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## Effects of Broiler Litter in an Irrigated, Double-Cropped, Conservation-Tilled Rotation

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### ABSTRACT

Broiler production is increasing rapidly in the Southern Coastal Plain, and little research has been conducted to evaluate broiler litter applications on the sandy soils of the region. We conducted a 4-yr field study to determine optimum rates of broiler litter, its economic value, changes in soil tests to a depth of 90 cm, and effects on pathogens and nematodes. Summer crops were cotton (*Gossypium hirsutum* L.), pearl millet [*Pennisetum glaucum* (L.) R. Br.] for grain, and peanut (*Arachis hypogaea* L.). Winter crops were wheat (*Triticum aestivum* L.) and oilseed canola (*Brassica napus* L.). Litter rates were 0, 4.5, 9.0, and 13.5 Mg ha<sup>-1</sup> for each crop. Litter application increased yields of cotton, pearl millet, wheat, and canola and decreased yield of peanut. Average crop value increase from application of a megagram of broiler litter was estimated to be \$42 ha<sup>-1</sup> yr<sup>-1</sup> when the application was made to all crops and \$68 ha<sup>-1</sup> yr<sup>-1</sup> when none was applied to peanut. The mean cost of applied litter was approximately \$12 Mg<sup>-1</sup>. Surface soil P, K, Cu, Zn, and Mn were increased in direct relation to litter rate. Data indicate that it would be prudent to limit applications to about 4.5 Mg ha<sup>-1</sup>. Litter applications had little effect on soil nematodes, but *Rhizoctonia* limb rot (*Rhizoctonia solani* AG-4) of peanut increased. Lodging of canola, due to *Sclerotinia* spp., was doubled by any application of broiler litter.

THE BROILER INDUSTRY has experienced rapid expansion in the Southern Coastal Plain of Georgia as well as in the coastal plain regions of other states in the Southeast. In 1999, Georgia produced 1.24 billion broilers with an estimated farm gate value of \$3.27 billion, the greatest number and value of any state in the USA (Georgia Agric. Stat. Serv., 2000). Each broiler produces 1.13 kg of manure, resulting in 1.4 million Mg of litter generated annually. A primary reason for expansion of broiler production in the Southern Coastal Plain is the availability of cropland litter spreading. Data from

previous studies that were mainly confined to the Southern Piedmont and mountain soils will likely not relate directly to the more sandy soils of the Southern Coastal Plain. Because broiler litter is applied and will continue to be applied to croplands, guidelines for the best use of the litter need to be assessed.

Much research has indicated that litter application is most effective when it is incorporated into the soil soon after application. However, conservation tillage does not allow for any (no-till) or allows for only partial (strip-till) incorporation of litter. Other considerations involved when land-applying broiler litter are plant nutrition, pathogenic fungi, nematodes, environmental effects, and economics.

Broiler litter provides nutrition for crop plants but not necessarily the correct balance of nutrition required for top yield and quality. Providing litter for fertilization of 'Coastal' bermudagrass (*Cynodon dactylon* L.) (Sharp-ley et al., 1993), perennial tall fescue (*Festuca arundinacea* Schreb.) (Kingery et al., 1994), and corn (*Zea mays* L.) (Wood et al., 1996) resulted in application of excess P in relation to plant needs and accumulations of P in surface soils. Kingery et al. (1994) found that soil profile (0–60 cm) extractable P in long-term (15–28 yr) perennial tall fescue in the Sand Mountain region of Alabama was more than sixfold greater in soils that received broiler litter than in similar soils that received no litter. Application of P greater than plant utilization and its accumulation in surface soils is of environmental concern due to the potential for runoff and eutrophication of adjacent bodies of water (Moore et al., 1995).

Significant increases in soil NO<sub>3</sub> have also been found due to broiler litter application at rates greater than plant needs. Excess soil NO<sub>3</sub>-N can also be leached to depths that depend on soil properties, rainfall, and irrigation. Wood et al. (1996) measured NO<sub>3</sub> concentrations at 1 m that were directly related to the rate of application. Kingery et al. (1994) found elevated NO<sub>3</sub> concentrations due to litter applications nearly to bedrock of their Sand Mountain sites. Sharp-ley et al. (1993) found most of the NO<sub>3</sub> accumulation in an eastern Oklahoma site to be in the surface 5 cm. Soil pH and extractable K, Ca,

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and Mg increases are likely in soils receiving long-term, repeated applications of litter (Kingery et al., 1994), but such increases are not considered to have any detrimental significance to the environment. However, application of excess amounts of heavy metals is a concern when fertilizing with broiler litter. Sims and Wolf (1994) reported that As, Co, Cu, Fe, Mn, Se, and Zn occur in poultry diets and their wastes. When repeated applications of litter have been made, surface soils have high concentrations of Cu and Zn (Mitchell et al., 1992; Han et al., 2000) that can potentially contribute to runoff. Peanut, an important crop in the Southern Coastal Plain, is sensitive to high concentrations of soil Zn (Gascho and Davis, 1994).

Broiler litter may also increase soilborne pathogens such as *Rhizoctonia solani*, *Fusarium* spp., and *Pythium* spp. (Hoitinik et al., 1997). Conversely, broiler litter can reduce the numbers of *Meloidogyne incognita*, a nematode detrimental to cotton (Riegel et al., 1996).

Most estimates of broiler litter value are based on its nutrient content. Mean concentrations of N, P, K, and Ca in broiler litter are estimated to be 33, 11, 17, and 20 kg Mg<sup>-1</sup>, respectively (Vest et al., 1994). Lesser contents of other secondary and micronutrients may also be of value. In addition, the organic matter in the litter may improve soil quality, but that is difficult to quantify. Recently, Vervoot and Keeler (1999) estimated the price of broiler litter at \$5.25 Mg<sup>-1</sup> and the cost of transportation at \$0.028 Mg<sup>-1</sup> km<sup>-1</sup>. Given and Shurley (1995) estimate the cost of spreading litter at \$6.35 Mg<sup>-1</sup>; therefore, the cost of transporting (≤16 km) and applying litter was estimated to be <\$12 Mg<sup>-1</sup>.

The objectives of this research were to (i) determine optimum application rates of broiler litter to an irrigated, conservation-tilled, intensive double-crop system in a sandy Coastal Plain soil; (ii) determine the gross economic value of the broiler litter based on crop response; (iii) determine changes in soil tests in the soil profile resulting from broiler litter application; and (iv) evaluate any effects of the litter on pathogens and nematodes.

## MATERIALS AND METHODS

A double-cropped, irrigated 3-yr rotation was conducted from 1996 to 2000 at the Coastal Plain Experiment Station in Tifton, GA (31°28' N, 83° W) on Tifton loamy sand (fine-loamy siliceous Plinthic Kandiudults). Surface soil (0–15 cm) pH (water) was 6.1 on 16 Apr. 1996, 2 mo after application of 1.8 Mg ha<sup>-1</sup> dolomite. Mehlich-1 soil test P and K were 23 and 57 mg kg<sup>-1</sup>, respectively, and organic matter was 6 g kg<sup>-1</sup>. Both P and K were rated as *medium* (Plank, 1989). Calcium and Mg were 191 and 22 mg kg<sup>-1</sup>, respectively. Both are considered *adequate* (Plank, 1989). Cotton, runner-type peanut, and pearl millet for grain were planted in the spring. Wheat and canola for grain were planted in the fall. Following cotton, the plots were winter fallowed. All summer and winter crops were grown each year in the same cropping sequence (Table 1).

Broiler litter [manure and pine (*Pinus palustris* L. and *P. elliotti* L.) tree wood shavings] rates of 0, 4.5, 9.0, and 13.5 Mg ha<sup>-1</sup> were broadcast 1 to 3 wk before both summer and winter crops in a randomized complete block design with four blocks. Plot size was 5.49 by 7.62 m (six rows of cotton, peanut, and

**Table 1. Sequence of crops in a 3-yr double cropped rotation practiced from 1996 to 2000.**

Year	Cycle 1	Cycle 2	Cycle 3
1996–1997	cotton–fallow	millet–wheat	peanut–canola
1997–1998	peanut–canola	cotton–fallow	millet–wheat
1998–1999	millet–wheat	peanut–canola	cotton–fallow
1999–2000	cotton–fallow	millet–wheat	peanut–canola

millet and eight rows of wheat and canola). For the initial summer crops in 1996, the litter was broadcast on fallow soil, incorporated by disking, and planted. For the duration of the 4-yr experiment, winter crops were no-tilled and summer crops were in-row subsoiled and strip-tilled into residues remaining from the previous crop. No additional tillage was performed, and no commercial fertilizer was applied during the experiment. Irrigation was applied for full yield potential by a lateral-move sprinkler system. All crops were grown with best management practices.

Broiler litter used throughout the study originated from the same broiler houses but was stored in a covered stack house for variable amounts of time before transportation and application to the plots each spring and fall. Samples were analyzed for total N (Dumas method; Bremner and Mulvaney, 1982) and total concentrations of other elements by inductively coupled plasma analyses.

Crop yields were determined on the center one-third of the plots by mechanical harvests, using a cotton picker, a peanut combine, and a grain combine. Thereafter, the other two-thirds were harvested. Only harvested grains, peanut seeds and pods, and cotton lint and seeds were removed from the plots. The economic values of the crops were calculated from prices in the Southern Coastal Plain during the study. Economic value of litter was calculated as the gross economic response from crops for each megagram of litter applied.

Soil samples collected in February of each year from 0- to 15-, 15- to 30-, 30- to 60-, and 60- to 90-cm depth increments were analyzed for pH, P, K, Ca, Mg, Cu, Mn, and Zn. Only the analyses from 1997 and 2000 are included in this paper. The 1997 data were chosen because the initial samples in 1996 were collected before liming. Soil pH was determined in a 1:2 soil/water suspension after an equilibration period of 30 min. Phosphorus, K, Ca, Mg, Cu, Mn, and Zn were extracted by Mehlich-1 (Donohue et al., 1983). Phosphorus was determined by colorimetry and the other elements by atomic absorption spectroscopy (Donohue et al., 1983). Nitrate-N was extracted in 1 M KCl and determined by colorimetry (Keeney and Nelson, 1982). Soil organic matter was determined only in the 0- to 15-cm samples by the Walkley–Black titration method (Nelson and Sommers, 1982).

Both *Rhizoctonia* limb rot and stem rot (*Sclerotium rolfsii*) were evaluated in peanut immediately after the pods were dug and inverted. Incidence of stem rot (portion of 30.5-cm section of a linear row per plot with at least one diseased locus) and the severity of limb rot (portion of vines colonized by *R. solani* in six 0.6-m sections of a linear row per plot) were evaluated. Excessive lodging in canola harvested in 2000 prompted an evaluation of *Sclerotinia* spp. damage by counting the number of stems with lesions (girdling lesion or a large, easily visible, nongirdling lesion) immediately following harvest. Four counts of 25 plants were made in each plot.

To evaluate nematode populations, 20 soil cores, 2.5 cm in diam. by 12.5 cm deep, were collected each month in the two center rows of cotton, peanut, and millet plots. Soil cores from a plot were mixed, and nematodes were extracted from a 150-cm<sup>3</sup> subsample by centrifugal flotation (Jenkins, 1964). Roots from 20 plants plot<sup>-1</sup> were dug at harvest and exam-

**Table 2. Elemental concentrations in broiler litter by season of application.**

Element	S1996†	F1996‡	S1997	F1997	S1998	F1998	S1999	F1999	Mean	CV
	kg Mg <sup>-1</sup>									%
N	25	20	22	22	29	22	32	28	25	18
P	10	9	11	10	12	10	14	12	11	15
K	14	12	17	14	17	15	18	18	16	14
Ca	13	13	15	19	18	13	19	16	16	17
Mg	3	3	3	5	3	3	4	4	3	23
S	3	2	3	3	4	3	4	4	3	21
	g Mg <sup>-1</sup>									
Zn	194	185	203	188	213	188	301	260	216	19
Mn	242	219	259	251	264	247	350	317	269	16
Cu	203	203	165	160	155	175	201	209	184	12
Fe	2300	1200	900	1600	1500	1100	1500	2100	1525	31
B	15	25	22	19	22	22	19	18	20	15
Al	2700	900	900	2100	1600	1300	1600	2800	1738	43
Cl	4180	4830	3570	7630	nd§	nd	nd	nd	5052	35
Na	3500	2700	3600	3200	5200	3400	7800	4600	4250	39
Pb	4	2	2	4	2	2	nd	nd	3	19
Cd	0.6	0.3	0.3	0.5	0.4	0.3	nd	nd	0.4	30
Ni	5	4	4	4	8	5	nd	nd	5	29
Cr	6	4	3	5	5	4	nd	nd	4	19
Mo	2	2	2	2	2	2	nd	nd	2	18

† S, spring.

‡ F, fall.

§ nd, not determined.

ined and rated for galling by *M. incognita* on a scale of 1 to 5 (Barker et al., 1986).

Crop yield, economic value, and disease and nematode ratings were statistically analyzed by the ANOVA procedure as a randomized complete block design (SAS Inst., 1998). Soil data with depth were analyzed by the method of Cochran and Cox (1955), using a split-plot arrangement with subunits (depths) in strips. Means were separated by LSD ( $P = 0.05$ ).

## RESULTS AND DISCUSSION

The mean N concentration in broiler litter used in this study (Table 2) was less than the N concentration in fresh litter reported by Vest et al. (1994). The difference was likely due to NH<sub>3</sub> losses by volatilization during stacking. Total P, K, Ca, and Mg concentrations were also slightly less than those reported by Vest et al. (1994). In spite of the care to obtain uniform litter, analyses of the litter transported from the stack house before planting crops each spring and fall season varied considerably (Table 2). Such variability is inherent in litter due to differences in the ratios of manure to wood shavings, time of house cleaning, feed conversion, and length of time and temperature conditions for stacking. Because of the heterogeneous composition of broiler litter, precise analyses are often difficult to obtain and variation in analyses should be expected.

Increasing the litter rate from 0 to 9.0 Mg ha<sup>-1</sup> increased cotton yields in 1996 and 1997. Rates >4.5 Mg ha<sup>-1</sup> did not increase yields in 1998 and 1999 (Table 3). Grain yield of pearl millet increased to the 13.5 Mg ha<sup>-1</sup> rate in 1996 and then either to the 4.5 or 9.0 Mg ha<sup>-1</sup> rate thereafter. Peanut yield and value per hectare were decreased by broiler litter each year, except 1999. Wheat and canola yields were increased by litter to either the 9.0 or 13.5 Mg ha<sup>-1</sup> rate each year (Table 4).

The gross economic value of a megagram of broiler litter for a given crop is presented in Table 5. Considering a cost of applied litter at \$12 Mg<sup>-1</sup> (Given and Shur-

ley, 1995; Vervoot and Keeler, 1999), broiler litter was a valuable amendment for cotton; less valuable for millet, canola, and wheat; and detrimental for peanut. The objectives of this study did not include a comparison of the costs of nutrients in litter with those purchased as fertilizer. But, without any consideration of the potential value of other nutrients, application of litter could be justified on the basis of N alone. At the current cost of commercial fertilizer N (approximately \$0.66 kg<sup>-1</sup>), N in litter could be purchased at a cost less than commercial fertilizer. For the rotation, litter value was greatest when 4.5 Mg ha<sup>-1</sup> was applied for each crop. Application of

**Table 3. Yield and value of three summer crops in rotation and fertilized only with four rates of broiler litter over 4 yr.**

Litter rate†	1996	1997	1998	1999	Mean	Gross value‡
	kg ha <sup>-1</sup> lint					\$ ha <sup>-1</sup> yr <sup>-1</sup>
<b>Cotton</b>						
0	963c§	684c	402b	563b	653b	833b
4.5	1187b	1228b	1322a	1492a	1307a	1666a
9.0	1415a	1566a	1402a	1521a	1476a	1882a
13.5	1427a	1541a	1272a	1393a	1408a	1795a
<b>Grain Pearl Millet</b>						
	kg ha <sup>-1</sup> grain					
0	2054b	1514b	3325b	1929b	2206b	207b
4.5	2239b	3666a	4212b	4487a	3651a	342a
9.0	2564b	3704a	5413a	4053a	3934a	369a
13.5	3175a	3373a	6064a	4081a	4173a	391a
<b>Peanut</b>						
	kg ha <sup>-1</sup> pods					
0	4275a	4375a	5854a	3761ab	4566a	3262a
4.5	3399b	3576b	5612ab	4311a	4224ab	2979ab
9.0	4028ab	3422b	5460ab	3741ab	4163ab	2930ab
13.5	3567b	3689b	4960b	3418b	3908b	2716b

† Litter reapplied to each summer and winter crop.

‡ Futures prices on 6 June 2000; corn price used for pearl millet grain, and peanut value from yield and grade using the Peanut Loan Schedule. Cotton = \$1.275 kg<sup>-1</sup> lint and millet = \$0.0937 kg<sup>-1</sup> grain.§ Yields and gross economic values within a column followed by a common letter are not significantly different by LSD ( $P = 0.05$ ).

**Table 4. Yield and value of two winter crops in rotation and fertilized only with four rates of broiler litter over 4 yr.**

Litter rate†	1997	1998	1999	2000	Mean	Gross value‡
	kg ha <sup>-1</sup>					\$ ha <sup>-1</sup> yr <sup>-1</sup>
<b>Wheat</b>						
0	672b§	470d	806c	1344d	823b	81b
4.5	941b	1210c	2150b	3696c	1999ab	196ab
9.0	1613a	2150b	2554a	6653a	3242a	318a
13.5	1613a	3494a	2554a	5578b	3310a	325a
<b>Canola</b>						
	kg ha <sup>-1</sup>					
0	1288c	336c	1176d	1176c	994c	182c
4.5	1680b	1512b	1624c	2184b	1750b	320b
9.0	2128a	1792a	2296b	2800a	2254a	412a
13.5	2352a	1792a	2688a	2016b	2212a	404a

† Litter reapplied to each summer and winter crop.

‡ Futures prices 6 June 2000; canola price based on Winnipeg, Canada price with adjustment for the Southeast USA. Wheat = \$0.0981 kg<sup>-1</sup> and canola = \$0.1826 kg<sup>-1</sup>.§ Yields and gross economic values within a column followed by a common letter are not significantly different by LSD ( $P = 0.05$ ).

9.0 or 13.5 Mg ha<sup>-1</sup> for each crop over the 4-yr period resulted in reduced value received per megagram of litter compared with the 4.5 Mg ha<sup>-1</sup> rate. If no application had been made to peanut, the calculated value of a megagram of litter in the rotation increased from \$42 to \$68 ha<sup>-1</sup> yr<sup>-1</sup> where the 4.5 Mg ha<sup>-1</sup> rate was applied to the other rotational crops. The economic calculations in this study are time dependent. The value of broiler litter application will vary with changes in crop prices, litter price, transportation cost, and application cost. In addition, broiler litter has some residual value. An investigation is ongoing to determine the residual value of broiler litter for crops in the rotation.

Soil analyses by depth in February 2000 indicate chemical alteration of the soil profile due to litter application (Table 6) and changes in soil test values from

**Table 5. Unit economic value† of broiler litter applied to individual crops, the rotation, and the rotation without peanut.**

Broiler litter rate	Cotton	Millet	Peanut	Wheat	Canola	All crops	All crops except peanut
	Mg ha <sup>-1</sup> ————— \$ Mg <sup>-1</sup>						
4.5	185a‡	30a	-63b	26a	29a	42a	68a
9.0	117b	18b	-37a	23ab	25b	29b	46b
13.5	71c	14c	-40a	18b	17c	16c	30c

† Value calculated by subtracting the gross value obtained without litter from the gross value obtained for a given rate (Tables 3 and 4) and dividing by the litter rate.

‡ Values in a column followed by a common letter are not different by LSD ( $P = 0.05$ ).

February 1997 to February 2000 (Table 7). Broiler litter also increased soil organic matter by 1.0, 2.4, and 2.5 g kg<sup>-1</sup> in the surface 0 to 15 cm in 4 yr for the 4.5, 9.0, and 13.5 Mg ha<sup>-1</sup> rates, respectively (data not shown). Litter application rate did not affect soil pH in the soil profile (0–90 cm). Increased soil pH has been obtained from broiler litter application in other studies (Han et al., 2000), but the Tifton soil is well buffered compared with some other Coastal Plain soils when the pH approaches neutrality (Gascho and Parker, unpublished data, 2000).

Nitrate-N did not increase with litter rate for any of the depths sampled in 2000. Those results are different than those found by Kingery et al. (1994) and Wood et al. (1996) on other soils. The difference may be due to leaching of N, as we irrigated for greatest yield in this study. In a previous study on the Tifton soil, we found that NO<sub>3</sub>-N can leach and accumulate on a plinthite layer that can be as deep as 90 cm (Menezes et al., 1997). However, not all of the N was leached; in addition to plant uptake, some of the applied N was retained in the measured increase of soil organic matter. Mehlich-1 extractable Ca, Mg, Cu, Zn, and Mn concentrations

**Table 6. Effect of 4 yr of broiler litter application on nutrient concentrations and pH in soil in February 2000.†**

Depth	Litter rate, Mg ha <sup>-1</sup>											
	0	4.5	9.0	13.5	0	4.5	9.0	13.5	0	4.5	9.0	13.5
	pH				P				NO <sub>3</sub> -N			
cm					mg kg <sup>-1</sup>							
0–15	6.8a‡	6.9a	6.8a	6.8a	32c	69b	93a	107a	8a	7a	11a	10a
15–30	6.3a	6.4a	6.5a	6.4a	20b	27b	39b	72a	8a	8a	9a	9a
30–60	5.8a	5.8a	5.8a	5.6a	6a	3a	7a	12a	8a	7a	9a	8a
60–90	5.5a	5.7a	5.6a	5.4a	1a	2a	1a	2a	8a	7a	8a	10a
	K				Ca				Mg			
					mg kg <sup>-1</sup>							
0–15	48b	71ab	85a	107a	287c	322bc	444ab	562a	34b	40ab	48ab	53a
15–30	19b	50ab	92a	92a	174a	178a	238a	191a	21a	27a	34a	29a
30–60	21b	41ab	62a	79a	163a	177a	174a	135a	27a	32a	39a	34a
60–90	36a	38a	30a	64a	182a	206a	188a	222a	37a	40a	40a	42a
	Cu				Zn				Mn			
					mg kg <sup>-1</sup>							
0–15	0.6b	0.9b	1.5a	1.7a	1.0b	2.1b	3.3b	6.4a	4.5c	5.1bc	7.3b	10.2a
15–30	0.6a	0.7a	0.8a	1.0a	0.8a	1.2a	1.5a	2.6a	2.4a	2.7a	2.8a	4.0a
30–60	0.4a	0.6a	0.5a	0.6a	0.5a	0.4a	0.4a	0.6a	1.8a	2.2a	1.9a	2.8a
60–90	0.4a	0.5a	0.4a	0.5a	0.9a	0.3a	0.3a	0.2a	1.0a	1.2a	0.4a	1.4a

† pH in water, NO<sub>3</sub>-N extracted by 1 M KCl, and other elements extracted by the Mehlich-1 extractant.‡ Data are means of 12 determinations. Means for a given analysis and depth followed by a common letter are not different by LSD ( $P = 0.05$ ).

**Table 7. Effect of broiler litter on changes in nutrient concentrations and pH over a 3-yr period from February 1997 to February 2000.†**

Depth	Litter rate, Mg ha <sup>-1</sup>											
	0	4.5	9.0	13.5	0	4.5	9.0	13.5	0	4.5	9.0	13.5
	pH				P				NO <sub>3</sub> -N			
cm					mg kg <sup>-1</sup>							
0-15	0.9a‡	1.1a	0.9a	0.9a	13c	48b	60ab	74a	7a	6a	10a	8a
15-30	0.5a	0.7a	0.6a	0.6a	6c	14bc	24b	55a	7a	8a	9a	8a
30-60	0.3a	0.2a	0.1a	0.1a	4a	2a	5a	12a	8a	7a	9a	8a
60-90	0.1a	0.4a	0.0a	-0.1a	-4a	1a	1a	2a	8a	7a	8a	9a
	K				Ca				Mg			
					mg kg <sup>-1</sup>							
0-15	17a	32a	39a	48a	97c	139bc	235ab	338a	3a	10a	14a	15a
15-30	-10b	14ab	41ab	46a	28a	50a	67a	39a	2a	11a	10a	8a
30-60	-5a	10a	29a	43a	34a	16a	-4a	-23a	3a	5a	11a	6a
60-90	15a	16a	7a	39a	27a	11a	-11a	39a	7a	3a	3a	7a
	Cu				Zn				Mn			
					mg kg <sup>-1</sup>							
0-15	0.0c	0.3bc	0.7ab	0.8a	0.1b	1.0b	1.9b	4.5a	1.6b	2.5b	4.1ab	6.5a
15-30	0.1a	0.1a	0.2a	0.5a	-0.1a	0.4a	0.5a	1.6a	0.7a	0.8a	0.9a	1.7a
30-60	0.1a	0.0a	0.2a	0.2a	0.3a	0.1a	0.1a	0.4a	0.8a	1.0a	0.8a	1.8a
60-90	-0.1a	0.2a	-0.1a	0.2a	0.6a	0.2a	-0.1a	0.1a	0.5a	0.6a	-0.2a	0.9a

† pH in water, NO<sub>3</sub>-N extracted by 1 M KCl, and other elements extracted by the Mehlich-1 extractant.

‡ Means of 12 determinations. Means for a given analysis and depth followed by a common letter are not different by LSD ( $P = 0.05$ ).

were increased by litter application only in the surface soil (0-15 cm).

Soil P increased with litter rate to 30 cm, and soil K increased to 60 cm. Of the elements analyzed, increasing concentrations of P and Zn in the surface soil with increasing litter rates (Tables 6 and 7) are the greatest concern. Soil P increases can lead to particulate P runoff from the Tifton soil (Gascho et al., 1998), and Zn increases are a concern because Zn is toxic to peanut when Mehlich-1 Zn is >12 mg kg<sup>-1</sup> (Gascho and Davis, 1994). Raising soil pH can alleviate the toxicity, but concentrations >20 mg kg<sup>-1</sup> will likely be toxic even at the pH values (6.8-6.9) in this study. Even though Zn concentrations did not approach toxicity levels in this study, increases of two- to sixfold indicate that long-term application at high rates could result in problems for peanut. The soil data support the current Georgia recommendation to limit broiler litter application rates to 4.5 Mg ha<sup>-1</sup>.

Peanut plant assessments at harvest indicated high incidences of stem rot that were not related to litter rate (data not shown). However, severity of *Rhizoctonia* limb rot increased with litter rate in 1998 and 1999 (Table 8). The increased severity may have been an important reason for decreased yield of peanut where litter was applied. Excessive lodging in the 2000 canola crop was due to *Sclerotinia* spp., and the incidence was related to broiler litter application. Plant damage was approximately doubled by any application of broiler litter, regardless of rate of application (Table 8). In spite of damage from *Sclerotinia* spp., canola yield was greatest for the 9 Mg ha<sup>-1</sup> litter rate (Table 4).

Nematode populations in all 4 yr and in the three summer crops were not great enough to show any depression by litter application (data not shown). Numbers of root-knot nematodes (*M. incognita* and *M. arenaria*)

were low in cotton but slightly higher in millet and peanut. There were no galls on roots in any year. Numbers of stubby-root nematodes (*Paratrichodorus minor*) increased in cotton, millet, and peanut plots with the age of the rotation but not to population densities that were harmful. Likewise, populations of ring nematode (*Mesocriconema ornata*) were low. Overall, nematodes were not a problem in the plots and were not affected by rates of broiler litter application. A review of data from all 4 yr suggests that nematode populations were increasing, but there was no indication that broiler litter stimulated this increase.

## SUMMARY

Broiler litter was a valuable amendment for cotton, pearl millet, wheat, and canola grown using conservation tillage. Application of litter to land before planting peanut decreased yield and economic value of that crop. Using the value of harvested crops, the value of a megagram of stack-house broiler litter added \$42 ha<sup>-1</sup> yr<sup>-1</sup> to crop value when the currently recommended rate of

**Table 8. Significant damage due to *Rhizoctonia solani* in peanut and *Sclerotinia* spp. in canola as related to broiler litter rate.**

Broiler litter rate	<i>R. solani</i> damage in peanut		<i>Sclerotinia</i> spp. damage in canola
	1998	1999	2000
Mg ha <sup>-1</sup>	hits/plot		lesions (25 plants)
0	9b†	9c	4c
4.5	18a	13b	8b
9.0	22a	20a	15a
13.5	23a	18a	18a

† Values for *R. solani* damage in peanut and *Sclerotinia* spp. damage in canola are means of 4 and 16 observations, respectively. Values in a column followed by a common letter are not significantly different by LSD ( $P = 0.05$ ).

4.5 Mg ha<sup>-1</sup> was applied to all crops and \$68 ha<sup>-1</sup> yr<sup>-1</sup> when none was applied to peanut. Presently, litter near points of production can be obtained, transported, and applied for about \$12 Mg<sup>-1</sup>.

Broiler litter application increased P, K, Ca, Mg, Zn, Mn, and Cu concentrations in surface soil. Of these elements, P and Zn accumulations may result in problems in the long term. High concentrations of P in surface soil can add to P in water bodies via particulate P erosion and runoff, and high concentrations of Zn can result in toxicity in peanut.

*Rhizoctonia* limb rot damage in peanut was increased where litter was applied. That damage may have contributed to the decreased yield and value of peanut. *Sclerotinia* spp. damage (lodging) in canola was severe in plots amended with broiler litter in the final year of study, but yield was not affected. It would appear prudent to limit biyearly or even yearly broiler litter applications to about 4.5 Mg ha<sup>-1</sup> and supply additional nutrient requirements with commercial fertilizers. Research to determine the residual effects of broiler litter on crops in the rotation is continuing.

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