Published January, 2005

MANURE MANAGEMENT

Effects of Broiler Litter on Soybean Production and Soil Nitrogen and Phosphorus Concentrations

Ardeshir Adeli,* Karamat R. Sistani, Dennis E. Rowe, and Haile Tewolde

ABSTRACT

Although most of the N required by soybean [*Glycine max* (L.) Merr.] is provided through the process of symbiotic N_2 fixation, supplemental N using broiler litter may boost soybean grain yields. The effects of broiler litter and commercial fertilizer applications on soybean yield, N and P uptake, and residual soil N and P were evaluated on a Leeper silty clay loam (fine, smectitic, nonacid, thermic Vertic Epiaquepts) at the Mississippi Agriculture and Forestry Experiment Station in Starkville, MS. Treatments were broiler litter application at the rates of 0, 40, 80, 160 kg plant available N (PAN) ha^{-1} and commercial fertilizer at equivalent to broiler litter PAN and P rates. Soybean grain yield and N and P uptake were quadratically increased with increasing broiler litter and commercial fertilizer application rates. Soybean grain yield and N uptake from broiler litter applications were significantly greater than those from commercial fertilizer. Soybean grain yield was not correlated to soybean P uptake but linearly increased with increasing N uptake. Application of broiler litter at rates > 80 kg PAN ha^{-1} were not effectively used by soybean as evidenced by declining apparent recovery values, increasing residual soil NO_3–N concentrations, and increasing P accumulation at the top 15 cm of the soil profile. For every unit of N uptake, broiler litter treatment produced 3.4% more grain yield than commercial fertilizer. The results of this study indicate that application of broiler litter to soybean may be beneficial.

Soybean is a major crop in Mississippi. Production of this crop significantly contributes to the state's economy. Because of nutritional and industrial properties of soybean products, there is substantial incentive to increase soybean yield (Helms and Watt, 1991). Commercial broiler production in Mississippi generates 450 000 Mg yr^{-1} of broiler litter (manure and bedding material), which is applied to nearby pastures or cropland (Mississippi State Univ., 1998). Continued broiler litter application increases the potential for enrichment of NO_3–N in groundwater and P in surface water (Edwards et al., 1992; Sharpley et al., 1996). To minimize these risks, producers must obtain additional land area to dilute the litter using N-demanding crops and/or use alternative crops to receive broiler litter.

Several studies have been conducted on broiler litter application on corn (*Zea mays* L.) (Brown et al., 1994; Wood et al., 1999) and cotton (*Gossypium hirsutum* L.) (Burmster et al., 1991; Glover and Vories, 1998; Malik and Reddy, 1999). However, application of animal manure to soybean has been discouraged because of the potential for decreasing the amount of symbiotic N_2 fixation. In contrast, Lory et al. (1992) reported that topdressed manure addition to alfalfa (*Medicago sativa* L.) did not affect N_2 fixation. Gates and Muller (1979) reported that application of fertilizer containing N, P, and S to soybean contributed to forming a stronger symbiotic mechanism and more active N_2 fixation. Since broiler litter contains N, P, and S (Sharpley et al., 1993), its applications to soybean could be beneficial.

A survey of university fertilizer recommendations indicated that no N or only small amounts (22 to 67 kg ha^{-1}) of N were recommended for pure legume stand establishment in most states (Hojjati et al., 1978). However, other studies reported that fertilizer N application increased soybean yield and N utilization potential. For example, Lamb et al. (1990) reported that soybean grain yield increased with increasing N fertilizer rate; but its response strongly related to soil NO_3–N content. They reported that when soil NO_3–N content was greater than 90 kg ha^{-1} at 0- to 30-cm depth, there was no response to applied N. Brevedan et al. (1978) reported a 22 to 32% soybean yield increase with an application of 168 kg N ha^{-1} to soybean at bloom initiation. Varvel and Peterson (1992) reported that soybean is a net N sink, removing approximately 150 to 200 kg N ha^{-1} yr^{-1} at grain yield levels of 2.5 to 3.4 Mg ha^{-1}, which ultimately reduces the amount of soil N available for leaching. Shibles (1998) stated that total annual N uptake for high-yielding soybean can be as high as 385 kg ha^{-1}.

Soybean not only requires considerable amounts of N to produce a crop (Schmidt et al., 2001), but it requires a constant supply of available P to maintain rapid growth and development (Hariston et al., 1990). Phosphorus fertilization has been shown to increase the number of nodules and their weight as well as the number of pods per plant (Jones et al., 1977). Since P requirement by crops is in much lower quantities than N, Sharpley et al. (1993) reported that 72% of the applied P from broiler litter retained in the soil profile. Using an alternative crop to remove a large portion of soil P could be advantageous. Does added N in the broiler litter boost soybean grain yield enough to allow for the removal of a large portion of the P in broiler litter? Knowing this information could help broiler producers in applying the litter locally before exceeding the soil P-holding capacity.

Soybean has a relatively high requirement for P, K,

USDA-ARS, Waste Manage. and Forage Res. Unit, 810 Hwy. 12 East, Mississippi State, MS 39762. Contribution of the Mississippi Agric. and Forestry Exp. Stn. Journal paper no. J10318. Received 1 July 2004. *Corresponding author (aadeli@msa-msstate.ars.usda.gov).

Published in Agron. J. 97:314–321 (2005).

677 S. Segoe Rd., Madison, WI 53711 USA

Abbreviations: ANR, apparent nitrogen recovery; APR, apparent phosphorus recovery; DM, dry matter; ICP, inductively coupled plasma; NUE, nitrogen utilization efficiency; PAN, plant available nitrogen; PUE, phosphorus utilization efficiency.

and micronutrients (Varco, 1999). Soybean early growth requires adequate soil N supply (Harper et al., 1989), and there is a high N requirement during flowering and grain filling (Brevedan et al.,1978; Varco, 1999; Wesley et al., 1998). Given those requirements, broiler litter can be considered as a good alternative source of nutrients for soybean production. Shibles (1998) reported that N_2–fixing capacity of soybean begins to decline after growth stage R5, which is approximately the same time as peak N demand for protein synthesis. Organic N in broiler litter gradually mineralized to PAN during the year of its application (Bitzer and Sims, 1988). As a consequence of continual N mineralization, the slow release of N appeared to be beneficial to soybean grain yield, especially at its peak N demand (grain filling) (Wesley et al., 1998).

Although manure has not traditionally been applied to soybean, the potential for favorable agronomic response exists. Few reports in the literature document the effects of animal manure applications on soybean production. Dejong (1995) studied the effect of swine manure on general agronomic production issues in soybean and reported significant increase in grain yields with swine manure treatments. Garcia and Blancaver (1983) found that application of poultry manure increased soybean yield by 62% over the control. Schmidt et al. (2001) reported that soybean seed yield at three of seven locations in southern Minnesota increased linearly with increasing swine manure rate (avg. 1.4 kg kg^{-1} of applied N).

Some studies have reported soybean grain yield increases with applied commercial fertilizer N (Al-Ithawi et al., 1980; Lamb et al., 1990; Wesley et al., 1998). Most studies have compared the effects of animal waste rates on crop growth using only a single rate of commercial fertilizer (Liu et al., 1997; Eghball and Power, 1999) or in combination with fertilizer (Beauchamp, 1983; Jokela, 1992). Reports in the literature discussing the relative efficiency of broiler litter compared with commercial fertilizer at corresponding rates were not found. Thus, the objective of this study was to determine the effects of comparable rates of N and P derived from broiler litter and commercial fertilizer on soybean grain yield, N and P uptake, and residual soil N and P.

MATERIALS AND METHODS

Research was conducted at the Mississippi Agriculture and Forestry Experiment Station (MAFES), on a Leeper silty clay loam (fine, smectitic, nonacid, thermic Vertic Epiaquepts), at the Mississippi Agriculture and Forestry Experiment Station in Starkville, MS, on the same block of land in 2001 and 2002. Initial surface soil samples (0 to 15 cm) were collected, dried, and ground to pass a 1-mm sieve. These samples were analyzed for NH_4–N and NO_3–N (Keeney and Nelson, 1982). Extractable P was determined using Mississippi State University Soil Testing Laboratory (Lancaster, unpublished, 1970). In this procedure, 5 g of soil was extracted using 5 mL of Solution A and 20 mL of Solution B shaken for 10 min. Solution A is 0.05 *M* HCl and Solution B is a mixture of 90 mL of glacial acetic acid, 6.5 g of malonic acid, 12.5 g of malic acid, and 1.38 g of ammonium florid adjusted to pH of 4.0. Soil texture was also determined (Day, 1965). Soil pH was measured using 1:1 soil/water ratio (w/w). Initial soil physical and chemical characteristics are presented in Table 1. Broiler litter (mixture of manure and wood shavings) samples were collected at the time of application and stored at 4°C until analyzed. Broiler litter samples were digested for total N using a modified micro-Kjeldahl procedure described by Nelson and Sommers (1973). Phosphorus, K, and other macro- and micronutrient contents of broiler litter were determined by dry ashing (Isaac and Kerber, 1977) and measured using inductively coupled plasma (ICP) analysis. The results of chemical analyses of broiler litter are shown in Table 2.

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

	Soil properties
pH	7.1
OM, g kg^{-1}†	10.6
NH_4–N, mg kg^{-1}	3.78
NO_3–N, mg kg^{-1}	14.5
MSTP, kg ha^{-1}‡	40.3
K, mg kg^{-1}	168
Ca, mg kg^{-1}	2500
Mg, mg kg^{-1}	100
Bulk density, g cm^{-3}	1.36
Texture	silty clay
Sand, g kg^{-1}	10
Silt, g kg^{-1}	40
Clay, g kg^{-1}	50

† OM, organic matter.
‡ MSTP, Mississippi Soil Test P (Lancaster, unpublished, 1970).

The experimental design was a randomized complete block, with seven treatments and four replications. Individual plot dimensions were 3.8 m wide by 9 m long with a 3-m alleyway between the blocks. Broiler litter was applied at PAN rates of 0, 40, 80, 160 kg PAN ha^{-1} yr^{-1}. Plant available N was calculated based on the assumption that 67% of organic N in broiler litter mineralized in the first year of application (Bitzer and Sims, 1988). For comparison purposes, commercial fertilizer N (ammonium nitrate) and P (concentrated superphosphate) were applied at rates equivalent to broiler litter PAN and P rates. Fertilizer K was not applied to the soil due to initial soil test K level (168 mg kg^{-1}) at 0- to 15-cm depth. Yearly broiler litter and corresponding N and P fertilizer application rates are defined as low, medium, and high (Table 3). Broiler litter and commercial fertilizer P were applied entirely at planting time, but fertilizer N was split-applied, one-half at planting and at flowering as recommended by Wesley et al. (1998). Broiler litter and commercial fertilizer were incorporated into the soil immediately after applications and before planting.

Soybean was planted with 96 cm in row spacing in mid-April using the same conventional four-row planter each year. Soybean variety Pioneer ‘9492’ (Maturity Group IV) was seeded

Table 2. Yearly and overall average of broiler litter analysis.

Parameters	2001	2002	Average
Moisture, g kg^{-1}	249	231	240
pH, 1:5	7.1	7.4	7.3
Total N, g kg^{-1}	22	32	27
Total C, g kg^{-1}	254	323	289
NH_4–N, mg kg^{-1}	3456	6652	5054
NO_3–N, mg kg^{-1}	121	85	103
Total P, g kg^{-1}	15	16	16
Water soluble P, g kg^{-1}	2.6	3.4	3.00
N/P ratio	1.5	2.0	1.8
K, g kg^{-1}	19	32	26
Ca, g kg^{-1}	19	38	29
Mg, g kg^{-1}	4.4	8.6	6.5
S, g kg^{-1}	2.5	4.5	3.5
Cu, mg kg^{-1}	814	1050	932
Zn, mg kg^{-1}	394	585	490
Fe, mg kg^{-1}	845	1193	1019

Table 3. Nitrogen and P rates supplied by broiler litter and commercial fertilizer applications in 2001 and 2002.

	2001				2002			
	BL†	TN‡	PAN§	TP¶	BL	TN	PAN	TP
	Mg ha^{-1}	—— kg ha^{-1} ——			Mg ha^{-1}	— kg ha^{-1} —		
Broiler litter								
Low	2.7	59	40	41	1.9	60	40	30
Medium	5.4	119	80	81	3.75	120	80	60
High	10.9	240	160	164	7.51	240	160	120
Fertilizer								
Low	–	–	40	41	–	–	40	30
Medium	–	–	80	81	–	–	80	60
High	–	–	160	164	–	–	160	120

† BL, broiler litter.
‡ TN, total N.
§ PAN, plant available N.
¶ TP, total P.

at a density of 180 000 seeds ha^{-1}. Weeds were controlled with labeled rates of conventional herbicides uniformly applied across entire study.

Total aboveground plant samples were collected at the R6, the growth stage considered to represent maximum dry matter (DM) accumulation before leaf drop begins, to determine maximum N, P, and DM accumulation by the plants (Ritchie et al., 1994). In each plot, aboveground plant samples were obtained from 1-m length of one of the border row. These samples were dried at 65°C for 48 h in a forced-air oven, weighed, and ground to pass a 1-mm sieve for chemical analysis. Total N content was measured using an automated dry-combustion analyzer (Model NA 1500 NC, Carlo Erba, Milan, Italy). Total P content was determined by dry-ashing 1-g samples according to procedures outlined by Isaac and Kerber (1977) and measured using ICP.

Soybean grain yields were taken at physiological maturity by mechanically harvesting the middle two rows of each plot. Grain yields are reported at grain moisture content of 150 g kg^{-1}. Grain samples were dried at 65°C for 48 h, ground, and then analyzed for N and P concentrations using the same procedures.

Soybean N and P uptake in either grain or aboveground plant samples were calculated using N and P concentrations multiplied by their yields. Since grain removal of N and P represents about 70 and 80% of total N and P uptakes by the plants, respectively (Schmidt et al., 2001), apparent N and P recovery by soybean were calculated based on total N and P uptake. Apparent N and P recovery were calculated by subtracting total N and P uptake of the control (no broiler litter and fertilizer) from each broiler litter and fertilizer treatment, dividing by the amount of PAN and plant available P applied in broiler litter or fertilizer, and multiplying by 100. Soybean grain N utilization efficiency (NUE) and P utilization efficiency (PUE) were calculated by dividing soybean grain yield by the total N and P uptake contained in stover and grain (Wen et al., 2003).

Soil samples were taken in mid-September to a depth of 90 cm to determine residual soil NO_3–N and P accumulation at the end of growing season. In each plot, nine soil cores (5-cm diam.) were randomly taken and divided into depth increments of 0 to 5, 5 to 15, 15 to 30, 30 to 60, and 60 to 90 cm. Samples were combined by depth, placed in plastic bags, and frozen at −4°C until analyzed. Soil NO_3–N was determined by extracting soil samples with 2 *M* KCl (1:10 ratio w/w), shaking for 1 h, filtering, and analyzing using an automated segmented flow analyzer (Flow Solution III, Perstop Analytical Environmental, Wilsonville, OR). At the same time, soil moisture was determined and soil NO_3–N reported on a dry basis. Extractable soil P was determined by the Mississippi Soil Testing Laboratory (Lancaster, unpublished, 1970) and analyzed using ICP.

The General Linear Model (GLM) procedure in SAS (SAS Inst., 1996) was used to perform analysis of variance for each of the dependent variables of grain yield, total DM yield at R6, plant N and P concentration at R6, estimated seed N and P removal, and residual soil N and P at the end of growing season. Since the effect of year on dependent variables was significant, each year was evaluated separately. Data were analyzed using simple regression models, which included linear and quadratic trends. Analysis of variance using single degree-of-freedom contrasts was used to compare broiler litter with the commercial fertilizer treatments. In addition, the correlation between grain yield and total N and P uptake was used to estimate NUE and PUE. Statistical tests were performed at a 0.05 level of significance.

RESULTS AND DISCUSSION

Soil and Broiler Litter Analyses

Yearly analysis of broiler litter samples obtained at the time of application is shown in Table 2. Results indicate that 98% of the inorganic N of the litter was ammonium with 2% nitrate N. The N/P ratio of broiler litter ranged from 1.5 to 2.0 and averaged 1.8 for the 2-yr period. Relative to N application, excess application of P is predictable using broiler litter because fertilized soybean accumulates N and P in a ratio 10:1.

Soybean Grain Yield and Total Aboveground Biomass

Soybean grain yields and total DM yield, aboveground biomass at R6, were quadratically increased with increasing broiler litter and commercial fertilizer applications in 2001 and 2002 (Tables 4 and 5). For both years, soybean grain and total aboveground DM yields were greater ($P < 0.05$) with broiler litter than commercial fertilizer applications (Tables 4 and 5). Average soybean grain and total aboveground DM yields were approximately 10 and 8% greater with broiler litter than commercial fertilizer application, respectively. These results indicate that broiler litter has yield-enhancing factors other than N and P. Since broiler litter contains most of the secondary and micronutrients required for crop growth (Sharpley et al., 1993), increased soybean grain yield with broiler litter relative to commercial fertilizer at equivalent N and P rates could be related to the availability of macro- and micronutrients along with available N and P in the litter. Soybean grain and total aboveground DM yields were greater in 2002 than in 2001 for both broiler litter and commercial fertilizer. Averaged across treatments, soybean grain yield and total aboveground biomass were 17% greater in 2002 than in 2001 possibly due to more rainfall during the growing season months in 2002 (Fig. 1). Due to quadratic response of soybean yield to both broiler litter and commercial fertilizer, it appears that application of broiler litter to soybean at a rate > 5.4 Mg ha^{-1} or 80 kg PAN ha^{-1} did not enhance soybean grain yield and exceeded the crop utilization potential as evidenced by increasing postharvest soil profile NO_3–N concentration.

This is in agreement with the results reported by

Table 4. Effects of N source and rate on soybean grain yield, total aboveground biomass, N concentration, N uptake, and N utilization efficiency in 2001.

	Grain			Aboveground biomass at R6			
Source	Yield	N conc.	N uptake	Yield	N conc.	N uptake	NUE†
	Mg ha^{-1}	g kg^{-1}	kg ha^{-1}	Mg ha^{-1}	g kg^{-1}	kg ha^{-1}	kg kg^{-1}
Control	2.47	51.4	127	5.9	30.5	180	13.7
Broiler litter							
Low	2.77	57.0	158	6.7	31.3	209	13.3
Medium	3.11	59.8	186	7.4	31.0	229	13.6
High	3.18	61.0	194	7.6	31.0	236	13.5
Fertilizer							
Low	2.58	57.0	147	6.4	31.7	203	12.7
Medium	2.83	58.7	166	6.8	31.7	215	13.1
High	2.90	59.3	172	7.0	31.6	221	13.1
				Analysis of variance			
Litter linear	NS‡	NS	NS	NS	NS	NS	NS
Litter quadratic	**	**	**	**	NS	**	NS
Fertilizer linear	NS	NS	NS	NS	NS	NS	NS
Fertilizer quadratic	*	**	*	**	NS	**	NS
				Contrast			
Litter vs. fertilizer	*	*	*	*	NS	**	*

* Significant at 0.05 probability level.
** Significant at 0.01 probability level.
† NUE, N utilization efficiency.
‡ NS, not significant.

Schmidt et al. (2000), who reported that applying swine manure at N rates greater than required for maximum yield increased potential for nitrate loss to the environment.

Soybean Nitrogen Uptake, Apparent Nitrogen Recovery, and Nitrogen Utilization Efficiency

Averaged across the years, N concentration in the aboveground biomass at R6 ranged from 30.8 g kg^{-1} (control treatment) to 32.1 g kg^{-1} and was not affected by any of the treatments. However, total N uptake at R6, calculated as the product of total aboveground biomass and biomass N concentration, was quadratically increased with increasing broiler litter and commercial fertilizer applications. Therefore, total N uptake by soybean aboveground DM was primarily a function of DM yield rather than DM N concentration.

Grain N concentration was quadratically increased with increasing broiler litter and commercial fertilizer applications each year (Tables 4 and 5), suggesting optimization of grain yield when sufficiency levels were reached or possibly a decline in assimilation efficiency with excessive rates. Grain N uptake was quadratically increased with increasing broiler litter and commercial fertilizer applications. Since similar trends were observed for grain N concentration and grain yield, the quantity of N removed by harvested portion of soybean was a function of both soybean grain N concentration and soybean grain yield. This is in agreement with the work by Hanway and Weber (1971), who reported an increase in soy-

Table 5. Effects of N source and rate on soybean grain yield, total aboveground biomass, N concentration, N uptake, and N utilization efficiency in 2002.

	Grain			Above ground biomass at R6			
Source	Yield	N conc.	N uptake	Yield	N conc.	N uptake	NUE†
	Mg ha^{-1}	g kg^{-1}	kg ha^{-1}	Mg ha^{-1}	g kg^{-1}	kg ha^{-1}	kg kg^{-1}
Control	3.01	50.8	153	7.2	31.0	223	13.5
Broiler litter							
Low	3.34	56.3	188	8.0	31.8	254	13.1
Medium	3.76	58.0	218	9.0	31.4	283	13.3
High	3.82	60.2	230	9.1	31.3	285	13.4
Fertilizer							
Low	3.10	57.7	179	7.7	32.1	247	12.8
Medium	3.38	59.5	201	8.1	31.8	258	13.1
High	3.44	59.0	203	8.4	31.6	265	12.9
				Analysis of variance			
Litter linear	NS‡	NS	NS	NS	NS	NS	NS
Litter quadratic	**	**	**	**	NS	**	NS
Fertilizer linear	NS	NS	NS	NS	NS	NS	NS
Fertilizer quadratic	*	**	*	**	NS	**	NS
				Contrasts			
Litter vs. fertilizer	*	*	NS	*	NS	*	*

* Significant at 0.05 probability level.
** Significant at 0.01 probability level.
† NUE, N utilization efficiency.
‡ NS, not significant.

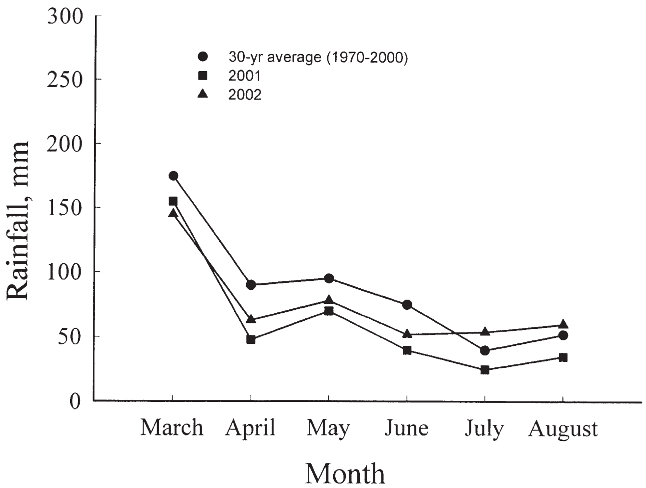

Fig. 1. Observed monthly rainfall compared with long-term average at the study site.

bean N uptake with the addition of N fertilizer. Averaged across treatments, soybean grain N uptake and total N uptake, respectively, was 14 and 18% greater in 2002 than in 2001 due to greater grain yield in 2002. Soybean grain N uptake and total aboveground biomass N uptake were greater ($P < 0.05$) with broiler litter than with commercial fertilizer applications in 2001 and 2002 (Tables 4 and 5). Averaged across the rate and year, grain and total aboveground N uptake were 9 and 6% greater with broiler litter than with commercial fertilizer, respectively. A large portion of soybean N was removed by the grain. Regardless of N source, grain removal of N represented about 77% of total soybean uptake.

Recovery of N is an important indicator of NUE and potentially reflects relative quantities of N remaining in or lost from the soil. Apparent N recovery (ANR) by soybean decreased linearly with increasing broiler litter and commercial fertilizer application rates in 2001 and 2002 (Table 6). In each year, a significant difference in ANR was detected between broiler litter and commercial fertilizer at corresponding N rates. Apparent N recovery was greater ($P < 0.05$) for broiler litter than commercial fertilizer, indicating that N availability may have been higher for the broiler litter due to greater N mineralization than anticipated.

Table 6. Effects of N and P source and rate on soybean apparent N and P recovery (ANR and APR, respectively) and N/P ratio.

	2001			2002		
Source	**ANR**	**APR**	**N/P ratio**	**ANR**	**APR**	**N/P ratio**
	—— % ——			—— % ——		
Control	–	–	12.2	–	–	11.5
Broiler litter						
Low	73	15	10.0	78	18	10.2
Medium	61	10	10.2	75	14	10.1
High	35	5	10.4	39	7	10.1
Fertilizer						
Low	58	12	10.3	60	15	10.4
Medium	44	8	10.2	44	10	10.3
High	26	4	10.2	26	5	10.5
			Analysis of variance			
Litter linear	**	*	NS†	**	*	NS
Fertilizer linear	*	*	NS	**	*	NS
			Contrast			
Litter vs. fertilizer	**	**	NS	**	**	NS

* Significant at 0.05 probability level.
** Significant at 0.01 probability level.
† NS, not significant.

Table 7. Soybean grain yield dependency on total N and P uptake.

Source	Regression equation	R^2
	Grain yield vs. total N uptake	
	2001	
Broiler litter	$y = 108 + 12.9x$†	0.98**
Fertilizer	$y = 514 + 10.6x$	0.89**
	2002	
Broiler litter	$y = 89 + 12.8x$	0.96**
Fertilizer	$y = 615 + 10.5x$	0.86*
	Grain yield vs. total P uptake	
	2001	
Broiler litter	NS	–
Fertilizer	NS	–
	2002	
Broiler litter	$y = 1097 + 73x$	0.66‡
Fertilizer	NS	–

* Significant at 0.05 probability level.
** Significant at 0.01 probability level.
† y, soybean grain yield (kg ha^{-1}); x, soybean total N and P uptake (kg ha^{-1}).
‡ Significant at 0.10 probability level.

To measure the grain NUE, the relationships between soybean grain yield and total N uptake (grain plus stover) were determined. In 2001 and 2002, a linear correlation resulted for both broiler litter and commercial fertilizer (Table 7). In the linear model, the slope of the line that reflects the increase in grain yield with each increment of N uptake is considered as NUE. In each year, the slope of the linear model was greater ($P < 0.05$) for broiler litter than commercial fertilizer, suggesting that N from broiler litter was more effectively used by soybean to produce yield. Using calculated NUE in Tables 4 and 5, for every unit of total N uptake by soybean, broiler litter treatment produced 3.4% more grain than commercial fertilizer treatment.

Residual Soil Nitrate Nitrogen Concentration

Residual NO_3–N concentrations in the soil profile following 2 yr of soybean production where broiler litter and commercial fertilizer were applied in each year are shown in Fig. 2. For both broiler litter and commercial fertilizer, no significant differences in residual soil NO_3–N occurred among the control, low, and medium rates. This lack of difference may have been due to utilization of most of the applied N by the plant as evidenced by high N recovery. This would imply the PAN approach supplied enough N for crop growth and that the potential for NO_3–N leaching effects would be minimal. At N rates greater than 80 kg PAN ha^{-1}, residual soil NO_3–N levels at the 0- to 5-cm depth increased from 36 kg ha^{-1} with broiler litter to as much as 43 kg ha^{-1} with commercial fertilizer, which was evidenced by lower N recovery at these rates. While this amount of residual N is not large, excess N is a potential environmental risk. For both broiler litter and commercial fertilizer, the pattern of NO_3–N distribution in the soil profile showed that the greatest amount of residual NO_3–N accumulated in

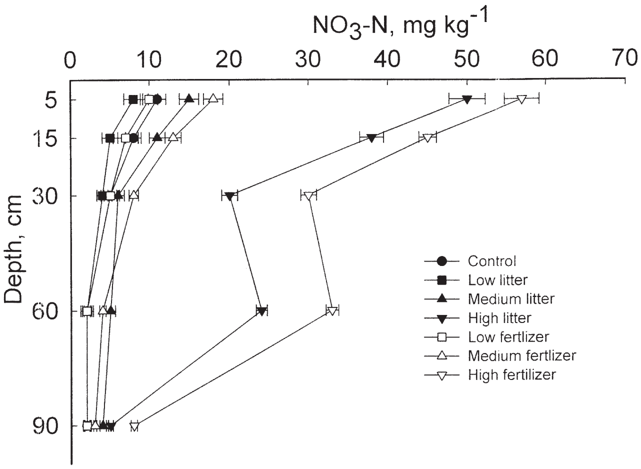

Fig. 2. Effects of broiler litter and commercial fertilizer application rates on postharvest residual soil NO_3–N in 2002.

the top 30 cm of the soil profile at high application rate (160 kg PAN ha^{-1}) (Fig. 2). At high application rate, the concentration of residual soil NO_3–N was significantly greater with commercial fertilizer than broiler litter application in all depths. For both sources at the high N application rate, there was a significant increase in residual NO_3–N in the 30- to 60-cm depth. The presence of NO_3–N at the 30- to 60-cm depth likely occurred because this N rate supplied more available N than required by soybean at the grain yields attained. Postharvest soil nitrate suggests limited NO_3–N leaching below the 90-cm depth after broiler litter and commercial applications for 2 yr.

Soybean Phosphorus Uptake, Apparent Phosphorus Recovery, and Phosphorus Utilization Efficiency

Broiler litter application rates resulted in cumulative P application of 71, 141, and 284 kg P ha^{-1} in the soil for low, medium, and high loading rates for 2 yr (Table 3). In 2001 and 2002, total P uptake at R6, calculated as the product of total aboveground biomass and biomass P concentration, was quadratically increased with increasing broiler litter and commercial fertilizer applications. Broiler litter and commercial fertilizer applications increased aboveground biomass (DM) P concentration compared with the control (no litter or commercial fertilizer added) (Tables 8 and 9). However, no significant differences in biomass P concentration were obtained among broiler litter and commercial fertilizer applications. In some cases, P concentration declined, suggesting total P uptake by soybean DM was primarily a function of DM production rather than DM P concentration.

Soybean grain P uptake was quadratically increased with increasing broiler litter and commercial fertilizer applications. Since similar trends were observed for grain P concentration and grain yield, the quantity of P removed by harvested portion of soybean was a function of both grain P concentration and grain yield. Averaged across rates and year, soybean grain P removal was 20.1 and 18 kg ha^{-1} at the yield level of 3.3 and 3.1 Mg ha^{-1} for broiler litter and commercial fertilizer, respectively. This is in agreement with the work of McVickar and Walker (1987), who reported a soybean grain P uptake of 19.6 kg ha^{-1} at the yield level of 2.7 Mg ha^{-1}. Grain P uptake and total P uptake were greater ($P < 0.05$) with broiler litter than with commercial fertilizer applications in 2001 and 2002 (Tables 8 and 9). Averaged across the rate and year, soybean grain P uptake and total P uptake were 9 and 7% greater with broiler litter than with commercial fertilizer, respectively. Regardless of P source, it was calculated that grain removal of P represents about 81% of total P uptake. However, 77%

Table 8. Effects of P source and rate on soybean grain P concentration, total aboveground biomass P concentration, P uptake, and P utilization efficiency in 2001.

Source	Grain		Aboveground biomass at R6		
	P conc.	P uptake	P conc.	P uptake	PUE†
	g kg^{-1}	kg ha^{-1}	g kg^{-1}	kg ha^{-1}	kg kg^{-1}
Control	4.8	11.9	2.5	14.8	167
Broiler litter					
Low	6.1	16.9	3.1	20.8	133
Medium	6.0	18.7	3.0	22.5	138
High	6.1	19.4	3.0	22.8	139
Fertilizer					
Low	6.0	15.5	3.2	19.8	132
Medium	5.9	16.7	3.1	21.1	134
High	6.0	17.4	3.1	21.7	134
			Analysis of variance		
Litter linear	NS‡	NS	NS	NS	NS
Litter quadratic	**	**	NS	**	NS
Fertilizer linear	NS	NS	NS	NS	NS
Fertilizer quadratic	**	*	NS	**	NS
			Contrasts		
Litter vs. fertilizer	NS	*	NS	*	NS

* Significant at 0.05 probability level.
** Significant at 0.01 probability level.
† PUE, P utilization efficiency.
‡ NS, not significant.

Table 9. Effects of P source and rate on soybean grain P concentration, total aboveground biomass P concentration, P uptake, and P utilization efficiency in 2002.

Source	Grain		Aboveground biomass at R6		
	P conc.	P uptake	P conc.	P uptake	PUE†
	g kg^{-1}	kg ha^{-1}	g kg^{-1}	kg ha^{-1}	kg kg^{-1}
Control	4.6	13.9	2.7	19.4	155
Broiler litter					
Low	5.9	19.7	3.0	24.8	135
Medium	6.0	22.6	3.0	27.9	135
High	6.1	23.3	3.0	28.2	135
Fertilizer					
Low	5.7	17.7	3.1	23.8	130
Medium	6.1	20.6	3.1	25.1	135
High	5.9	20.3	3.0	25.2	136
			Analysis of variance		
Litter linear	NS‡	NS	NS	NS	NS
Litter quadratic	**	**	NS	**	NS
Fertilizer linear	NS	NS	NS	NS	NS
Fertilizer quadratic	**	*	NS	**	NS
			Contrasts		
Litter vs. fertilizer	NS	*	NS	**	NS

* Significant at 0.05 probability level.
** Significant at 0.01 probability level.
† PUE, P utilization efficiency.
‡ NS, not significant.

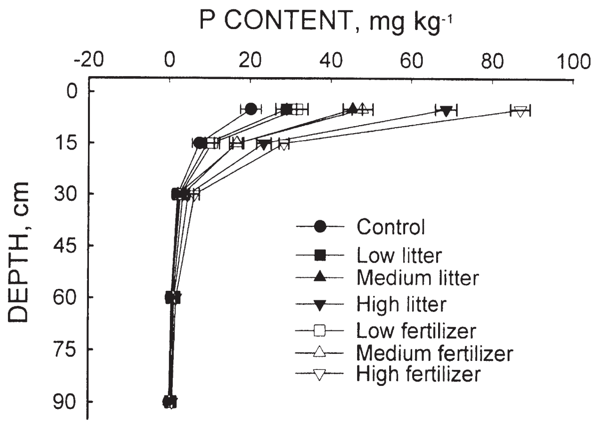

Fig. 3. Effects of broiler litter and commercial fertilizer application rates on soil P content in fall 2002.

of total N uptake by soybean is accumulated in the grain and removed as harvested portion.

Although P uptake increased with increasing broiler litter and commercial fertilizer P application rates, apparent P recovery (APR) decreased (Table 6). Linear decreases in recovery efficiency were observed, which suggests at greater rates, proportionally more P would remain in the soil. In each year, a significant difference in APR was detected between broiler litter and commercial fertilizer at corresponding P rates. Apparent P recovery was greater ($P < 0.05$) with broiler litter than commercial fertilizer, which was related to greater P uptake from broiler litter treatment.

No significant difference in PUE was obtained between broiler litter and commercial fertilizer at equivalent rates (Tables 8 and 9). Regardless of the source, the calculated soybean PUE (grain yield/total P uptake) was 135 and 134 kg kg^{-1} in 2001 and 2002, respectively. Comparing PUE [135 kg grain (kg P uptake ha^{-1})$^{-1}$] with NUE [13.3 kg grain (kg N uptake ha^{-1})$^{-1}$] indicated that soybean requires 10-fold more N than P to yield 1 kg of grain.

Soil Profile Phosphorus Accumulation

Extractable soil P significantly increased ($P < 0.001$) with increasing P rates for both broiler litter and commercial fertilizer applications (Fig. 3). Extractable P value at the highest rates (cumulative 284 kg P ha^{-1}) of broiler litter and commercial fertilizer was increased by 71 and 77% relative to the untreated control, respectively. An accumulation of extractable P was observed in the 0- to 5-cm depth. The net increase in extractable soil P ranged from 8.7 to 48.4 mg kg^{-1} for broiler litter application and 11.5 to 66.7 mg kg^{-1} for commercial fertilizer at the cumulative rates of 71 to 284 kg P ha^{-1}, respectively.

No significant difference in soil test P levels in the surface 0 to 5 cm was observed between broiler litter and commercial fertilizer at the low and medium rates. However, at the high rate, soil P concentration was significantly greater for commercial fertilizer than broiler litter application (Fig. 3). Since the soil surface is the most interactive zone to rainfall and runoff events, increased soil P value at the surface may have a potential to release P in runoff events.

Phosphorus concentrations at the 0- to 5-cm depth from commercial fertilizer and broiler litter applications were directly related to loading rate, but no effect of treatment was observed below 15-cm depth (Fig. 3). Although total P application at the high rate during 2-yr period was 284 kg ha^{-1}, downward movement of extractable P was limited to about 30 cm.

Soybean Grain Nitrogen/ Phosphorus Uptake Ratio

No significant difference in soybean grain N/P ratio was obtained between broiler litter and commercial fertilizer in 2001 and 2002 (Table 6). Average N/P uptake ratio was 12:1 in the untreated control and 10:1 for broiler litter and commercial fertilizer. A small decrease in the ratio from broiler litter or commercial fertilizer compared with the untreated control suggests that soybean has the potential to remove P from the soil when broiler litter is applied.

CONCLUSIONS

Soybean grain yield was greater with broiler litter than with commercial fertilizer. Averaged across the rates and year, application of broiler litter increased soybean grain yield by 9% compared with commercial fertilizer. Broiler litter applied at rates greater than medium rate or 80 kg PAN ha^{-1} was not effectively used by soybean as evidenced by declining apparent recovery values, increasing postharvest residual soil NO^3–N concentrations, and increasing P accumulation at the top 15 cm of the soil profile. For every unit of N uptake, broiler litter treatment produced 3.4% more grain yield than commercial fertilizer. Compared with N uptake, soybean grain yield did not remove large portion of the P applied in broiler litter. Soybean grain yield was not correlated to soybean P uptake but linearly increased with increasing N uptake. The potential of soybean in removing soil N and increasing yield for broiler litter application should encourage soybean as an alternative crop for broiler litter fertilization. Application of broiler litter to soybean at rate < 80 kg PAN ha^{-1} appears to be agronomically and environmentally sound.

REFERENCES

Al-Ithawi, B., E.J. Deibert, and R.A. Olson. 1980. Applied N and moisture level effects on yield, depth of root activity, and nutrient uptake by soybeans. Agron. J. 72:827–832.

Beauchamp, A.E. 1983. Response of corn to nitrogen in preplant and sidedress application of liquid cattle manure. Can. J. Soil Sci. 63: 377–386.

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

Brevedan, R.E., D.B. Egli, and J.E. Leggett. 1978. Influence of N nutrition on flower and pod abortion and yield of soybeans. Agron. J. 70:81–84.

Brown, J.E., J.M. Dangler, C.H. Gilliam, D.W. Porch, and R.L. Shumack. 1994. Comparison of broiler litter and inorganic N, P, and K fertilizer for double-cropped sweet corn and broccoli. J. Plant Nutr. 17(5):859–867.

Burmster, C.H., C.W. Wood, and C.C. Mitchell. 1991. Effects of rates of broiler litter on cotton. p. 903–904. *In* C.H. Herber and D.J. Richter (ed.) Proc. Beltwide Cotton Conf., Nashville, TN. 6–10 Jan. 1991. Natl. Cotton Counc. of Am., Memphis, TN.
Day, P.R. 1965. Particle fractionation and particle size analysis. p. 82–84. *In* C.A. Black et al. (ed.) Methods of soil analysis. Part 1. Agron. Monogr. 9. ASA, Madison, WI.
Dejong, J. 1995. Liquid swine manure and nitrogen fertilizer effects on soybean yield, soil profile nitrogen, and mineralization rates. MS. thesis. Iowa State Univ., Ames.
Edwards, D.R., T.C. Daniel, and O. Marbun. 1992. Determination of best timing for poultry waste disposal: A modeling approach. Water Res. Bull. 28:487–494.
Eghball, B., and J.F. Power. 1999. Phosphorus and nitrogen based manure and compost application: Corn production and soil phosphorus. Soil Sci. Soc. Am. J. 63:895–901.
Garcia, J.M., and A.T. Blancaver. 1983. Effect of animal manure on the growth and yield of soybean and physical properties of the soil. J. Agric. Food Nutr. 4(2):196–212.
Gates, C.T., and W.J. Muller. 1979. Nodule and plant development in the soybean: Growth response to nitrogen, phosphorus and sulfur. Aust. J. Bot. 27:203–215.
Glover, R.E., and E.D. Vories. 1998. Poultry litter as a nitrogen source for dry land cotton on clay soil. p. 681–683. *In* C.P. Dugger and D.J. Richter (ed.) Proc. Beltwide Cotton Conf., San Diego, CA. 5–9 Jan. 1998. Natl. Cotton Counc. of Am., Memphis, TN.
Hanway, J.J., and C.R. Weber. 1971. Accumulation of N, P, and K by soybean plants. Agron. J. 63:406–408.
Hariston, J.E., W.F. Jones, L.K. Marshall, and K.B. Gill. 1990. Tillage and fertilizer management effects on soybean growth and yield on three Mississippi Soils. J. Prod. Agric. 3:317–323.
Harper, L.A., J.E. Giddens, G.W. Langdale, and R.R. Sharpe. 1989. Environmental effects on nitrogen dynamics in soybean under conservation and clean tillage systems. Agron. J. 81:623–631.
Helms, T.C., and D.L. Watt. 1991. Protein and oil discount/premium price structure and soybean cultivars selection criteria. J. Prod. Agric. 4:120–124.
Hojjati, S.M., W.C. Templeton, and T.H. Taylor. 1978. Nitrogen fertilization in establishing forage legumes. Agron. J. 70:429–433.
Isaac, R.A., and J.D. Kerber. 1977. Atomic absorption and flame photometry: Techniques and uses in soil, plant, and water analysis. p. 17–37. *In* L.M. Walsh (ed.) Instrumental methods for analysis of soils and plant tissue. SSSA, Madison, WI.
Jokela, W.E. 1992. Nitrogen fertilizer and dairy manure effects on corn yield and soil nitrate. Soil Sci. Soc. Am. J. 56:148–154.
Jones, G.D., J.A. Lutz, Jr., and T.J. Smith. 1977. Effects of phosphorus and potassium on soybean nodules and seed yield. Agron. J. 69: 1003–1006.
Keeney, D.R., and D.W. Nelson. 1982. Nitrogen–inorganic forms. p. 643–698. *In* A.L. Page et al. (ed.) Methods of soil analysis. Part 2. 2nd ed. Agron. Monogr. 9. ASA and SSSA, Madison, WI.
Lamb, J.A., G.W. Rehm, R.K. Severson, and T.E. Cymbaluk. 1990. Impact of inoculation and use of fertilizer N on soybean production where growing seasons are short. J. Prod. Agric. 3:241–245.
Liu, F., C.C. Mitchell, J.W. Odom, D.T. Hill, and E.W. Rochester. 1997. Swine lagoon effluent disposal by overland flow: Effects on forage production and uptake of nitrogen and phosphorus. Agron. J. 89:900–904.
Lory, J.A., M.P. Russelle, and G.W. Randall. 1992. Surface applied manure effects on soil inorganic N, N uptake, and symbiotic dinitrogen fixation of alfalfa. p. 150. *In* Agronomy abstracts, ASA, Madison, WI.
Malik, R.K., and K.C. Reddy. 1999. Effects of poultry litter on cotton yield. p. 1293–1295. *In* C.P. Dugger and D.J. Richter (ed.) Proc. Beltwide Cotton Conf., Orlando, FL. 3–7 Jan. 1999. Natl. Cotton Counc. of Am., Memphis, TN.
McVickar, M.H., and W.M. Walker. 1987. Using commercial fertilizers. Interstate Printers and Publ., Danville, IL.
Mississippi State University. 1998. How can I dispose of poultry wastes. Spec. Rep. 68. Mississippi State Univ. Coop. Ext. Serv., Mississippi State.
Nelson, D.W., and R.F. Sommers. 1973. Determination of total nitrogen in plant material. Agron. J. 65:109–111.
Ritchie, S.W., J.J. Hanway, H.E. Thompson, and G.O. Benson. 1994. How a soybean develops. Spec. Rep. 53. Iowa State Univ. Coop. Ext. Serv., Ames.
SAS Institute. 1996. SAS user's guide. Statistics. Version 5. SAS Inst., Cary, NC.
Schmidt, J.P., J.A. Lamb, M.A. Schmitt, G.W. Randall, J.H. Orf, and H.T. Gollany. 2001. Soybean varietal response to liquid swine manure application. Agron. J. 93:358–363.
Schmidt, J.P., M.A. Schmitt, G.W. Randall, J.A. Lamb, J.H. Orf, and H.T. Gollay. 2000. Swine manure application to nodulating and nonnodulating soybean. Agron. J. 92:987–992.
Sharpley, A.N., J.J. Meisinger, A. Breeuwsma, T. Sims, T.C. Daniel, and J.S. Schepers. 1996. Impacts of animal manure management on ground and surface water quality. p. 173–242. *In* J. Hatfield (ed.) Effective management of animal waste as a soil resource. Lewis Publ., Boca Raton, FL.
Sharpley, A.N., S.J. Smith, and W.R. Bain. 1993. Nitrogen and phosphorus fate from long-term poultry application to Oklahoma soils. Soil Sci. Soc. Am. J. 57:1131–1137.
Shibles, R.M. 1998. Soybean nitrogen acquisition and utilization. p. 5–11. *In* Proc. North Central Ext. Industry Soil Fertil. Conf., 28th, St. Louis, MO. 11–12 Nov. 1998. Potash and Phosphate Inst., Brookings, SD.
Varco, J.J. 1999. Nutrition and fertility requirements. p. 53–70. *In* L.G. Heatherly and H.F. Hodges (ed.) Soybean production in the Midsouth. CRC Press, Washington, DC.
Varvel, G.E., and T.A. Peterson. 1992. Nitrogen fertilizer recovery by soybean in monoculture and rotation systems. Agron. J. 84:215–218.
Wen, G., J.J. Schoenau, and J.L. Charles. 2003. Efficiency parameters of nitrogen in hog and cattle manure in the second year following application. J. Plant Nutr. Soil Sci. 166:490–498.
Wesley, T.L., R.E. Lamond, V.L. Martin, and S.R. Duncan. 1998. Effects of late-season nitrogen fertilizer on irrigated soybean yield and composition. J. Prod. Agric. 11:331–336.
Wood, B.H., C.W. Wood, K.H. Yoo, K.S. Yoon, and D.P. Delaney. 1999. Seasonal surface runoff losses of nutrients and metals from soils fertilized with broiler litter and commercial fertilizer. J. Environ. Qual. 28:1210–1218.