Supplemental Nitrogen Effect on Broiler-Litter–Fertilized Cotton

K. R. Sistani,* D. E. Rowe, J. Johnson, and H. Tewolde

ABSTRACT

Nitrogen nutrition plays a critical role in cotton (Gossypium hirsutum L.) production. However, increasing N fertilization may not always be desirable because production problems occur when N supply exceeds the crop requirement. A field experiment was conducted during 2000–2002 to study the optimal quantity of N needed from litter or combination of litter N and supplemental inorganic N for optimum cotton yield production. Poultry litter (2.24 Mg ha⁻¹ equivalent to 1 ton acre⁻¹) has been applied to the site annually for the past 20 yr. The experiment included four inorganic N rates (0, 34, 67, and 101 kg N ha⁻¹) as sidedress in addition to litter application. The smallest overall average cotton lint yield of 562 kg ha⁻¹ was obtained during 2000 (an exceptionally dry year) followed by 1551 kg ha⁻¹ in 2001 and 880 kg ha⁻¹ in 2002. The supplemental N application did not impact the cotton yield in 2 of 3 yr. In the 2000 growing season, cotton yield was significantly greater for 0 and 34 than 67 and 101 kg N ha⁻¹ rates. This indicates the negative effect of excess N application on cotton yield under drought conditions. However, under more favorable soil moisture conditions, no significant yield differences were observed by increasing the supplemental N rate up to 101 kg N ha⁻¹. The 2.24 Mg ha⁻¹ broiler litter application to all plots before planting each year provided approximately 80 kg N ha⁻¹, which proved to be adequate in three consecutive years for optimum cotton production under a no-till system.

Improving the N nutrition of cotton could substantially increase plant growth and yield. However, increasing the rate of N fertilization to overcome N limitations may not be successful because production problems occur when N supply exceeds the quantity required by the crop (Anderson, 1975). Nitrogen nutrition plays a critical role in cotton production, and it is also very difficult to manage relative to other essential nutrients. Nitrogen plays an important role in balancing vegetative and reproductive growth, yield, and lint quality. Growers use different techniques such as multiple N applications, use of starter fertilizer, petiole monitoring, plant leaf analysis, and N fertilizer placement to optimize N use efficiency in cotton (Mitchell, 2000).

In southeastern USA, N recommendations for cotton are based on the results of field trials research, which are generally satisfactory for continuous cotton crops in years with optimal rainfall. However, recommendations become less reliable for cotton where it follows other crops and where residual N is not quantified or during years of excessive rainfall when N loss via leaching, runoff, and denitrification is not estimated (Breitenbeck, 1990). Excessive N fertilizer application may also lead to the accumulation of NO₃ in the subsoil, which may or may not be beneficial depending on the surface soil N availability and the rooting system of the crop. Nitrogen fertilizer recommendations normally range from 67 to 112 kg N ha⁻¹ (60 to 100 lb N acre⁻¹) depending on soil texture. Higher N rates are applied to finer-textured soils to overcome N losses due to denitrification in poorly aerated soils. On upland soils of the southeastern USA, recommendations are closely related to the soil moisture regime because these soils are typically dry in July and August when cotton has higher water demands (Robinson, 1990). Phillips et al. (1987) reported that on an irrigated Grenada silt loam, cotton receiving 67 kg N ha⁻¹ had significantly greater yield than the control and the 34 kg N ha⁻¹ rate. However, cotton receiving 101 kg N ha⁻¹ and 134 kg N ha⁻¹ did not yield significantly greater than cotton receiving 67 kg N ha⁻¹. On the Grenada soil, N applications significantly increased cotton yields in only 2 of 5 yr, whereas on a Commerce very fine sandy loam soil, yield increased each of the 5 yr.

Miley and Maples (1988) reported that the petiole NO₃-N test proved to be a reliable indicator of the N status of cotton from third week of squaring through the eighth week of flowering.

In areas of intensive poultry production, most poultry litter (a combination of manure plus bedding materials) is commonly applied to pastures and hay fields as an alternative source of plant nutrients. However, the use of litter on row crops such as corn (Zea mays L.) and cotton has not been as extensive as on pasture (Bitzer and Sims, 1988; Kingery et al., 1994; Burmester et al., 1991). Many row crop farmers have been reluctant to use litter on their crops, particularly cotton, for many reasons, partially due to lack of extensive and applied research to demonstrate the agronomic and environmental benefit of poultry litter on cotton production.

Poultry litter is a relatively inexpensive source of both macronutrients (N, P, K, Ca, Mg, and S) and micronutrients (Cu, Zn, Fe, Mn, and B) and has been reported to increase soil organic C and enhance soil microbial activity (Nyakatawa et al., 2001). This study was conducted to further the understanding of using poultry litter on cotton production. Specifically, this study investigates the optimal quantity of N from litter or the combination of litter N and supplemental inorganic N for optimum cotton yield production.

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MATERIALS AND METHODS

A field plot experiment was conducted on cotton farmland during 2000–2002 for three growing seasons. The plots were 15 m long with eight rows of 96.5-cm spacing. The site is located on a Ora soil (fine-loamy, mixed, thermic, Vertic Hapludalfs) in Itawamba County, Mississippi. Poultry litter has been applied (2.24 Mg ha⁻¹ corresponding to 1 ton acre⁻¹) by our cooperator to the site for the past 20 yr as a source of nutrients for cotton production. The same rate of litter was also applied to all research plots each year during the life of the experiment. Broiler litter had the following properties on an average basis: percentage moisture, 26%; pH, 6.9; total N, 3.41%; NO₃⁻-N, 0.65%; NH₄⁺-N, 0.52%; total P, 1.87%; Ca, 28.5 g kg⁻¹; Mg, 6.2 g kg⁻¹; K, 27.9 g kg⁻¹; Cu, 741 mg kg⁻¹; Fe, 1529 mg kg⁻¹; Mn, 514 mg kg⁻¹; and Zn, 469 mg kg⁻¹.

Additionally, our cooperator has been applying approximately 67 kg N ha⁻¹ of inorganic N (urea ammonium nitrogen solution) as a sidedress to cotton plants.

The experiment was designed as randomized complete block to include four inorganic N rates of 0, 34, 67, and 101 kg N ha⁻¹ (corresponding to 0, 30, 60, and 90 lb N acre⁻¹, respectively) as sidedress during the four- to six-leaf growth stage. Ten random cotton leaves (blade plus petiole), the fifth leaf below the terminal, were collected from Rows 2 and 3 and 10 from Rows 6 and 7 of each plot at the first week of full bloom, fifth week of bloom, and first week of cutout for nutrient concentration determination. The two center rows were harvested for yield (lint plus seed) determination.

In April 2000, before litter application, initial soil samples were taken from each plot at the 0- to 5- and 5- to 15-cm soil depth. Table 1 shows background soil chemical properties of the site. Surface soil samples (0–5 cm) were also taken before the sidedress N application in each growing season. The following chemical analyses were performed on dried (65°C) cotton leaves and soil samples (air dried). The pH was measured in a 1:1 soil/water ratio using 10 g of soil. Total N (TN) and total C (TC) were measured by dry combustion using CE Elantec (formerly known as Carlo Erba; CE Elantec, Lakewood, NJ) CN analyzer. Soil samples were extracted with 0.01 M KCl (1:10 soil/KCl) using 2 g of soil and analyzed for nitrate (NO₃⁻-N) and ammonium (NH₄⁺-N) using a Dionex-500 Ion Chromatograph (Dionex Corp., Sunnyvale, CA) (Mulvaney, 1996). Soil samples were also extracted with Mehlich-3 soil extractant (Mehlich, 1984) (1:10 soil/extractant) using 2 g of soil, shaken for 30 min and filtered through 2V Whatman-brand filter paper for the determination of P and metals using a Thermo Jarrell-Ash Inductively Coupled Plasma Spectrophotometer (Thermo Jarrell-Ash, Franklin, MA). Approximately 0.8 g of plant tissue was ashed in a muffle furnace (30400, Thermolyne Corp., Dubuque, IA) at 500°C for 4 h. The ash was dissolved first in 1.0 mL of 6 M HCl for 1 h, followed by 50 mL of a double-acid solution of 0.0125 M H₂SO₄ and 0.05 M HCl, and the mixture was allowed to stand to condenser for another hour before filtration (Southern Coop. Ser., 1983). The ashed samples were used for the following analyses using inductively coupled plasma: total P, K, Ca, Mg, Cu, Fe, Mn, and Zn.

The data were analyzed using the GLM procedure of SAS (SAS Inst., 1998). Because of the significant (P ≤ 0.05) differences in yield among years, the data were sorted, analyzed, and reported by year. Annual yield means and nutrient uptake were separated by LSD (P ≤ 0.05).

RESULTS AND DISCUSSION

Initial soil N determination indicated a greater quantity of N in the deeper soil layer (5–15 cm) than the surface layer (0–5 cm) (Table 1). This is attributed to the fact that inorganic N (urea ammonium nitrate) solution has been injected as a sidedress to the experimental site in previous years. Figure 1 shows the precipitation quantity and distribution during the three cotton grow-

<table>
<thead>
<tr>
<th>Soil depth cm</th>
<th>pH</th>
<th>N  (g kg⁻¹)</th>
<th>C  (mg kg⁻¹)</th>
<th>M₃-P (mg kg⁻¹)</th>
<th>Ca (mg kg⁻¹)</th>
<th>Mg (mg kg⁻¹)</th>
<th>K (mg kg⁻¹)</th>
<th>Cu (mg kg⁻¹)</th>
<th>Fe (mg kg⁻¹)</th>
<th>Mn (mg kg⁻¹)</th>
<th>Zn (mg kg⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0–5</td>
<td>6.6</td>
<td>0.58</td>
<td>7.0</td>
<td>0.36</td>
<td>1.05</td>
<td>0.07</td>
<td>0.28</td>
<td>4.71</td>
<td>388</td>
<td>144</td>
<td>10.9</td>
</tr>
<tr>
<td>5–15</td>
<td>6.7</td>
<td>0.62</td>
<td>7.8</td>
<td>0.39</td>
<td>1.14</td>
<td>0.07</td>
<td>0.26</td>
<td>5.14</td>
<td>403</td>
<td>138</td>
<td>11.5</td>
</tr>
</tbody>
</table>

† Mehlich-3 (M₃) extractant was used to extract soil samples.
ing seasons. In 2000, very wet soil condition in April delayed the planting, and the lack of adequate soil moisture during July, August, and September impacted the cotton yield tremendously. The most favorable precipitation quantity and distribution was during 2001, which resulted in a high cotton yield. In 2002, wet April and May delayed planting, and a wet September and October delayed harvest, which resulted in a lower yield than in 2001 (Fig. 1).

**Cotton Yield**

The weather conditions, particularly precipitation, during the three growing seasons varied considerably, which impacted the cotton yield significantly. The smallest yield was obtained during the 2000 growing season (an exceptionally dry year) followed by the 2002 and 2001 yields (Fig. 2). This trend followed the precipitation pattern in which the 2000 growing season was the driest, and the 2001 growing season represented one having optimal soil moisture conditions. The supplemental N application did not have an impact on cotton yield in 2 of the 3 yr. In the 2000 growing season, the cotton yield was significantly greater under no supplemental N or 34 kg N ha\(^{-1}\) than higher N rates (Fig. 2). However, under the more favorable soil moisture conditions in 2001, no significant yield differences were observed by increasing supplemental N rates up to 101 kg N ha\(^{-1}\). This indicates the negative effect of too much N application on cotton yield under drought conditions. The 2.24 Mg ha\(^{-1}\) (1 ton acre\(^{-1}\)) broiler litter application to all plots before planting provided approximately 80 kg N ha\(^{-1}\) (based on litter analysis), which proved to be adequate in each growing season for cotton under no-till production. At the same time, our cooperator was applying 67 kg N ha\(^{-1}\) (60 lb N acre\(^{-1}\)) on his cotton field, just for assurance. It must be noted that the high yield from control plots is attributed to the optimum soil fertility condition, which has resulted from long-term broiler litter application annually and an efficient mineralization of litter N during cotton growing season (Guthrie et al., 1994). The background soil analysis indicated a good supply of C, N, and P in the topsoil (0–15 cm). The C/N ratio of the background soil was 12:1, a ratio that favors mineralization of litter N in contrast to immobilization of N under a greater C/N ratio (Table 1).

**Leaf Nutrient Composition**

The total N content of cotton leaves (average of three growth stages) varied among the treatments from year to year without following a particular trend (Table 2). In 2000 (a dry year), leaf N content was significantly greater for the 34 kg N ha\(^{-1}\) supplemental N rate than other rates while leaf N content of cotton for the 0, 34, and 101 kg N ha\(^{-1}\) rates was the same. However, in 2001, leaf N content for cotton plants receiving zero supplemental N was significantly lower than for other N rates, suggesting a better N use efficiency under optimum soil moisture conditions. The average petiole NO\(_3\)-N of the control plots (zero supplemental N) at peak bloom (determined to monitor the N status of the plants) was 28.31 g kg\(^{-1}\) while the corresponding leaf

![Fig. 2. Cotton lint yield related to four supplemental N rates in addition to application of 2.24 Mg ha\(^{-1}\) broiler litter in 2000, 2001, and 2002.](image-url)
crease was smaller for the 0- to 5-cm soil depth than for the 5- to 15-cm soil depth for the 2000 to 2001 growing seasons. Supplemental N was injected in the soil as sidedress in the form of urea ammonium nitrate solution. This is an indication of adequate N availability from broiler litter without any supplemental N application as sidedress. Supplemental N application did not impact the leaf P content in any growing season. No increase in leaf P content was associated with an increase in the supplemental N rates up to 101 kg ha⁻¹. The same trend was observed for leaf K content. Cotton leaf N and Ca contents were consistently greater than other nutrients in all 3 yr (Table 2). Tables 3a, 3b, and 3c show the leaf N, P, and K contents determined at different cotton growth stages for three consecutive growing seasons. Leaf N, P, and K content at the first week of bloom stage was consistently greater than for samples taken at later stages for all 3 yr. Based on the calculation from Tables 3a, 3b, and 3c, the rate of N depletion from the first week of bloom to the week after cutout for all 3 yr ranged from 22 to 37% for the zero rate while this range was 11.5 to 29% for the highest supplemental N rate. Since there were no significant differences in cotton lint yield among the supplemental N rates, the results also demonstrate that there was sufficient quantity of N throughout the growing season for plants receiving only broiler litter as a source of N. The cotton leaf P and K concentration depletion from the first week of bloom to the week after cutout was much greater in 2000 (a dry year) than in 2001 or 2002. The decrease of P and K for control plots was 42 and 44% while the corresponding values for the highest supplemental N rate (101 kg ha⁻¹) were 43 and 43% (calculated from Tables 3a, 3b, and 3c).

### Soil Nutrient Composition

Soil pH, averaged across all treatments, decreased approximately by one unit from 2000 to 2002. The decrease was smaller for the 0- to 5-cm soil depth than for the 5- to 15-cm soil depth for the 2000 to 2001 growing seasons. Supplemental N was injected in the soil as sidedress in the form of urea ammonium nitrate solution. This is an indication of adequate N availability from broiler litter without any supplemental N application as sidedress. Supplemental N application did not impact the leaf P content in any growing season. No increase in leaf P content was associated with an increase in the supplemental N rates up to 101 kg ha⁻¹. The same trend was observed for leaf K content. Cotton leaf N and Ca contents were consistently greater than other nutrients in all 3 yr (Table 2). Tables 3a, 3b, and 3c show the leaf N, P, and K contents determined at different cotton growth stages for three consecutive growing seasons. Leaf N, P, and K content at the first week of bloom stage was consistently greater than for samples taken at later stages for all 3 yr. Based on the calculation from Tables 3a, 3b, and 3c, the rate of N depletion from the first week of bloom to the week after cutout for all 3 yr ranged from 22 to 37% for the zero rate while this range was 11.5 to 29% for the highest supplemental N rate. Since there were no significant differences in cotton lint yield among the supplemental N rates, the results also demonstrate that there was sufficient quantity of N throughout the growing season for plants receiving only broiler litter as a source of N. The cotton leaf P and K concentration depletion from the first week of bloom to the week after cutout was much greater in 2000 (a dry year) than in 2001 or 2002. The decrease of P and K for control plots was 42 and 44% while the corresponding values for the highest supplemental N rate (101 kg ha⁻¹) were 43 and 43% (calculated from Tables 3a, 3b, and 3c).

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Mehlich-3 extractant was used to extract the soil samples.

Table 4. Soil pH and nutrient analyses of cotton plots taken before cotton planting and after planting before N sidedressing.†

<table>
<thead>
<tr>
<th>N rate kg ha⁻¹</th>
<th>pH</th>
<th>N</th>
<th>C</th>
<th>P</th>
<th>Ca</th>
<th>Mg</th>
<th>K</th>
<th>Cu</th>
<th>Fe</th>
<th>Mn</th>
<th>Zn</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>6.7</td>
<td>0.69</td>
<td>8.2</td>
<td>0.32</td>
<td>1.06</td>
<td>0.07</td>
<td>0.31</td>
<td>5.2</td>
<td>352</td>
<td>121</td>
<td>9.5</td>
</tr>
<tr>
<td>34</td>
<td>6.6</td>
<td>0.67</td>
<td>8.3</td>
<td>0.35</td>
<td>1.09</td>
<td>0.07</td>
<td>0.32</td>
<td>5.3</td>
<td>370</td>
<td>127</td>
<td>10.4</td>
</tr>
<tr>
<td>67</td>
<td>6.6</td>
<td>0.68</td>
<td>8.5</td>
<td>0.36</td>
<td>1.02</td>
<td>0.07</td>
<td>0.33</td>
<td>5.3</td>
<td>370</td>
<td>132</td>
<td>10.8</td>
</tr>
<tr>
<td>101</td>
<td>6.5</td>
<td>0.74</td>
<td>8.6</td>
<td>0.39</td>
<td>1.01</td>
<td>0.07</td>
<td>0.33</td>
<td>5.3</td>
<td>389</td>
<td>135</td>
<td>10.9</td>
</tr>
<tr>
<td>LSD 0.3</td>
<td>0.10</td>
<td>1.1</td>
<td>0.04</td>
<td>0.12</td>
<td>0.01</td>
<td>0.06</td>
<td>0.63</td>
<td>31</td>
<td>32</td>
<td>1.4</td>
<td></td>
</tr>
</tbody>
</table>

| 2001          | 6.5 | 0.78 | 8.4 | 0.29 | 0.88 | 0.05 | 0.24 | 4.0 | 101 | 92 | 8.3 |
| 34            | 6.4 | 0.83 | 8.5 | 0.27 | 0.93 | 0.05 | 0.23 | 3.7 | 101 | 77 | 7.5 |
| 67            | 6.4 | 0.84 | 8.7 | 0.34 | 0.91 | 0.06 | 0.24 | 4.2 | 102 | 92 | 9.1 |
| 101           | 6.3 | 0.82 | 8.5 | 0.32 | 0.83 | 0.05 | 0.24 | 4.1 | 103 | 96 | 9.0 |
| LSD 0.2 | 0.12 | 1.1 | 0.05 | 0.11 | 0.01 | 0.05 | 0.7 | 2 | 21 | 1.5 |

| 2002          | 5.8 | 0.78 | 8.6 | 0.26 | 1.05 | 0.06 | 0.23 | 4.6 | 256 | 75 | 8.6 |
| 34            | 5.7 | 0.83 | 9.1 | 0.27 | 1.10 | 0.06 | 0.22 | 4.5 | 255 | 79 | 8.9 |
| 67            | 5.7 | 0.82 | 9.1 | 0.31 | 1.06 | 0.06 | 0.24 | 4.8 | 272 | 88 | 10.4 |
| 101           | 5.6 | 0.79 | 8.8 | 0.39 | 0.96 | 0.05 | 0.23 | 4.4 | 280 | 86 | 10.1 |
| LSD 0.2 | 0.11 | 1.2 | 0.03 | 0.12 | 0.01 | 0.02 | 0.46 | 15 | 16 | 0.97 |

† Mehlich-3 extractant was used to extract the soil samples.

 Growing season (Tables 4 and 5). The supplemental N rates did not impact soil pH. Soil N and C content did not increase with the addition of supplemental N (Table 4). There was an increase in soil N and C content at the 0- to 5-cm soil depth from 2000 to 2002. However, the concentration of these elements decreased for the 5- to 15-cm depth for the same period (Table 5). The increase is credited to the residual N and C from litter, inorganic N, and plant residue from the surface application of broiler litter. The overall soil C/N ratios ranged from 10.4 to 12.1 for 3 yr, which may perhaps be credited to the continuous litter application on a yearly basis. Soil P did not change considerably with supplemental N rate increase for all growing seasons. Due to the no-till management system and the surface application of broiler litter without incorporation, the N, C, K, and P content of the surface layer soil (0–5 cm) was greater than that of the 5- to 15-cm layer (Table 5). The C content of the soil surface increased from 8.7 g kg⁻¹ in 2000 to 9.7 g kg⁻¹ in 2001 and to 10.5 g kg⁻¹ in 2002 while the increase in N was from 0.73 to 0.94 to 0.97 g kg⁻¹ for the same years, respectively. The soil Cu, Fe, Mn, and Zn were smaller in 2001 (with optimum moisture condition) than in 2000 (a very dry year). Greater soil moisture may have enhanced the uptake of these nutrients by cotton plants.

CONCLUSIONS

The conclusion drawn from this research study may be of assistance to cotton producers that are using broiler litter as an alternative fertilizer source and seeking to improve N use efficiency under a no-till system. During the life of this study, precipitation had the greatest impact on cotton yield and N use efficiency. In the 2000 growing season, 0 and 34 kg ha⁻¹ supplemental N produced significantly greater cotton yield than 67 and 101 kg ha⁻¹. However, under normal soil moisture conditions (2001 and 2002), no yield increase was obtained by supplying more N up to 101 kg ha⁻¹. Therefore, supplemental N had no impact on cotton yield in three consecutive years. Our results strongly suggest that soils receiving broiler litter at approximately 2.24 Mg ha⁻¹ (1 ton acre⁻¹) on an annual basis for a long time (20 yr in this study) may not require additional N for optimal cotton yield production.

ACKNOWLEDGMENTS

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REFERENCES


