Scientific Research and Essay Vol. 2 (4), pp. 089-094, April 2007
Available online at http://www.academicjournals.org/SRE
ISSN 1992-2248 © 2007 Academic Journals

Full Length Research Paper

Determination of bioavailable nitrogen and phosphorus from pelletized broiler litter

W. A. Hammac II[1], C. W. Wood[1*], B. H. Wood[1], O. O. Fasina[2], Y. Feng[1], and J. N. Shaw[1]

[1]Department of Agronomy and Soils, 202 Funchess Hall, Auburn University, Alabama U.S.A., 36849-5412.
[2]Department of Biosystems Engineering, 200 Corley Building, Auburn University, Alabama U.S.A., 36849.

Accepted 14 March, 2007

Improved methods for broiler chicken (*Gallus gallus domesticus*) litter utilization are needed to alleviate potential impacts of pollution around broiler production operations. Pelletization may constitute one improved method for handling broiler litter. The objective of this study was to determine the change in nutrient concentration from pelletizing broiler litter, and determine availability of nitrogen (N) and phosphorus (P) from pelletized broiler litter in a greenhouse experiment. Ryegrass (*Lolium multiflorum* Lam.) and sorghum-sudangrass (*Sorghum bicolor* L. Moench) were grown to determine dry matter accumulation and uptake of N and P. Cumulative data for all cuttings showed that pelletized broiler litter had lower uptake of N and P compared to inorganic N and P. Dry biomass production from pellets was less than ammonium nitrate (NH_4NO_3) in the N experiment. Biomass production from pellets was similar to calcium phosphate ($CaHPO_4$) for the P experiment. This indicates pelletized broiler litter can serve as N and P sources for plants. However, N and P in broiler litter pellets may not be as available as that from inorganic fertilizer.

Key words: pelletization, bioavailability, broiler litter, yield, uptake.

INTRODUCTION

The value of broiler chicken production has increased significantly over the past decade, with the majority of broilers produced in the Southeast in 2002 (USDA, NASS, 2003). With large broiler production comes large broiler litter production, which leaves the problem of litter disposal. Broiler litter, a common soil amendment in broiler production areas, has the risk of being applied in excess leading to pollution from nutrients (Wood et al., 1996). Some undesira-ble attributes that result from over-application of broiler litter are nitrate leaching, phosphorus runoff, and pathogen runoff (Moore et al., 1995). Transportation cost for broiler litter, due to its low nutrient density and bulkiness, is a problem that often leaves producers no other choice but to apply litter on land near production areas (Moore et al., 1998). Increasingly stringent regulations put in place for applying poultry litter further decrease the amount of available land for litter spreading (Lichtenberg et al., 2002). Donald and Blake (1990) found that litter can be hauled upto 160 km and be utilized economically as a fertilizer. The critical factors involved with transporting litter are change in nutrient content, pathogen population, and moisture content. The cost of poultry litter depends on stage of storage (that is, nutrient content and labor input), weight of load, and hauling distance (Donald and Blake, 1990).

One possible way to increase the economical hauling distance of broiler litter is pelletization. Pelletization increases the bulk density and particle size uniformity of litter (McMullen, 2005) allowing a more nutrient dense litter to be transported and thus more area to be utilized for land application (Moore et al., 1998). This eases the pressure on land where pollution from nutrients, metals, and pathogens is a concern. Pelletization will likely affect the dynamics of nutrients in poultry litter. Processing may also affect survivability of pathogens in poultry litter. With pelletization, litter temperature is raised to 70°C which decreases pathogens making the transportation process safer. However, little research has been done to investigate the value of pelletized poultry litter as a fertilizer.

Pelletization of broiler litter could prove to benefit its marketability by adding value through safer handling, greater nutrient density, and more uniform spreading. Wilhoit et al. (1993) found that poultry litter in its raw state is spread un-

*Corresponding author. E-mail: woodcha@auburn.edu. Phone: (334) 844-3997. Fax: (334) 844-3945.

Table 1. Nitrogen analysis of broiler litter as affected by source and processing.

	Total N (g N kg litter^{-1})			NH_4-N (mg NH_4-N kg litter^{-1})			NO_3-N (mg NO_3-N kg litter^{-1})		
Process	**PH †**	**WS**	**Mean**	**PH**	**WS**	**Mean**	**PH**	**WS**	**Mean**
Unprocessed	33.8	38.9	36.4	477	2161	1319	455	1033	744
Hammer-milled	32.4	37.5	35.0	744	2330	1537	681	1250	966
Pelletized	32.5	37.6	35.1	1053	2853	1953	593	1381	987
Mean	32.9	38.0		758	2448		576	1221	
Analysis of Variance	**P>F**	**$LSD_{0.05}$**		**P>F**	**$LSD_{0.05}$**		**P>F**	**$LSD_{0.05}$**	
Source (S)	0.0001	1.0		0.0001	130		0.0022	444	
Process (P)	0.0201	0.8		0.0001	106		0.4446		
S x P	0.9974			0.2413			0.8319		

† PH = peanut hulls, WS = wood shavings

Table 2. Phosphorus analysis of broiler litter as affected by source and processing.

	Total P (g P kg litter^{-1})			WSP † (mg WSP kg litter^{-1})		
Process	**PH ‡**	**WS**	**Mean**	**PH**	**WS**	**Mean**
Unprocessed	22.9	21.4	22.1	3630	3784	3707
Hammer-milled	20.9	28.1	24.5	3384	4414	3899
Pelletized	25.3	23.8	24.5	2977	1923	2450
Mean	23.0	24.4		3331	3374	
Analysis of Variance	**P>F**	**$LSD_{0.05}$**		**P>F**		
Source (S)	0.2079			0.9448		
Process (P)	0.1284			0.1496		
S x P	0.0031	2.7		0.4007		

† WSP = water soluble P
‡ PH = peanut hulls, WS = wood shavings

evenly due to particle size variability. Pelletized broiler litter enriched with N, P, and potassium (K) has been shown to be a more effective fertilizer than unprocessed broiler litter and resulted in similar N uptake and plant yield when compared to ammonium nitrate (NH_4NO_3) (Hamilton and Sims, 1995). Pelletization of manures has been shown to yield more rapidly mineralizable N, resulting in higher concentrations of NH_4 in the soil (Hadas et al., 1983). Duffera et al. (1999) reported pelletized swine lagoon solids to be an excellent source of P but required additional N for application to most agronomic crops. Koen et al. (1999) recommended inorganic P fertilizer over pelletized poultry litter due to cost and lack of difference in rice yield.

Processing leading to pelletization will likely affect the concentration, release and availability of nutrients in broiler litter. The objective of this study was to determine the change in nutrient concentration from pelletizing broiler litter, and determine availability of N and P from pelletized broiler litter in a greenhouse experiment.

MATERIALS AND METHODS

Pelletization

A wood shaving (WS) based broiler litter from Sand Mountain Research and Extension Center, Crossville, Austrailia, and a peanut hull (PH) based broiler litter from Wiregrass Research and Extension Center, Headland, AL were collected. A laboratory-scale hammer mill (C.S. Bell Company, Tiffin, OH: model number 10HMBLPK) and pellet mill (California Pellet Mill Company, Merrimack, NH: model number PMCL5) were used to produce ground and pelletized broiler litter, respectively. The hammer-mill had a screen size of 3.2 mm (1/8 in diameter). The pellet mill was modified and equipped to inject steam (by means of a steam generator (Electro-Steam Generator Corporation, Alexandria, VA: model number LG-10)) and dry heat (by means of a heat gun (Steinel Corporation, Germany: model number HL15025)). Broiler litter that was pelletized was first hammer-milled then incorporated with soybean (*Glycine max* L.) oil (3% by wt.) to facilitate the pelletization process. While undergoing pelletization, broiler litter received dry heat and steam and reached a temperature of at least 70EC. Upon their exit, pellets were 4.8 mm in diameter and had a length that ranged from 6 to 25 mm. Once produced, they were kept in a chamber maintained at 20EC and 45% relative humidity for 48 h to allow pellets to cool and become stable in their physical form.

Nutrient concentration

Nutrient concentration of poultry litter as affected by processing was determined (Tables 1 and 2). Unprocessed, hammer-milled, and pelletized broiler litter from the two sources (WS and PH) was analyzed for nutrients in triplicate. Total nitrogen (N) was determined via dry combustion on a LECO CHN-600 analyzer (St. Joseph, MI). Inorganic N (ammonium (NH_4)-N and nitrate (NO_3)-N) was extracted with 2 M potassium chloride (KCl), and measured by colorimetric procedures (Keeney and Nelson, 1982). Total phosphorus (TP) was

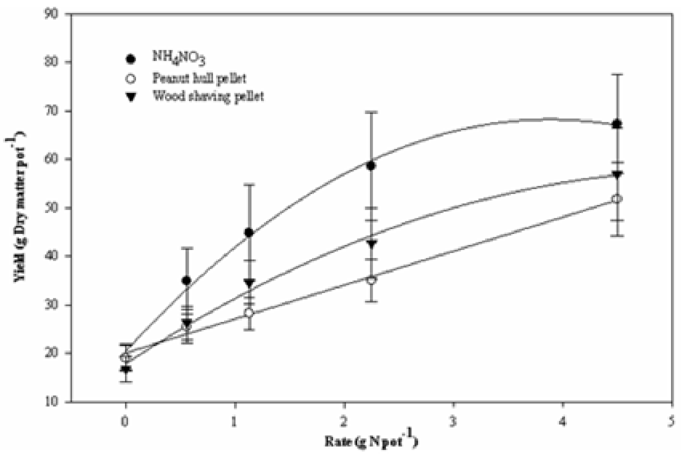

Figure 1. Cumulative yield data from first and second cutting of annual ryegrass and first cutting of sorghum sudangrass N test.

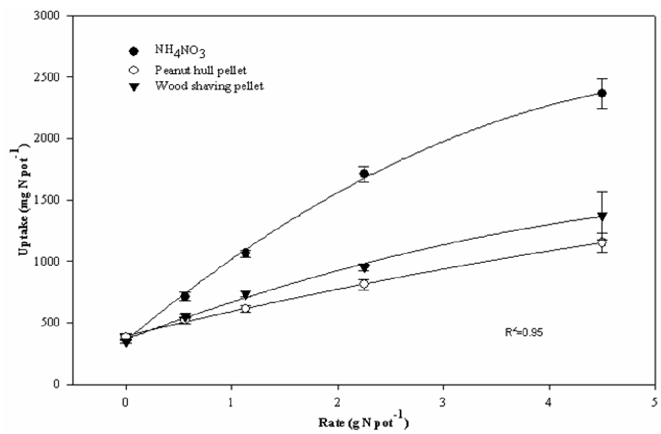

Figure 2. Cumulative N uptake data from first and second cutting of annual ryegrass and first cutting of sorghum sudangrass for the N test.

measured using inductively coupled plasma (ICP) spectroscopy according to the procedures of Olsen and Sommers (1982). Water soluble P (WSP) was measured by the method described by Self-Davis and Moore (2000). Statistical analysis for nutrient concentration was performed using Analysis of Variance (ANOVA) procedure (SAS Institute, 1991).

Greenhouse experiment

One greenhouse experiment was conducted to compare two sources of pelletized broiler litter with ammonium nitrate (NH_4NO_3), where the inorganic N served as a control. Another greenhouse experiment was conducted to compare two sources of pelletized broiler litter with calcium phosphate ($CaHPO_4$), where the inorganic P source served as a control. Dry matter accumulation and uptake was measured in each experiment using annual ryegrass and sorghum-sudangrass in 11 L pots that were 30 cm in diameter. Experiments with annual ryegrass were conducted during fall/winter of 2003/2004 while those with sorghum-sudangrass were conducted in the spring/summer of 2004. Within each time period, two experiments were arranged in a factorial design, that is, N source (3) by N rate (5) or P source (3) by P rate (5). Both experiments were completely random arrangements with four replications.

Soil from the Monroeville, AL area, (Lucedale loam: fine-loamy, siliceous, subactive, thermic Rhodic Paleudult) was collected, sieved, fumigated using methyl bromide (CH_3Br) injection and treated with polyacrylamide (PAM) at the rate of 7 mg pot^{-1} to increase water infiltration. The soil was tested prior to litter application to correct nutrient deficiencies other than the nutrient in question. Potassium chloride (KCl) was applied to all treatments at the rate of 4.50 g K_2O pot^{-1}, NH_4NO_3 was added to the P experiment at the rate of 4.50 g N pot^{-1}, and $CaHPO_4$ was added to the N experiment at the rate of 3.60 g P_2O_5 pot^{-1}. The N experiment received five treatments at the rates of 0, 0.56, 1.13, 2.25, and 4.50 g N pot^{-1} as reagent grade NH_4NO_3, peanut-hull litter pellets, or wood-shaving litter pellets. The P experiment received five treatments at the rates of 0, 0.45, 0.90, 1.80, and 3.60 g P_2O_5 pot^{-1} as reagent grade $CaHPO_4$, peanut-hull litter pellets, or wood-shaving litter pellets.

Thirty annual ryegrass seeds were planted and thinned to 15 plants after one week. After the final annual ryegrass harvest plants were terminated, soil was re-sieved, and re-treated with PAM at the rate of 7 mg pot^{-1}. Twenty sorghum-sudangrass seeds were planted and thinned to 8 plants after one week. Soil moisture was maintained at -30 kPa of moisture tension using gravimetric procedures. Pots were rotated after watering to maintain even lighting.

Plant material was used to determine N and P uptake and removal, a measure of bioavailability. Plant biomass was harvested at maturity twice for annual ryegrass, and once for sorghum-sudangrass. Data for the second cutting of sorghum-sudangrass was lost. Annual ryegrass and sorghum-sudangrass were cut to a stubble height of 5 and 13 cm, respectively. General greenhouse techniques used in these studies followed guidelines established by Tennessee Valley Authority National Fertilizer Development Center, Muscle Shoals, AL (Allen et al., 1976). Weed removal was performed by hand, and insect control was perfor-med routinely using a variety of different insecticides.

Yields were determined via cutting, drying at 60EC and measuring mass of total dry matter gravimetrically. Sub samples of harvested biomass were collected for N and P determinations. Plant samples were ground to pass a 1 mm sieve for total N and P determination. Nitrogen concentration for ground plant materials was determined by the dry combustion method with a LECO CHN-600 analyzer (St. Joseph, MI). Phosphorus concentration was determined via ICP spectroscopy (SPECTRO CIROS CCD, side-on plasma, GERMANY) after dry ashing and dissolution of the remaining ash according to the procedures of Olsen and Sommers (1982). Nitrogen and P uptake/removal was calcu-lated as the product of yield and N or P concentration of biomass.

Categorical variable regression analysis procedures were utilized in all phases of data analysis for these experiments (SAS Institute, 1991). Categorical variable regression yielded a baseline equation for the rea-gent grade N or P source, and peanut hull and wood shaving litter pellets were tested for deviation from the baseline equations, using the proce-dure outlined by Montgomery et al. (2001). The equation contained the following parameters:

$$Y = (\beta_0 + \Delta\beta_{\rho 0}U_{\rho 0} + \Delta\beta_{\omega 0}U_{\omega 0}) + (\beta_1 + \Delta\beta_{\rho 1}U_{\rho 1} + \Delta\beta_{\omega 1}U_{\omega 1})\ X + (\beta_2 + \Delta\beta_{\rho 2}U_{\rho 2} + \Delta\beta_{\omega 2}U_{\omega 2})\ X^2$$

Where Y = the dependent variable either yield in g dry matter pot^{-1} or uptake in mg N or P pot^{-1}, X = application rate g N or P pot^{-1}, β_0 = baseline Y intercept, β_1 = baseline slope coefficient of the linear rate, β_2 = baseline slope coefficient of the quadratic rate, $\Delta\beta_\rho$ = deviation from baseline term owing to the use of peanut hull litter pellets, $\Delta\beta_\omega$ = deviation from baseline term owing to the use of wood shaving litter pellets, U_ρ = 1 if peanut hull litter pellets were used, 0 if otherwise, and U_ω = 1 if wood shaving litter pellets were used, 0 if otherwise. Lines

Table 3. Regression analysis for the nitrogen experiment dry matter yield and N uptake for combined annual ryegrass and sorghum-sudangrass.

Test/Grass/Analysis/Cutting	β_0 †	$\Delta\beta_{\rho 0}$	$\Delta\beta_{\omega 0}$	β_1	$\Delta\beta_{\rho 1}$	$\Delta\beta_{\omega 1}$	β_2	$\Delta\beta_{\rho 2}$	$\Delta\beta_{\omega 2}$	R^2
	---------g pot^{-1}---------			---------------------Response------------------------						
N/ARG/Dry matter/1 ‡	9.4	-0.9	-1.4	1.4	0.9	0.8	-0.5	0.0	-0.1	0.44
N/ARG/Dry matter/2	9.6	-0.3	-1.6	20.9	-17.1	-10.6	-3.4	3.6	2.4	0.87
N/SS/Dry matter/1	1.4	0.9	0.5	2.3	-1.4	0.1	0.7	-0.4	-0.6	0.89
N/ARG/Dry matter/1+2	19.0	-1.2	-3.0	22.3	-16.2	-9.8	-3.9	3.5	2.4	0.84
N/ARG+SS/Dry matter/1+2	20.4	-0.3	-2.6	49.3	-35.3	-19.5	-12.7	12.7	7.2	0.91
	---------mg pot^{-1}--------			---------------------Response------------------------						
N/ARG/Uptake/1	324.6	-50.9	-61.0	141.9	17.3	26.8	-30.9	2.6	-2.9	0.52
N/ARG/Uptake/2	-1.3	98.5	81.0	626.5	-589.9	-489.5	-64.5	80.4	71.1	0.92
N/SS/Uptake/1	31.1	-9.7	-9.9	-44.0	55.1	62.9	33.9	-29.9	-29.5	0.76
N/ARG/Uptake/1+2	323.3	47.6	20.0	768.4	-572.6	-462.6	-95.4	82.9	68.2	0.90
N/ARG+SS/Uptake/1+2	354.4	37.9	10.2	724.4	-517.6	-399.7	-61.5	53.0	38.7	0.95

† $\beta 0$ = baseline Y intercept, $\beta 1$ = baseline slope coefficient of the linear rate, $\beta 2$ = baseline slope coefficient of the quadratic rate, $\Delta\beta\rho 0$ = deviation from baseline term owing to the use of peanut hull litter pellets, $\Delta\beta\omega 0$ = deviation from baseline term owing to the use of wood shaving litter
‡ N = nitrogen, ARG = annual ryegrass, SS = sorghum-sudangrass

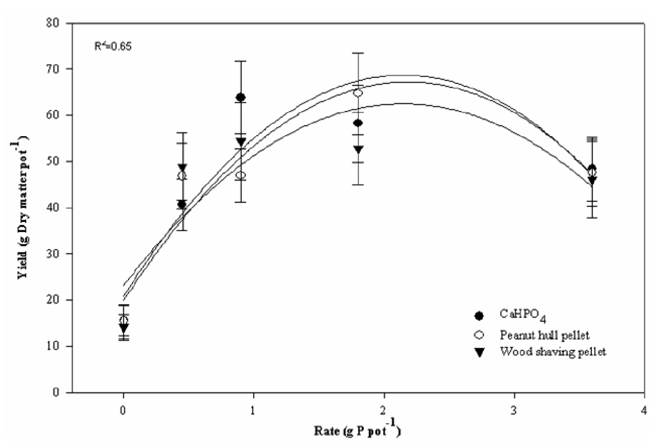

Figure 3. Cumulative yield data from first and second cutting of annual ryegrass and first cutting of sorghum sudangrass P test.

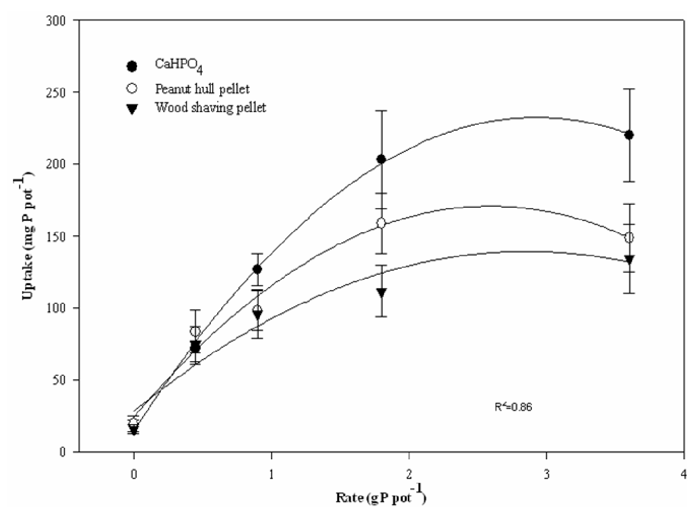

Figure 4. Cumulative P uptake data from first and second cutting of annual ryegrass and first cutting of sorghum sudangrass P test.

on Figures 1-4 represent predicted values obtained from equations in Tables 3 and 4.

RESULTS AND DISCUSSION

Nutrient concentration

The analysis for total N of broiler litter pellets showed a significant decrease ($P = 0.05$) in N affected by processing (pelletized < unprocessed = hammer-milled) averaged across broiler litter source, (WS and PH) (Table 1). This change, though statistically significant, is not likely to be economically significant. A similar study (Hadas et al., 1983) showed that manure pellets had greater total N when compared to ground manure. There was also a significant difference in total nitrogen affected by source ($P = 0.05$), with WS having greater total N than PH. Hileman (1967) also found that bedding material used had an effect on N, P, and K content of litter.

The analysis for NH_4-N and NO_3-N showed a significant difference ($P = 0.05$) in N as affected by source (PH < WS) for both NH_4-N and NO_3-N (Table 1). There was also a

Table 4. Regression analysis for the phosphorus experiment dry matter yield and P uptake for combined annual ryegrass and sorghum-sudangrass.

Test/Grass/Analysis/Cutting	β_0 †	$\Delta\beta_{\rho 0}$	$\Delta\beta_{\omega 0}$	β_1	$\Delta\beta_{\rho 1}$	$\Delta\beta_{\omega 1}$	β_2	$\Delta\beta_{\rho 2}$	$\Delta\beta_{\omega 2}$	R^2
	---------g pot^{-1}---------			----------------------Response------------------------						
P/ARG/Dry matter/1 ‡	4.8	-1.5	0.1	8.5	-0.5	-6.2	-4.7	0.6	2.5	0.51
P/ARG/Dry matter/2	11.7	1.4	2.2	43.5	-12.3	-9.4	-21.5	7.0	4.5	0.47
P/SS/Dry matter/1	4.4	-0.8	0.0	37.0	10.4	-0.2	-15.2	-5.9	0.4	0.63
P/ARG/Dry matter/1+2	16.5	-0.1	2.3	52.0	-12.8	-15.6	-26.2	7.6	7.0	0.49
P/ARG+SS/Dry matter/1+2	20.9	-0.9	2.3	89.0	-2.4	-15.8	-41.5	1.7	7.3	0.65
	---------mg pot^{-1}--------			----------------------Response------------------------						
P/ARG/Uptake/1	4.8	-0.5	2.0	52.0	-23.2	-39.2	-23.8	10.0	16.3	0.74
P/ARG/Uptake/2	5.8	14.6	11.1	180.5	-79.9	-85.1	-71.1	30.0	31.6	0.65
P/SS/Uptake/1	4.4	-4.6	0.4	65.0	31.7	-17.5	-6.8	-25.6	-0.7	0.87
P/ARG/Uptake/1+2	10.6	14.1	13.1	232.6	-103.3	-124.4	-95.0	40.1	47.9	0.69
P/ARG+SS/Uptake/1+2	15.0	9.5	13.5	297.6	-71.5	-141.9	-101.7	14.5	47.2	0.86

† $\beta 0$ = baseline Y intercept, $\beta 1$ = baseline slope coefficient of the linear rate, $\beta 2$ = baseline slope coefficient of the quadratic rate, $\Delta\beta\rho 0$ = deviation from baseline term owing to the use of peanut hull litter pellets, $\Delta\beta\omega 0$ = deviation from baseline term owing to the use of wood shaving litter
‡ P = phosphorus, ARG = annual ryegrass, SS = sorghum-sudangrass

significant increase in NH_4-N due to processing (unprocessed <hammer-milled <pelletized) (Table 1). Change was expected; however, the expectation was that N would decrease with each processing level due to NH_3 volatilization from aeration and heating from the hammer-milling and pelletization processes, respectively. It is possible that more NH_3 was made available during pelletization due to lysing of cellular material in the litter. The lysis of cells, from the addition of heat in pelletization, would account for a reduction in total N and an increase in inorganic N. Hadas et al. (1983) noted a decrease in NH_4-N, and no change in NO_3-N, due to pelletization of manures. Broiler litter total P was affected by the interaction of source and processing (Table 2). Pelletization resulted in greatest total P for PH litter, while greatest total P for WS litter resulted from grinding with a hammer-mill. This interaction does not allow discernment of a pattern for these litter sources owing to processing. However, there was a trend ($P > F = 0.1284$) for total P to increase with processing when averaged across source (Table 2). Hadas et al. (1990) mentioned that pelletizing decreases the amount of detectable P in soil compared to ground manure. There was no significant change in water soluble P owing to processing or litter source (Table 2).

Nitrogen greenhouse experiment

Yield data generally deviated from the baseline equation when litter pellets were used in place of NH_4NO_3. The intercept and quadratic terms were repeatedly similar, but the linear term for litter pellets had a significantly lower slope than for NH_4NO_3 (Table 3). At the first cutting the linear slope was similar for all three treatments, however, as the experiment progressed, the linear slope for the pellet treatments decreased. Cumulative yield data showed a significantly lower linear and quadratic term for broiler litter pellets when compared to NH_4NO_3 (Figure 1 and Table 3), which translates into lower yields owing to the use of pellets. Nitrogen uptake data showed trends similar to the yield data (Figure 2 and Table 3). These data show that pelletized peanut hull and wood shaving litter adequately supply N to a plant, but NH_4NO_3 was more readily available allowing greater dry matter production and N uptake. Hamilton and Sims (1995) found that enriched poultry litter pellets showed similar yield and N uptake when compared to an inorganic N source, and outperformed unprocessed broiler litter when growing corn and tomatoes in a greenhouse experiment.

Phosphorus greenhouse experiment

Yield data showed significant deviation from the baseline equation where litter pellets were compared to an inorganic P source. The intercept terms were repeatedly similar, but the linear and quadratic terms for litter pellets had a significantly lower slope than for $CaHPO_4$ (Table 4). At the first cutting the linear slope was different among treatments however, as the experiment continued and the P became more available, the trend for each treatment became increasingly similar. Phosphorus uptake curves showed trends similar to the yield data. Cumulative data from three cuttings revealed almost overlapping curves from all three sources for yield data (Figure 3). However, cumulative uptake data followed the normal trend with a lower linear and quadratic term owing to the use of pellets (Figure 4 and Table 4). These trends show that pelletized peanut hull and wood shaving litter adequately supply P to a plant. Tunney and Pommel (1987) showed in most instances that pig manure was comparable to $CaHPO_4$ at supplying P to perennial ryegrass in a greenhouse experiment.

Conclusion

This study showed that pelletized broiler litter can serve as a source of N and P for plants. Pelletized broiler litter is not as readily available as inorganic N and P sources, due to the substantial amount of organic N and P found in broiler litter. Another possibility is the effect of CH_3Br fumigation on microbial activity (Elliot et al., 2001; Ibekwe et al., 2001). A decrease in microbial activity could decrease the rate of nutrient release. However Elliot (2001) found that microbial populations were greater than or equal to the amount prior to CH_3Br fumigation after one month.

It should be noted that even with less yield, the use of pelletized broiler litter may be more economical due to the decreased cost when compared to inorganic fertilizer. Pelletization yields a product that is easily transported and spread, while not reducing the nutrient value of broiler litter. More research should be done, however, to determine the economic impact of pelletization on the value of broiler litter.

REFERENCES

Allen SE, Terman GL, Clements LB (1976). Greenhouse techniques for soilBBplantBBfertilizer research. National Fertilizer Development Center, Tennessee Valley Authority. Bull. Y-104. Muscle Shoals, AL.

Donald JO, Blake JP (1990). Economics of transporting poultry litter as a fertilizer. Ext Circ. 10/90-007. Al. Coop. Ext., Auburn University, Auburn, AL. pp.1-4.

Duffera M, Robarge WP, Mikkelsen RL (1999). Estimating the availability of nutrients from processed swine lagoon solids through incubation studies. Bioresour. Technol. 70: 261-268.

Elliot ML, Des Jardin EA (2001). Fumigation effects on bacterial populations in new golf course bermudagrass putting greens. Soil Biol. Biochem. 33: 1841-1849.

Hadas, A, Bar Yosef B, Portnoy R (1990). Extractability of phosphorus in manure pellets enriched with fertilizer phosphorus. Soil Sci. Soc. Am. J. 54: 443-448.

Hadas A, Bar-Yosef B, Davidov S, Sofer M (1983). Effect of pelleting, temperature, and soil type on mineral nitrogen release from poultry and dairy manures. Soil Sci. Soc. Am. J. 47: 1129-1133.

Hamilton CM, Sims JT (1995). Nitrogen and phosphorus availability in enriched, pelletized poultry litters. J. Sust. Agric. 5: 115-132.

Hileman LH (1967). The fertilizer value of broiler litter. Bull. 158. Ar. Agric. Exp. Stn. University of Arkansas, Fayetteville.

Ibekwe AM, Papiernik SK, Gan J, Yates SR, Yang CH, Crowley DE (2001). Impact of fumigants on soil microbial communities. Appl. Envrion. Microbiol. 67: 3245-3257.

Keeney DR, Nelson DW (1982). Nitrogen-inorganic forms. In: Page AL, Miller RH, Keeney DR (eds) Methods of soil analysis. Part 2. 2nd ed. ASA and SSSA, Madison, WI. pp. 643-698.

Koen WB, Wilson Jr. CE, Slaton NE, Norman RJ (1999). Effects of using poultry litter as a preplant fertilizer in rice on high-pH soils. In Wells BR (ed) Arkansas Rice Research Studies. Univ. of Ar. Agric. Exp. Stn. Res. Ser. 476: 238-245.

Lichtenberg E, Parker D, Lynch L (2002). Economic value of poultry litter supplies in alternative uses. Center Agric. Nat. Resour. Policy, University of Maryland, College Park.

McMullen J, Fasina OO, Wood CW, Feng Y (2005). Storage and handling characteristics of pellets from poultry litter. Appl. Eng. Agric. 21(4): 645-651.

Montgomery DC, Peck EA, Vining GG (eds.). 2001. Indicator Variables. In *Introduction to linear regression analysis.* 265-290. 3rd ed. John Wiley & Sons, Inc., New York.

Moore PA Jr., Daniel TC, Sharpley AN, Wood CW (1998). Poultry manure management. In: Wright Rj, Kemper Wd, Millner PD, Power JF, Korcak RF (eds) Agricultural uses of municipal, animal, and industrial byproducts. USDA-ARS Res. Rep. 44. pp. 60-77.

Moore Jr. PA, Daniel TC, Sharpley AN, Wood CW (1995). Poultry manure management: environmentally sound options. J. Soil Water Conserv. 50: 321-327.

Olsen SR, Sommers LE (1982). Total carbon, organic carbon, and organic matter. p. 403-427. In: Page AL, Miller RH, Keeney DR (eds) Methods of soil analysis. Part 2. 2nd ed. ASA and SSSA, Madison, WI.

SAS Institute. 1991. SAS system for linear models. 3rd ed. SAS, Cary, NC, USA.

Davis LA, Moore Jr. PA (2000). Determining water soluble phosphorus in animal manure. In: Pierzynski GA (ed) Methods of phosphorus analysis for soils, sediments, residuals, and waters. Southern Coop. Series Bull. 396: 74-76.

Tunney H, Pommel B (1987). Phosphorus uptake by ryegrass from monocalcium phosphate and pig manure on two soils in pots. Irish J. Agric. Res. 26: 189-198.

U.S. Department of Agriculture, National Agricultural Statistics Service (2003). Summary: poultry-production and value 2002. USDA Rep. Pou 3-1 (03). U.S. Gov. Print Office, Washington, DC.

Wilhoit JH, Wood CW, Yoo KH, Minkara MY (1993). Evaluation of spreader distribution patterns for poultry litter. ASAE Publ. 9(4): 359-363.

Wood BH, Wood CW, Yoo KH, Yoon KS, Delaney DP (1996). Nutrient accumulation and nitrate leaching under broiler litter amended corn fields. Commun. Soil Sci. Plant Anal. 27: 2875-2894.