Published September 20, 2013

Fall- and Spring-Applied Poultry Litter Effectiveness as Corn Fertilizer in the Mid-Southern United States

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ABSTRACT

The effectiveness of fall- or winter-applied poultry litter, relative to spring-applied litter, as row crop fertilizer in the southern and southeastern United States has not been well researched. A 3-yr field study was conducted in northern Mississippi to determine the effectiveness of litter as corn (*Zea mays* L.) fertilizer and quantify loss of its potency when applied in the fall. The grain yield and biomass of corn that received fall-applied poultry litter (9 or 18 Mg ha^{-1}) or 202 kg ha^{-1} NH_4NO_3–N was compared against that of corn that received the same fertilization treatments applied in the spring including an unfertilized control. Corn fertilized with 18 Mg ha^{-1} litter applied in the spring produced 24% less grain yield in the first year but up to 21% more grain yield in the last 2 yr than corn fertilized with spring-applied NH_4NO_3. Unlike the common assumption that 50 to 65% of the total litter N is available in the same year of application, we estimated only 31% of the total N from 18 Mg ha^{-1} spring-applied litter was available to corn in the first year. Applying 18 Mg ha^{-1} litter in the fall, relative to spring, reduced grain yield by 12.8% and biomass by 15.0% when averaged across the 3 yr. These results show that applying poultry litter in the fall in regions with warm fall and winter months similar to that of northern Mississippi reduces its value as a fertilizer and could potentially increase environmental risk.

Poultry litter has proven to be an effective fertilizer for row crops including corn (Endale et al., 2008; Watts and Torbert, 2011), cotton (*Gossypium hirsutum* L.) (Mitchell and Tu, 2005; Tewolde et al., 2010), and soybean (*Glycine max* L.) (Adeli et al., 2005; Watts and Torbert, 2011). Sometimes, it can be more effective and more valuable than synthetic fertilizers (Tewolde et al., 2010). Poultry litter also has other advantages related to row crop production including liming effect on low pH soils (Adeli et al., 2011; Tewolde et al., 2011b) and increasing soil organic matter (Adeli et al., 2011; Watts et al., 2010). These values and benefits of poultry litter have been well recognized and its use as a row crop fertilizer has steadily increased over the last 10 yr.

Typically, spring is the ideal time to apply litter to spring-planted crops including corn, cotton, and other row crops. However, many row crop farmers find applying litter in the spring interferes with other more critical farm operations and choose to apply litter and other manures in the fall if local regulations allow such practices. In addition to the convenience, litter cost and availability also become important factors that determine the timing of application. Litter is generated steadily throughout the year in poultry production houses but is available in more abundance and at more attractive pricing in the fall than in the spring. Sometimes, it may be available free of charge for those who can remove it from the poultry farms, a situation that entices many row crop farmers to acquire and apply litter in the fall or winter many months before planting in the spring.

Applying poultry litter and other manures many months before establishing the crop may be effective agronomically depending on the region. In regions with colder fall and winter months, fall application of poultry litter has been shown to be as effective as spring application. In Iowa, Ruiz Diaz and Sawyer (2008) reported that corn fertilized with fall- or winter-applied chicken (*Gallus gallus*) and turkey (*Meleagris gallopavo*) manure produced equal grain yield as corn fertilized with spring-applied manure. Similarly, in Kentucky, Jn-Baptiste et al. (2012) reported that the grain yield of corn fertilized with poultry litter was not affected whether the litter was applied in the fall or spring.

Research with other animal manures confirms that fall-applied manures may be as effective as or more effective than spring-applied manures. In Denmark, barley (*Hordeum vulgare* L.) fertilized with farmyard manure in December produced the same grain yield as barley fertilized with manure in March (Thomsen, 2005). Barley yield was reduced only if the manure was applied in September suggesting that ideal soil temperature and moisture conditions between September and December accelerated mineralization and eventual loss of manure N. Thomsen (2005) estimated about 6 to 10% loss of the total manure N by leaching in the first winter if the manure was applied in September. In Iowa, Loecke et al. (2004) reported that fall-applied composted or raw swine (*Sus scrofa*) manure was better for corn grain yield than spring-applied manure. These reports overall suggest that applying poultry litter and other manures in the fall or winter may be an effective agronomic practice for corn and other crops in regions where freezing temperature prevails during the fall and winter.

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Published in Agron. J. 105:1743–1748 (2013)
doi:10.2134/agronj2013.0137

Abbreviations: CI, chlorophyll index.

Table 1. Moisture, total C, and mineral nutrient concentration of poultry litter applied to plots at the R.R. Foil Plant Science Research Center of Mississippi State University. Concentrations of Ca, K, Mg, P, Cu, Fe, Mn, and Zn were determined with inductively coupled plasma spectrophotometer after extracting soil with Mehlich-3 extractants (Mehlich, 1984) and after ashing and acid digestion litter samples.

Year	Moisture	Total N	NH_4–N	NO_3–N	Total C	Ca	K	Mg	P	Cu	Fe	Mn	Zn
	g kg^{-1}									mg kg^{-1}			
					Soil, background (2 Dec. 2005)								
2005	—	0.6	0.0	0.01	7.18	2.84	0.19	0.06	0.08	0.51	98.8	30.5	1.51
					Litter								
2006	352	27.3	5.0	0.01	241	19.8	31.2	6.1	12.8	321	649	459	398
2007	405	23.7	5.9	0.03	224	16.3	23.3	5.2	11.0	252	409	472	348
2008	195	32.7	3.1	0.20	307	20.6	25.9	5.9	11.3	313	436	550	413

The reason fall or winter application of manures is as effective as spring application in regions with cold fall and winter is likely because mineralization and subsequent loss of manure N is suppressed or inhibited after application and before planting. Equal corn grain yield from fall-applied as spring-applied liquid swine manure at a site in southwestern Ontario, Canada, was attributed to consistently colder, snowier winter months and fewer thawing temperatures than a site where fall application reduced grain yield relative to spring application (Coelho et al., 2009).

Much of the poultry litter in the United States is generated in the southern and southeastern United States and a considerable amount of it is applied in the fall or winter months. The consequence of applying poultry litter in the fall or winter, relative to spring, on row crop production in the region has not been well researched, documented, or quantified. Anecdotal information seems to exist among some experts that manures should not be applied in the fall, but this information is not well documented and overall is inadequate to develop effective guidance for row crop farmers and regulators in the region. The widely accepted N availability factor—that 50 to 65% of the litter N becomes available for corn during the year of application—is also not supported by research in the southern and southeastern region. The objective of this study was to determine the effectiveness of poultry litter as a corn fertilizer and quantify loss of its potency as a fertilizer when applied in the fall in the mid-southern United States with mild fall and winter months.

MATERIALS AND METHODS

The study was conducted in 2006–2008 at the R.R. Foil Plant Science Research Center of Mississippi State University near Starkville, MS, in a Leeper silty clay loam (fine, smectitic, nonacid, thermic Vertic Epiaquepts) soil with ≈1.4% organic matter, ≈7.0 pH, 81 mg kg^{-1} Mehlich-3 P, and 191 mg kg^{-1} Mehlich-3 K (Table 1) (Mehlich, 1984). The field had a nearly level surface and was planted to soybean in the prior year but never received poultry litter or any other manure.

The study compared fertilization of corn with 9 Mg ha^{-1} broiler litter, 18 Mg ha^{-1} broiler litter, and 202 kg ha^{-1} N as NH_4NO_3 applied in the fall vs. spring in a 3 × 2 factorial combination (Table 2). These treatment combinations plus an unfertilized control (UTC) treatment were tested in a randomized complete block design with four replications. Each plot consisted of six 0.97 m-wide bedded rows with 16.8-m length.

In each of the 3 yr, broiler litter was obtained from a local broiler chicken producer in the fall several months before corn planting. Litter for the fall-applied treatments was weighed in large plastic tubs for each plot and applied immediately by hand on 10 Nov. 2005, 13 Nov. 2006, and 8 Nov. 2007. Litter for the spring-applied treatments was weighed, double-bagged in large plastic bags, placed in large plastic tubs with lids, and stored under shade during the winter until application on 12 Apr. 2006, 30 Mar. 2007, and 15 Apr. 2008. The NH_4NO_3 for the fall-applied treatment was applied on the same dates as the fall-applied litter to estimate the magnitude of loss of mineral N applied in the fall. The NH_4NO_3 for the spring-applied treatment was split-applied, one-third on the same day as the spring-applied litter and the remaining two-thirds on 9 May 2006, 25 May 2007, and 5 June 2008. This treatment was intended to be equivalent to a standard corn fertilization based on recommendations of Mississippi State University Soil Testing Laboratory for the region. Each year, the litter and NH_4NO_3 fertilizers were spread over the soil surface by hand and incorporated on the same day of application. The incorporation in the fall or before planting in the spring was accomplished by disking the entire field and reforming the beds or by running a do-all implement without breaking the beds if maintaining the beds was necessary. Incorporation of the NH_4NO_3 applied after planting in 2006 and 2007 was accomplished by post-plant cultivation. In 2008, rain and advanced corn growth stages prevented mechanical cultivation and so the NH_4NO_3 was applied by placing in a shallow (≈5 cm) hand-opened trench about 15 cm away from the row and covering the trench with soil. The fall and spring NH_4NO_3 treatments received 75 kg K ha^{-1} as KCl on 3 May 2006 and 13 Nov. 2006 (fall application for 2007) but did not require P fertilization in 2006 and 2007 based on soil analysis and Mississippi State University recommendations. In 2008, 20 kg P ha^{-1} as triple superphosphate and 42 kg K ha^{-1}

Table 2. Treatment description and designation of an experiment in which the effectiveness of fall-applied poultry litter on corn was studied at the R.R. Foil Plant Science Research Center of Mississippi State University.

Treatment designation	Amount of poultry litter applied	Amount of NH_4NO_3–N applied	Time of application
	Mg ha^{-1}	kg ha^{-1}	
UTC	0	0	–
L9-F	9	0	fall
L9-S	9	0	spring
L18-F	18	0	fall
L18-S	18	0	spring
AN202-F	0	202	fall
AN202-S	0	202	spring

Table 3. Monthly average air temperature and total rainfall starting in November 2005 when the first litter application was made through the end of the corn experiment in October 2008 at the R.R. Foil Plant Science Research Center of Mississippi State University.

Month	Monthly average air temperature				Monthly total rainfall				Monthly average soil temperature				Monthly average soil moisture			
	2005	2006	2007	2008	2005	2006	2007	2008	2005	2006	2007	2008	2005	2006	2007	2008
	°C				mm				°C				m^3m^{-3}			
January		9.9	7.1	5.4		170	112	96		9.5	8.4	6.8		0.28	0.25	0.23
February		6.8	6.7	9.2		265	78	170		7.3	7.2	9.3		0.28	0.24	0.29
March		13.0	16.0	12.9		98	15	88		12.8	16.7	13.4		0.24	0.22	0.27
April		19.9	16.0	15.8		77	53	149		21.1	18.3	16.7		0.23	0.18	0.28
May		22.3	22.5	21.5		60	17	100		23.4	25.4	–†		0.21	0.20	–†
June		26.1	26.3	25.8		36	72	47		26.9	26.7	–†		0.06	0.20	–†
July		28.1	26.0	27.5		57	140	34		27.7	26.0	27.5		0.12	0.26	0.12
August		29.1	29.7	25.7		98	47	32		28.7	30.4	25.9		0.14	0.16	0.25
September		24.0	26.9	24.3		99	114	119		23.5	27.3	25.1		0.23	0.21	0.25
October		12.6	18.7	16.5		266	119	63		14.2	0.0	–†		0.35	0.00	–†
November	12.7	10.6	11.6		59	56	44		15.2	12.0	13.2		–	0.27	0.21	
December	6.0	8.3	10.1		97	120	48		8.4	9.6	11.1		–	0.22	0.23	

† No soil temperature and moisture data recorded in May, June, and October 2008 because of malfunctioning sensors.

as KCl were applied to the fall and spring NH_4NO_3 treatments on 21 May 2008 as maintenance rates to replace removal by harvested grain in 2007. Winter weeds were controlled in 2007 and 2008 by applying glyphosate [N-(phosphonomethyl) glycine] but not in 2006. Henbit (*Lamium amplexicaule* L.) was the predominant winter weed in 2006.

All plots were planted with cultivar Pioneer 33M53 RR corn on 12 Apr. 2006, 17 Apr. 2007, and 17 Apr. 2008. Supplemental irrigation was applied in 2006 and 2007. In 2006, two furrow irrigations, about 40 to 50 mm each, were applied on 14 June 2006 and 12 July 2006. In 2007, the field was irrigated by drip irrigation with one drip line placed on top of each bed on 1 May 2007 and 18 May 2007 and by furrow irrigation on 15 June 2007. The irrigation on 1 May 2007 was intended to help crop establishment. No irrigation was applied in 2008. The crop was managed following locally established management practices for weed control during each growing season.

Measurements

Chlorophyll index (CI) of corn leaves was measured periodically during each season to assess the relative N nutrition differences among the treatments. The CI was measured on five to six youngest fully expanded upper leaves or the ear leaf (after corn ear emergence) using Minolta's hand-held SPAD-502 m (Minolta Corp., Ramsey, NJ). Corn ear leaf samples were also taken at the silking stage on 22 June 2006, 29 June 2007, and 23 June 2008 for nutrient analysis. The leaf samples were dried in a forced-air oven at 80°C, ground to pass a 1-mm screen and analyzed for total N by the dry combustion method.

Aboveground corn plant biomass was measured by harvesting plants from 1-m row sections of the middle four rows at physiological maturity on 20 July 2006, 8 Aug. 2007, and 7 Aug. 2008. The plants were cut at soil level; separated into stalk, leaf, husk, cob, and grain; further cut into pieces small enough to facilitate drying; dried at 80°C in forced-air oven to constant weight; and weighed. Grain yield was measured by harvesting all four middle rows with a small-plot combine on 11 Sept. 2006, 6 Sept. 2007, and 10 Sept.2008. Grain moisture content was determined by drying 100-g subsamples from each plot at 103°C for 72 h in forced-air oven and used to adjust reported grain yield to 15.5% moisture content.

Soil temperature and moisture at ≈20-cm depth and air temperature were measured onsite and rainfall data were obtained from the National Weather Service (Table 3).

The data were analyzed using the MIXED model analysis of SAS (Littell et al., 2002) as a randomized complete block design. The data from all years were analyzed with year and fertilization treatment effects as the fixed effect factors and replication as the random effect factor. The data for each year were further analyzed separately if the interaction between years and fertilization treatments was significant. In addition to comparison of the means using LSD, group comparisons between fall vs. spring application and NH_4NO_3 vs. litter effects were made to facilitate data interpretation. All differences mentioned in the discussion are significant at $P \leq 0.05$ unless stated otherwise.

RESULTS AND DISCUSSION

The statistical analysis results showed that the year × treatment interactions were significant for most measurements (Tables 4 and 5). These interactions reflected mostly the performance of litter being less than that of the NH_4NO_3 in 2006 but better than NH_4NO_3 in 2007 and 2008. The results are therefore presented and discussed separately by year when such interactions occurred.

Corn Response to Litter vs. NH_4NO_3

Application of 18 Mg ha^{-1} poultry litter, regardless of the timing, was not sufficient for grain production in the first year of application. Corn fertilized in the spring with 202 kg ha^{-1} N as NH_4NO_3 produced 10.1 Mg ha^{-1} grain in 2006 (Table 4). Corn fertilized with 18 Mg ha^{-1} litter, which supplied 490 kg ha^{-1} total N, in the spring of 2006 produced only 7.67 Mg ha^{-1} grain, 24% less grain yield than the NH_4NO_3–fertilized corn. The reductions in 100-grain weight and aboveground biomass if fertilized with 18 Mg ha^{-1} litter, relative to fertilization with 202 kg ha^{-1} NH_4NO_3–N, in the first year were 9.3% (Table 4) and 19.7% (Fig. 1), respectively. Leaf CI was also consistently less in the 18 Mg ha^{-1} litter than the 202 kg ha^{-1} NH_4NO_3–N across the 2006 growing season, with greater differences late in the season (Fig. 2). These results show that the 18 Mg ha^{-1} litter in the first season did not supply adequate N to support corn yield to equal that of 202 kg ha^{-1} mineral N. Ear leaf N measurements

Table 4. Grain yield adjusted to 15.5% moisture content and 100-grain weight of corn fertilized with poultry litter or NH_4NO_3 applied in the fall or spring at the R.R. Foil Plant Science Research Center of Mississippi State University.

Treatment†	Grain yield				100-grain weight			
	2006	2007	2008	Avg.	2006	2007	2008	Avg.
	Mg ha^{-1}				g			
UTC	2.98e‡	3.48f	2.32d	2.93e	19.8e	24.4d	19.5d	21.3c
L9-F	4.71d	5.74e	5.52c	5.32d	20.2de	26.2cd	21.0cd	22.5bc
L9-S	5.67cd	7.24cd	6.24c	6.39c	21.4cd	27.3bc	20.6cd	23.1b
L18-F	6.66bc	8.34b	9.18ab	8.06b	22.4c	29.2ab	26.2a	25.8a
L18-S	7.67b	9.90a	10.17a	9.24a	24.4b	29.8a	26.9a	27.0a
AN202-F	7.44b	6.61de	8.25b	7.43b	22.0c	26.0d	23.3bc	23.8b
AN202-S	10.10a	8.21bc	9.31ab	9.21a	26.9a	29.2ab	25.5ab	27.2a
ANOVA	*P* > *F*							
Year (Y)				0.119				<0.001
Treatment (T)	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Y × T				<0.001				<0.001
CONTRAST								
Fall vs. Spring (all)	0.001	<0.001	0.023	<0.001	<0.001	0.018	0.306	0.001
Fall vs. Spring (Litter)	0.053	0.001	0.077	0.004	0.004	0.283	0.868	0.123
NH_4NO_3 vs. L18	0.003	0.000	0.066	0.339	0.039	0.018	0.047	0.115

† See Table 2 for descriptions of treatments.

‡ Values followed by the same letter within a column are not significantly different from each other at $P \leq 0.05$ level.

Table 5. Ear leaf N concentration of corn fertilized with poultry litter or NH_4NO_3 applied in the fall or spring at the R.R. Foil Plant Science Research Center of Mississippi State University.

Treatment†	Ear leaf total N concentration			
	2006	2007	2008	Avg.
	g kg^{-1}			
UTC	12.1e‡	13.9e	13.1c	13.0d
L9-F	14.6cde	17.1de	17.9b	16.5c
L9-S	14.3de	21.2bcd	19.7b	18.4c
L18-F	16.0bcd	21.6bc	27.5a	21.7b
L18-S	17.7bc	26.1a	30.2a	24.7a
AN202-F	19.3b	20.9cd	28.6a	22.9ab
AN202-S	23.3a	25.1ab	28.2a	25.5a
	P > *F*			
Year (Y)				<0.001
Treatment (T)	<0.001	<0.001	<0.001	<0.001
Y × T				<0.001
CONTRAST				
Fall vs. Spring (all)	0.068	0.001	0.106	0.002
Fall vs. Spring (Litter)	0.545	0.006	0.034	0.022
NH_4NO_3 vs. L18	0.001	0.549	0.664	0.240

† See Table 2 for descriptions of treatments.

‡ Values followed by the same letter within a column are not significantly different from each other at $P \leq 0.05$ level.

confirmed that corn fertilized with any amount of the litter did not receive N nutrition equivalent to corn fertilized with spring-applied NH_4NO_3 in the first season. Corn fertilized with 18 Mg ha^{-1} litter applied in the spring of 2006 had 24% less ear leaf N (17.7 g kg^{-1}) than corn fertilized with NH_4NO_3 (23.3 g kg^{-1}) (Table 5). This shows the 18 Mg ha^{-1} litter, despite supplying 490 kg ha^{-1} total N, was inadequate for optimum corn growth and grain production in the first season.

Repeating the application of 18 Mg ha^{-1} litter to the same plots in the following 2 yr in 2007 and 2008 reversed the response, with 18 Mg ha^{-1} litter producing more grain and biomass than the 202 kg ha^{-1} NH_4NO_3–N application. The spring-applied 18 Mg ha^{-1} litter produced 20.6% more grain and 21.4% more biomass in 2007 and 9.2% more grain and 15.7% more biomass in 2008 than the spring-applied 202 kg ha^{-1} NH_4NO_3–N (Table 4 and Fig. 1). The inability of the 18 Mg ha^{-1} litter to support grain yield equal to the 202 kg ha^{-1} NH_4NO_3–N in the first year, but the ability of the same litter rate applied to the same plots in the subsequent 2 yr to result in greater grain and biomass production suggests that some amount of the litter N in the first year did not become plant available and therefore carried over to subsequent seasons. The spring-applied 18 Mg ha^{-1} litter in 2007 and 2008 elevated ear leaf N to equal or exceed that of the spring applied 202 kg ha^{-1} NH_4NO_3, which is consistent with the argument that litter N from the 2006 application is carried over to the subsequent 2 yr. In a Cecil sandy loam soil (fine, kaolinitic, thermic Typic Kanhapludults) in Georgia, Schomberg et al. (2011) reported that long-term poultry litter application to no-till corn created a greater reserve of organic N which increased aboveground biomass above that of commercial N fertilization following its gradual mineralization. As reported earlier in cotton by Tewolde et al. (2011a), litter nutrient carry-over from year to year is a well-known phenomenon. Tewolde et al. (2011a) found 6.7 Mg ha^{-1} yr^{-1} litter applied to conventionally tilled soil was inadequate for cotton lint yield in the first 3 yr, but continuing the application to the same soil in the fourth year and subsequent 2 yr increased the yield to equal that of standard inorganic fertilization. Their results suggest that, although it took longer than 1 yr, there was a cumulative carryover from 6.7 Mg ha^{-1} yr^{-1} litter application that met the fertilization deficit of this relatively low rate for cotton lint yield.

The common assumption about litter N availability is that as much as 50 to 65% of the total litter N becomes plant available in the first growing season. Some fraction of the 35 to 50% balance is expected to remain in the soil mostly as organic form and some of it is lost by various pathways. Our results demonstrate that the commonly accepted 50 to 65% first year availability factor is not a reliable estimator of the litter N availability for corn. Our findings are consistent with those reported by Warren et al. (2006), who applied poultry litter based on the assumption that 60% of the organic N would be plant-available and found as much as 32% corn grain yield reduction, because the overestimation of N

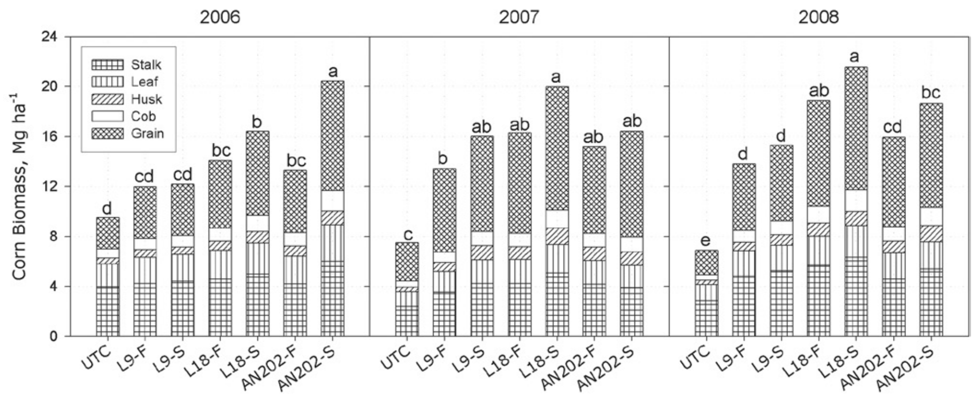

Fig. 1. Aboveground dry biomass of corn fertilized with poultry litter or NH_4NO_3 applied in the fall or spring at the R.R. Foil Plant Science Research Center of Mississippi State University. Total biomass values followed by the same letter within a year are not significantly different from each other at $P \leq 0.05$ level. (See Table 2 for description of treatments shown on *x* axis.)

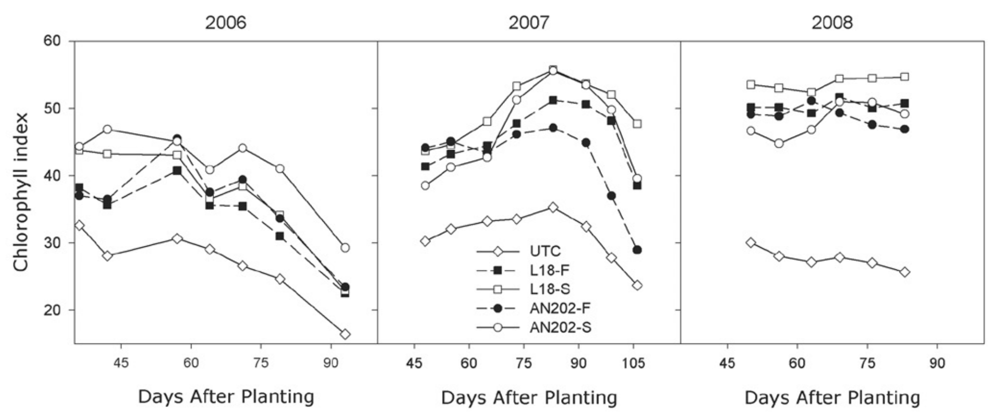

Fig. 2. Chlorophyll index during the growing season of corn fertilized with NH_4NO_3 or litter applied in the fall or spring at the R.R. Foil Plant Science Research Center of Mississippi State University. Curves representing the two treatments that received 9 Mg ha^{-1} litter (L9-F and L9-S) omitted for clarity of presentation. (See Table 2 for description of treatments as listed in the legend.)

availability led to applying inadequate litter rates. Bitzer and Sims (1988) also applied poultry litter based on the same assumption (60% availability) and reported that corn fertilized with litter at two locations had lower ear leaf N concentration than corn fertilized with equivalent inorganic N.

In our study, estimating the amount of N that was supplied by the spring-applied litter based on the grain yield and biomass production in 2006 confirms that the N availability factor is much less than 50%. Assuming the limiting nutrient for grain and biomass production in this soil was N and that the yield or biomass response to mineral N application was linear up to 202 kg ha^{-1}, which is not an unreasonable assumption, each 1 kg ha^{-1} NH_4NO_3–N applied in the spring of 2006 resulted in 50 kg ha^{-1} grain (Table 4) and 108 kg ha^{-1} aboveground biomass (Fig. 1). Based on these conversion factors, the 18 Mg ha^{-1} spring-applied litter supplied 153 kg ha^{-1} plant available N to produce 7.67 Mg ha^{-1} grain or 162 kg ha^{-1} available N to produce 17.6 Mg ha^{-1} biomass in 2006. This means only 31% (if based on grain yield) or 33% (if based on biomass) of the total 490 kg ha^{-1} litter N (Table 1) was available for corn in 2006. This percentage was greater than 31% if calculated based on the suboptimal 9 Mg ha^{-1} litter rate: 46% based on either grain yield or biomass. In Iowa, Ruiz Diaz and Sawyer (2008), who used high and low application rates, reported a 35% first-year N availability from chicken manure applied to corn in the spring. This estimate somewhat agrees with our calculation if averaged over the 9 Mg ha^{-1} (46% availability) and 18 Mg ha^{-1} (31% availability) litter rates. Overall, our results show growers in the mid-southern United States or in regions with similar climate should not use the commonly used 50 to 65% litter N availability for corn. Only about 30 to 35% of the total N from spring-applied litter should be expected to become available for corn in the first year in the region. The availability factor may be as much as 46% if applying suboptimal rates as our data shows, but this availability factor must be confirmed with further research.

Corn Response to Fall vs. Spring Fertilization

Applying poultry litter in the fall clearly reduced corn growth and grain yield relative to applying the same amount of litter in the spring. Fall litter application, relative to spring application, reduced grain yield each of the 3 yr although the *P* values for the fall vs. spring contrast comparisons were not always significant (Table 4). When pooled across the 3 yr, the grain yield reductions were 16.7% at the 9 Mg ha^{-1} rate and 12.8% at the 18 Mg ha^{-1} rate. Fall application of 100% mineral N in the form of NH_4NO_3 reduced grain yield by an average of 19.3%. Measurements of aboveground biomass and CI were less consistent but confirmed that applying litter in the fall leads to loss of litter value. The reduction in biomass pooled across the 3 yr was 9.8% for the 9 Mg ha^{-1} rate, 15.0% for the 18 Mg ha^{-1} rate, and was largest at 20.0% for the NH_4NO_3–N treatment (Fig. 1).

The reduction in grain yield and biomass when the litter was applied in the fall, relative to that applied in the spring, likely is associated with loss of N during the fall and winter months as indicated by ear leaf N measurements. Ear leaf N concentration averaged across the 3 yr was ≈11% less if the litter was applied in the fall than in the spring (Table 5). The reduced ear leaf N level in corn that received litter in the fall relative to that which received litter in the spring suggests that some amount of the fall-applied litter-N was lost during the fall and winter months, as the amount of total N applied in the fall was the same as that applied in the spring.

Denitrification, volatilization, leaching, and surface runoff are the typical avenues of mineral N loss (Zhao et al., 2012). We consider loss of N or any other nutrient by runoff in these plots to be minimal because the field had nearly level surface with slow water movement and low runoff potential. We consider leaching, denitrification, and volatilization as the most likely avenues of N loss in this research. The litter used in this study had approximately 17% of the total N in mineral forms, predominantly as NH_4–N (Table 1). This implies >80% of the total N was in the organic form which is not as vulnerable to loss as the mineral forms. But organic N is mineralized once applied to the soil under ideal moisture and temperature conditions. Measurements of soil temperature and moisture showed that the soil never froze at any point during the 3-yr period and had ample moisture, indicating that the litter-derived organic N may have mineralized continuously throughout the fall and winter months. This mineralized N, plus the 17% mineral N that existed at the time of application, is subject to loss by leaching as NO_3, volatilization as NH_3, and denitrification and eventual emission as N_2O or N_2. We did not monitor such losses but the ear leaf N measurements (Table 5) indicated that some fraction of the N applied as litter in the fall was lost by a combination of any of these three avenues before planting corn in the spring. Zebarth et al. (1996) attributed lack of corn response to 600 kg ha^{-1} fall-applied N from liquid dairy and hog manure in south coastal British Columbia, Canada, to loss as nitrate leaching and denitrification during the fall and winter months.

The relatively greater effectiveness of the fall-applied litter than fall-applied NH_4NO_3 for biomass and grain yield suggests that the litter N is somewhat less vulnerable to loss during the fall and winter months. This likely is because the organic form of litter N has to undergo mineralization before it is subject to loss. But the reduction of about 15% grain and biomass yield if the litter is applied in the fall is substantial considering fall-applied litter in colder regions does not lead to yield reduction (Jn-Baptiste et al., 2012; Ruiz Diaz and Sawyer, 2008). Overall, our results suggest up to 15% grain yield reduction should be expected if poultry litter is applied in the fall in regions with similar environments as that of northern Mississippi with an added risk of adverse environmental effects which have not been determined in this study.

CONCLUSION

The results of this research show that broiler litter is an effective corn fertilizer but must be applied in the spring to receive the full benefit in regions with no or minimal freezing fall and winter temperatures similar to that of northern Mississippi. Poultry litter in this region loses its fertilizer potency by up to 15% if it is applied in the fall to fertilize spring-planted corn. Our results also show that only 30 to 35% of the total N from spring-applied litter becomes plant available for corn during the first season. The availability factor may be >35% if applying suboptimal rates as our data show, but this availability factor must be confirmed with further research. Overall, we expect our results to help develop guidelines for fertilizing corn efficiently and effectively with poultry litter and improve corn production and economics in the mid-southern United States and other similar environments.

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