Nutrient Dynamics from Broiler Litter Applied to No-Till Cotton in an Upland Soil

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ABSTRACT
Applying broiler litter to the soil surface of a no-till field of cotton (*Gossypium hirsutum* L.) increases the potential loss of its nutrients via runoff and volatilization. An experiment was conducted over 3 yr on an upland Atwood silt loam soil (fine-silty, mixed, semiaactive, thermic Typic Paleudalfs) near Pontotoc, MS, to determine the effect of broiler litter incorporation into the surface soil of no-till cotton on nutrient availability, movement, and accumulation. The experimental design was a randomized complete block with six treatments replicated four times. Treatments were an unfertilized control, inorganic N–P–K fertilizer at the recommended rate, broiler litter at the rate of 5.2 Mg ha⁻¹ plus 34 kg ha⁻¹ supplemental N, and broiler litter at 7.8 Mg ha⁻¹ without supplemental N. A surface incorporated treatment was also included for each litter rate to test for the effects of incorporation. Broiler litter significantly increased soil nutrient concentrations compared to the control. Incorporating litter into the surface soil retained more nutrients in the soil and enhanced C sequestration over nonincorporation, indicating losses of nutrients without incorporation. Application of litter at the higher rate exceeded cotton nutrient utilization as evidenced by increasing soil NO₃⁻N and accumulation of P, K, Cu, and Zn in the top 5 cm of the soil. Incorporating litter increased soil nutrient content higher than nonincorporation. Incorporation of litter into the surface soil of a no-till cotton significantly reduces nutrient losses from the field.

Commercial broiler production generates enormous amounts of litter (a mixture of manure and bedding materials) that is often applied to nearby pastures and croplands. This litter contains high concentrations of N, P, and K, as well as secondary and micronutrients (Edwards et al., 1992; Jackson et al., 2003; Tewolde et al., 2005a, 2005b). It is considered an excellent organic fertilizer (Sims and Wolf, 1994). Land application of litter has increased the yield of bermudagrass (*Cynodon dactylon* (L.) Pers) (Evers, 1998; Franzluebbers et al., 2004); corn (*Zea mays* L.) (Brown et al., 1994; Wood et al., 1996); soybean (*Glycine max* L.) (Adeli et al., 2005); and cotton (Malik and Reddy, 2002; Mitchell and Tu, 2005; Tewolde et al., 2007b). In addition to enhancing yields, litter improves soil quality indicators (Nyakatawa et al., 2001; Franzluebbers et al., 2004).

Long-term broiler litter application increases soil nutrient levels. Kingery et al. (1993) found higher extractable soil P, K, Ca, Mg, Cu, and Zn in litter-amended soils than in commercially fertilized pasture soils planted to tall fescue (*Festuca erundinacea* L.). Edwards et al. (1992) reported that broiler litter is a good source of trace elements that accumulate in the soil with repeated applications. From a greenhouse study with cotton grown in pots, Tewolde et al. (2005a) reported that more than 90% of the micronutrients applied with broiler litter are not removed and may accumulate if litter is the primary fertilizer. Other researchers found higher concentrations of nutrients in surface runoff from corn fields following litter application (Wood et al., 1996).

No-till cotton production in the southeastern United States has increased dramatically to 57% of the total cotton area in that region (National Cotton Council of America, 2003). In the Delta of Mississippi, about 40% of the cotton production is produced using no-till (Martin and Cooke, 2004). With cover crops, a large amount of no-till cotton is also produced in the upland soils of the midsouth (Meyer et al., 1999; Boquet et al., 2004).

Implementation of conservation tillage systems, such as no-till and including poultry litter applications to cotton in Mississippi, may significantly increase nutrient concentrations in soil and create soil nutrient imbalances. Broiler litter applied to no-till soils acts as a mulch to reduce soil erosion while simultaneously improving soil organic matter, conserving soil moisture, and providing nutrients for crops (Nyakatawa et al., 2001). However, manure application to no-till without incorporation may reduce its effectiveness as a nutrient source because of potential losses via runoff and volatilization (Eghball and Power, 1999). Therefore, producers should consider alternative management in no-till systems that minimize runoff and volatilization losses of N from surface applications while increasing available nutrients at the same time. Shallow surface incorporation of broiler litter into the soil can decrease losses from organic fertilizers in some cropping systems. For
example, in a laboratory experiment, Giddens and Rao (1975) found that incorporating poultry manure into the top surface of the soil reduced NH$_3$–N volatilization by 55% and nearly doubled soil NO$_3$–N concentrations. Poultry manure incorporation into the surface soil in no-till systems may also increase organic C levels while decreasing CO$_2$ emissions into the atmosphere (Pote et al., 2003). Increased soil N and organic matter improved soil fertility which increased crop productivity (Pote et al., 2003). Nichols et al. (1994) reported that incorporating poultry manure into the top 2 to 3 cm of the soil could reduce nutrient losses in runoff. Broiler litter fertilization resulted in higher corn grain yield in conventional tillage than in no-till (Sims, 1987). He reported that poultry manure application to no-till without incorporation may reduce its effectiveness as a nutrient source. However, he did not compare the effect of incorporated and nonincorporated poultry manure on soil nutrient status. Understanding the accumulation and movement of nutrients derived from broiler litter in the soils under a no-till system play an important role in management practices for any farmer or regulator to avoid undesirable environmental impact and optimize animal manure resource.

The effects on soil chemical properties and nutrient accumulations of poultry litter application to corn crops under no-till vs. tillage systems have been reported (Wood et al., 1996; Adeli et al., 2005; Mitchell and Tu, 2005; Adeli et al., 2007). Applying broiler litter to the soil surface of no-till cotton increases the potential loss of nutrients via runoff and volatilization of the NH$_3$–N. Any cultural practice that reduces those nutrient losses increases their potential availability for crops. The objective of this study was to determine the effect of incorporation of broiler litter into the soil surface in no-till cotton on nutrient availability, movement, and accumulation.

**MATERIALS AND METHODS**

This research was conducted 2003 through 2005 on an upland Atwood silt loam soil under rainfed conditions on the Pontotoc Ridge-Flatwoods Branch Station, Mississippi Agricultural and Forestry Experiment Station near Pontotoc. The study site was located on an upland marginally productive soil low in organic matter. The experimental design was a randomized complete block replicated four times. Treatments included: (i) an unfertilized control, (ii) inorganic N–P–K fertilizer at the recommended rate (as determined by the Mississippi Soil Test Laboratory), (iii) broiler litter at the rate of 5.2 Mg ha$^{-1}$ plus 34 kg ha$^{-1}$ supplemental N, and (iv) broiler litter at 7.8 Mg ha$^{-1}$ without supplemental N. A surface incorporated treatment was also included for each litter rate to test for the effect of incorporation. Individual plots included six rows spaced 1.01 m apart and 13.7 m long.

In 2003 and 2004, broiler litter was applied before planting cotton using a small-plot spreader. In 2005, litter was applied by hand. Litter for the incorporated treatment was lightly mixed in the top 5 cm of the soil using a rotary tiller within a few hours of application. The supplemental N was applied as UAN, urea ammonium nitrate, solution (32% N) at the initial square stage by injection into the soil about 0.15 to 0.20 m away from the row and at a depth of 0.10 m using a commercial liquid fertilizer applicator. Cotton variety DPL 451 BR was planted on 22, 20, and 6 May in the 3 successive years.

Total N and C in the broiler litter were determined using an automated dry combustion method using a ThermoQuest (CE Elantec, Inc., Lakewood, NJ) C/N analyzer. Total P content of the litter was estimated by dry-ashing a 1.0-g sample according to the procedures outlined by Isaac and Kerber (1977) and measured using ICP, inductively coupled argon plasma spectrophotometry (Thermo Jarrel-Asht model 1000, Franklin, MA).

To determine nutrient movement in the soil profile, after cotton harvest, the soil was sampled in the center of each plot to a 60-cm depth and divided into 0- to 5-, 5- to 15-, 15- to 30-, and 30- to 60-cm increments. Five cores (2.5 cm in diameter) were taken and composited for each plot and depth, mixed thoroughly, and a representative subsample used for analysis. Soil samples were air-dried, ground to pass through a 2-mm sieve, and stored for chemical analysis. Soil samples were analyzed for pH, total C, total N, Mehlich III-P, secondary and micronutrients, NO$_3$–N, and NH$_4$–N. Soil and litter pH were determined in water using a glass electrode and 1:2.5 soil/litter to water ratio (pH/EC/TDS meter model H19813–0; Hanna, Woonsocket, RI). Total C and total N for soil were determined using an automated dry combustion method using a ThermoQuest (CE Elantec, Inc., Lakewood, NJ) C/N analyzer. Soil organic matter was calculated from total C (percent of organic matter = Total C × 1.72). Soil NO$_3$–N and NH$_4$–N were determined by extracting 2 g soil with 20 mL of 2 M KCl (Keeney and Nelson, 1982) and analyzing for inorganic N (NH$_4$ and NO$_3$) using a Lachat instrument (QC 8000 flow injection analyzer; Lachat, Loveland, CO). These samples were also extracted using Mehlich-III extractant (Mehlich, 1984) and analyzed for plant-available P, K, Ca, and Mg using inductively coupled argon plasma spectrophotometry. Total soil trace elements were determined by digesting 0.5 g of air-dried soil using sulfuric acid, hydrogen peroxide, and hydrofluoric acid (Kuo, 1996) and analyzing for total P and trace elements using inductively coupled plasma (ICP). Ten grams of soil were added to 25 mL of 0.01 M CaCl$_2$ and shaken for 10 min. Resulting solutions were filtered using # 42 Whatman filter paper and analyzed for water soluble Cu and Zn concentrations using ICP.

Analyses of variance were used to determine differences among year, treatments and year by treatment interaction using the General Linear Model procedure in SAS (SAS Institute, 1996). Statistical differences among means were compared with Fisher’s protected Least Significant Difference at the probability level of 0.05.

**RESULTS AND DISCUSSION**

The initial chemical properties of the soil used in this study at the 0- to 15-cm depth are shown in Table 1. Soil organic matter (Total C × 1.72) was typically low and the unamended field had a soil test P levels of 12.7 mg kg$^{-1}$ which is considered low in the Mississippi State University Extension Service calibration. Soil Cu and Zn were also low. The chemical properties of the broiler litter used each year are summarized in Table 2.

**Soil pH**

After 3 yr of the highest broiler litter application when incorporated in no-till cotton, soil pH in the top 15- and 30-cm depths was significantly greater than the other treat-
ments (Fig. 1). These increases in pH were probably at least partly due to the calcium carbonate added to the poultry diet as a source of Ca (Hue, 1992). Soil pH at the 0- to 15-cm depth significantly increased from 2003 and 2004 to 2005 when averaged across treatments (Table 3). Averaged across years, soil pH did not differ by treatments except at the 7.8 Mg ha⁻¹ in which incorporation broiler litter into the soil surface increased soil pH by 0.4 units as compared to nonincorporated one (Table 3). Soil pH was lower by 0.2 units in the inorganic fertilizer treatment than in the control which is likely the result of proton (H⁺) production during nitrification of ammonical fertilizer in the inorganic fertilizer treatment (Adams, 1984) compared with the liming effect of poultry manure produced by poultry fed rations with mineral supplements (Hue, 1992).

**Soil Total Carbon and Nitrogen**

After 3 yr of litter application to no-till cotton, soil total C concentration at the surface 0 to 5 cm increased with increasing litter rates and ranged from 12.4 g kg⁻¹ for the control to 22.4 g kg⁻¹ with 7.8 Mg litter ha⁻¹ incorporated (Fig. 2). Incorporation of broiler litter into the soil surface (0 to 5 cm) appeared to play a key role in sequestering C and thereby building up soil fertility. For example, at the rate of 7.8 Mg ha⁻¹, total C was 16% higher when incorporated vs. nonincorporated. These results are in agreement with those of Pote et al. (2003) who reported that incorporation of broiler litter into the soil surface under no-till systems decreases CO₂ emissions to the atmosphere and increases soil C levels. Soil C concentration was not influenced at greater soil depths below 15 cm (Fig. 2) due to the accumulation of organic residue from broiler litter application or decomposition of plant residue in the surface soil layer. To evaluate the effects of treatments on soil chemical changes at the 0- to 15-cm soil depth (common in soil testing), soil chemical properties were weighted across 0- to 5- and 5- to 15-cm depth and shown in Tables 3 and 4. Averaged across treatments, soil total C at 0 to 15 cm increased from 2003 and 2004 to 2005 (Table 3). Across 3 yr, litter application increased soil C as compared to the control at the 0- to 15-cm depth (contrast comparison) (Table 3). The litter-alone treatment (7.8 Mg ha⁻¹) increased soil C over the control by 1.8 g kg⁻¹ (23%) when it was soil incorporated and by 1.1 g kg⁻¹ (14%) with nonincorporation (Table 3). Our results correspond to those of Parker et al. (2002) who reported that poultry litter applied to cotton at the rate of 6.7 Mg ha⁻¹ significantly increased soil C by 26% at the 0- to 15-cm depth when compared to the control. Soil C decreased under inorganic fertilizer N as compared to control but the difference was not statistically significant (contrast comparison), indicating lack of organic residue application from inorganic fertilizer N (Table 3). Litter application had also greater effects on soil C than the fertilizer treatment and the differences were highly significant (contrast comparison). For example at the litter rate of 7.8 Mg ha⁻¹, soil C increased over the fertilizer treatment by 2.3 g kg⁻¹ (31%) when it was incorporated and by 1.6 g kg⁻¹ (21%) when it was left into the soil surface without incorporation (Table 3).

After 3 yr, soil total N increased with application of litter in the top 5- and 15-cm soil compared to the control and to inorganic fertilization (Fig. 2). Soil total N at the 0- to 5-cm depth increased by 35% when 7.8 Mg ha⁻¹ litter was incorpor-
rated (Fig. 2). Similar to total C, no residual effects of the treatments were observed below 15 cm (Fig. 2). Averaged across treatments, soil total N at 0 to 15 cm increased from 2003 to 2004 and from 2004 to 2005 (Table 3). Averaged across years, the fertilizer treatment increased soil total N compared to the control but the difference was not statistically significant (contrast comparison) (Table 3). Across 3 yr, litter application increased soil total N as compared to the control and fertilizer treatments (contrast comparison) (Table 3).

For example, at the 0- to 15-cm soil depth, the litter-only treatment (7.8 Mg ha\(^{-1}\)) increased soil total N over the control and fertilizer by 0.48 and 0.40 g kg\(^{-1}\) (56 and 43%), respectively when it was incorporated and by 0.21 and 0.13 g kg\(^{-1}\) (24 and 14%), respectively when it was not incorporated (Table 3). The effects of litter application on soil total N was much greater when broiler litter incorporated than nonincorporated (contrast comparison) (Table 3). For example, at the rate of 7.8 Mg ha\(^{-1}\), incorporation into the soil surface resulted in an increased soil total N concentration of 25% compared to nonincorporation (Table 3). Our results correspond to those of Reganold (1988) who also found that incorporation of broiler litter into the soil surface resulted in significant increases in total N.

### Soil Nitrate Nitrogen

After 3 yr, application of broiler litter at the rate of 7.8 Mg ha\(^{-1}\) when it was incorporated resulted in greater NO\(_3^-\)N in the top 5 and 15 cm of the soil than when it was not soil-incorporated (Fig. 3). Not incorporating the broiler litter at the rate of 7.8 Mg ha\(^{-1}\)
increased soil NO3–N compared to the control but the difference over years (Table 3). Across years, the fertilizer treatment to 2005, indicating a cumulative effect of broiler litter application in the top 15 cm significantly increased from 2003 and 2004 and 30%, respectively when it was incorporated and by 25 and 11% when it was not incorporated (Table 3). This indicates that leaving litter on the soil surface increases the potential loss of P from the soil, presumably in runoff.

After 3 yr of litter applications, Mehlich III-P in the top 5 cm of the soil increased with increasing litter application (Fig. 4). Incorporation of litter at each rate in the top 5 cm of soil also led to greater P concentration. Incorporation of litter at the rate of 7.8 Mg ha–1 led to 15% more soil P in the upper 0 to 5 cm than did nonincorporation (Fig. 4). At the high litter rate when incorporated, Mehlich III-P was nearly six times greater than the control (115 vs. 20 mg kg–1)(Fig. 4). The efficiency of cotton in removing P from the soil was not high enough to prevent P accumulation. Tewolde et al. (2007a) reported that, regardless of the tillage system, broiler litter application at a rate ≥2.2 Mg ha–1 did not increase cotton P uptake resulting in P accumulation in the soil surface. Dorahy et al. (2004) found that average P uptake values at physiologic cut-out and P removal in seedcotton fertilized with inorganic fertilizer were 21 and 15 kg ha–1, respectively. In a Coastal Plain soil, the potential of seedcotton to remove P from the soil was reported as 9.1 and 27 kg ha–1 yr–1 by Mullins and Burmester (1990) and Mitchell and Tu (2005), respectively.

Soil P concentrations increased as broiler litter applications continued from year to year (Table 3). At the litter concentrations reported in Table 2, about 300 kg P ha–1 was applied to the soil with application of litter at the rate of 7.8 Mg ha–1 after 3 yr. Averaged across treatments at the 0- to 15-cm soil depth, Mehlich III-P increased from 2003 to 2004 and from 2004 to 2005 (Table 3). Across 3 yr, litter application increased Mehlich III-P as compared to the control and fertilizer treatments (contrast comparison) (Table 3). For example, at the rate of 7.8 Mg ha–1 litter application increased Mehlich III-P over the control and fertilizer by 17.8 and 16.6 mg kg–1, respectively when it was incorporated and by 14.6 and 13.4 mg kg–1 when it was not incorporated (Table 3). Incorporation of broiler litter into the soil surface resulted in higher levels of P at 15 cm (Table 3). However, there was no indication of P leaching below 15 cm (Fig. 4).

**Potassium and Calcium Distribution in the Soil Profile**

Broiler litter at the high rate increased soil K in the top 0 to 5 and 5 to 15 cm (Fig. 5), the net increase ranged from 35 to 127 mg kg–1. At the higher rate, incorporation of litter significantly increased soil K over nonincorporation in the top 0 to 5 and 5 to 15 cm of the soil (Fig. 5). Soil K concentration increased each year with repeated litter application over the 3-yr period, indicating cumulative effects (Table 4). Averaged across years, the treatments did not differ for soil K. At the lower and higher litter rates, incorporation increased soil K levels by 14 and 15%, respectively, compared to nonincorporation (Table 4), indicating possible losses of K in the runoff from this soil.

**Soil Phosphorus**

Adding broiler litter to no-till cotton increased water soluble P as compared to the control and fertilizer treatments (contrast comparison) (Table 3). Water soluble P was also influenced by incorporation of broiler litter into the soil surface. For example, the litter treatment at the rate of 7.8 Mg ha–1 significantly increased soil water soluble P over the control and fertilizer treatments by 4.6 and 4.4 mg kg–1, respectively, when it was incorporated and by 3.9 and 3.7 mg kg–1 when it was not incorporated (Table 3). This indicates that leaving litter on the soil surface increases the potential loss of P from the soil, presumably in runoff.
After 3 yr of treatments, soil Ca concentration was increased by broiler litter applications only at the high rate with incorporation (Table 4, Fig. 5).

**Copper and Zinc Distribution in the Soil Profile**

After 3 yr of litter applications, total Cu and Zn concentrations in the soil significantly increased at both the 0- to 5- and 5- to 15-cm depths (Fig. 6). Maximum soil concentration for Cu and Zn was obtained with application of 7.8 Mg litter ha$^{-1}$ at the 0- to 5-cm depth (Fig. 6). Surface incorporation of litter increased soil concentration of Cu (8.6 mg kg$^{-1}$) and Zn (14.5 mg kg$^{-1}$) vs. nonincorporation (6.5 mg Cu kg$^{-1}$ and 8.9 mg Zn kg$^{-1}$) (Fig. 6). Lower soil Cu and Zn concentrations in the nonincorporation treatment may be related to losses of those elements by runoff (Moore, 1998). Jackson et al. (2003) reported that application of 9 Mg ha$^{-1}$ of broiler litter to meet the N requirements of row crops such as cotton in the southeastern United States, resulted in the addition of 3.4 kg Cu and 2.7 kg of Zn ha$^{-1}$ to the soil. Because more than 90% of the micronutrients applied with broiler litter are not removed by cotton and have the potential to accumulate (Tewolde et al., 2005a), addition of Cu and Zn from litter application to the soil can potentially contribute to runoff if is not incorporated (Han et al., 2000). Averaged across treatments, soil Cu and Zn concentrations increased with time as litter applications continued, indicating cumulative effects. Across 3 yr, litter application increased soil Cu and Zn concentrations as compared to the control and fertilizer treatments (contrast comparison) (Table 4). For example, at the rate of 7.8 Mg ha$^{-1}$ litter application increased soil Cu and Zn over the control by 1.71 and 3.91 mg kg$^{-1}$, respectively when it was incorporated and by 1.13 and 1.14 mg kg$^{-1}$ when it was not incorporated (Table 4). Incorporation of broiler litter into the soil surface resulted in higher levels of Cu and Zn at 15 cm (Table 4).

**CONCLUSIONS**

The incorporation of broiler litter into the soil surface of no-till cotton conserves nutrients in the soil, increases C sequestration, reduces the potential losses of nutrients, and builds up soil fertility. No incorporation lowers litter effectiveness as a nutrient source as evidenced by lower yield and could pose some environmental threat from runoff P and trace elements to the ecosystems.

**ACKNOWLEDGMENTS**

Authors extend their great appreciations to Walter Woolfolk, Richard Switzer, Steve Stocks, USDA-ARS, and Trevor Garrett, Pontotoc Ridge-Flatwoods Branch Experiment Station, for providing great technical assistance.

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