This paper was peer-reviewed for scientific content.
Pages 371-377. In: D.E. Stott, R.H. Mohtar and G.C. Steinhardt (eds). 2001. Sustaining the Global Farm. Selected papers from the 10th International Soil Conservation Organization Meeting held May 24-29, 1999 at Purdue University and the USDA-ARS National Soil Erosion Research Laboratory.

Effects of Nitrification Inhibitor on Nitrate Leaching in Cotton Production Systems

Ravi. K. Malik and K.C. Reddy*

ABSTRACT

In the light of energy and environmental concerns, the efficient utilization of nitrogen fertilizer has become an important goal. Nitrate, a product of mineralization process, is mobile and considered a significant ground water contaminant. This study was designed to investigate the potential use of poultry litter as an alternative to commercial N in cotton production and evaluate the effects of nitrification inhibitor, Carboxymethyl Pyrazole (CMP), on nitrate leaching. Three sources of nitrogen, fresh poultry litter (FPL), composted poultry litter (CPL) and urea at 45, 90, and 135 kg N ha^{-1} rates were treated with CMP. These were compared with non-CMP treated plots. The treatments were arranged in a randomized complete block design (RCBD) and replicated four times. Nitrification inhibitor significantly reduced NO_3-N formation in soils up to 41 days after cotton planting. Also, the increase in nitrogen application rate has increased NO_3-N significantly up to 41 days after planting (DAP). The plots that received CPL had significantly lower NO_3-N than those that received FPL and urea, on 41 DAP. However, these early season differences dissipated by the end of the cropping season. These results indicate the possibility of using CMP as a means to reduce nitrification. Out of three sources of nitrogen, the FPL had significantly increased cotton yields compared to urea and CPL, which resulted in similar yields.

INTRODUCTION

The poultry industry is growing rapidly in the southeastern region of the United States. In Alabama, it is concentrated in the Sand Mountain region of the state (Kingery et al., 1994). Broiler producers marketed about 900 million birds and their cash receipts amounted to 1.44 billion dollars in 1995 (Vanderberry and Placke, 1995). Alabama poultry industry produces about 2.04 million tons of poultry litter per year (Mitchell et al., 1989).

Application of poultry litter to cropland may serve as an important means of waste disposal. However, there is a growing concern that the indiscriminate disposal of poultry litter could cause non-point water contamination; ground water contamination through NO_3-N leaching and lakes and water sources eutrophication with run off of P (Liebhardt et al., 1979; Pratt, 1979; Sallade and Sims, 1992; Sharpley et al., 1991). Currently, several studies are underway to study the feasibility of transporting the litter from poultry production areas to other areas where it could be distributed in low amounts. Another solution may be to compost the litter into a more stable product that may release N more slowly than fresh litter and thus decrease the possibility of polluting underground water.

Poultry litter has approximately 3.04:1.25:1.37 % of N P K (Mitchell et al., 1989). Composting poultry litter addresses many problems associated with its use as a fertilizer by lowering moisture content, reducing odor, giving looser and more friable texture, reducing weed seed viability, and providing uniform and stable particles that are easier to handle (Victor et al., 1991; Schelegel, 1992). Typically, 50% to 60% of the total N in fresh manure will be mineralized and become available for crop use in the first year. On the other hand, some reports indicate that composting can reduce the nutrient value by 20 to 30% (Brinton, 1985; Castellanos and Pratt, 1981).

Guthrie and Bomke (1980) reported that use of chemical nitrification inhibitor helped in delaying nitrification of ammonium based fertilizers. By preventing rapid formation of nitrate in the soil, leaching and denitrification losses of nitrogen are limited, thus increasing the efficiency of fertilizers. Lower concentration of nitrate in soil should result in less nitrate contamination of the ground water as well as reduced emission of nitrous oxide from denitrifcation. While benefits are well documented in cereals, there are relatively few studies on cotton.

The ability of farmyard manure (FYM) to provide enhanced ammonium nutrition (EAN) supply has been suggested as a major reason for the yield responses to manure in many crops (Olson, 1986). Therefore, the potential of poultry litter to provide EAN could be significantly increased by applying an effective nitrification inhibitor. Radin and Sell (1975) suggested that with an effective nitrification inhibitor, EAN might reduce the risk of rank growth associated with manure. To our knowledge, second generation inhibitors such as CMP have not been tested on cotton. Mikkelsen et al. (1989) reported that treating composted poultry litter with nitrification inhibitor improved the nutrient value. The nitrification inhibitor sustains a higher ratio of ammonium to nitrate in soil by slowing the conversion process of ammonium to nitrate (Mikkelsen et al., 1989).

OBJECTIVES

The following were the major objectives of this study:

- Evaluating the role of an experimental nitrification inhibitor, CMP, on the inhibition of nitrate formation from poultry litter and urea.

*R.K. Malik and K.C. Reddy, Alabama A&M University, Dept. Plant & Soil Science, P.O. Box 1208, Normal, AL 35762. *Corresponding author: ravi_malik@hotmail.com.

- To test the effects of both fresh and composted poultry litter on cotton yield and leaching of nitrate nitrogen.

MATERIALS AND METHODS

Location

Experiment was conducted at the of Alabama Agricultural Experiment Station, Belle Mina, Alabama, situated at 34º 41' latitude and 86º 52' 30" longitude. The soil is classified as Decatur silt loam (Rhodic Paleudult).

Experimental Design and Plot Layout

The experiment was laid out in a randomized complete block design (RCBD) with 20 treatments and four replications. The treatments included three sources of nitrogen (Urea, FPL, and CPL); three nitrogen rates (45, 90, and 135 kg N ha^{-1}); with and without nitrification inhibitor, CMP. In addition, two control plots (i) no nitrogen and no CMP and (ii) no nitrogen and CMP treatment were included thus forming a total of 20 treatments. Each experimental plot consisted of 6 rows of cotton; 6 m x 9 m (0.00558 ha=0.0056 ha).

Poultry Litter

The FPL was collected from Mills Poultry Farm, Russelville, AL. In 1994, FPL had a moisture content of 36%, 2.8% N, and a C:N ratio of 9.1:1. In 1995, it had 26.74% of moisture, 2.6% N and a C:N ratio of 9.1:1. The composted litter was prepared at the Tennessee Valley Authority (TVA) facilities at Muscle Shoals, AL. CPL was prepared by constructing two piles, approximately 3.04 m in diameter and 1.52 m in height, using 2910 kg of FPL and 1630 kg of water per pile. Saw dust was added to adjust the C:N ratio. A front-end loader was used to construct the piles. An overhead crane with a clamshell bucket was used to aerate the piles.

The poultry litter piles were aerated every day for the first 35 days then twice a week for the next eight weeks. During the last six months, the piles were aerated when oxygen levels dropped below 5%. The compost reached a maximum temperature of 66 ºC, which was maintained for 30 days. After 30 days, the temperature was maintained at 38 ºC and above which was maintained for next six months. The litter was composted for a total of nine months. The finished compost had moisture content of 52% and contained 1.8%N, with a C:N ratio of 8.8 to 1 in 1994. In 1995, compost was prepared in a similar fashion and contained 33% moisture, 2.325% N, and the C:N ratio was 8.73:1. Available N from CPL and FPL was estimated at 60% (Bitzer and Sims, 1988).

Carboxymethyl Pyrazole (CMP)

The nitrification inhibitor sustains a higher ratio of ammonium to nitrate in soils by delaying conversion of ammonium to nitrate and thus improves nutrient value of composted poultry litter (Mickkelson et al., 1989). The nitrification inhibitor, CMP, was obtained from Department of Botany and Plant Pathology, Purdue University. It was applied at 0.56 kg ha^{-1} active ingredient. The inhibitor was diluted in 50:50 solution of ethanol and acetone; a total of 116 ml per plot was used. Urea, FPL and CPL were mixed thoroughly with CMP. In CMP alone plots, the inhibitor was directly sprayed on to the soil surface with a hand held gardener's sprayer.

Cultural Operations

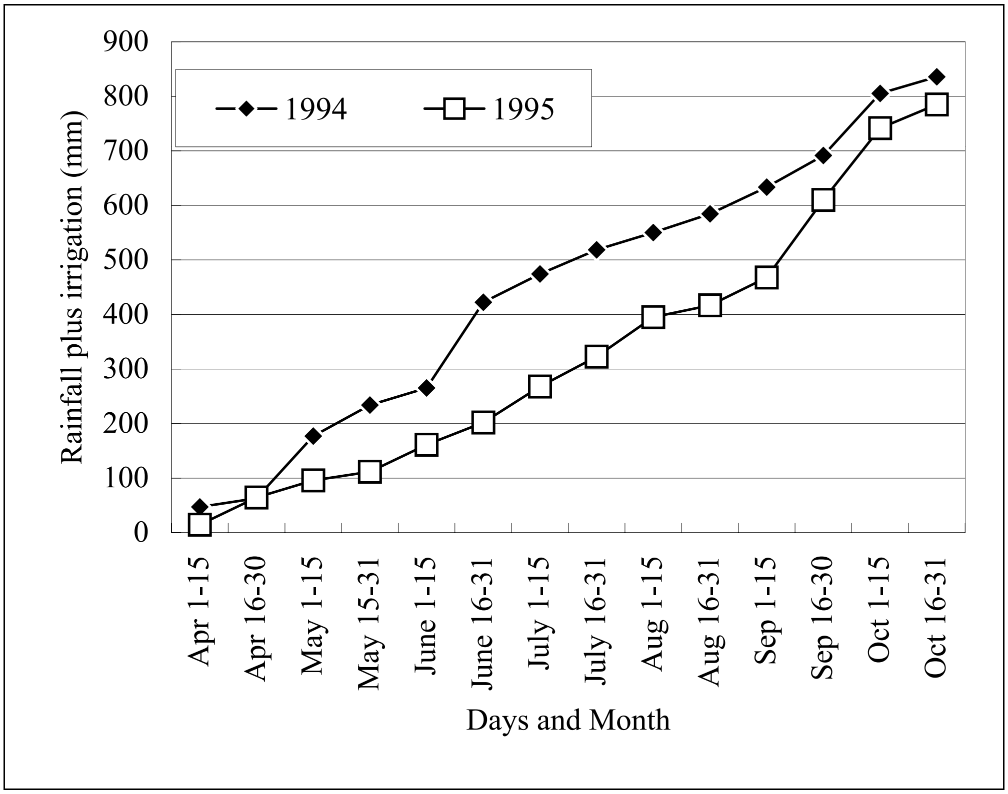
Based on initial soil chemical analysis at the beginning of the experiment in 1994, a blanket application of 336 kg ha^{-1} of 0-20-20 fertilizer was applied as a basal dose to all plots resulting in 67.2 kg ha^{-1} of P_2O_5 and K_2O. Also to correct Ca and Mg deficiencies, 3359 kg ha^{-1} of dolomite limestone was also applied in 1994. The inhibitor was sprayed directly on the soil. Urea, FPL and CPL were broadcasted and incorporated immediately into soil with a disk harrow. The cotton variety used for this research was Deltapine-51. It was planted on April 20, in 1994 and April 12, in 1995. Weeds were controlled each year with recommended pre-emergence and post-emergence herbicides. Early season seedling pests were controlled with an in-furrow application of insecticide and fungicide. The growth regulator, PIX (Mepiquat chloride), was applied at the first bloom stage. Amount of rainfall from April to September was 562.18 mm in 1994 and 524.8 mm in 1995; in addition, irrigation was provided to the extent of 50.8 mm in 1994 and 85.2 mm in 1995 (Figure 1).

Soil Analysis

Initial soil samples were collected on 21 March, 1994, and the second after first harvesting on 31 October, 1994, third at the beginning of the second year planting on 28 March, 1995, and the final at the end of the second year harvest on 11 December 1995. In each plot, three cores were collected to the depth of 105 cm using a tractor mounted soil sampler and sectioned to 0-15, 16-30, 31-45, 46-75, and 76-105 cm. These samples were air-dried and ground using a mechanical grinder and passed through a 2 mm sieve and stored for soil analysis. In addition, during growing season in 1994, surface soil (0-15 cm) samples were collected four times 41, 71, 102 and 111 days after planting (DAP) for NO_3-N estimation. Total N was determined using a Leco CHIN-600 (Hue and Evans 1986). NO_3-N was determined by the Ion Chromatographic method using Dionex Model DX-100 Ion Chromatography (Dick and Tabatabai, 1997).

Statistical Analysis

The cotton lint yield and soils data were analyzed for each year using RCBD and a combined analysis for both years were conducted using Split-plot design with years as main- plots. Data were analyzed using the general linear model (GLM) procedure of SAS Institute (1985). A Duncan's multiple-range test was employed for mean separation.



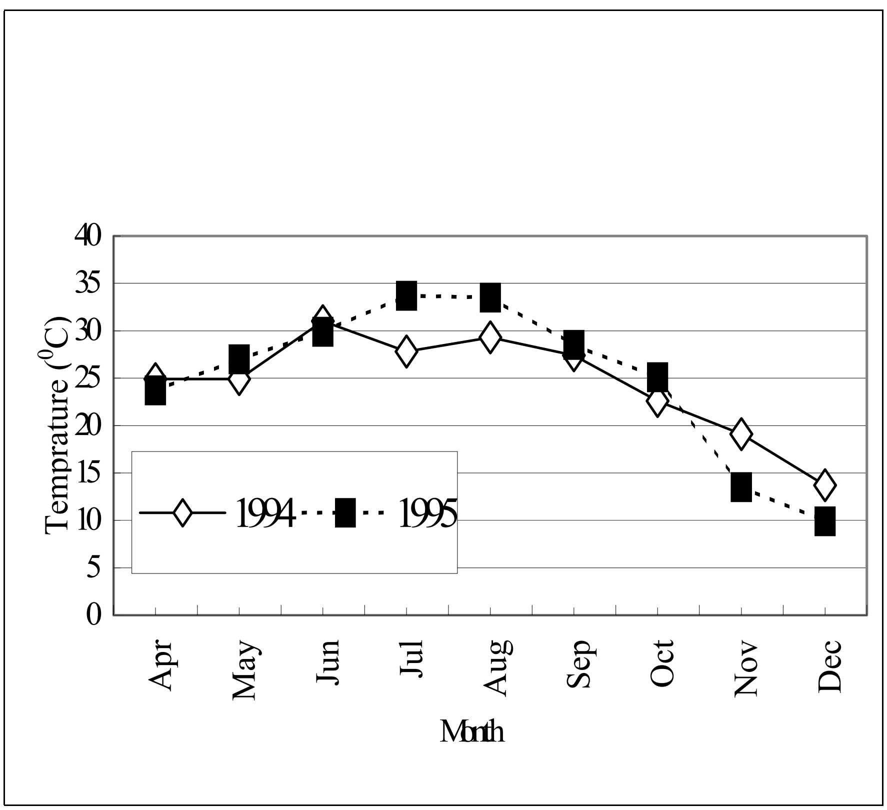


Figure 1. Mean monthly temperature and total rainfall plus irrigation water at 15 days intervals applied to cotton plots, Belle Mina, AL, 1994 and 1995.

Table 1. Nitrification inhibitor, nitrogen source and level effect on surface (0-15 cm) soil nitrate concentration during cotton growing season, Belle Mina, AL, 1994

Treatments	Nitrate concentration ($mg\ kg^{-1}$) (Days after planting)				
	41	71	102	111	224
Control	25.67e[§]	13.84c	11.30ab	9.62ab	17.65abc
Control+CMP*	27.98e	13.85c	12.27ab	8.56abc	18.75abc
45 kg N ha^{-1} Urea	39.01cde	13.94c	11.41ab	5.91abcd	17.69abc
45 kg N ha^{-1} Urea+CMP	54.14bcd	16.92cb	14.72a	8.92abc	18.76abc
45 kg N ha^{-1} FPL❅	38.23ed	15.74cb	12.35ab	4.52abcd	18.50abc
45 kg N ha^{-1} FPL+CMP	44.46cde	17.66cb	9.42ab	5.09abcd	19.48abc
45 kg N ha^{-1} CPL♈	29.70e	17.89cb	11.34ab	5.96abcd	19.00abc
45 kg N ha^{-1} CPL+CMP	29.61e	14.17c	16.86a	7.54abc	17.48abc
90 kg N ha^{-1} Urea	53.64cde	27.31cb	10.41ab	5.23abcd	15.53c
90 kg N ha^{-1} Urea+CMP	119.05a	21.62cb	16.35a	10.38a	19.11abc
90 kg N ha^{-1} FPL	67.30a	16.22cb	6.37ab	8.00abcd	17.59abc
90 kg N ha^{-1} FPL+CMP	73.58bc	33.91abc	9.16ab	2.73cd	20.06abc
90 kg N ha^{-1} CPL	33.20e	15.05cb	3.27b	4.28abcd	18.37abc
90 kg N ha^{-1} CPL+CMP	37.18ed	15.44cb	14.06ab	6.93abc	18.81abc
135 kg N ha^{-1} Urea	90.59ab	25.11cb	14.28a	5.96abcd	16.66bc
135 kg N ha^{-1} Urea+CMP	118.20a	43.77a	12.88ab	8.58abc	18.05abc
135 kg N ha^{-1} FPL	112.76a	22.66cb	8.02ab	2.75cd	21.93ab
135 kg N ha^{-1} FPL+CMP	104.88a	34.83ab	9.77ab	3.82abcd	22.24a
135 kg N ha^{-1} CPL	47.93cde	17.71cb	11.69ab	3.38bcd	21.72ab
135 kg N ha^{-1} CPL+CMP	43.12cde	16.76cb	9.24ab	0.00d	15.44c

*Carboxymethyl pyarazole
❅Fresh poultry litter
♈Composted poultry litter

[§]Means by the same letter are not significantly different based on Duncan's Multiple Range Test at $P < 0.05$.

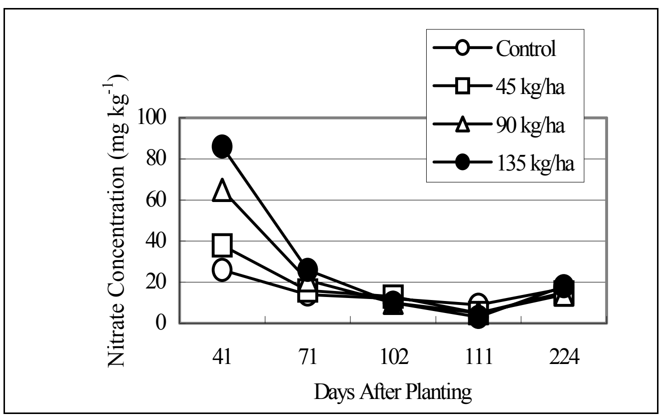


Figure 2. Nitrate N concentration during cotton growing season, 0-15 cm soil depth, Belle Mina, AL, 1994.

RESULTS AND DISCUSSION

Nitrate Concentration in Surface Soil (0-15 cm)

In 1994, at 41 DAP, the NO_3-N concentration among the treatments ranged from 25.67 mg kg^{-1} in the control to 119.05 mg kg^{-1} in 90 kg N ha^{-1} urea with CMP. At 71 DAP, NO_3-N concentration dramatically decreased in all the treatments (Figure 2). This drastic change could be attributed to the plant uptake of N and leaching to deeper layers of soil. At 102 DAP, NO_3-N concentration continued to decrease albeit at a slower rate as the plant N needs are lowest at this stage. In general, at 111 DAP, NO_3-N concentration was at its lowest (Figure 2). The final soil analyses at 224 DAP showed that the NO_3-N concentration was higher in all treatments as compared to 102 and 111 DAP. The soil tillage operations conducted immediately after the harvest must have increased the aeration and nitrification process. This coupled with lack of plants to utilize NO_3-N might have resulted in higher NO_3-N concentration at this last sampling.

The nitrification inhibitor reduced NO_3-N significantly on 41 DAP, however, the differences were not significant in later samplings (Table 1). Increase in N application rates increased the surface NO_3-N concentration at all sampling days but differences were significant only on 41 DAP (Table 1). The NO_3-N concentration from CPL treated plots was significantly lower compared to urea and FPL treated plots at 41 and 71 DAP (Table 1). However, by the end of the year, these differences became insignificant (Table 1). The FPL source of N significantly increased NO_3-N concentration compared to urea by the end of the season in 1994. Also in two years, it was found that FPL significantly increased the NO_3-N concentration compared to CPL (Table 2). Interestingly, the differences in NO_3-N concentration due to the experimental treatments were not, generally, significant.

Nitrate Movement in Soil Profile (up to 105 cm)

It was observed that in 1994, all treatments at the end of cotton growing season had more NO_3-N in the soil profile compared to early spring soil samples, the smallest change in the NO_3-N concentration was in the control plots. The changes in soil profile, however, in 1995 were different as compared to the changes in 1994.

All treatments, accumulated greater NO_3-N by the end of the cropping season compared to early spring, in the soil profile. The smallest changes were observed in the 135 kg N ha^{-1} CPL and the largest in 135 kg N ha^{-1} of urea with CMP.

Change in NO_3-N concentration in soil profile was significantly increased by 135 kg N ha^{-1} level compared to the other two levels. FPL and urea N sources had significantly increased NO_3-N concentration compared to CPL in soil profile (Figure 3). The composted litter had much lower concentration of nitrogen (1.8%) as the readily available ammonical portion was lost during the composting process. The remaining nitrogen, presumably, was available slowly and resulted in less leaching compared to N from urea and FPL. However, CMP showed a tendency to decrease NO_3-N (Table 3). The NO_3-N concentration was higher at deeper soil profiles compared to surface soil in both the years.

In summary, the use of nitrification inhibitor, CMP, reduced NO_3N leaching up to 41 DAP. It may be needed to further examine on the quantity and timing of CMP treatment to have continuous effect on nitrification inhibition. Also, the use of CPL reduced soil profile nitrate. Urea and fresh poultry litter increased soil profile NO_3-N by 8 mg kg^{-1} in two years whereas composted poultry litter had only increased it by 4 mg kg^{-1}. The possible reason for differences in NO^-_3 during 1994 and 1995 could be attributed to higher rainfall and lower temperature in 1994 compared to 1995 (Figures 1 and 3).

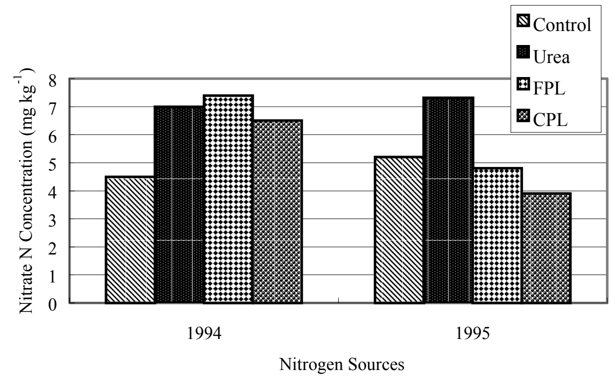


Figure 3. Change in nitrate N concentration in soil profile due to N source, Belle Mina, AL, 1994 and 1995

Cotton Lint Yield

Cotton yield was not significantly affected by the nitrification inhibitor both in 1994 and 1995 (Table 4). The poor performance of nitrification inhibitor in Southeastern US may be because of warm temperature during the winter (Touchton and Boswell, 1980). Soil in the fall tend to reduce the effectiveness of surface applied nitrification inhibitors (Gerik et al., 1994).

Table 2. Nitrification inhibitor, nitrogen source, and level effect on surface (0-15 cm) soil nitrate concentration in cotton production systems, Belle Mina, AL, 1994 and 1995

Treatments	Changes in nitrate concentration (mg kg^{-1}) (Year)		
	1994[1]	1995[2]	Two years[3]
Control	1.62abc[§]	- 3.50a	1.05ab
Control+CMP*	2.72abc	- 1.85a	1.33ab
45 kg N ha^{-1} Urea	1.65abc	3.51a	1.35ab
45 kg N ha^{-1} Urea+CMP	2.72abc	- 2.78a	2.09ab
45 kg N ha^{-1} FPL❁	2.46abc	2.56a	5.62a
45 kg N ha^{-1} FPL+CMP	3.45abc	- 4.84a	1.48ab
45 kg N ha^{-1} CPL♈	2.97abc	-5.35a	- 0.637ab
45 kg N ha^{-1} CPL+CMP	1.45abc	3.57a	2.96ab
90 kg N ha^{-1} Urea	-0.51c	- 0.33a	0.73ab
90 kg N ha^{-1} Urea+CMP	3.07abc	- 3.03a	- 0.75ab
90 kg N ha^{-1} FPL	1.55abc	- 8.29a	-0.83ab
90 kg N ha^{-1} FPL+CMP	4.02abc	1.81a	1.97ab
90 kg N ha^{-1} CPL	2.34abc	- 4.05a	0.32ab
90 kg N ha^{-1} CPL+CMP	2.78abc	1.65a	1.74ab
135 kg N ha^{-1} Urea	0.63bc	- 2.00a	1.26ab
135 kg N ha^{-1} Urea+CMP	2.01abc	-0.30a	3.56ab
135 kg N ha^{-1} FPL	5.90ab	- 4.88a	1.59ab
135 kg N ha^{-1} FPL+CMP	6.2a	1.53a	1.63ab
135 kg N ha^{-1} CPL	2.68ab	- 7.38a	- 3.94b
135 kg N ha^{-1} CPL+CMP	- 0.60c	- 9.36a	- 3.87b

*Carboxymethyl pyrazole
❁Fresh poultry litter
♈Composted poultry litter

[1]Changes in 1994 (11/31/94 - 3/21/94)
[2]Changes in 1995 (12/11/95 - 3/28/95)
[3]Changes in two years (12/11/95 - 3/21/94)

[§]Means by the same letter are not significantly different based on Duncan's Multiple Range Test at $P < 0.05$.

Table 3. Nitrification inhibitor, nitrogen source, and level effect on soil nitrate concentration (0-135 cm depth) in cotton production systems, Belle Mina, AL, 1994 and 1995.

Treatments	Changes in nitrate concentration (mg kg^{-1}) (Year)		
	1994[1]	**1995[2]**	**Two years**
Control	2.03c[§]	2.18ab	6.38bcde
Control+CMP*	7.20abc	1.39ab	7.28abcde
45 kg N ha^{-1} Urea	8.18abc	1.72ab	5.31bcde
45 kg N ha^{-1} Urea+CMP	5.31abc	-3.43b	2.72de
45 kg N ha^{-1} FPL❅	6.43abc	5.57ab	11.05abc
45 kg N ha^{-1} FPL+CMP	8.69abc	0.24ab	6.30cde
45 kg N ha^{-1} CPL♈	8.41abc	- 4.49b	1.72ed
45 kg N ha^{-1} CPL+CMP	5.20abc	5.11ab	5.67bcde
90 kg N ha^{-1} Urea	3.03bc	1.97ab	8.41abcd
90 kg N ha^{-1} Urea+CMP	12.36ab	0.25ab	6.57abcde
90 kg N ha^{-1} FPL	5.78abc	-2.10b	4.29cde
90 kg N ha^{-1} FPL+CMP	13.15a	5.61ab	8.35abcd
90 kg N ha^{-1} CPL	7.57abc	1.17ab	6.15bcde
90 kg N ha^{-1} CPL+CMP	6.94abc	0.09ab	3.48de
135 kg N ha^{-1} Urea	7.28abc	4.68ab	13.28a
135 kg N ha^{-1} Urea+CMP	5.59abc	- 0.77ab	11.61ab
135 kg N ha^{-1} FPL	6.16abc	5.41ab	10.53abc
135 kg N ha^{-1} FPL+CMP	4.14abc	8.40a	11.88ab
135 kg N ha^{-1} CPL	7.43abc	- 5.00b	0.52e
135 kg N ha^{-1} CPL+CMP	3.53abc	3.18ab	6.05bced

*Carboxymethyl pyrazole
❅Fresh poultry litter
♈Composted poultry litter
[1]Changes in 1994 (11/31/94 - 3/21/94)
2Changes in 1995 (12/11/95 - 3/28/95)
[3]Changes in two years (12/11/95 - 3/21/94)
[§]Means by the same letter are not significantly different based on Duncan's Multiple Range Test at $P < 0.05$.

Table 4. Nitrification inhibitor, nitrogen source and level effect on cotton lint yield, Belle Mina, AL, 1994 and 1995

Treatments	Lint yield (kg ha^{-1}) (Year)		
	1994	**1995**	**Mean**
Control	1300fg[§]	630c	960b
Control+CMP*	1260g	720c	990b
45 kg N ha^{-1} Urea	1400efg	960b	1180ab
45 kg N ha^{-1} Urea+CMP	1380efg	970b	1180ab
45 kg N ha^{-1} FPL❅	1520bcdef	1110ab	1320ab
45 kg N ha^{-1} FPL+CMP	1490bcdefg	1100ab	1300ab
45 kg N ha^{-1} CPL♈	1430defg	980b	1200ab
45 kg N ha^{-1} CPL+CMP	1510bcdefg	1010b	1260ab
90 kg N ha^{-1} Urea	1600abcde	990b	1300ab
90 kg N ha^{-1} Urea+CMP	1460cdefg	1080ab	1270ab
90 kg N ha^{-1} FPL	1690abc	1080ab	1390a
90 kg N ha^{-1} FPL+CMP	1670abcd	1100ab	1390a
90 kg N ha^{-1} CPL	1460cdef	1080ab	1270ab
90 kg N ha^{-1} CPL+CMP	1500bcdef	1060ab	1300ab
135 kg N ha^{-1} Urea	1570abcde	1030ab	1300ab
135 kg N ha^{-1} Urea+CMP	1710abc	1030ab	1370ab
135 kg N ha^{-1} FPL	1730ab	1080ab	1400a
135 kg N ha^{-1} FPL+CMP	1800a	1010b	1400a
135 kg N ha^{-1} CPL	1630abcde	1190a	1410a
135 kg N ha^{-1} CPL+CMP	1460cdefg	1070ab	1260a

*Carboxymethyl pyrazole
❅Fresh poultry litter
♈Composted poultry litter
[§]Means by the same letter are not significantly different based on Duncan's Multiple Range Test at $P < 0.05$.

The effect of nitrogen was significant and accounted for between 73 and 43 percent of the cotton lint yield increase in 1994 and 1995, respectively (Figure 4). The combined years analysis indicate that the FPL was significantly better than urea and CPL and urea was better than CPL (Table 4). These data indicate clearly that poultry litter is at least as an efficient source of nitrogen as commercial inorganic nitrogen. Other studies conducted by Nyakatawa et al. (2000) in the region indicate similar results.

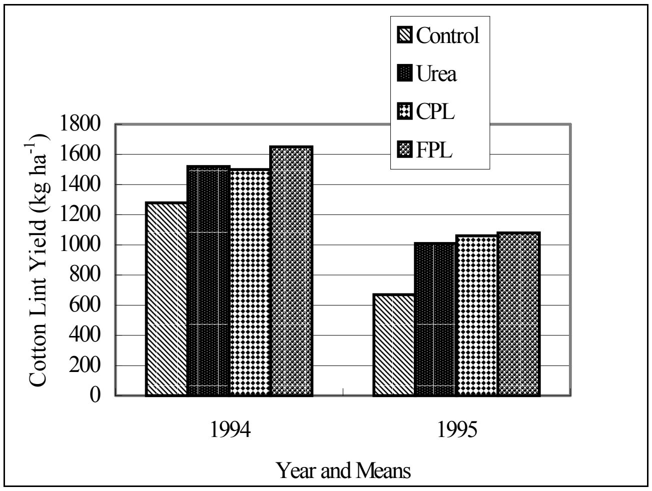


Figure 4. Effects of N sources on cotton lint yield, Belle Mina, AL, 1994 and 1995.

CONCLUSIONS

1. Poultry litter can be used as an alternative source of N in cotton production systems.
2. CPL was more efficient in reducing nitrate leaching compared to FPL and urea.
3. Experimental nitrification inhibitor, CMP, did significantly inhibit nitrification process up to 41 DAP but had no significant effect on cotton lint yield.

ACKNOWLEDGEMENT

The research was funded by USDA grant no. 93-38820-8890.

REFERENCES

Bitzer, C.C., and J.T. Sims. 1988. Estimating the availability of nitrogen in poultry manure through laboratory and field studies. J. Environ. Qual. 17:47-54.

Brinton, W.F. 1985. Nitrogen response of maize to fresh and composted manure. Biol. Agric. Hort. 3:55-64.

Castellanos, J.Z. and P.F. Pratt. 1981. Mineralization of manure nitrogen-correlation with laboratory indices. Soil Sci. Soc. Am. J. 45:354-357.

Dick, W.A. and A. Tabatabai. 1979. Ion chromatographic determination of sulfate and nitrate in soils. Soil Sci. Soc. Am. J. 43: 899-904.

Gerik, T.J., B.S. Jackson, C.O. Stocckel and W.D. Resenthal. 1994. Plant nitrogen status and boll load of cotton. Agron. J. 86: 514-518.

Guthrie, T.F. and A.A. Bomke. 1980. Nitrification inhibitor by microbial and nitrogen changes in poultry manure. J. Environ. Qual. 4:275-278.

Hue, N.V. and C.E. Evans. 1986. Procedures used for soil and plant analysis by Auburn University Soil Testing Laboratory. Department of Agronomy and Soils. Department Series No. 106. AL. Agric. Exp. Stn., Auburn Univ. AL.

Kingery, W.L., C.W. Wood, D.P. Delaney, J.C. William and G.L. Mullins. 1994. Impact of long-term land application of broiler litter on environmental related soil properties. J. Environ. Qual. 23:139-147.

Liebhardt, W.C., C. Golt and J. Turpin. 1979. Nitrate and ammonium concentration of ground water resulting from poultry manure applications. J. Environ Qual. 8:99-125.

Mitchell, C.C., J.O. Donald and J. Martin. 1989. The value and use of poultry waste as fertilizer. Agriculture and natural resources. Circular ANR-244.

Mikkelsen, R.L., J.B. Martin and C.M. Hunt. 1989. Response of sorghum to additions of poultry waste and a nitrification inhibitor. TVA Muscle Shoals Greenhouse Exp. 423-A. Muscle Shoal, AL.

Nyakatawa, E.Z., K.C. Reddy and D.A. Mays. 2000. Tillage, Cover Cropping, and Poultry Litter Effects on Cotton: II. Growth and Yield Parameters. Agron. J. 92:1000-1007.

Olson, S.R. 1986. The role of organic matter and NH_4^+ in producing high corn yields. pp. 29-54. In: The Role of Organic Matter in Modern Agriculture (Y. Chen and Y. Avenmelech eds.) Maartinus Nijhoff, Dordrecht, the Netherlands.

Pratt, F.P. 1979. Management restrictions in soil application of manure. J. Anim. Sci. 48:134-43.

Radin, J.W. and C.R. Sell. 1975. Growth of Cotton plants on nitrate and ammonium nitrogen. Crop Sci. 15:707-710.

Sallade, Y.E. and J.T. Sims. 1992. Evaluation of thiosulphate as a nitrification inhibitor for manures and fertilizers. Plant Soil. 147:283-291.

SAS Institute. 1985. SAS/STAT user's guide for personal computers. Version 6. SAS Inst., Cary, NC.

Schelegel, A.J. 1992. Effect of composted manure on soil chemical properties and nitrogen use by grain sorghum. J. Prod. Agric. 5:153-157.

Sharpley, A.N., W.W. Troeger and S.J. Smith. 1991. The measurement of bioavailable phosphorus in agricultural runoff. J. Environ. Qual. 20:235-238.

Touchton, J.T. and F.C. Bosewell. 1980. Performance of nitrification inhibitors in the southeast. pp. 63-74. In J. J. Meisinger (ed) Nitirification inhibitors: Potential and limitation. ASA Spec. Publ. ASA and SSSA, Madison, WI.

Vanderberry, H.L. and W T. Placke. 1996. Alabama agricultural Statistics. Montgomery, Alabama. Bulletin 38. 1994-1995.

Victor, W., E., Payne and J.O. Donald. 1991. Poultry management and environmental protection manual. Circular AANR-580. Auburn, AL