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AGRONOMY AND SOILS

Cotton Growth and Yield Response to Nitrogen Applied Through Fresh and Composted Poultry Litter

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ABSTRACT

Intensive poultry production in the southeastern United States has created problems with poultry litter disposal. An option is to use poultry litter as a source of N on row crops, such as cotton (*Gossypium hirsutum* L.). Three sources of nitrogen: urea, fresh poultry litter (FPL), and composted poultry litter (CPL) at 40, 80, and 120 kg plant available N ha^{-1} with and without the second generation nitrification inhibitor carboxymethyl pyrazole (CP) were evaluated for cotton growth and yield on a Decatur silt loam soil in Alabama from 1994 through 1998. In general, the three sources of N significantly increased cotton growth and lint yield compared with the control (0 N). The increase in lint yields was correlated with an increase in plant height, main stem nodes, and nodes above white flower at maturity. Among the three N sources, FPL produced the highest mean lint yield over the five year period (1492 kg ha^{-1}) compared with CPL (1392 kg ha^{-1}) and urea (1391 kg ha^{-1}). Composting FPL to make CPL did not improve its impact on cotton growth or yield. The nitrification inhibitor had no significant effect on cotton growth or lint yield. Substitution of poultry litter for commercial N sources, such as urea, in crop production would help solve the growing poultry litter disposal problem in Alabama and other parts of the southeastern United States.

Broiler production in the United States increased by 21% from 1993 to 2003 (USDA-NASS, 2004). As a result of this growth, large quantities of litter are produced. Litter, a mixture of bedding and manure, is considered a source of plant nutrients, as well as a waste material. On average, each broiler produces about 1.13 kg of manure per year (Gary et al., 2001), resulting in about 10 billion kg of litter produced annually in the United States. Alabama, Arkansas, Georgia, Mississippi, and North Carolina account for 59% (5.14 billion) of total broiler production. Alabama ranks third in U.S. broiler production with 12% of the total (USDA-NASS, 2004).

Nutrients provided by poultry litter have been reported to have positive effects on crop production (Miller, 1996; Mitchell et al., 1993; 1995); however, economic factors, such as high transportation costs relative to nutrient value, limit the application of this litter to agricultural soils within the broiler production regions (Simpson, 1991). A national survey indicated that 90% of litter is applied on the poultry grower's acreage in the south central and southeastern United States, which causes nutrient overloading of soils near chicken houses and creates potential water quality problems (Eghball and Power, 1999; Simard et al., 1995). If the unsafe practice of disposing litter in this way continues, growth of the poultry industry in the region could be restricted.

Composting poultry litter addresses many problems associated with the agricultural use of fresh litter, such as lowering moisture content, reducing odor, and providing a looser and more friable texture. Composting also provides a more uniform and stable particle that is easier to handle (Dao, 1999; Millner et al., 1998; Schelegel, 1992).

The primary source of N in poultry litter is NH_4^+. Under field conditions, the nitrification process converts NH_4^+ to NO_3^-. Nitrification inhibitors are capable of delaying the conversion of NH_4^+ to NO_3^- in fertilizers (Rao, 1996), which enhances the availability of nitrate N to the plants for a longer period (Burmester, 1993; Crawford and Chalk, 1993; Touchton and Bosewell, 1980). While benefits of nitrification inhibitors are well documented for cereals (Goose and Johnson, 1999; Randall et al., 2003; Rao, 1996), there are relatively few studies of nitrification inhibitors with cotton (Radin and Sell, 1975).

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Through hydroponics experiments, Radin and Sell (1975) concluded that, unlike wheat and corn, cotton did not respond to enhanced ammonium nutrition as measured by growth or yield. Second generation inhibitors, such as carboxymethyl pyrazole (CP), have not been tested on cotton. Mikkelson et al. (1989) reported that applying composted poultry litter treated with a nitrification inhibitor to sorghum improved nutrient value of the manure.

The objective of this study was to explore the effects of fresh and composted poultry litter treated with the nitrification inhibitor carboxymethyl pyrazole on cotton growth and yield.

MATERIALS AND METHODS

Experimental site and treatments. Field experiments were conducted at the Alabama Agricultural Experiment Station, Belle Mina, Alabama, situated at 34° 41' lat and 86° 52' 30" long on Decatur silt loam (fine, kaolinitic, thermic Rhodic Paleudults) from 1994 through 1998. Treatments consisted of a factorial combination of three N sources applied at three N rates with and without the nitrification inhibitor carboxymethyl pyrazole, (CP) resulting in 18 treatments. The three N sources were urea, fresh poultry litter (FPL), and composted poultry litter (CPL) and the three rates were 40, 80, 120 kg ha^{-1} N. In addition, two control plots, 0 N without CP (control) and 0 N with CP soil application (CP control), were included. The 20 treatments were arranged in a RCBD with four replications.

Cotton cultivar Deltapine 51 (Delta and Pine Land Co., Scott, MS) was planted on 20 Apr. 1994, 12 Apr. 1995, and 15 Apr. 1996. Deltapine 33B (Delta Pine and Co.) was planted on 8 May 1997 and 5 May 1998. Treatments were applied to the same experimental plots every year and cotton was grown under irrigation (Fig. 1).

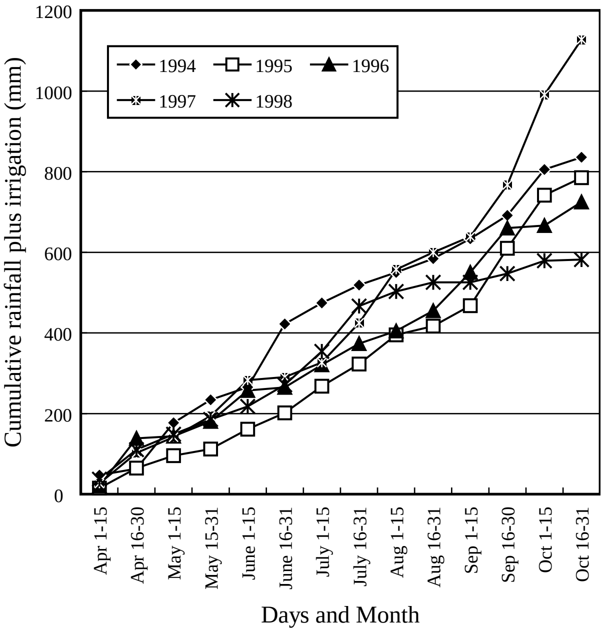

Figure 1. Cumulative rainfall and irrigation water applied to cotton from April through October for 1994 through 1998.

Fresh poultry litter (FPL) was collected from poultry farms in Alabama. Composted poultry litter (CPL) was prepared by constructing two piles each approximately 3.0 m in diameter and 1.5 m in height, using 2910 kg of fresh poultry litter and 1630 kg of water per pile. An overhead crane with a clean bucket was used to aerate the piles. The poultry litter piles were aerated daily for the first 5 wk then twice a week for the next 8 wk. During the last 6 mo, the piles were aerated only when oxygen levels dropped below 5%. The compost was maintained at a maximum temperature of 66 °C for 30 d, then greater than 38 °C for the next 6 mo. The total N concentration in FPL on a dry weight basis was 2.8, 2.6, 2.4, 2.2, and 3.2%, and in CPL it was 1.8, 2.3, 1.9, 2.1, and 2.5% in 1994, 1995, 1996, 1997, and 1998, respectively. Total N content on dry weight basis was determined by digestion of 0.5-g samples using the Kjeldahl wet digestion method (Bremner and Mulvaney, 1982). FPL contains 30 to 40% inorganic (ammoniacal and nitrate forms) and 60 to 70% organic nitrogen. In general, 80% of the inorganic N and 60% of the organic N is available for plant uptake during the first year of poultry litter application (Bitzer and Sims, 1988). During the composting process, the inorganic N is lost and only organic N remains, which is approximately 60% available. While it can be argued that the available N in FPL is slightly higher than N available in the composted litter, experiments dealing with the available N in poultry litter reported that the mineralizable organic N in poultry manure ranges from 40 to 90% (Castellanos and Pratt, 1981; Pratt et al., 1973; Sims, 1986). Bitzer and Sims (1988) reported that the average amount of organic N mineralized from 20 poultry manures was 66%. To simplify the protocol that would eventually be communicated to farmers on the use of poultry litter, an average level of 60% available N was used both for FPL and CPL in this experiment.

The nitrification inhibitor, carboxymethyl pyrazole (CP), was obtained from the Department of Botany and Plant Pathology, Purdue University. Carboxymethyl pyrazole is an experimental nitrification inhibitor, two to four times more effective and less volatile than the more commonly used nitrapyrin ($C_6H_3Cl_4N$). Carboxymethyl pyrazole was applied at 0.56 kg ha^{-1} a.i. The inhibitor was diluted in ethanol at 50:50 % (v). A volume of 116 ml of CP solution (58 ml CP + 58 ml ethanol) per plot was used. Each N source calculated per plot was put in a mixer and CP solution was dribbled on it as it was mixed. Urea, FLP, and CPL treated with CP were broadcast by hand and incorporated immediately into soil with a disk harrow before planting cotton. In the control plot, the inhibitor was sprayed with a hand-held garden sprayer directly on the soil and then incorporated.

Based on initial soil chemical analysis at the beginning of the experiment in 1994, 67.2 kg ha^{-1} P_2O_5 and K_2O in the form of 0-20-20 fertilizer and 3359 kg ha^{-1} of dolomite limestone were applied as a basal rate to all plots to nullify the effects of P, K, Ca, and Mg additions from the poultry litter. The experimental plots were prepared under conventional tillage. All cultural practices recommended by the Alabama Extension Service for cotton cultivation were uniformly followed in all years to all the treatments.

Data collection. Growth characteristics were measured on five randomly selected plants from rows 2 and 5 and averaged for statistical analysis. Cotton lint yield was measured from two pickings from rows 3 and 4. Rows 1 and 6 served as guard rows. In 1994 (65 and 94 d after planting) and in 1995 (80 and 100 d after planting), the plant height, total number of main stem nodes, nodes above white flower (NAWF), and internode lengths were determined. Plant height was measured as the distance between the cotyledonary node and the plant terminal. The node count was made from the cotyledonary node to the highest node on the main stem. NAWF were the number of nodes from the uppermost first position white flower to the highest node of the main stem. Internode length was calculated by dividing plant height by number of nodes. Total dry matter per hectare was estimated by sampling plants from 0.5 m^2. Lint plus seed yields were estimated from 18.6 m^2 by combining the two harvests. Lint yield was calculated by using a ginning turnout percentage of 39%. Data on rainfall (Fig. 1) and soil temperatures (Fig. 2) were collected from Alabama Agricultural Experiment Station, Belle Mina, Alabama.

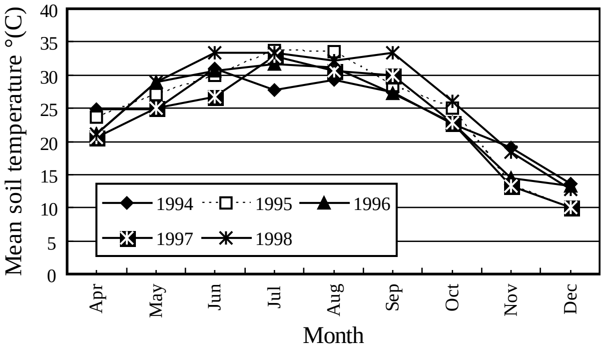

Figure 2. Mean soil temperature from April through December for 1994 through 1998.

Statistical analysis. All 20 treatments were compared using the General Linear Model procedure of Statistical Analysis System (ver. 9.1; SAS Institute; Cary, NC) and means were separated using Duncan's Multiple Range Test at the 5% probability level. Because the effect of CP and interactions between CP, N rates, and N sources were not significant, only main effects are presented. Data were combined across years where year by treatment interactions were not significant. In cases where the interaction was significant, data are presented by year. Correlation analysis was used to determine the association of plant growth components with cotton lint yield.

RESULTS AND DISCUSSION

Effect of nitrification inhibitor. Carboxymethyl pyrazole (CP) had no significant main or interaction effects with N rates and sources on cotton plant height (Fig. 3). CP did not influence the number of main stem nodes in 1994 (Fig. 4) and significantly reduced main stem nodes in 1995 at 80 d after planting (Fig. 5a). Number of nodes above white flower at 94 d after planting in 1994 (Fig. 7a) and dry matter yield in 1995 (Fig. 8) were also lower in plots treated with CP. Carboxymethyl pyrazole did not influence the lint yield in any year (Table 1), so application of CP was not beneficial for cotton growth or lint yield. The poor performance of nitrification inhibitors in the southeastern United States may be due to warmer soil temperatures during the winter (Gerik et al., 1994; Touchton and Boswell, 1980). Puttanna et al. (1999) observed that an increase in temperature from 10 to 30 °C decreased the efficacy of nitrification inhibitors by 6 to 62% at 30 d. Brundy and Bremner (1973) found that most nitrification inhibitors are more effective at soil temperatures of 15 °C as opposed to 30 °C. These studies suggest that soil temperature is a key factor influencing the performance of nitrification inhibitors. In all five years of this study, soil temperatures ranged from 25 to 35 °C during the growing season (May through September) (Fig. 2).

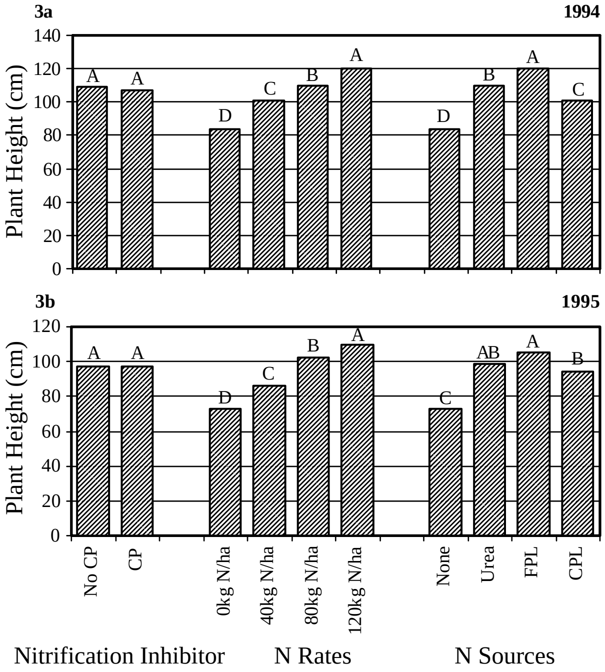

Figure 3. Response of cotton plant height at maturity to the nitrification inhibitor carboxymethyl pyrazole (CP), nitrogen rates, and nitrogen sources for 1994 and 1995.

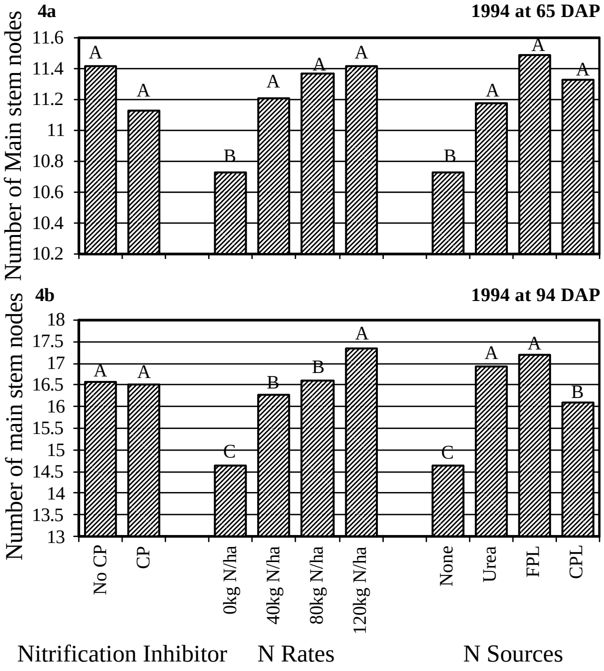

Figure 4. Response of main stem node number to the nitrification inhibitor carboxymethyl pyrazole (CP), nitrogen rates, and nitrogen sources in 1994 at 65 and 95 days after planting (DAP).

Effect of N rates. Application of N, irrespective of the source, significantly increased cotton plant height (Fig. 3), number of main stem nodes (Fig. 4 and 5), dry matter (Fig. 8), and lint yield (Table 1). There was

Table 1. Response of cotton lint yield to the nitrification inhibitor carboxymethyl pyrazole (CP), nitrogen rates, and nitrogen sources

Treatment	Lint yield (kg ha^{-1})				
	1994	1995	1996	1997	1998
No CP	1533	1013	1704	1288	1292
CP	1528	1014	1738	1330	1316
LSD (*P* = 0.05)	67.13	57.31	92.2	56.88	50.89
N rates					
0 kg/ha	1277	671	1135	814	761
40 kg/ha	1455	1023	1547	1207	1223
80 kg/ha	1570	1065	1876	1402	1460
120 kg/ha	1651	1066	1935	1484	1409
LSD (*P* = 0.05)	106.15	90.16	145.78	89.93	80.46
N sources					
Control	1277	671	1135	814	761
Urea	1521	1013	1778	1361	1284
Fresh poultry litter	1650	1078	1868	1442	1420
Composted poultry litter	1505	1064	1713	1290	1388
LSD (*P* = 0.05)	106.15	90.61	145.78	89.93	80.46

also a significant correlation between plant height and lint yield in 1994 ($r = 0.56$, $P < 0.001$) and 1995 ($r = 0.43$, $P < 0.01$) (Table 2). This suggests that vigorous growth of the cotton crop contributes to higher cotton yields. Boquet et al. (2004b) found highly significant correlations between plant height and lint yield.

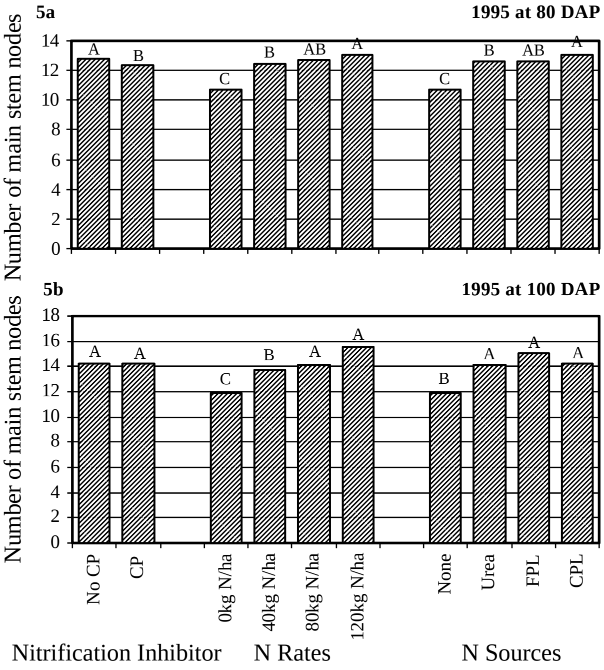

Figure 5. Response of main stem node number to the nitrification inhibitor carboxymethyl pyrazole (CP), nitrogen rates, and nitogren sources in 1995 at 80 and 100 days after planting (DAP).

As N rate increased, the number of main stem nodes increased in a manner similar to plant height (Fig. 4 and 5). Node number is an indicator of the lint yield potential, because nodes produce fruiting branches that support bolls. The number of main stem nodes increased significantly at all N rates (40, 80, and 120 kg N ha^{-1}) compared with the control. The increase in the number of main stem nodes with increase in N rate was not significant until 120 kg ha^{-1}. The number of main stem nodes was also positively correlated with lint yield (Table 2).

Internode length is often used as an indicator of plant vigor in cotton. Greater internode length indicates more rapid growth. Internode length also determines the stature and potential carrying capacity of the plant (Oosterhuis et al., 1996). Lint yield has been positively associated with internode length (Boquet et al., 2004b). Internode length increased significantly with 80 and 120 kg N ha^{-1} compared with the control in 1994 but not in 1995 (Fig. 6). Like internode length, number of nodes above white flower (NAWF) reflects the plant growth rate and is used to determine developmental progress during the boll set period (Bourland et al., 1992). Higher NAWF is indicative of the maximum amount of photosynthates available for developing bolls (Iqbal et al., 2003). Number of NAWF was significantly greater with all three levels of N applied in 1995 but only 120 kg ha^{-1} N significantly increased NAWF in 1994 compared with the control (Fig. 7). A correlation was observed between NAWF

Table 2. Correlation coefficients for cotton lint yield and growth characteristics

Growth parameter	**Growth parameter^{z}**						
	Year	**Lint yield**	**Height (cm) at maturity**	**Main stem nodes (65 -80 DAP)**	**Main stem nodes (80-100 DAP)**	**Main stem nodes (94-125 DAP)**	**Nodes above white flower (94-100 DAP)**
Lint yield	**1994**	**-**	**0.56****	**0.40***	**0.37***	**0.34***	**0.23***
	1995	**-**	**0.43***	**0.21***	**0.54****	**0.19***	**0.33***
Height (cm) at maturity	**1994**	**-**	**-**	**0.60****	**0.38***	**0.40***	**0.50****
	1995	**-**	**-**	**0.06NS**	**0.60****	**0.57****	**0.37****
Main stem nodes (65 -80 DAP)	**1994**	**-**	**-**	**-**	**0.24***	**0.11**	**0.44***
	1995	**-**	**-**	**-**	**0.09**	**0.15**	**0.09**
Main stem nodes (80-100 DAP)	**1994**	**-**	**-**	**-**	**-**	**0.40***	**0.19**
	1995	**-**	**-**	**-**	**-**	**0.42***	**0.34***
Main stem nodes (94-125 DAP)	**1994**	**-**	**-**	**-**	**-**	**-**	**0.04**
	1995	**-**	**-**	**-**	**-**	**-**	**0.41***
Nodes above white flower (94-100 DAP)	**1994**	**-**	**-**	**-**	**-**	**-**	**-**
	1995	**-**	**-**	**-**	**-**	**-**	**-**

^{z} Correlation values followed by * or ** are significantly different at $P = 0.05$ and $P = 0.01$, respectively. DAP = days after planting.

at 94 and 100 d after planting and lint yield in 1994 and 1995 (Table 2). All three levels of N significantly increased dry matter per hectare over the 0 N control in 1994 and 1995 (Fig. 8).

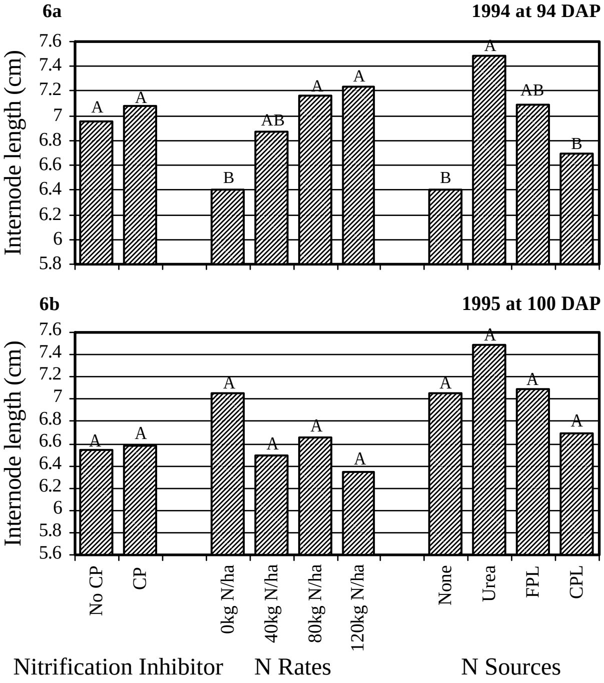

Figure 6. Response of internode length to the nitrification inhibitor carboxymethyl pyrazole (CP), nitrogen rates, and nitrogen sources at 94 days after planting (DAP) in 1994 and 100 DAP in 1995.

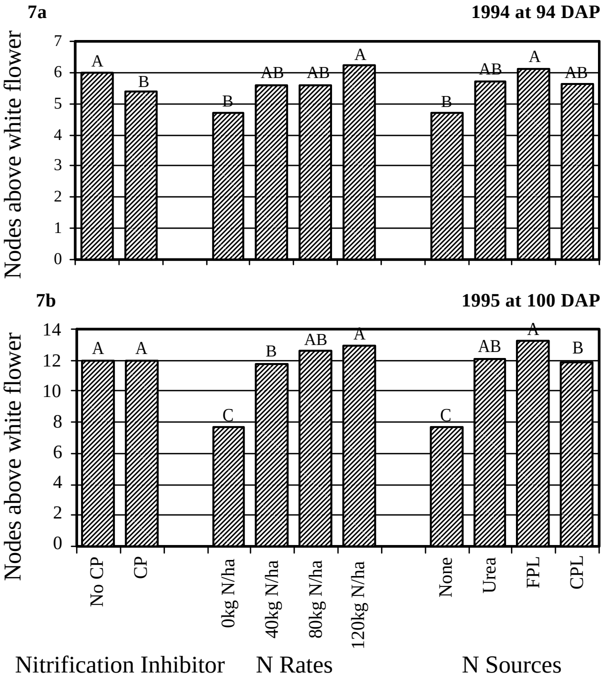

Figure 7. Response of nodes above white flower to the nitrification inhibitor carboxymethyl pyrazole (CP), nitrogen rates, and nitrogen sources at 94 days after planting (DAP) in 1994 and 100 DAP in 1995.

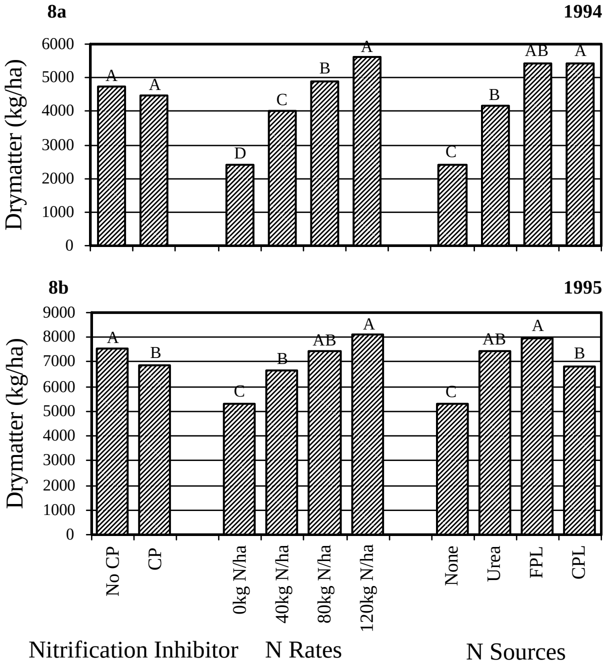

Figure 8. Response of cotton dry matter at maturity to the nitrification inhibitor carboxymethyl pyrazole (CP), nitrogen rates, and nitrogen sources in 1994 and 1995.

Increased rates of N application significantly increased lint yield compared with the control in all years (Table 1). Nitrogen at 80 and 120 kg ha^{-1} significantly increased lint yield compared with 40 kg N ha^{-1} every year except 1995. The 120 kg N rate did not significantly increase lint yield compared to 80 kg N ha^{-1}. These results support the general recommendations for cotton production using commercial fertilizer in Alabama, which range from 67 to 134 kg N ha^{-1} (Adams et al., 1994; Burmester, 1993). Boquet et al. (2004a) reported that application of 78 kg N ha^{-1} under traditional tillage systems and 118 kg N ha^{-1} under no-till systems was needed to optimize yields of cotton.

Effect of sources of N. During 1994, FPL significantly increased plant height compared with CPL and urea. Urea significantly increased plant height compared with CPL in 1994 (Fig. 3). Averaged over N levels, plant height was increased with the use of FPL, CPL, and urea in 1994 and 1995 compared with the control.

Results for main stem nodes were inconsistent among the different N sources (Fig. 4 and 5). Internode length increased significantly with urea compared with CPL in 1994 but did not differ significantly in 1995 (Fig. 6). In 1994, NAWF was similar with all sources of N, whereas in 1995 FPL and urea produced significantly higher

NAWF compared with CPL (Fig 7). Differences in dry matter production from applying FPL and CPL were not consistent from year to year. All N sources significantly increased dry matter compared with control treatments every year. FPL application increased dry matter 226% and 50%; CPL application increased dry matter 226% and 29%; and urea application increased dry matter 74% and 40% in 1994 and 1995, respectively (Fig. 8). Positive correlations were also observed between cotton lint yield and plant height at maturity (r = 0.43 to 0.56), main stem nodes (r = 0.19 to 0.54), and nodes above white flower (r = 0.23 to 0.33) in 1994 and 1995 (Table 2).

In all years, N application increased lint yield compared with the control (Table 1). Significantly higher lint yield was obtained with FPL compared with urea in 1994 and 1998. FPL also increased lint yield compared with CPL in 1994, 1996, and 1997. CPL provided greater yields over urea in 1998 only. Among three N sources, FPL produced the highest mean lint yield over the five-year period (1492 kg ha^{-1}) compared with CPL (1392 kg ha^{-1}) and urea (1391 kg ha^{-1}). The yield differences between the fresh and composted poultry litter could be because of the inaccurate estimation of available nitrogen from these two sources. Still, the costly process of composting the litter did not improve its effectiveness as an N source for cotton.

Studies by Nyakatawa et al. (2000) and Reddy et al. (2004) on a Decatur silt loam soil at Belle Mina, Alabama, indicate that application of poultry litter at the rate of 100 kg N ha^{-1} provided similar cotton growth and lint yield as ammonium nitrate at the same N rate. Other studies have also shown that poultry litter significantly increased plant growth and yield of forages (Bagley et al., 1996), rice (Govindasamy et al., 1994), cotton (Danforth et al., 1993; Lucero et al., 1995), and bermudagrass (Evers, 1998; Wood et al., 1993). Previous research in Alabama indicated that N in broiler litter was as effective as ammonium nitrate applied at 27 to 55 kg N ha^{-1} in increasing seed cotton yield (Mitchell et al., 1995).

CONCLUSIONS

The results from this five-year study indicate that the fresh and composted forms of poultry litter were as effective as urea in improving cotton plant growth characteristics, such as plant height, number of main stem nodes, number of nodes above white flower, and lint yield. Composting the litter, however, did not improve its effectiveness as an N source for cotton. The second generation nitrification inhibitor carboxymethyl pyrazole had no significant effect on cotton growth or lint yield. Applying poultry litter to row crops like cotton as a substitute for commercial fertilizers, such as urea, can help in the safe utilization of poultry litter, which is a growing problem in the southeastern United States. Use of poultry litter rather than commercial fertilizer has the advantages of not only benefiting the growth of cotton, but also making use of an inexpensive local nutrient source and at the same time, ameliorating the ever-increasing poultry litter disposal problem.

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