Nitrogen and Phosphorus Availability in Composted and Uncomposted Poultry Litter

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ABSTRACT

Poultry litter applications to land have been based on crop N requirements, resulting in application of P in excess of plant requirements, which may cause degradation of water quality in the Chesapeake Bay watershed. The effect of litter source (the Delmarva Peninsula and Moorefield, West Virginia) and composting of poultry litter on N mineralization and availability of P in two soil types (sandy loam and silt loam) was determined in a controlled environment for 120 d. Nitrogen mineralization (percent total organic N converted to inorganic nitrogen) rates were higher for fresh litter (range of 42 to 64%) than composted litter (range of 1 to 9%). The N mineralization rate of fresh litter from the Delmarva Peninsula was consistently lower than the fresh litter from Moorefield, WV. The N mineralization rate of composted litter from either source was not significantly different for each soil type (7 to 9% in sandy loam and 1 to 5% in silt loam) even though composting conditions were completely different at the two composting facilities. Litter source had a large effect on N mineralization rates of fresh but not composted poultry litter. Composting yielded a more predictable and reliable source of mineralizable N than fresh litter. Water-extractable phosphorus (WEP) was similar in soils amended with composted litter from WV and fresh litter from both sources (approximately 10 to 25 and 2 to 14 mg P kg^{-1} for sandy loam and silt loam, respectively). Mehlich 1–extractable phosphorus (MEP) was similar in soils amended with WV fresh litter and composted litter from both sources (approximately 100 to 140 and 60 to 90 mg P kg^{-1} for sandy loam and silt loam, respectively). These results suggest that the composting process did not consistently reduce WEP and MEP, and P can be as available in composted poultry litter as in fresh poultry litter.

ACCELERATED EUTROPHICATION of waterways often results from repeated high rate agricultural applications of poultry manure and other manure (Mullins, 2000). Excess nutrients from surface water runoff cause algal blooms that can produce toxins that are harmful to humans and to the ecosystem (Sharpley et al., 1994). Both phosphorus and nitrogen are important limiting nutrients for algal growth in freshwater and marine areas of the Chesapeake Bay watershed (Laws, 1993).

Excessive amounts of fresh poultry litter (FPL) are currently being generated by high-density poultry operations in the Chesapeake Bay watershed. Approximately

680 250 Mg of litter were applied to farmland in 1999 on the Delmarva (Delaware, Maryland, and Virginia) Peninsula and 425 666 Mg in the remainder of Virginia (Turner, 2000). The large number of high density poultry operations along the Potomac River in West Virginia and on rivers on the eastern shore of Maryland has been the focus of states attempting to solve water quality problems associated with excess applications of poultry litter to farm land (Sims, 2000).

Composting poultry litter may provide a beneficial alternative method for handling litter due to immobilization of nutrients and a reduction of litter volume. Compost is safer due to pathogen reduction and is easier to handle, store, transport, and apply than noncomposted organic residues (Millner et al., 1998). Studies have shown that the composting process immobilizes N in the litter and produces humus that can be used as a source of organic materials and slow the release of nutrients (Paul and Clark, 1996). The slow release of nutrients from composted poultry litter (CPL) may lessen adverse environmental effects from leaching of N in runoff from farmlands (Chang and Janzen, 1996). Increased soil organic matter and cation exchange capacity from CPL applications may improve nutrient retention in soils. Thus, applications of CPL to fields could reduce both synthetic fertilizer inputs and improve soil qualities. However, loss of P from fields where composted manures have been applied is less well understood.

Mineralization and immobilization rates of N and P from CPL added to soil must be quantified (Chang and Janzen, 1996). These data will enable growers to determine the timing and application rate for CPL and improve our understanding of N and P mobility to the environment. Good management of N is based on data from mineralization rates, timing of application to coincide with plant uptake, and N placement close to the plant roots to maximize uptake (Bruulsema and Lanyon, 2000). Release of N from composted poultry litter is slower than from uncomposted poultry litter and poses little environmental risk (Tyson and Cabrera, 1993).

The correlation between P soil test levels and manure applications in different soils is needed to establish the relationship between P applications and eutrophication in nearby water bodies. Since plants need 10 times more available P than algae, excess amounts of P in runoff from fields need to be controlled to maintain ecosystem health (Bruulsema and Lanyon, 2000). Regional com-

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Abbreviations: CPL, composted poultry litter; D, Delmarva; DAA, days after application; FPL, fresh poultry litter; M, Moorefield; MEP, Mehlich 1–extractable phosphorus; WEP, water-extractable phosphorus.

Table 1. Chemical characteristics and particle size analysis of soils used in the incubation study

Soil type	pH	Organic matter	C to N ratio (w/w)	C to P ratio (w/w)	CEC†	Sand	Silt	Clay
		g kg⁻¹			cmol kg⁻¹		· % -	
Sandy loam	4.4	11	13:1	78:1	4.0	77.9	10.6	11.5
Silt loam	5.4	17	9.9:1	495:1	6.1	37.4	34.8	27.7

† Cation exchange capacity.

mittees have been established to develop a P index that combines extractable P levels, erosion potential, and crop selection to guide users in application of P-containing amendments.

Nitrogen mineralization rates of FPL and CPL have been the focus of many studies, but the availability of P in both forms of litter has been less widely studied. The objectives of this study were to determine and compare the mineralization rate of N and availability of P from CPL and FPL incubated with two different soils (sandy loam and silt loam) that are representative of soils where the poultry litter was produced and where it would be land-applied.

MATERIALS AND METHODS

Soils and Litter

Sassafras sandy loam (fine-loamy, siliceous, mesic Typic Hapludult) is a typical soil on the Delmarva Peninsula. Hagerstown silt loam (residuum from limestone; fine, mixed, mesic Typic Hapludalf) is a typical soil in the Piedmont region extending from Maryland into Pennsylvania and West Virginia. The Hagerstown silt loam was collected at the USDA Appalachian Fruit Station in Kearneysville, WV and had not been treated with organic or inorganic fertilizers for the previous 10 yr. The sandy loam was collected from Caroline County, Maryland from the edge of a field that had not received organic or inorganic fertilizer in 2 yr. Both soils were collected from the Ap horizon and were air-dried, sieved to pass through a 2-mm screen, and stored at room temperature (23 ± 1°C) until use. Soil chemical and physical characteristics analysis (Table 1) was performed by the Agricultural Analytical Services Laboratory of the Pennsylvania State University, University Park, PA.

Composted and fresh litters were obtained from Moorefield, WV and from Dorchester County, MD on the Delmarva Peninsula, two major poultry production areas. Throughout this study we refer to "fresh" litter as litter that has no further processing between the chicken house and the field, even though some decomposition of litter probably occurs in the poultry house. Both fresh litters had been removed from poultry houses within one week prior to our collection of them.

The fresh and composted litters obtained from the West Virginia composting site were a mixture of turkey and chicken (broiler) litter. In preparation for composting, the turkey and broiler litter mixture was combined with hardwood chips to adjust the C to N ratio to 60:1. The wood chips were about 5 mm long by 3 mm wide by 1 mm thick. The composting mixture was kept under a roofed structure in windrows that

were turned and mixed for aeration once a week. The moisture level in the mixture was maintained at 50% (on a dry wt basis) for 3 mo with periodic additions of water as necessary.

Both fresh and composted litter obtained from the Delmarva Peninsula was from chicken broiler production. In preparation for composting, the fresh poultry litter was mixed with pine sawdust to adjust the C to N ratio to 60:1 for composting. Composting was conducted in uncovered windrows for 12 mo with monthly turning.

Fresh poultry litter and CPL from both locations were passed through a 2-mm screen and stored in uncovered plastic jars at 5°C until use. Litters were used within 2 wk of collection. Water content was established with 2 g fresh litter dried at 65°C to a constant weight.

Litter samples were characterized (Table 2). Ten grams of litter were combusted in a muffle furnace (400°C) to gravimetrically determine total carbon content (Ben-Dor and Banin, 1989; Davies, 1974). Total N was determined with a LECO (St. Joseph, MI) FP 228 nitrogen determinator. Total P in litter was measured colorimetrically (Murphy and Riley, 1962) after digestion with $HClO_4$ (Adler and Wilcox, 1985).

Soil and Litter Incubation

Fresh and composted poultry litter from both locations was mixed with each soil to obtain a total N content of 0.23 g N kg⁻¹ soil or 302.4 kg N ha⁻¹ (assuming incorporation depth of 10 cm and a bulk density of 1.3 Mg m⁻³). This N recommendation was based on N requirements of fruit trees (454 g of N per fruit tree in a low-density planting with approximately 335 trees ha⁻¹) because of an associated field experiment. The rate of litter to soil applied was 7.92, 11.09, 8.66, and 20.00 g litter kg⁻¹ soil for Moorefield-FPL (M-FPL), Moorefield-CPL (M-CPL), Delmarva-FPL (D-FPL), and Delmarva-CPL (D-CPL), respectively. Phosphorus concentration in the soil–compost mixtures varied due to different P concentrations in the litter. The concentrations of P in the poultry litters were 0.21, 0.16, 0.16, and 0.28 g P kg⁻¹ soil for M-FPL, M-CPL, D-FPL, and D-CPL, respectively. At the N-based rate of application, the amount of P applied in the litter was highest in D-CPL (473.8 kg P ha⁻¹) and lowest in D-FPL and M-CPL (312.5 kg P ha⁻¹). Moorefield-FPL had an initial P concentration of 341.6 kg P ha⁻¹.

Three 1-kg plastic bags of each soil–litter combination and each soil type (no treatment added) were prepared, each representing an experimental unit. The bags were loosely sealed to allow gas exchange and maintained in an incubation chamber at a constant temperature of 25°C. The floor of the chamber was flooded with water to maintain high humidity. A soil-moisture retention curve was established for each soil prior to initiation of the experiment. Each soil–litter mixture was

Table 2. Nutrient and pH analysis in January 2000 of fresh and composted poultry litter from Delmarva Peninsula and Moorefield, WV.

Litter source	Litter treatment	C to N ratio (w/w)	C to P ratio (w/w)	N to P ratio (w/w)	pH
Delmarva	fresh	9:1	12:1	1.4:1.0	
	compost	11:1	6:1	1.0:1.8	7.0
Moorefield	fresh	8:1	9:1	1.0:1.0	
	compost	15:1	25:1	1.7:1.0	6.0–7.0†

Haig, personal communication, 2000.

maintained at -0.01 MPa soil water potential determined by periodic gravimetric measurements. At 0, 14, 30, 60, 90, and 120 d after application (DAA) the soil–litter mixtures were mixed thoroughly, and 100-g subsamples were taken and stored frozen at $-20°C$. Soil controls were sampled at 0 and 120 DAA. The sampling method provided a representative sample from litter that may have heterogeneous quality. These samples were analyzed for ammonium (NH_4^+–N) and nitrate (NO_3^-–N) content and for WEP and MEP as described below. A subsample (1 g) of each sample was used to determine moisture content of the soil.

Nitrogen and Phosphorus Analysis

Ammonium and Nitrate

Five-gram samples of soil and litter were extracted with 40 mL 2 M KCl for 1 h with shaking (Keeney and Nelson, 1982). Following centrifugation, the supernatant was removed and analyzed colorimetrically with a Bran + Luebbe (Buffalo Grove, IL) autoanalyzer. Ammonium and nitrate were measured by the method of Markus et al. (1985).

Mehlich 1–Extractable Phosphorus

Five-gram samples of soil and litter were extracted with 20 mL 0.05 M HCl and 0.025 M H_2SO_4 for 5 min with shaking (Mehlich, 1953). Samples were then centrifuged for 15 min (3500 rpm) and filtered (Whatman [Maidstone, UK] #42). Phosphorus was measured as ortho-P by Method 696 B-82W with a Bran + Luebbe autoanalyzer.

Water-Extractable Phosphorus

One-gram samples of soil and litter were extracted with 25 mL water for 1 h with shaking. The samples were centrifuged at 3500 rpm and filtered through 0.45-μm nylon filters. Phosphorus was analyzed as described previously.

Nitrogen Mineralization Rate

The net N mineralized was calculated by subtracting the initial total of mineralized N (NH_4^+ and NO_3^-) in poultry litter and soil mixtures from the final total mineralized N (NH_4^+ and NO_3^-), divided by the original amount of organic N in the poultry litter and soil mixtures. Initial organic N varied among soil–litter mixtures. There was 182 mg organic N kg^{-1} soil in Delmarva FPL (D-FPL) and Moorefield FPL (M-FPL), 214 mg organic N kg^{-1} soil in Delmarva CPL (D-CPL), and 198 mg organic N kg^{-1} soil in the Moorefield CPL (M-CPL). The totals of NH_4^+ and NO_3^- were adjusted for the amount of NH_4^+ and NO_3^- (N mineralized) in the control soils (Bitzer and Sims, 1988). The resulting N mineralization rates indicate the percentage of organic N mineralized in poultry litter alone after incubation of soil–litter mixtures at $25°C$ for 120 d. The nitrogen mineralization formula is:

$$\% \ N_{min} = (N_f - S_f) - (N_i - S_i)/N_o \times 100$$

where N_{min} = N mineralization in poultry litter; N_f = poultry litter and soil mixture total (mg NH_4^+–N + NO_3^-–N kg^{-1} soil) at final sampling date; N_i = poultry litter and soil mixture total (mg NH_4^+–N + NO_3^-–N kg^{-1} soil) at initial sampling date; S_f = control soil total (mg NH_4^+–N + NO_3^-–N kg^{-1} soil) at final sampling date; S_i = control soil total (mg NH_4^+–N + NO_3^-–N kg^{-1} soil) at initial sampling date; N_o = initial organic N (mg kg^{-1} soil in poultry litter and soil mixture) = soil N added in poultry litter and soil mixture (mg total N kg^{-1}) – N in poultry litter and soil mixture at initial sampling date (mg NH_4^+–N + NO_3^-–N kg^{-1} soil).

Experimental Design and Data Analysis

The experimental design was split plot with litter treatments as main effects and time as the subplot. Each soil was analyzed as a separate experiment with combinations of two main effects (litter source and quality). There were six repeated measurements and three replications of each treatment group (144 experimental units or samples).

Analysis of variance (ANOVA) was conducted to test the effect of the source and compost treatments on total N mineralized, NH_4^+–N, NO_3^-–N, MEP, and WEP with the general linear models procedure of the Statistical Analysis System (SAS Institute, 1990). Orthogonal contrasts were used to determine differences due to litter source and quality within each soil type and time.

RESULTS AND DISCUSSION

Nitrogen Mineralization

Nitrogen mineralization rates differed between M-FPL and D-FPL in both soils (Table 3). The N mineralization rates in sandy loam were 62% in M-FPL and 42% in D-FPL. However, there was no source difference for N mineralization rates for composted litter in sandy loam and silt loam. The N mineralization rates of composted litters averaged 5.5% in sandy loam and silt loam. These rates represent potential N mineralization since conditions were conducive for mineralization during the experiment.

Nitrogen mineralization rates of poultry litter varied widely in previous studies from 21% to approximately 100%, with different sources of fresh litter in sandy loam (Bitzer and Sims 1988). In another study, N mineralization ranged from 20% (dried chicken manure) to 2% (plant residue compost) where the treatments were mixed with silt loam (Hartz et al., 2000). Differences that affect N mineralization rates of fresh litter include uric acid concentration in broiler litter (which depends on diet), number of flocks grown on the litter, and moisture content of the litter (Gordillo and Cabrera, 1997). Moisture content is particularly important because it supports bacterial activity and thus the production of the enzyme urease, which breaks down uric acid molecules to simpler N forms (Cabrera et al., 1993).

The current study agrees with previous research that fresh litter had higher N mineralization rates than composted litter (Hadas and Portnoy, 1994; Paul and Beauchamp, 1994; Gagnon et al., 1998; Hartz et al., 2000). Fresh litter probably contained recently formed organic N that was less stable than N previously incorporated

Table 3. Nitrogen mineralization rates over 120 d from two sources and two qualities of poultry litter mixed with two soils.

Litter source	Litter treatment	Average mineralization rate	
		Sandy loam	Silt loam
		— % of initial organic N —	
Delmarva	fresh	42b†	49b
	compost	7c	5c
Moorefield	fresh	62a	64a
	compost	9c	1c

† Means followed by the same letter within each soil type do not differ at $P \le 0.05$.
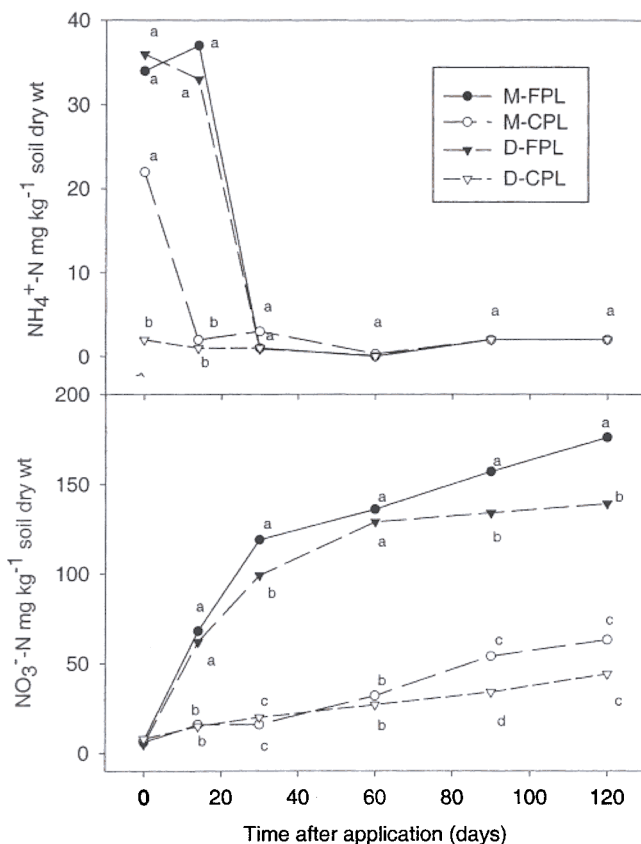
Fig. 1. Nitrate (bottom) and ammonium (top) extracted from sandy loam and treatment mixtures of fresh and composted litter from two sources. Within each sampling day, means with the same letter do not differ at $P \leq 0.05$.
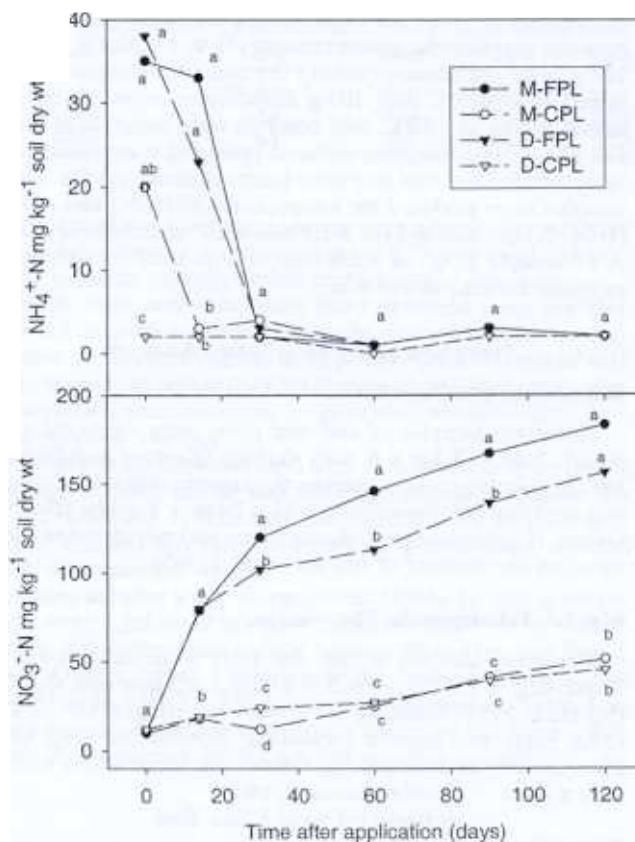

Fig. 2. Nitrate (bottom) and ammonium (top) extracted from silt loam and treatment mixtures of fresh and composted litter from two sources. Within each sampling day, means with the same letter do not differ at $P \leq 0.05$.

into the organic fraction, which is often found in composted litter (Broadbent, 1986).

The C to N ratio was lower in FPL than CPL, which probably contributed to higher N mineralization rates with FPL (Tables 2 and 3). In the current research, C to N ratios of 9:1 (D-FPL) and 8:1 (M-FPL) supported mineralization rates of 42 to 64%, respectively. Nitrogen mineralization rates of soil amended with composted litter were lower, generally less than 10%, even though the C to N ratio of litter treatments ranged from 11:1 to 15:1 (Tables 2 and 3). A significant finding of the current work was that litter source had a large effect on mineralization rates of fresh but not composted poultry litter. Composting yields a more predictable and reliable source of mineralizable N than fresh litter.

Nitrogen and Phosphorus

Ammonium

Concentrations of NH_4^+–N extracted from sandy loam and silt loam treated with FPL were similar regardless of source (Fig. 1 and 2). However, NH_4^+–N from composted litter differed between sources at 0 d after application (DAA). The M-CPL contained 10 times more NH_4^+–N than D-CPL in sandy loam. The NH_4^+–N extracted from soil treated with D-CPL was low at the time of application and remained low for the duration

of the study (1 to 2 mg kg^{-1} soil). It is likely that the 12-mo-long composting process for the D-CPL created a stable end-product that was more resistant to nutrient release than the 3-mo-long process for M-CPL (Henis, 1986). Source differences decreased with increasing time and NH_4^+–N concentrations were similar for composted or fresh litters from 30 to 120 DAA.

The NH_4^+–N extracted from fresh litters in sandy loam and silt loam declined during the first 30 DAA to 1 to 2 mg NH_4^+–N kg^{-1} soil. The NH_4^+–N in composted litter declined to near 0 mg NH_4^+–N kg^{-1} soil by 14 DAA (Fig. 1 and 2). These data support the practice of fresh litter application close to time of crop plant uptake of N to reduce losses due to volatilization and NO_3^-–N movement in the soil (Norton, 1999). Trends of NH_4^+–N extracted over time were similar in both soils, and the amount of NH_4^+–N extracted from both soils was similar.

Nitrate

In FPL, there was a rapid increase in NO_3^-–N during the first 30 DAA (Fig. 1 and 2), coinciding with a rapid drop in NH_4^+–N. The combination of this rapidly mineralized fraction from applied litter and the inorganic N already present in soil may contribute to significant losses of N from the field early in the growing season when crop uptake is low (Bitzer and Sims, 1988).

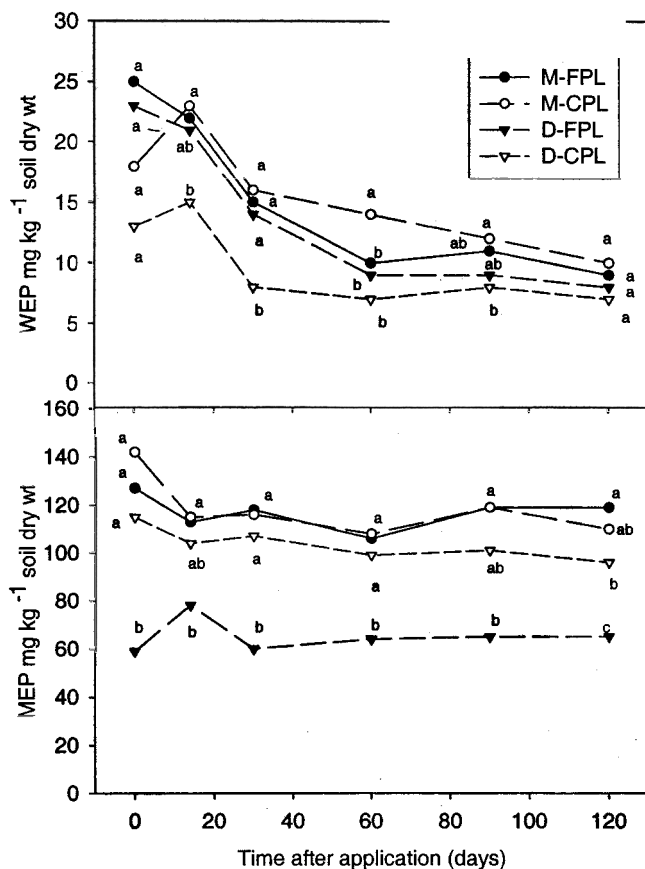In sandy loam and silt loam, NO_3^-–N extracted from

Fig. 3. Mehlich 1–extractable (bottom) and water-extractable (top) phosphorus extracted from sandy loam and treatment mixtures of fresh and composted litter from two sources. Within each sampling day, means with the same letter do not differ at $P \leq 0.05$.
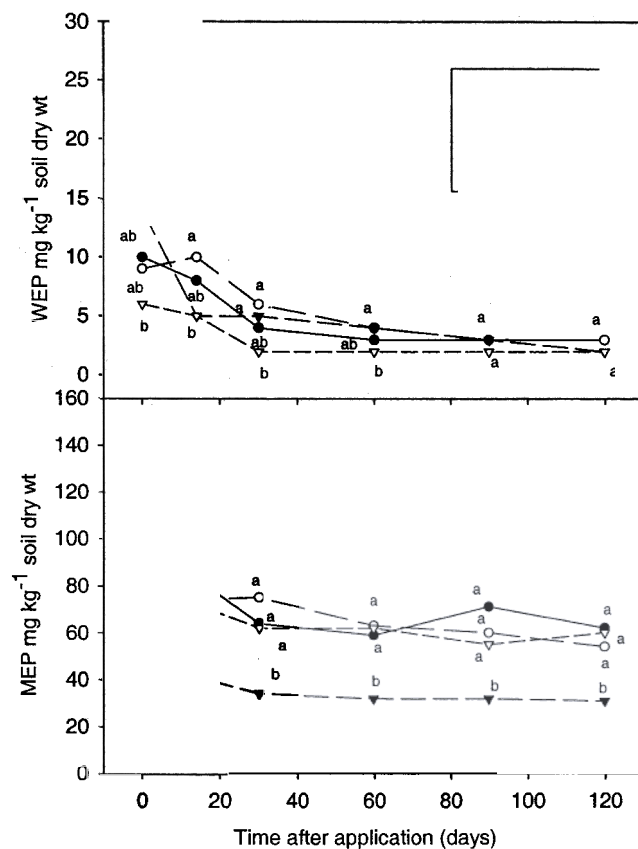

Fig. 4. Mehlich 1–extractable (bottom) and water-extractable (top) phosphorus extracted from silt loam and treatment mixtures of fresh and composted litter from two sources. Within each sampling day, means with the same letter do not differ at $P \leq 0.05$.

soils amended with D-FPL was lower than NO_3^--N extracted from M-FPL (Fig. 1 and 2). In general, there was no significant source effect on NO_3^--N concentration from composted litter in sandy loam or silt loam for the duration of the study.

The NO_3^--N extracted from fresh litter treatments was four to five times higher than NO_3^--N from composted litter treatments at 14 to 120 DAA (Fig. 1 and 2). The high percentage of organic nitrogen as fulvic and humic acids in compost reduces decomposition and transformation of organic N to NO_3^--N (Tan, 1996). Thus, applications of composted poultry litter will provide plant-available N more slowly over time than fresh litter applications.

Water-Extractable Phosphorus

Source did not affect WEP extracted from soil treated with fresh litter (Fig. 3 and 4). In contrast, source significantly affected WEP extracted from soil treated with composted litter for most of the study in both soils. Water-extractable phosphorus extracted from soil treated with D-CPL was lower than WEP extracted from soil treated with M-CPL until 100 to 120 DAA, even though more equivalent kg P ha^{-1} was applied in D-CPL than the other treatments (Table 2 and Fig. 3 and 4). The C to P ratio was 6:1 for D-CPL and 25:1

for M-CPL. The C to P ratio of the litter thus was not an indicator of WEP availability. This contrasts with the usefulness of the C to N ratio for indicating N mineralization.

The difference between sources in WEP extracted from composted litter may be due to the greater "maturity" of the D-CPL. Organic P forms include relatively nonlabile phospholipids, inositols, and fulvic and humic acids, which are more resistant to degradation (Withers and Sharpley, 1995). However, significant concentrations of P were found in runoff from pastures fertilized with CPL (Vervoort et al., 1998). In both soil types WEP declined over time. More WEP was extracted from treatments in sandy loam, possibly due to a lower P adsorption capacity of the sandy loam.

Mehlich 1–Extractable Phosphorus

There was no change in MEP extracted over time in all litter treatments in sandy loam (Fig. 3). In contrast, there was a decrease over time in MEP extracted from M-FPL, D-CPL, and M-CPL mixed with silt loam (Fig. 4). There was no change over time in MEP extracted from D-FPL and silt loam.

Source significantly affected MEP extracted from the fresh litter mixtures of the sandy loam and silt loam on all sampling days (Fig. 3 and 4). Mehlich 1–extractable P extracted from D-FPL treatments was about 50%

the amount extracted from M-FPL treatments for the duration of the study. Potential reasons for lower MEP from D-FPL could be due to the use of additives such as ferrous–ferric hydrogen sulfate or alum litter treatments. These treatments were used routinely on the Delmarva Peninsula in 1997 (Donald Rollyson, Cooperative Extension Nutrient Management Advisor, Dorchester County, personal communication, 1999). Moore et al. (2000) applied alum-treated poultry litter to pastures for 3 yr and found that soluble reactive P concentrations in runoff were 75% lower than normal litter.

Both composted treatments (from two very different processes) provided similar MEP, unlike the differences already discussed in WEP extracted from these treatments. These results highlight the importance of the P extraction technique to estimate P availability. Plant-available P was reflected in MEP extractions and WEP extractions reflected water-soluble, potentially environmentally labile P that may wash readily into surface waters. The results also suggest that compost maturity is a more important consideration to prevent environmental degradation than it is to determine plant-available P (fertilizer value). The more "mature" CPL from Delmarva had consistently less WEP than CPL from Moorefield, with diminished differences toward the end of the experiment.

CONCLUSIONS

The overall goal of this study was to determine N and P availability from different forms of poultry litter (fresh or composted) that could be considered for application to different soils over a larger geographic area than is currently used. Broader use of animal manure can help fulfill nutrient requirements of conventional and organic crops, but excess nutrients (particularly N and P) can degrade aquatic ecosystems.

Nitrogen mineralization rates were lower for composted poultry litter than for fresh litter. The two different composting procedures affected initial availability of NH_4–N without affecting overall N mineralization rates. However, source of fresh litter significantly affected N mineralization rates. Growers must know the N compounds that are available in litter as well as past treatments, which affect N mineralization of a litter to improve the accuracy of litter application rates based on nitrogen crop requirements. In general, longer composting reduced the amount of extractable N.

It seems likely that the shorter composting process at Moorefield created a P dynamic that was more similar to fresh litter than the more mature Delmarva compost. Phosphorus availability to plants and the environment from Moorefield composted litter was equal to, if not greater than, that from fresh litter. Further research that includes organic farming practices and the use of composted manures will be needed to verify the movement of P from agricultural land with applications of composted poultry litter.

Phosphorus extractions were affected by characteristics of the two soil types. The extraction of plant-available P (MEP) remained at a steady state in the sandy

loam, but environmentally labile P (WEP) declined over time. These results were related to initial high soil levels of P rather than extractable P in the treatments. The silt loam fixed and/or adsorbed more P than the other soils as shown by lower amounts extracted of WEP and MEP from all treatments. These variations suggest that soil type and P fertility values should be considered in relationship to P availability to the environment and for plant availability.

Composting did not have as consistent an effect on P as it did on N. Results indicate that application of CPL solely based on N requirements may result in significant P inputs to the environment.

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