Cover Crop Use for Managing Broiler Litter Applied in the Fall

A. Adeli,* H. Tewolde, J. N. Jenkins, and D.E. Rowe

ABSTRACT

Increasing interest of using broiler litter in the fall for row crops has implications for leaching losses of nutrients, particularly N. Any cultural practice that prevents nutrient losses could be agronomically beneficial and improve soil fertility. A field study was conducted in 2007 and 2008 on Leeper silty clay loam (fine, smectitic, nonacid, thermic Vertic Epiaquepts) soil to evaluate the impacts of a winter rye (*Secale cereal* L.) cover crop and broiler litter timing on cotton (*Gossypium hirsutum* L.) yield, yield components and leaching loss of NO_3–N. Broiler litter was applied to the soil at the rates of 0, 4.5, 9, and 13.4 Mg ha^{-1} in the fall and spring for both cover and no cover crop and incorporated immediately. Winter rye cover crop was planted following broiler litter application in the fall. Averaged across cropping system and broiler litter timing, cotton lint yield and yield components increased with increasing broiler litter application. Application of broiler litter at a rate >9 Mg ha^{-1} was not advantageous and exceeded N need for optimum lint yield as evidenced by increasing postharvest NO_3–N in the soil profile. In the absence of cover crop and averaged across litter rates, spring-applied broiler litter had the best agronomic response and increased lint yield by 19 and 18% compared with fall-applied litter in 2007 and 2008, respectively. Seeding a winter rye cover crop to fall-applied broiler litter did not benefit cotton lint yield and yield components but substantially reduced leaching loss of NO_3–N.

Currently, the use of broiler litter as a source of plant nutrients for row crops is expanding. A substantial number of studies have been conducted to determine the effects of N-based broiler litter on corn (*Zea mays* L.) (Brown et al., 1994; Wood et al., 1999) and cotton growth and yield (Mitchell and Tu, 2005; Sistani et al., 2004; Tewolde et al., 2005, 2007). However, accurately determining the availability of broiler litter N to crops is a difficult task and influenced by many factors, including litter N composition, timing, and soil type (Sharpley et al., 1998).

Timing of manure application may affect soil N content, crop N use efficiency and crop performance. For example, Hanna et al. (2000) reported that spring application of manure to corn provides the best agronomic response in most instances and manure N use efficiency increases with spring application compared with fall application. However, Loecke et al. (2004) suggested that fall application of solid swine (*Sus scrofa*) manure to corn increased available N and improved corn yield compared with spring application. In addition, Loecke et al. (2004) reported that fall applied manure produced higher corn grain yields than did spring applied manure due to more timely net N mineralization relative to plant N demand with fall application.

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Published in Agron. J. 103:200–210 (2011)
Published online 6 Dec 2010
Available freely online through the author-supported open access option.
doi:10.2134/agronj2010.0173

While spring application of manure provided the best agronomic response in most instances, manures are often applied to the soils in the fall, possibly because of greater availability, lower cost, more time to apply and busy spring planting schedules for farmers. In addition, weather risks of applying manure in the spring which allows small windows of opportunity for planting and is less favorable for land preparation (Ruiz Diaz and Sawyer, 2008). In Mississippi, due to wet winter months and in most cases early spring, row crop farmers are forced to apply broiler litter in the fall to prevent delayed manure over a winter fallow is risky because considerable amount of the litter N can be lost to leaching rendering the litter less effective for spring-planted crops. Fall litter application is also associated with potential environmental contamination (Smith and Chambers, 1998; Andraski and Bundy, 2005; Hansen et al., 2004; van Es et al., 2004). Loss of N derived from litter occurs both as leaching and denitrification of NO_3–N (Paul and Zebarth, 1997). Owens et al. (1995) reported that most of the N loss occurs as NO_3–N leaching during the late fall and early spring months when the soil is fallow (Owens et al., 1995).

The capability of applying litter in the fall is vitally important to row crop growers and poultry producers in the Mid-South and southeastern United States. Many apply broiler litter in the fall as a source of P and K, and then apply a full N rate from inorganic sources in the spring. This practice can lead to nutrient accumulation in the soil and adversely impact the environment. Therefore, management practices that prevent or minimize loss of broiler litter-derived N and enhance the cycling of N applied during the off-season for use by subsequent summer crops offers great practical benefit to growers.

Cover crops have been promoted as a means of maximizing the efficient use of available N to subsequent crops in agricultural systems, potentially enhancing profitability through reduced inorganic fertilizer N requirement (Dekker et al., 1994; Shipley et al., 1992). The use of winter cover crops to capture inorganic N and to reduce leaching losses by recycling NO_3–N, especially in areas that have high levels of winter and spring precipitation, is receiving renewed attention. During a 3-yr period, NO_3–N leaching losses under the winter-fallow treatment averaged 20 kg N ha^{-1} yr^{-1} compared with 1.2 kg N ha^{-1} yr^{-1} under the winter cover cropped treatment, when using an ammonium nitrate fertilizer for the preceding corn (McCracken et al., 1994). Winter rye cover crops have been shown to increase the efficient use of available N to subsequent crops in the spring, resulting in reduced NO_3–N leaching loss while potentially enhancing profitability through reduced inorganic fertilizer N requirements (Shipley et al., 1992; Dekker et al., 1994; Kowalenko, 1987). The scavenging ability of cover crops, particularly rye, to sequester and reducing N leaching loss has been documented. Wayland et al. (1996) reported that a winter cover crop reduced leached N 65 to 70% compared with winter-fallow soil that received animal manure. Davis and Garwood (1996) found that a rye winter cover crop reduced leaching loss by more than 90% as compared with winter-fallow. McCraken et al. (1994) reported that NO_3–N concentration of leachate was almost zero during the fall, winter, and early spring with a rye winter cover crop. Logsdon et al. (2002) showed that rye cover crops in corn–soybean rotation reduced nitrate losses more than 70%. In all of these studies, winter rye cover crop was used to deal with residual N left in the soil from previous spring application of organic or inorganic N fertilizer to row crops. However, the effect of cover crop followed with fall-applied broiler litter on NO_3–N sequestration has not been documented. We hypothesized that seeding of a cover crop, such as winter rye, following fall applied broiler litter is an effective practice in reducing leaching losses of litter-derived N during fall, winter, or early spring. The objective of this study was to evaluate the effects of cover crop (winter rye vs. winter fallow) along with broiler litter fertilization timing (fall vs. spring) on cotton, yield, leaching loss, and residual soil NO_3–N.

MATERIALS AND METHODS

A 2-yr study was conducted on Leeper silty clay loam soil in 2007–2008. In fall 2006, initial soil samples were taken at the 0- to 15-cm depth and analyzed for physical and chemical characteristics (Table 1). Soil pH were determined on 1:1 soil/water suspension with a glass electrode (pH/EC/TDS meter model H19813–0; Hanna, Woonsocket, RI). Total C and total N for soil were determined from air-dried, finely ground soil using an automated dry combustion C/N analyzer (Model NA 1500 NC; Carlo Erba, Milan, Italy). Soil organic matter was calculated from TC (percent of organic matter = TC × 1.72). Soil texture was determined by the method of Day (1965). Soil NO_3–N and NH_4–N were determined by extracting soil with 2 M KCl (Keeney and Nelson, 1982) and analyzed for inorganic N (NH_4 and NO_3) using a Lachat instrument (QC 8000 fl ow injection analyzer; Lachat, Loveland, CO). These samples were also extracted using Mehlich-III extractant (Mehlich, 1984) and analyzed for plant-available P, K, Ca, Mg using inductively coupled argon plasma spectrophotometer ICAP 9000 (Thermo Jerrell Ash, Franklin, MA). Soil bulk density was determined using procedure described by Grossman and Reinsch (2002). A typical double-cylinder, hammer-driven core sampler was used for obtaining soil samples for bulk density. A 15-cm ring was placed inside the sampler, inserted by force into the top 0- to 15-cm depth and the whole core was taken. Samples were weighed and oven-dried at 105°C and reweighed again to get a constant weight (Ws). Th e volume of soil assumed equivalent to the volume of the ring that contained soil. Soil D_b was calculated by dividing the mass of soil by the volume (D_b = Ws/Vs), where Ws = weight of dry soil (g) and Vs. = soil volume (cm^3). The experimental design was a randomized complete block design with a split-split plot treatment arrangement and four replications. Main plots consisted of cropping system (cover crop vs. no cover crop), subplots were time of application (fall vs. spring), and sub-subplots were broiler litter rates of 0, 4.5, 9, and 13.4 Mg ha^{-1} and inorganic N applied only in spring at the recommended rate determined by Mississippi Soil Testing Laboratory. The plots were 4 m wide and 9 m in length with a 3 m alley between the blocks. For the fall application, broiler litter was applied to the soil on 4 Oct. 2006 and 5 Oct 2007 and incorporated into the surface 15 cm within 1 h of application. Winter rye (*Secale cereal* L.) cultivar Elbon was planted on 5 Oct. 2006 and 6 Oct. 2007 as the cover crop treatment. The rye was drilled at seeding rate of 100 kg ha^{-1} with a row spacing of 17 cm.

Table 1. Initial chemical and physical properties at the 0- to 15-cm depth of the soil used in the study.

Soil property	Value
pH	7.1
Organic matter, g kg^{-1}	10.6
NH_4–N, mg kg^{-1}	3.7
NO3-N, mg kg^{-1}	14.1
P, mg kg^{-1}	40.3
K, mg kg^{-1}	168
Ca, mg kg^{-1}	2500
Mg, mg kg^{-1}	100
Cation exchange capacity, $cmol_c$ kg^{-1}	24
Bulk density, g cm^{-3}	1.28
Sand, g kg^{-1}	10
Silt, g kg^{-1}	40
Clay, g kg^{-1}	50

Broiler litter used in the research was obtained from a broiler chicken (*Gallus gallus*) producer in central Mississippi. Broiler litter for the spring application was taken from the same load used for the fall application. Litter from the load used for fall application was placed in black plastic bags, closed tightly, and stored in a cooler until spring application. Each year, broiler litter samples were taken at the time of application and moisture and nutrient contents of the litter determined (Table 2). Because litter in 2008 had less moisture than 2007, the total amount of N available from litter was approximately 25 kg ha^{-1} greater in 2008.

To monitor N leaching, after broiler litter application and planting rye, one suction lysimeter was installed at 60-cm depth in each of the plots receiving 0, 4.5, 9, and 13.4 Mg broiler litter ha^{-1} for winter rye and winter fallow, in two selected blocks for a total of 16 lysimeters. Leachate samples were collected 24 h after each rainfall event during late falls, winter and early spring in both 2006–2007 and 2007–2008. Leached water samples were kept frozen until analysis for NO_3–N concentrations. In each year, the quantity of aboveground winter rye biomass was determined by randomly harvesting two 0.5-m^2 areas in each plot approximately 6 wk before planting cotton. After weighing and mixing the samples thoroughly, a subsample (≈100 g fresh wt.) was collected for determinations of dry matter yield and N concentrations. Samples were dried at 65°C for 3 d in a forced-air

Table 2. Broiler litter characteristics and total amounts of N, P, and K applied with litter applications as calculated from broiler litter rate and broiler litter nutrient concentrations

Year	Applied litter	Moisture	Total C	Total N	NH_4–N	Total P	Total K	C/N ratio	pH
		g kg^{-1}							
2006–2007	–	350	264	27.9	3.46	12.5	28.6	9.5	7.1
2007–2008	–	257	324	33.6	5.61	15.2	30.4	10.4	7.2
Amount applied	Mg ha^{-1}		Mg ha^{-1}	kg ha^{-1}					
2006–2007	4.5	–	1.2	125	15.6	56	129	–	–
	9.0	–	2.4	251	31.1	113	257	–	–
	13.4	–	3.5	374	46.4	168	383	–	–
2007–2008	4.5	–	1.5	151	25	68	137	–	–
	9.0	–	2.9	302	50	137	274	–	–
	13.4	–	4.3	450	75	204	407	–	–

oven, weighed for dry matter production, ground to pass a 1-mm sieve and analyzed for total N by an automated dry combustion method using a ThermoQuest (CE Elantec, Inc., Lakewood, NJ) C/N analyze. After sampling, winter rye cover crops were chemically desiccated using glyphosate [N-(phosphonomethyl) glycine] at an application rate of 0.9 kg a.i. ha^{-1} in solution with 68 L water ha^{-1}. After the rye was fully desiccated, soil samples were collected from both the winter rye and winter fallow plots to a depth of 30 cm. The samples were air-dried, ground to pass a 2-mm screen, extracted with 2 M KCl (Keeney and Nelson, 1982) and analyzed for NO_3–N using a Lachat instrument (QC 8000 flow injection analyzer; Lachat, Loveland, CO).

In the spring, broiler litter was applied on 1 May 2007 and 4 May 2008 at the same rate applied in the fall and incorporated immediately. Cotton cultivar 'DP 444 BG/RR' was planted on 96-cm rows at approximately 65,000 seed ha^{-1} using a conventional four-row planter on 2 May 2007 and 5 May 2008. Dates of selected field operations in each year are presented in Table 3. To monitor plant N status, 20 fully expanded recently mature leaves from the main stem in each plot were taken at peak bloom for N concentrations. Before taking the leaves from the plant, chlorophyll meter readings were taken in each plot using a Minolta hand-held SPAD-502 chlorophyll meter (Minolta, Ramsey, NJ). At the beginning of boll opening, number of bolls was measured from a 1 m^2 area.

Cotton was defoliated with 1590 mL ha^{-1} of Finish, contains two active ingredient, including cyclanilide [1-(2,4-dichlorophenylaminocarbonyl)-cyclopropane carboxylic acid] and ethephon (2-chloroethylphosphonic acid), on 9 Sept. 2007 and 8 Sept. 2008 and harvested on 20 Sept. 2007 and 21 Sept. 2008 by picking the full length of the middle two rows using a spindle-picker. A subsample of seed cotton from each plot was taken (≈1.0 kg) for measuring ginning percentage. The samples were weighed before and after air-drying to constant weight in paper bags and ginned in a 10-saw tabletop microgin to determine lint percentage. Lint yields were determined by weighing lint and seed collected from each plot and multiplying corresponding seed cotton by the ginning percentage of each plot.

After picking, the cotton stalk were shredded and postharvest soil samples were taken to a depth of 90 cm from each sub-subplot to determine residual soil NO_3–N concentration. Soil samples consisting of five 5-cm diam. soil cores were randomly taken from 0 to 15, 15 to 30, 30 to 60 and 60 to 90 cm. Soil samples were combined by depth, placed in plastic bags and kept frozen until analyzed. Soil NO_3–N was determined by extracting soil samples with 2 M KCl (Keeney and Nelson, 1982).

All response variables within each year including lint yield, chlorophyll reading, and leaf N concentration, number of bolls, lint percentage, and residual and leaching loss of NO_3–N were analyzed by subjecting the data to statistical analysis using MIXED model analysis of SAS (Littell et al., 2006). Both cropping system and broiler litter fertilization timing were used as the fixed factors and replication and its interaction were used as random effect factors. Since the effects of year and year × rate interaction were significant for all dependent variables (Table 4), the effect of treatments in each year was evaluated separately. A significance level of $P < 0.05$ was established.

Table 3. Dates of selected field operations at Mississippi Plant Science Research Center.

Operation	Crop	Fall 2006	Spring 2007	Fall 2007	Spring 2008
Litter application		4 Oct.	1 May	5 Oct.	4 May
Planting	cover crop	5 Oct.	–	7 Oct.	–
	cotton	–	2 May	–	4 May
Killing	cover crop	–	28 Mar.	–	3 Apr.
Defoliation	cotton	–	9 Sept.	–	8 Sept.
Harvest	cotton	–	24 Sept.	–	28 Sept.

RESULTS AND DISCUSSION

Weather Conditions

The period from broiler litter application in October 2006 until cotton planting in May 2007 was warmer and drier than the 30-yr average (Fig. 1a and 1b). The late fall in 2007 and winter in 2008, on the other hand, was relatively colder and wetter than the normal. Mean monthly temperature in 2007 cotton growing season (from May–October) was similar to the average except in May and August in which the temperature was warmer than normal. In 2007, the monthly total precipitation during the cotton-growing season was less than the normal. In 2008, mean monthly temperature during cotton growing season in 2008 was similar to the normal, except in October in which the weather was colder than the normal. The 2007 cotton growing season had a different precipitation pattern than the 2008 season. The monthly mean total precipitation during cotton growing season in 2007 was lower than 30-yr average except in September in which the precipitation was greater than normal. In contrast, the

Table 4. Partial ANOVA probability values for the effect of cropping system, manure application time and rate on cotton lint yield, chlorophyll index, leaf N concentration, number of bolls, lint turnout, soil and leached NO_3–N.

Effect	df	Lint yield	Boll number	Lint turnout	Leaf N	Chlorophyll Index	Soil NO_3–N	Leached NO_3–N
				$P > F$				
Year (Yr)	1	0.0021	0.3769	0.0210	0.0010	0.0040	0.0312	0.0641
Cover crop (CC)	1	0.0037	0.2041	0.1495	0.2788	<0.0001	0.0034	<0.0001
Yr × CC	1	0.8176	0.7870	0.1085	0.5565	<0.0001	0.1651	0.4315
ManureTime (MT)	1	<0.0001	0.0002	<0.0001	<0.0001	<0.0001	–	–
Yr × MT	1	0.4114	0.7870	0.0954	0.0086	0.0240	–	–
CC × MT	1	<0.0001	0.0033	0.0021	<0.0001	<0.0001	–	–
Yr × CC × MT	1	0.3930	1.000	0.1156	0.0050	<0.0001	–	–
Manure rate (MR)	3	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0031	<0.0001
Yr × MR	3	0.0002	0.0665	0.0261	<0.0001	<0.0001	<0.0001	<0.0001
CC × MR	3	<0.0001	0.0058	0.4072	<0.0001	0.0004	0.0022	<0.0001
Yr × CC × MR	3	0.7758	0.8376	0.1994	0.0646	0.0578	0.0834	0.2673
MT × MR	3	<0.0001	0.0426	0.0508	<0.0001	<0.0001	–	–
Yr × MT × MR	3	0.3796	0.6901	0.2572	0.0043	<0.0001	–	–
CC × MT × MR	3	<0.0001	0.01189	0.0911	<0.0001	<0.0001	–	–
Yr × CC × MT × MR	3	0.9126	0.6975	0.7195	0.1988	<0.0001	–	–

2008 cotton growing season was wetter than normal except in June during which soil was drier than normal.

Cover Crop Yield and Nitrogen Utilization

Winter rye cover crop dry matter yields increased ($P < 0.001$) with increasing broiler litter rates and quadratic equations best described the cover crop dry matter response to increasing broiler litter applications in 2007 ($Y = 828 + 440x - 18.2x^2$, $r^2 = 0.98$) and in 2008 ($Y = 932 + 655x - 30.6x^2$, $r^2 = 0.96$). At the highest broiler litter rate (13.4 Mg ha^{-1}), winter rye cover crop dry matter yield in 2008 was 19% greater than in 2007 (Table 5). The higher dry matter yield in 2008 than 2007 was likely influenced by more precipitation in late fall and early spring, higher temperatures in March and April of 2008 than normal (Fig. 1). In addition, 17% more N was applied in 2008 than in 2007 due to greater broiler litter N concentration in 2008 than in 2007 (Table 2). In both 2007 and 2008, rye total dry matter yields were lower than those reported in literature (Vaughan and Evanylo, 1999; Odhiambo and Bomke, 2001). In Maryland, Clark et al. (1994) reported maximum winter rye biomass as cover crop in the range of 6400 and 7100 kg ha^{-1}. Wagger (1989) reported winter rye cover crop desiccated 2 wk beyond full anthesis had an average total aboveground biomass of 8.2 Mg ha^{-1}, low N concentration, high C/N ratio and supplied less total N into the system for subsequent crops. The reason for lower winter rye aboveground biomass productions in our study is that winter rye cover crop was desiccated before maturity (boot stage) (6 wk before planting cotton) to enhance the potential for net N mineralization during cotton growing season as C/N ratio was kept low. Our results are in agreement with others who reported that killing winter rye cover crop early in the spring would reduce biomass production and C accumulation, increase N concentration, reduce C/N ratio, and accelerate net N mineralization (Huntington et al., 1985; Evanylo, 1991). Huntington et al. (1985) reported that low C/N ratio would facilitate N mineralization during the subsequent crop growing season, increase available N for plant use, and reduce the dependence of the plant's N requirements from inorganic commercial N fertilizer. They showed that chemical desiccation of winter rye cover crop early in spring increased the potential release of cover crop N into the following crop. Synchronization of cover crop N mineralization with N uptake by the subsequent crop is important for efficient crop production. If release and uptake of N are not synchronized, yields may be reduced and risks of high postharvest soil NO_3–N concentrations and potential leaching losses may be increased (Meisinger et al., 1991).

Similar to cover crop dry matter yield, total N uptake in aboveground biomass of cover crop increased ($P < 0.0001$) with increasing broiler litter rates in a quadratic manner in 2007 ($Y = 11.9 + 6.5x - 0.25x^2$, $r^2 = 0.97$) and in 2008 ($Y = 12.5 + 10.2x - 0.44x^2$, $r^2 = 0.97$) but broiler litter had little effects on biomass N concentration (Table 4), indicating total N uptake by cover crop dry matter was primarily a function of dry matter production rather than dry matter N concentration. Averaged across year, cover crop N uptake ranged from 10.8 kg ha^{-1} for the control to 64 kg ha^{-1} for the 13.4 Mg ha^{-1} broiler litter application (Table 4). Winter rye cover crop taken up only 12% and 14% of total N applied with broiler litter at the highest rate of 13.4 Mg ha^{-1} in 2007 and 2008, respectively. Low winter rye N recoveries in our study was probably related to the low winter rye aboveground biomass, but could be due to the competition for N between plant and microbes. It has been reported that plant root exudation stimulate microbial activity, resulting in stimulated soil organic matter degradation and N immobilization by microbes (Griffiths and Robinson, 1992).

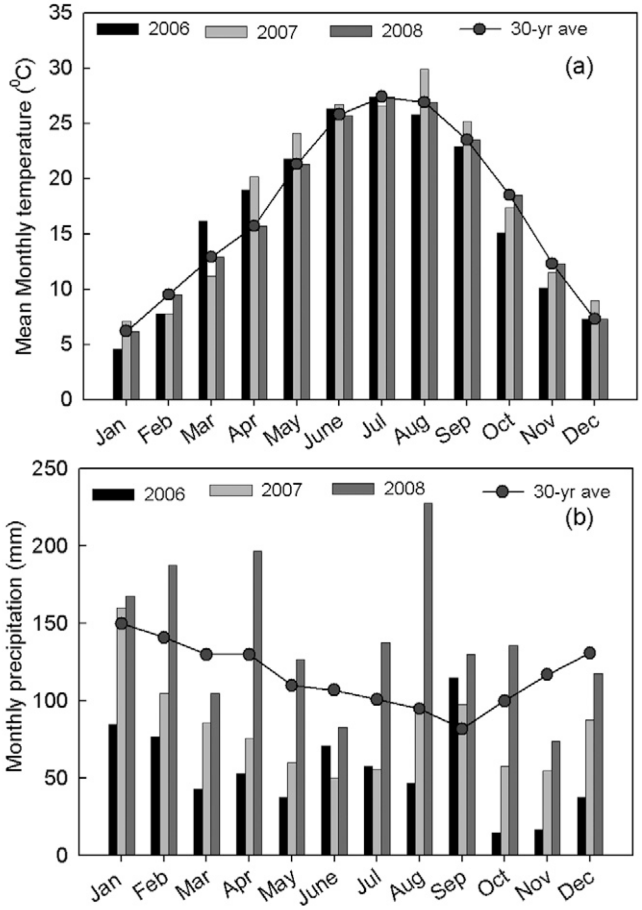

Fig. 1. (a) Monthly ambient temperature (bars), 30-yr (1978–2008) monthly average temperature (solid circle), and (b) 30-yr (1978–2008) monthly average amount of precipitation (solid circle) and monthly amount of precipitation for the 3-yr observation period received at the nearby (300 m) Mississippi Climate weather Station.

Table 5. Winter rye aboveground biomass production and N utilization from fall applied broiler litter.

Cropping system	Broiler litter rate	Dry matter yield	N concentration	N uptake
	Mg ha^{-1}	kg ha^{-1}	g kg^{-1}	kg ha^{-1}
		2007		
Winter rye	0	770	14.1	10.8
	4.5	2618	15.2	40.0
	9.0	3134	15.1	47.3
	13.4	3513	16.0	56.2
Litter linear		*		**
Litter quadratic		*		**
		2008		
Winter rye	0	813	13.3	10.8
	4.5	3621	15.1	54.7
	9.0	3981	15.9	63.3
	13.4	4329	16.7	72.0
Litter linear		**		**
Litter quadratic		*		*

* Significant at 0.05 level.

** Significant at 0.001 level.

Cotton Lint Yield

Cotton lint yield was greatly affected by cropping system, broiler litter rates and timing as evidenced by a significant interaction of these factors in 2007 ($P = 0.0006$) and 2008 ($P = 0.0001$) (Table 6). In 2007, cotton lint yield increased with broiler litter applications as compared with the control (Table 7). However, no differences in cotton lint yield was obtained among broiler litter rates, except in the absence of cover crop in which spring-applied broiler litter at the rate of 9 Mg ha^{-1} had the greatest cotton lint yield as evidence by broiler litter timing × litter rate interaction (Tables 6 and 7). Averaged across cropping system and application timing, cotton lint yield increased with increasing broiler litter rates and a quadratic equation best described the cotton yield response to increasing broiler litter applications ($Y = 697 + 133x - 6.7x^2$, $r^2 = 0.97$, $P < 0.001$). In this equation, the rate of litter that resulted in predicted peak lint yield was calculated by setting the first derivative of the equation to zero and solving for the litter rate. Based on this calculation, the predicted lint yield peaked when cotton was fertilized with 9.9 Mg ha^{-1}. The yield-maximizing 9.9 Mg ha^{-1} litter calculated based on the fitted model was approximately similar to the actual highest-yielding 9.0 Mg ha^{-1} litter rate (1357 kg ha^{-1} vs.1291 kg lint ha^{-1})

In 2008, regardless of cover crop and broiler litter timing, cotton lint yield increased with increasing broiler litter applications in a quadratic fashion ($Y = 658 + 152x - 7.6x^2$, $r^2 = 0.98$, $P < 0.001$). No difference in cotton lint yield was obtained between broiler litter at the rate of 9 and 13.4 Mg ha^{-1} (Table 8), indicating broiler litter at rate >9 Mg ha^{-1} was not advantageous to cotton lint yield. Application of broiler litter to cotton with more N necessary for maximum yield resulted in more vegetative growth and most likely delayed boll formation and maturity in which bolls were not contributed toward lint yield at the normal time of picking. This agrees with the results of Hunt et al. (1998) who reported that cotton had greater vegetative growth and less bolls with excessive N than required for maximum yield.

Averaged across broiler litter application rate and timing, significant difference in cotton lint yield was obtained between cover and no cover crop in 2007 ($P = 0.0427$) and 2008 ($P = 0.0403$) (Table 6). Cotton lint yield was smaller in the presence of cover crop (1104 and 1136 kg ha^{-1}) than in the absence of cover crop (1134 and 1160 kg ha^{-1}) in 2007 and 2008, respectively (Table 7 and 8). Lower yield in the presence of cover could be related to rapid immobilization of available inorganic N into organic fraction (Green et al., 1995) and delayed release of N for cotton uptake.

The effect of broiler litter application timing on cotton lint yield (averaged across cropping system) was greater for spring than fall application in 2007 (1193 vs. 1046 kg ha^{-1}, $P < 0.0001$) and in 2008 (1228 vs. 1068 kg ha^{-1}, $P < 0.0001$, repectively) as evidenced by the significant broiler litter timing × litter rate interaction in both years ($P < 00001$)(Table 6). In the absence of cover crop, low cotton yield response to fall-applied broiler litter compared with spring application was attributed to leaching losses of nutrients due to typical high precipitation during winter and early spring in the southeastern United States (Tables 7 and 8 and Fig. 2). In the presence of cover crop residue, cotton lint yield was also greater for spring than fall application in 2007 and 2008 as evidenced by cover crop × broiler litter timing interactions in 2007 ($P < 0.0001$) and in 2008 ($P < 0.0001$) (Table 6). In the presence of cover crop residue, greater lint yield most likely

Table 6. Partial ANOVA probability values for the effect of cropping system, manure application time and rate on cotton lint yield, chlorophyll index, leaf N concentration, number of bolls, lint turnout, soil and leached NO_3–N.

Effect	df	Lint yield	Boll number	Lint turnout	Leaf N	Chlorophyll Index	Leached NO_3–N
		P > *F*					
					2007		
Cover crop (CC)	1	0.0416	0.4927	0.6708	0.2481	0.0500	0.0647
Manure time (MT)	1	<0.0001	0.0083	<0.0001	<0.0001	<0.0001	–
CC × MT	1	<0.0001	0.0513	0.0071	<0.0001	<0.0001	–
Manure rate (MR)	3	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
CC × MR	3	0.0004	0.0872	0.9816	<0.0001	<0.0001	0.0022
MT × MR	3	<0.0001	0.2671	0.0566	<0.0001	<0.0001	–
CC × MT × MR	3	0.0006	0.4326	0.3754	<0.0001	<0.0001	–
					2008		
Cover crop (CC)	1	0.0403	0.0897	0.0998	0.5254	<0.0001	0.0501
Manure time (MT)	1	<0.0001	<0.0001	0.0005	<0.0001	<0.0001	–
CC × MT	1	<0.0001	0.0009	0.1428	<0.0001	<0.0001	–
Manure rate (MR)	3	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
CC × MR	3	<0.0001	0.0002	0.0132	<0.0001	<0.0001	<0.0001
MT × MR	3	<0.0001	0.0560	0.8702	<0.0001	<0.0001	–
CC × MT × MR	3	0.0001	0.0317	0.1269	<0.0001	<0.0001	–

related to this reason that applying broiler litter to the cover crop residue in the spring before planting cotton provided greater available N for microbial activities, enhanced decomposition of cover crop residue, and accelerated the release of plant-available N for subsequent crops (Wilson and Hargrove, 1986; Utomo et al., 1990; Varco et al., 1999). However, fall-applied broiler litter coupled with cover crop, with no supplemental N in spring, resulted in rapid immobilization of available inorganic N (Green et al., 1995) and delayed release of N for cotton uptake. Therefore, in the presence of cover crop residue, spring application

Table 7. Effects of broiler litter rate, timing and cover crop on cotton lint yield in 2007.

Cropping system	Timing	Fertilization BL†	Fertilization CF‡	Growth	Boll no.	Lint turnout	Leaf N	Chlo.§ index
		Mg ha^{-1}	kg N ha^{-1}	kg ha^{-1}		%	g kg^{-1}	
Cover crop (CC)	fall	0	0	711i	41ef	40.3abcd	30.1g	36.1l
		4.5	0	1148gh	47cde	40.1abcd	31.6f	40.3i
		9	0	1196egf	53bcd	39.6bcd	33.2d	41.2h
		13.4	0	1249edf	54bcd	39.1cdef	34.1c	43.3f
	spring	0	0	711i	41ef	40.3abc	30.1g	36.1l
		4.5	0	1249edf	49cde	39.9abcd	32.4e	42.4g
		9	0	1264ed	54bcd	39.2cdef	34.1c	44.1e
		13.4	0	1311cd	56abc	38.1fg	36.3b	48.2b
			125	1256edf	51abc	38.5fg	36.5b	50.3b
No-cover crop (NC)	fall	0	0	644i	36f	40.1abcd	29.3h	35.1m
		4.5	0	1108h	46de	41.0a	30.4g	36.5l
		9	0	1136hg	52bcd	40.6ab	31.8f	38.5k
		13.4	0	1174hgf	52bcd	39.4bcde	33.2d	39.7j
	spring	0	0	644i	36f	40.1abcd	29.3h	35.1m
		4.5	0	1363cb	60ab	39.0def	34.3c	45.3d
		9	0	1567a	65a	38.2efg	36.3b	47.3c
		13.4	0	1431b	56abc	37.4g	39.1a	50.1a
			125	1392cb	54abc	37.6g	39.4a	50.4a
						P > |t|		
Fall vs. spring				<0.0001	0.0820	<0.0001	<0.0001	<0.0001
CC vs. NC				0.0427	0.4929	0.6708	0.2481	0.06100

† Broiler litter.

‡ Commercial fertilizer N at the rate of 125 kg ha^{-1} recommended by Mississippi Soil Testing.

§ Chlorophyll index. Within each column and year, means followed by the same lowercaseletter are not significantly different at 0.05 probability level.

Table 8. Effects of broiler litter rate, timing and cover crop on cotton lint yield in 2008.

Cropping system	Timing	BL†	CF‡	Growth	Boll no.	Lint turnout	Leaf N	Chlo.§ index
		Mg ha^{-1}	kg N ha^{-1}	kg ha^{-1}		%	g kg^{-1}	
Cover crop	fall	0	0	678i	42g	40.2a	30.8j	36.9k
(CC)		4.5	0	1176gh	48f	39.6ab	33.3h	42.1g
		9	0	1245ef	56bcd	38.7cdef	34.5fg	44.6f
		13.4	0	1266def	57bc	37.8gh	37.6c	47.1d
	spring	0	0	678i	42g	40.2a	30.8j	36.9k
		4.5	0	1283de	50ef	39.2bcd	33.8gh	44.9f
		9	0	1369c	57bcd	38.5defg	36.3d	47.7d
		13.4	0	1388c	59b	37.8gh	39.2b	49.4c
			125	1288de	53def	37.6gh	38.8b	50.8c
No-cover crop	fall	0	0	612i	40g	40.1a	29.6k	35.2l
(NC)		4.5	0	1136h	51ef	38.9bcde	31.8i	37.8j
		9	0	1208fg	54cd	38.1efg	33.1h	39.1i
		13.4	0	1214fg	53def	38.0fgh	35.2ef	41.2h
	spring	0	0	612i	40g	40.1a	29.6k	35.2l
		4.5	0	1326cd	58bc	38.0fgh	35.9de	45.9e
		9	0	1659a	68a	37.2hi	39.7b	50.7b
		13.4	0	1509b	59b	36.8i	42.4a	52.4a
			125	1436b	55cd	37.1hi	42.1a	52.1a
						$P > \|t\|$		
Fall vs. spring				<0.0001	<0.0001	0.0005	<0.0001	<0.0001
CC vs. NC				0.0403	0.0897	0.0998	0.5254	<0.0001

† Broiler litter.

‡ Commercial fertilizer N at the rate of 125 kg ha^{-1} recommended by Mississippi Soil Testing.

§ Chlorophyll index. Within each column and year, means followed by the same lowercaseletter are not significantly different at 0.05 probability level.

of broiler litter could synchronize better with cotton N needs than fall- applied litter. This agrees with the results of Boquet et al. (2004) reported addition of even small amounts of fertilizer N to cover crop residue in spring accelerated mineralization of residues within the zone influenced by fertilization. In agreement with our results, Hanna et al. (2000) reported that spring application of manure to corn provides greater yield and manure N use efficiency than fall application.

Inorganic fertilizer N was applied to cotton only in spring at the recommended rate of 125 kg ha^{-1} (50 kg ha^{-1} at planting and 75 kg ha^{-1} at squaring). Application of inorganic fertilizer to cotton in spring in the presence of cover crop residue resulted in less lint yield than in the absence of cover crop residue (1256 vs. 1392 kg ha^{-1} in 2007 and 1288 vs. 1436 kg ha^{-1}in 2008) (Tables 7 and 8), suggesting N immobilization by cover crop residues.

Cotton lint components such as number of bolls and cotton lint turnout were also influenced by broiler litter management. Boll number was not affected by cover crops in 2007 ($P = 0.4927$) (Table 6) and averaged across broiler litter rate and timing, no differences in boll number was obtained between cover crop and no cover crop in 2007 (49 vs. 50)(Tables 7). Only in 2008, similar to cotton lint yield, boll number was affected by cropping system, broiler litter rate and timing as evidenced by a significant interaction of these factors (0.0317)(Table 6). Averaged across cropping system, boll number was greater for spring than fall application (54 vs. 50, $P < 0.0001$)(Table 6 and 8). In 2008, boll number increased with increasing spring-applied litter and maxiumum boll number was obtained at the rate of 9 Mg ha^{-1} (Table 8) as evidence by significant broiler litter rate and timing interaction ($P = 0.0560$)(Table 6). At rate >9 Mg ha^{-1}, boll number was not affected by broiler litter rates (Tables 8). This agrees with the results of Boquet et al. (2004) reported excess available N induces excessive vegetative growth and delayed boll formation and maturity which may not contribute toward cotton lint yield.

Cotton lint yield is determined not only by the number of bolls but also by boll weight and lint turnout. Cotton lint turnout had the highest value in the control plot with no manure and had the lowest magnitude with the highest broiler litter rate (Tables 7 and 8). Cotton lint turnout was not affected by cover crops in 2007 ($P = 0.6708$) and 2008 ($P = 0.0998$) (Table 6). Averaged across broiler rate and timing, no differences in cotton lint turnout was obtained between cover crop and no cover crop in 2007 (39.6 vs. 39.5%) and 2008 (39.0 vs. 38.6% (Tables 7 and 8). The effect of broiler litter application timing on cotton lint turnout (averaged across cropping system) was smaller for spring (39.0 and 38.5%) than fall application (39.9 and 38.9%) in 2007 and 2008, respectively. Since spring-applied broiler litter provides more available N for cotton than fall-applied litter, particularly in the absence of cover crop, cotton lint turnout was reduced with increasing spring-applied litter. Our results are in agreement with the work by Sawan (2008) and Tewolde et al. (2007) who reported that lint percentage decreased when N level increased.

Chlorophyll Meter Readings and Leaf Nitrogen Concentrations

Cotton chlorophyll index and leaf N were greatly affected by cover crop, broiler litter application timing and rates as evidenced by a significant interaction of these factors ($P < 0.0001$)(Table 6). In the presence of cover crop treatment, chlorophyll index increased linearly with increasing broiler litter rates for both fall ($Y = 37.6 + 0.58x$, $r^2 = 0.96$, $P < 0.001$) and spring-applied litter ($Y = 37.2 + 0.83x$, $r^2 = 0.94$, $P < 0.001$) as evidenced by the significant broiler litter rate and timing interaction in 2007 and 2008 (Table 6). In the absence of cover crop, averaged across cropping system, chlorophyll index was higher when litter was applied in spring (44.5 and 46.1) than in the fall (37.5 and 38.3) in 2007 and 2008, respectively as evidenced by the significant cover crop and litter timing interaction ($P < 0.0001$ (Tables 6, 7, and 8). Similar to chlorophyll readings, leaf N concentrations tended to increase linearly with increasing broiler litter rates for both fall ($Y = 30.5 + 0.38x$, $r^2 = 0.96$, $p < 0.001$) and spring-applied litter ($Y = 30.6 + 0.53x$, $r^2 = 0.98$, $p < 0.001$) in each year. Since chlorophyll readings and leaf N concentrations followed a similar pattern in response to broiler litter application to cotton, our results indicated leaf chlorophyll readings can be used as an indicator of N status in the plant as reported by others (Feibo et al., 1998; Bronson et al., 2003). In addition, Reddy and Kumari (2004) reported that cotton leaf chlorophyll meter reading is a good indicator of plant growth and soil conditions for crop productivity, and is positively correlated with biomass and lint yield of cotton.

Although, cotton lint yield peaked at broiler litter rate of 9 Mg ha^{-1}, leaf chlorophyll index and leaf N concentrations continue to increase to the highest broiler litter rate (13.4 Mg ha^{-1}). This suggests the cotton plant continues to extract soil N beyond that necessary to mature bolls. For example, for the spring application, leaf N concentration at flowering was about (36.3 g kg^{-1} in 2007 and 39.7 g kg^{-1} in 2008) when broiler litter was applied at the rate of 9 Mg ha^{-1}, but increased to approximately 39.1 g kg^{-1} in 2007 and to 42.4 g kg^{-1} in 2008 if fertilized with 13.4 Mg ha^{-1}. This suggests the cotton plant continues to extract soil N beyond that necessary to mature bolls and optimum yield.

Cropping system did not have significant effect on leaf N concentration ($P = 0.2788$)(Table 5). Averaged across broiler litter application rates and timing, no differences in leaf N concentrations was obtained between cover crop and no cover crop in 2007 (32.7 vs. 32.9 g kg^{-1}, $P = 0.2481$) and in 2008 (34.5 vs. 34.6 g kg^{-1}, $P = 0.5254$) (Tables 7 and 8). However, broiler litter application timing affected cotton leaf N concentrations ($P <$ 0.0001)(Table 6). Averaged across cropping system, cotton leaf N concentration was greater for spring (34.0 and 36 g kg^{-1}) than for fall application (31.4 and 33.2 g kg^{-1}) in 2007 and 2008, respectively as evidenced by the significant manure rate and timing interaction (Table 6). Low leaf N concentration with fall application could be related to the leaching losses of N during fall and winter, particularly where cover crop is not present, and reduce the

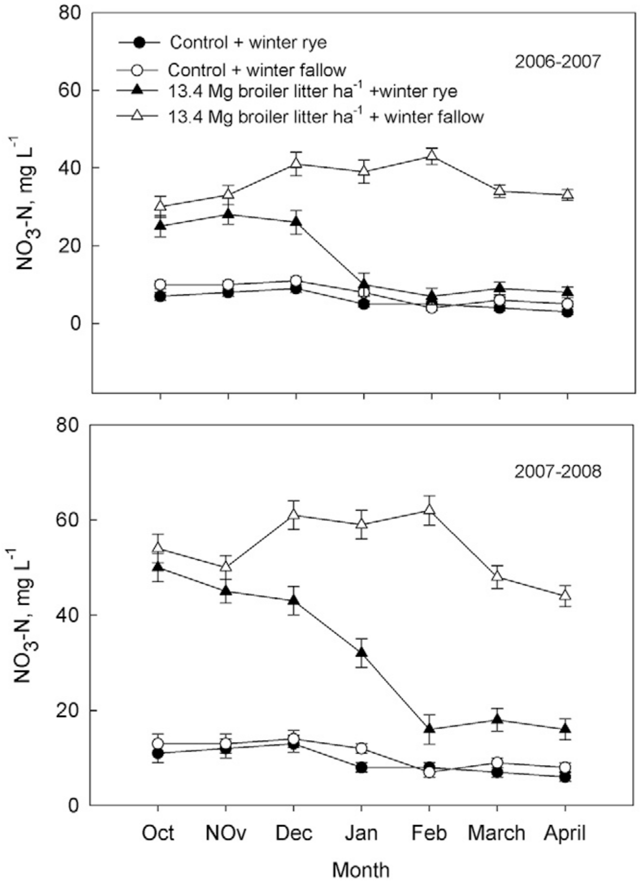

Fig. 2. Effects of cover crop on NO_3–N concentrations in leachate collected from the plots received broiler litter.

availability of N for subsequent crop in the spring. This agrees with the results of others who reported that fall application of manure resulted in considerable N losses through both leaching and denitrification NO_3–N and was usually associated with potential environmental contamination (Smith and Chambers, 1998; Hansen et al., 2004; van Es et al., 2004; Paul and Zebarth, 1997).

Nitrate Leaching and Soil Residual Nitrate Nitrogen

Soil NO_3–N at the 0- to 30-cm depth in spring, after killing cover crop and before planting cotton, was greater for the no cover crop than the rye cover crop each year (Table 9). This was

Table 9. Effects of fall-applied broiler litter and cover crop on mean NO_3–N concentrations in leachate collected at 45 cm depth and soil residual NO_3–N at the 0–30 cm depth in spring after killing cover crop and before planting cotton.

Cropping	Rate	2007			2008		
		Volume	NO_3–N leached	Soil NO_3–N	Volume	NO_3-N leached	Soil NO_3–N
	Mg ha^{-1}	mL	mg L^{-1}	mg kg^{-1}	mL	mg L^{-1}	mg kg^{-1}
Cover crop	0.0	171	6.1	5.1	274	7.1	4.3
	4.5	131	9.3	6.1	224	11.5	8.4
	9.0	133	10.5	7.2	232	12.3	9.1
	13.4	175	16.8	11.0	288	26.8	14.1
LSD (0.05)		10.2	2.6	1.3	12.5	3.4	1.8
Cover crop	0.0	236	6.2	6.2	380	9.1	5.2
	4.5	213	18.1	12.3	394	23.3	18.3
	9.0	221	20.5	16.6	412	27.2	19.7
	13.4	215	36.4	23.4	430	64.6	30.1
LSD (0.05)		22	2.1	2.4	11.3	4.3	3.2

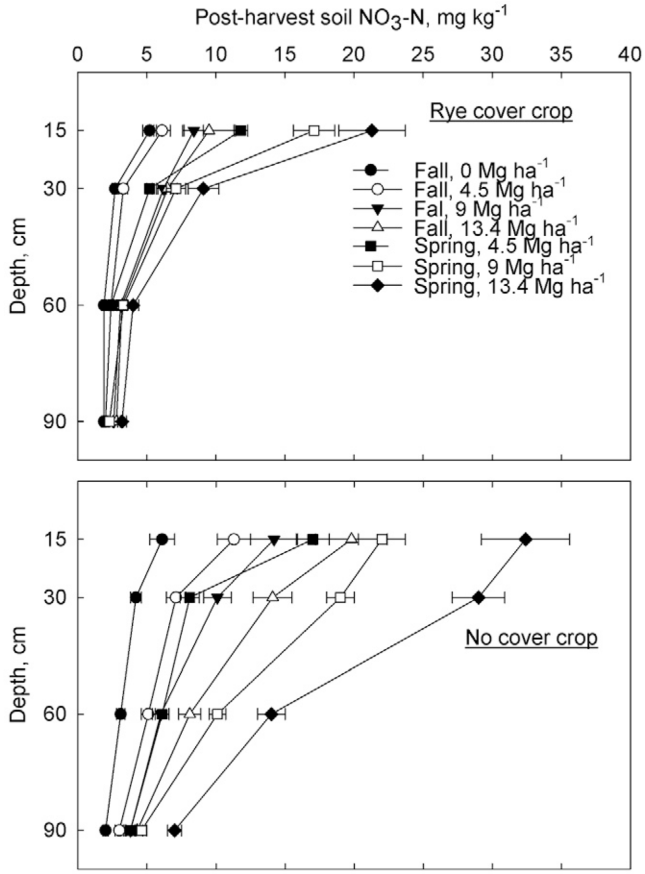

Fig. 3. Effect of winter cover crop on postharvest (fall 2008) soil NO_3–N concentrations in response to fall and spring application of broiler litter.

possibly related to N immobilization in which inorganic N taken up by winter rye cover crop in the fall and winter converted into organic N pool (Dabney et al., 2001; Parkin et al., 2006). In agreement with our results, Parkin et al. (2006) reported that the winter rye cover crop most likely reduced soil available N by accumulation of N in plant biomass. Kuo et al. (1997) reported that winter rye cover crop was effective at increasing soil organic N because of the great potential of biomass and C input. Similar effects were also observed by Vyn et al. (2000) who reported that winter rye cover crops were associated with lower spring soil NO_3–N concentrations where compared with winter fallow.

Cover crop resulted in a distinct difference in NO_3–N concentration in the leachate samples collected after cover crop establishment (Fig. 2). Nitrate-N concentrations in the leachate were significantly reduced in winter rye cover as compared to winter fallow plots probably due to greater N utilization by the established cover crop. Schroder et al. (1996) reported that the reduction in N leaching was similar to the N content of rye at the time of killing. In both years NO_3–N leached was significantly less in zero N plots than in higher rate N plots both with and without a cover crop. In 2007, the mean NO_3–N leached across sampling dates was 6.1 and 16.8 mg L^{-1} in winter rye cover crop and were 6.2 and 36.4 mg L^{-1} in no cover crop plots for the control and broiler litter application at the highest rate of 13.4 Mg ha^{-1}, respectively. In 2008, NO_3–N leached ranged from 7.1 to 26.8 mg L^{-1} in the cover crop and from 9.1 to 64.6 mg L^{-1} in the no cover crop plots when applied broiler litter increased from 0 to 13.4 Mg ha^{-1} (Table 9). The greater NO_3–N leached in 2008 were related to the greater amount of total N applied in 2008 with manure that was drier than the one in 2007 (Table 2). Each year the presence of cover crop reduced NO_3–N leaching. Averaged across years, cover crop reduced leaching losses of N by 57% as compared to no cover crop (Table 9). In agreement with our results, Kaspar et al. (2007) reported that a rye cover crop reduced 4-yr average flow-weighted nitrate concentrations by 59% compared with no cover crop. Meisinger et al. (1991) reported that a cover crop is known to be an effective strategy and can reduce NO_3–N concentrations in leachate from 20 to 80%. Losses of N as NH_4^+ were not affected by cover crop due to its low mobility in soils or retention on cation exchange complexes. With adequate cation exchange capacity in this Leeper silty clay loam soil NH_4^+-N would probably remain largely adsorbed (Dontsova et al., 2005). The total amount of N loss as NO_3–N is dependent on leachate concentrations and the volume of water drained from the soil profile. The rye cover crop likely reduced NO_3–N leaching through a combination of reduced drainage volume and concentration. The volumes of collected leachate were significantly less for the winter rye cover crop than winter fallow treatment. Averaged across the broiler litter rates and year, winter rye cover crop reduced the volume of leachate by 34% as compared to no cover (206 vs. 313 mL). Under no cover crop, there were no significant differences in the volume of leachate among the broiler litter rates. However, for winter rye cover crop, broiler litter at the low (4.5 Mg ha^{-1}) and medium (9 Mg ha^{-1}) rates had significantly less leachate than at the highest rate of 13.4 Mg ha^{-1} and the control. Therefore, the percentages of broiler litter N loss were significantly greater with winter fallow than winter rye cover crop where both received the same broiler litter rates.

Winter rye cover crop, relative to the winter fallow, reduced soil NO_3–N concentrations by 49 and 51% when measured on soil samples taken at the 0- to 30-cm depth after killing rye cover crop and before planting cotton in early spring (Table 8). Chantigny et al. (2002) reported that mineralization of organic N from fall-applied manure most likely happened during late fall, winter and early spring, increasing the potential of NO_3–N loss due to heavy precipitation (Beckwith et al., 1998). Soil NO_3–N concentrations in spring before planting cotton was increased with increasing broiler litter applications in both cover and no cover treatments (Table 8). Although living plants have the potential to increase net N mineralization (Griffiths and Robinson, 1992; Dormaar, 1990), the presence of cover crop with no broiler litter application in our study did not significantly increase soil residual NO_3–N. The reduction of soil residual NO_3–N in the spring for cover crop was attributed to the ability of the winter rye in sequestering soil NO_3–N as a component of organic compounds in the plant. Likewise, Sainju et al. (1998) found lower soil NO_3–N concentration following a rye cover crop due to its high root density which removes a considerable amount of soil NO_3–N. In the presence of winter rye cover crop, no significant difference in soil nitrate N was obtained between broiler litter at the rates of 4.5 and 9 Mg ha^{-1}, however, for winter fallow, soil NO_3–N increased with increasing broiler litter applications, particularly at the highest rate of 13.4 Mg ha^{-1} ($P < 0.001$) (Table 8).

Postharvest soil residual NO_3–N concentrations at the 0- to 15-cm depth were higher for the spring-applied broiler litter than for the fall-applied litter (Fig. 3). These results are in agreement with the work by Randall et al. (1999) who reported greater soil NO_3–N concentrations for spring-applied manure compared with fall application. The residual soil NO_3–N from fall-applied broiler litter in our study was more uniformly distributed in the soil profile in the presence of rye cover crop than in its absence. Further, litter rates did not differ significantly in residual soil NO_3–N and cover crop, suggesting that NO_3–N content in the soil profile most likely was depleted by the rye cover crop. When the litter was applied in the spring, residual NO_3–N at the 0- to 15-cm depth was increased by litter, particularly by the 9 and 13.4 Mg ha^{-1} rates. This likely is an indication that spring-applied broiler litter to cotton in the presence of cover crop residues increases the mineralization of organic N from crop residue and other sources of organic matter to increase the release of plant available forms of N as Boquet et al. (2004) reported. In the absence of cover crop, both fall and spring applications increased soil residual NO_3–N. Applying broiler litter >9 Mg ha^{-1} in the spring with no cover crop residue appeared to supply N in excess of cotton N need for optimum yield as evidenced by yields and substantial residual soil NO_3–N at the top 30-cm soil depth at the highest litter rate.

CONCLUSION

Cotton lint yield increased with increasing broiler litter applications and maxium lint yield was obtained at the rate of 9 Mg ha^{-1}. Application of broiler litter to cotton at rate >9 Mg ha^{-1} was not advantageous and showed a tendency to decline. This confirms that application of broiler litter to cotton with more N necessary for maximum yield may result in more vegetative growth and delay boll formation and maturity in which bolls are not contributing toward lint yield at the normal time of picking. Seeding a winter rye cover crop to fall-applied broiler litter did not benefit cotton lint yield but substantially reduced leaching loss of NO_3–N. This important work will help fill critical gaps in understanding wether detrimental effect of fall-applied broiler litter can be mitigated by a combination of cover cropping strategies.

ACKNOWLEDGMENTS

We would like to thank Walter Woolfolk for providing technical assistance in this research.

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