cover cropping increased cotton lint yields by 6 to 12% compared to cotton winter fallow cropping in 2000 and 2001. Poultry litter at 100 kg N ha^{-1} generally gave similar cotton lint yield to ammonium nitrate, 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. These treatments would be appropriate for use in the southeastern U.S.A. where soil erosion is a problem and the disposal of PL from the large poultry industry poses an environmental problem.

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Table 1. Total monthly rainfall during the duration of the experiment, Belle Mina, AL, 1996 to 2002.

	Year						
Month	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**70 Yr Av.**
	mm						
Jan	214.5	174.6	217.5	328.2	27.0	182.4	153.0
Feb	74.1	129.9	194.4	93.6	78.0	147	146.1
Mar	213	101.1	128.7	152.4	164.1	172.5	183.0
Apr	163.5	120.9	129.6	115.2	257.4	115.8	129.9
May	49.5	108.3	73.2	140.7	21.9	191.7	122.9
Jun	99.6	195.0	54.0	195.6	123.0	262.5	122.4
Jul	128.4	50.7	158.7	109.2	22.2	128.4	111.0
Aug	141.6	120.6	54.3	5.7	79.5	104.7	132.9
Sep	242.1	175.5	25.8	16.8	51.3	166.5	104.1
Oct	76.8	228.9	41.1	36.9	0.6	114.3	108.9
Nov	131.7	69.3	85.5	146.4	208.2	93.0	89.7
Dec	136.5	127.5	249.6	89.7	132.3	190.8	158.4

Table 2. Surface residue cover after cotton planting and cotton seedling counts in conventional till, mulch-till, and no-till systems under cotton winter-fallow (WF) and cotton-winter rye (WR) cropping systems, Belle Mina, AL, 1997 to 2001.

	Conventional till		Mulch-till	No-till	
Year	**WF**	**WR**	**WR**	**WF**	**WR**
	Surface residue cover (%)				
1997	1a	20b	65	17a	100b
1998	1a	13b	51	34 a	87b
2000	5a	31b	69	80a	100b
2001	6a	31b	69	81a	98b
	Seedlings (counts m^{-1})				
1997	10a	9a	10	10a	10a
1998	9b	8a	7	7a	9b
2000	9a	9a	9	9a	10b
2001	10a	10a	11	11a	10a

Table 3. Surface residue cover after cotton planting and cotton seedling counts in conventional till, mulch-till, and no-till systems under N treatments from ammonium nitrate (AN) and poultry litter (PL), Belle Mina, AL, 1997 to 2001.

	Conventional till			Mulch-till		No-till			
Year	**0N**	**100AN**	**100PL**	**100AN**	**100PL**	**0N**	**100AN**	**100PL**	**200PL**
	Surface residue cover (%)								
1997	20a	11a	22a	65a	65a	25a	54ab	100b	100b
1998	20a	24a	17a	58a	45a	29a	66a	79b	90b
2000	15a	21ab	42c	76a	62a	73a	93b	100b	100b
2001	15a	20a	42b	74a	63a	74a	94b	95b	100b
	Seedlings (counts m^{-1})								
1997	9a	10a	9a	10a	10a	10a	10a	10a	10a
1998	8a	8a	8a	8b	6a	6a	8b	10c	9bc
2000	9a	9a	9a	10a	9a	9a	9a	10a	10a
2001	10a	10a	10a	12a	12a	11b	10ab	9a	9a

Table 4. Pearson correlations coefficients between surface residue cover (SRC) after cotton planting and cotton growth and yield parameters, Belle Mina, AL, 1997 to 2001.

	Seedlings	Height	LAI	Bolls/plant	Biomass Yield	Lint Yield
	counts/m²	cm			kg/ha	
				1997		
SRC	0.01NS	0.28NS	0.04NS	0.40**	0.35*	0.28NS
Seedlings		-0.07NS	-0.16NS	-0.08NS	-0.03NS	-0.07NS
Height			0.69***	0.80***	0.75***	0.62***
LAI				0.62***	0.60***	0.49***
Bolls/plant					0.67***	0.57***
Biomass						0.71***
				1998		
SRC	0.38**	0.02NS	0.20NS	0.36**	0.38**	0.33*
Seedlings		0.22NS	0.42**	0.29*	0.44**	0.39**
Height			0.85***	0.66***	0.42**	0.72***
LAI				0.67***	0.61***	0.79***
Bolls/plant					0.41**	0.71***
Biomass						0.42**
				2000		
SRC	0.20NS	0.30*	0.32*	-----	0.30*	0.33*
Seedlings		0.05NS	0.03NS	-----	0.03NS	0.06NS
Height			0.94***	-----	0.88***	0.99***
LAI				-----	0.87***	0.95***
Bolls/plant					-----	-----
Biomass						0.88***
				2001		
SRC	-0.02NS	0.39**	0.19NS	0.49***	0.52***	0.30*
Seedlings		-0.12NS	-0.09NS	-0.08NS	0.02NS	-0.10NS
Height			0.78***	0.75***	0.72***	0.78***
LAI				0.61***	0.65***	0.63***
Bolls/plant					0.63***	0.66***
Biomass						0.58***

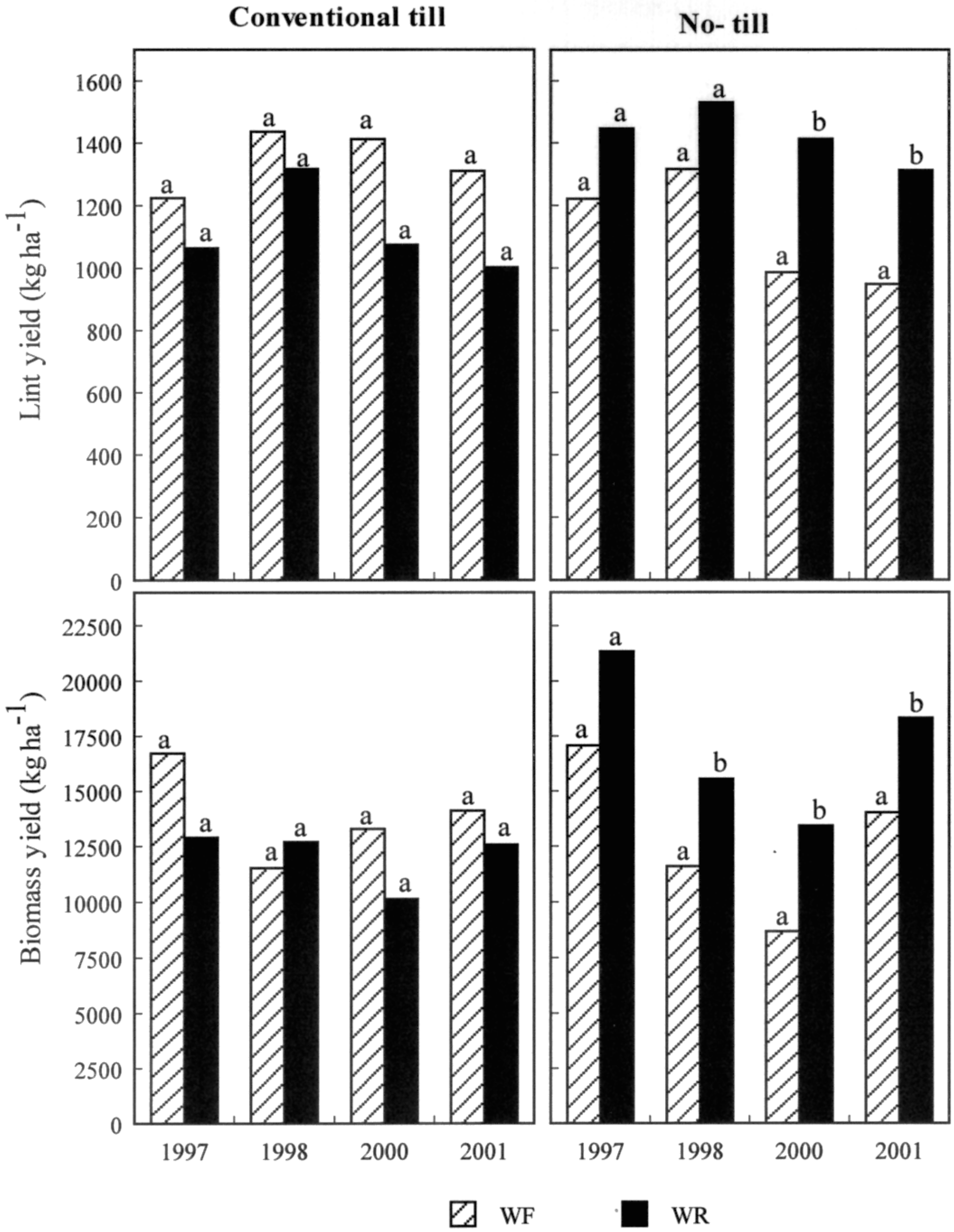

Figure 1. Lint and biomass yields of cotton as influenced by winter rye cover cropping (WR) and winter fallow cropping (WF) in conventional and no-till systems, Belle Mina, AL, 1997 to 2001 (Means for WF and WR in the same tillage system for each year followed by same letter are not significantly different from 5% level).

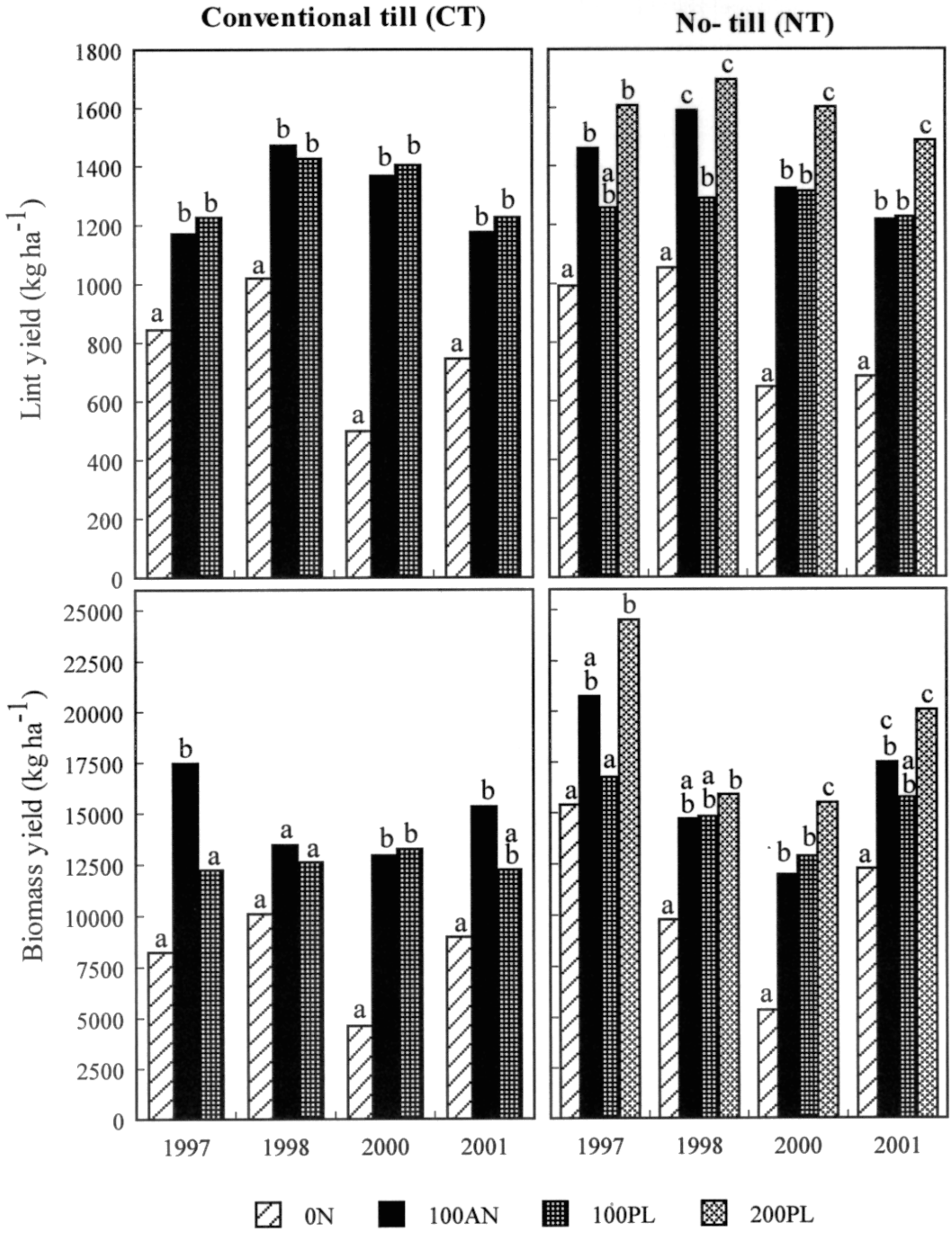

Figure 2. Lint and biomass yields of cotton as influenced by ammonium nitrate (AN) and poultry litter (PL) sources of N in conventional and no-till systems, Belle Mina, AL, 1997 to 2001 (Means for N treatments in the same tillage system for each year followed by same letter are not significantly different at the 5% level).