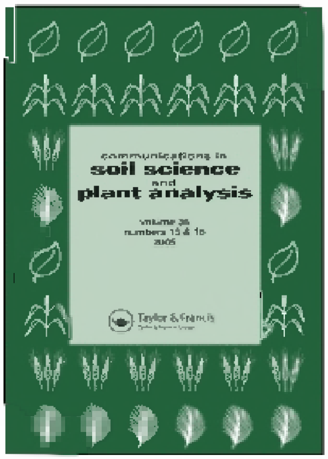

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Changes in Soil Test Phosphorus from Broiler Litter Additions

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Changes in Soil Test Phosphorus from Broiler Litter Additions

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Abstract: Nutrient surpluses on the Delmarva Peninsula have led to a continual accumulation of soil test phosphorus (STP), a potential source for transport of phosphorus (P) to surface waters. This article examines the effects of initial soil test P concentrations and broiler litter additions on STP accumulation. Broiler litter (BL) was applied at rates of 0, 2.5, 5, 7.5, and 10 g kg^{-1} (dry weight) to three soils: an Evesboro sandy loam (Mesic, coated Typic Quartzipsamments), a Pocomoke sandy loam (coarse-loamy, siliceous, thermic typic Umbraquults), and a Matapeake silt loam (fine-silty, mixed, semiactive, mesic Typic Hapludults). Soils and BL were incubated for 16 weeks with subsamples analyzed after 4 and 16 weeks. There was a linear increase in STP (Mehlich-3), water-soluble P (WS-P), iron-oxide strip-extractable P (FeO-P), and Mehlich-3 phosphorus saturation ratio (M3-PSR) with broiler litter additions. Regression analysis indicated few significant differences in STP response to added BL between soils within the same soil group having different initial STP levels. Correlation analysis and stepwise regression indicated that increases in WS-P and FeO-P from added BL were more closely related to the degree of P saturation of the soil rather than traditional STP measurements. Therefore, decisions regarding manure placement within a watershed should be based on the potential P sorption capacity of the soil as well as potential P transport pathways when the goal is the reduction of P transfer to waterbodies.

Keywords: Phosphorus, broiler litter, poultry, p-saturation

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INTRODUCTION

Agriculture on the Delmarva Peninsula is dominated by a large and geographically concentrated poultry industry that is vital to the overall economy of the region. Poultry production on Delmarva is concentrated in eight counties located in close proximity to each other (Sussex, DE; Caroline, Talbot, Dorchester, Somerset, Wicomico, and Worcester, MD; and Accomack, VA). Seven of the eight counties have less than 40,000 ha of cropland; Sussex County, Delaware, has the largest agricultural land base (~100,000 ha) and the largest annual production of broilers (~220 million per year). Nutrient imports in the form of feed, when combined with fertilizer nutrient use, have generated regional and farm-scale nutrient surpluses for many years and contribute to an agricultural setting that is prone to nonpoint source nutrient pollution of surface and shallow ground waters (Cabrera and Sims 2000; Sims and Coale 2002).

One of the nutrient management issues of greatest concern for water quality in this region has been the buildup of soil phosphorus (P) concentrations to values well above those needed for optimum crop production. Phosphorus losses to water by erosion, surface runoff, and subsurface drainage from agricultural fields have been implicated in the degradation of water quality in the Chesapeake Bay, its tributaries, and other surface waters in the Mid-Atlantic region (e.g., Delaware's Inland Bays) (Sims and Coale 2002; Ritter 1992). Most recently, nonpoint P pollution from agriculture has been identified as a cause of the water quality and human health problems associated with the accelerated growth of algae, nuisance seaweed blooms, and toxin-producing dinoflagellates (Burkholder et al. 1997). Because of these concerns, total maximum daily loads (TMDLs) have been established for a number of surface waters in Delaware and state and federal actions, such as the Delaware Nutrient Management Law of 1999 and the Code 590 nutrient management standard of USDA-NRCS, have been taken to limit the amount of P that can be applied to cropland in manures and fertilizers.

A major focus of all of these efforts to reduce agricultural nonpoint P pollution is the need for improved P management strategies for the broiler litters (BL) produced by the region's large and geographically concentrated poultry industry. Broiler litters have unfavorable nitrogen (N) to P ratios relative to most grain crops, resulting in overapplication of P when manures are applied to meet crop N requirements, the long-standing agronomic practice in this region. Because of this, 92% of the agricultural soils tested in the poultry-producing region of Delaware are now considered "optimum" or "excessive" in P relative to crop needs [agronomic STP (Mehlich 3 P) criteria used by the University of Delaware Soil Testing Program: *low* (<25 mg P kg^{-1}), *medium* (26–50 mg P kg^{-1}), *optimum* (51–100 mg P kg^{-1}), and *excessive* (>100 mg P kg^{-1})]. Recent studies show that, in addition to the potential for substantial P losses by erosion, many soils are sufficiently saturated with P to be of concern for soluble P transfer in leaching and runoff (Pautler and Sims 2000; Sims et al. 2002).

Because of the lack of alternative uses, land application is likely to continue to be the main end use for BL, despite the fact that many soils in this region do not need BL-P to attain optimum crop yields. Given this, there is a need for a better understanding of the potential environmental impacts of applying BL-P to soils that vary in soil P and the physicochemical properties important to P retention and release. Specifically, there is a need to determine whether the relationship between the current soil P status [STP, water-soluble P (WS-P), and soil P saturation] and BL-P additions is linear or curvilinear. Many studies have shown that additions of BL increase STP, which in turn increase total and dissolved P in runoff (Lucero et al. 1995; Mozaffari and Sims 1996; Shepherd and Withers 1999; Cox and Hendricks 2000). There has been little work that directly investigates how initial soil test P affects the relationship between the amount of manure P added and the resultant change in soil P. Pote et al. (2003) investigated the effects of initial soil P level on water-extractable P from BL applications. They found that application of BL to soils with higher initial STP levels did cause a greater increase in soil P than when BL was applied to soils with lower STP, although the relationship was quadratic with the slope of the curve becoming less steep as initial soil P levels increased. Griffin et al. (2003) investigated the effects of initial STP level on changes in extractable P with manure additions. In this study, the addition of BL to soils with varying initial STP levels did not necessarily produce greater increases in soil-extractable P from soils with higher initial STP levels.

It is believed that the nature of this relationship has implications for watershed scale manure P management. If the relationship between manure P application and soil P is linear, then the risk of WS-P and biologically-available P (BAP) transfer from soil to water for fields in the same soil test P category increases consistently with each additional manure application, assuming the hydrological conditions that control transport are the same for these fields. In this case, there is no reason to restrict manure applications based on initial STP values alone because, for soils with similar runoff and erosion potentials, the addition of manure P will increase the amount of P susceptible to transport equally, regardless of initial STP value. However, if this relationship is curvilinear and soil WS-P and BAP increase more when initial STP concentrations are higher, then the risk of P loss increases at a greater rate with each application of manure P for soils in the "high" or "excessive" STP categories than for soils in the "optimum" and lower STP categories, again assuming the transport processes are similar. In this situation, manure P should be preferentially directed toward fields with lower STP values because the incremental risk of P loss associated with manure applications will be lower for these fields. Consequently, the objectives in this study were to characterize the nature of the relationship between initial STP concentrations, broiler litter phosphorus (BL-P) application rate, and resultant increases in STP, FeO-P, WS-P, and soil P saturation for soils typical of the Mid-Atlantic United States.

MATERIALS AND METHODS

Soil Collection and Characterization

The soils used in this research came from three separate farms and are representative of major agricultural soil series in Delaware and the Mid-Atlantic United States. An Evesboro soil (Ev) and a Pocomoke soil (Pm) were obtained from Sussex county, Delaware, site of the poultry industry, whereas a Matapeake soil (Me) was obtained from a farm in New Castle County, a county with little animal production but where there is interest in transporting BL from southern Delaware. The Ev and Pm soils are located in the coastal plain and, respectively, comprise 14% and 8% of the soil area in the state and 27% and 11% of the soil area in Sussex County. The Me soil is found in the upper coastal plain and accounts for about 5% of the soil area in the state but about 25% of the soil area in New Castle County.

On each farm, four different soil samples were collected from different locations within each soil series (determined by the Natural Resource Conservation Service Soil Survey maps for Sussex and New Castle County) to represent STP concentrations ranging from "low" to "excessive" according to the agronomic STP (Mehlich-3 P) criteria used by the University of Delaware Soil Testing Program. At each site, bulk soils were collected from the surface horizon (0–15 cm), air dried, and sieved (<2 mm) prior to analysis and subsequent use in the incubation study described below.

Soil pH (1:1 soil to solution ratio), organic matter [(OM) by loss on ignition], and particle size analysis were measured by standard methods of the University of Delaware Soil Testing Program (UDSTP) (Sims and Heckendorn 1991). Each soil was also analyzed for P as follows:

1. Water-soluble P (WS-P): 1:10 soil to deionized water, 1-h reaction time, filtration through a 0.45 μm Millipore membrane
2. Iron-oxide strip-extractable P (FeO-P, an estimate of easily desorbable P): 1:40 soil to 0.01 *M* $CaCl_2$ + iron-oxide coated filter paper strip, 16-h reaction time, dissolving Fe and P from the filter paper strip for 1 h in 1 *M* H_2SO_4 (Chardon et al. 1996).
3. Mehlich-3-extractable P (M3-P): 1:10 soil to 0.2 *M* CH_3COOH + 0.25 *M* NH_4NO_3 + 0.015 *M* NH_4F + 0.13 *M* HNO_3 + 0.001 *M* EDTA, 5-min reaction time, filtration with Whatman No. 42 paper (Mehlich 1984)
4. Oxalate-extractable P (P_{ox}): 1:40 soil to 0.2 *M* acid ammonium oxalate (pH 3), 2-h reaction time (in darkness) (McKeague et al. 1971).

All extracts were analyzed for P by inductively coupled plasma-atomic emission spectroscopy (ICP-AES); Mehlich-3 and oxalate extracts were also analyzed for iron (Fe) and aluminum (Al). The M3-PSR (P saturation ratio using Mehlich-3-extractable P, Fe, and Al) was then calculated as follows (values of P, Fe, and Al are in mmol kg^{-1}) (Sims et al. 2002):

$$M3 - \mathrm{PSR} = [\mathrm{P_{M3}} \div (\mathrm{Al_{M3}} + \mathrm{Fe_{M3}})]$$

Broiler Litter Collection and Characterization

Broiler litter [(BL) mixture of poultry manure and sawdust] was collected from a cooperating farm in Delaware, dried at 60°C, ground, sieved (<0.8 mm), and analyzed for (1) total P by the USEPA 3050 acid-peroxide digestion (USEPA 1986); (2) WS-P and water-soluble Ca (WS-Ca), as described above; (3) pH (USEPA 1986); and (4) total C and N by combustion in an LECO (St. Joseph, MI) CNS analyzer. Total P and WS-P in the BL were 21 and 2.7 g kg^{-1}, respectively. The pH of the BL was 7.2, the C:N ratio was 8.5, and water-soluble calcium (WS-Ca) and total Ca were 38.8 mg kg^{-1} and 26.7 g kg^{-1}, respectively. These analyses confirm that the litter was representative of the typical BL produced in Delaware (Collins et al. 1999).

Incubation Study

Broiler litter was incorporated (in triplicate) into 100 g of 12 soils (three soil series at four different initial STP values) at five rates (0, 2.5, 5, 7.5, and 10 g kg^{-1}; dry weight basis, equivalent to 0, 5.4, 12, 16.8, and 22.4 Mg ha^{-1} and 113, 252, 352, and 470 kg BL-P ha^{-1}). The amended and control soils (no BL) were adjusted to 20% moisture content by using deionized water and incubated in polyethylene containers for 16 weeks at 25°C, with complete randomization. Two holes were cut in the tops of the incubation containers to prevent anaerobic conditions during the incubation. Soil moisture content was maintained by adding deionized water at weekly intervals. Subsamples (~5 g) from each incubating mixture were removed, air dried, and analyzed for M3-P, WS-P, FeO-P, and M3-PSR after 4 and 16 weeks by using the methods described above.

Statistical Analysis

Linear regression analyses were performed by using the PROC REG procedure in SAS, whereas correlations between data were performed by using PROC CORR (SAS Institute 1989). Comparisons of slopes between regression equations were performed with PROC REG using indicator variables (SAS Institute 2000). Relationships significant at the 0.05, 0.01, and 0.001 probability levels are marked in the text as *, **, ***, respectively.

RESULTS

Soil Analysis

The Ev and Pm soils were predominantly sandy (59–89%) with fairly low silt (0–22%) and clay (7–19%) contents (Table 1). In contrast to this, the Me soil had sand, silt, and clay contents ranging from 27 to 53%, 24 to 54%, and 19 to 23%, respectively. The Pm soils, which are poorly drained, had the highest OM content (28–45 g kg^{-1}), whereas the Ev and Me soils had OM contents ranging from 9 to 26 g kg^{-1} and 19 to 27 g kg^{-1}, respectively. These soils were slightly acidic with pH ranging from 5.0 to 6.4. Oxalate-extractable Al (Al_{ox}) and Fe (Fe_{ox}) ranged from 14 to 71 mmol kg^{-1} and 4–17 mmol kg^{-1}, respectively. On average, the Pm soil had the highest Al_{ox} concentration, and the Me had the highest Fe_{ox} concentration. Mehlich-3-extractable Al and Fe (Al_{M3} and Fe_{M3}) followed the same trends as oxalate Al and Fe, ranging from 18 to 48 mmol kg^{-1} and 2 to 5 mmol kg^{-1}, respectively.

There was a wide range in soil test P concentrations of the soils studied (Table 2). Mehlich-3-extractable P ranged from 17 to 372 mg kg^{-1}, 39 to 518 mg kg^{-1}, and 23 to 391 mg kg^{-1} for the Ev, Pm, and Me soils, respectively. Water-soluble P ranged from less than1–14 mg kg^{-1} for the Ev and Pm soils and from 1–45 mg kg^{-1} in the Me soil. Iron-oxide strip P ranged from 7 to 64 mg kg^{-1}, 0.9 to 63 mg kg^{-1}, and 9 to 160 mg kg^{-1} for the Ev, Pm, and Me soils, respectively. Oxalate-extractable P in the soils ranged from 38 to 669 mg kg^{-1}. The Mehlich-3 phosphorus saturation ratios had values ranging from 0.03 to 0.44.

Regression Analysis

The relationships between increases in soil test P with addition of BL were examined by linear regression analysis. There was a positive linear relationship between soil test P measurements (M3-P, M3-PSR, WS-P, FeO-P) and BL additions for all soils (Figures 1–4, week 16 data shown). There were changes in soil test P measurements between the 4- and 16-week sampling dates. The amount of WSP and FeO-P extracted at 16 weeks was less than that extracted at 4 weeks for the majority of the soils (Figure 5). This decrease in extractable P is likely due to the formation of more stable P complexes over time, therefore decreasing the solubility of P in these soils. There was little change in both M3-P and M3-PSR between the two sampling dates (Figure 6). Soils at higher M3-P values had slightly higher M3-P concentrations at the 16-weeks sampling date than at the 4-weeks sampling date. Because of the variability in soil test P availability over time, the 16-weeks sampling date information was used in further analyses.

The slopes of the regression equations for each soil at each initial soil test P concentration were determined and compared (within soils, $\alpha = 0.01$) to

Table 1. Selected chemical and physical properties of the 12 soils used in the incubation study

Soil and STP category	pH	OM ($g\ kg^{-1}$)	Sand (%)	Silt (%)	Clay (%)	Al_{ox} ($mmol\ kg^{-1}$)	Fe_{ox} ($mmol\ kg^{-1}$)	Al_{M3} ($mmol\ kg^{-1}$)	Fe_{M3} ($mmol\ kg^{-1}$)
Evesboro									
Ev-1 Low	5.5	12	87	6	7	14	5	20	2
Ev-2 Excessive	5.9	25	75	12	13	35	9	33	3
Ev-3 Excessive	6.4	9	85	8	7	14	4	18	2
Ev-4 Excessive	5.8	26	59	22	19	41	17	33	5
Pocomoke									
Pm-1 Medium	5.0	32	89	0	11	44	4	40	2
Pm-2 Excessive	5.1	45	77	12	11	71	4	48	2
Pm-3 Excessive	5.6	28	83	4	13	59	11	45	3
Pm-4 Excessive	5.8	30	83	0	17	48	6	37	2
Matapeake									
Me-1 Low	5.9	27	27	54	19	29	13	27	2
Me-2 Optimum	5.6	19	31	48	21	35	13	31	2
Me-3 Excessive	5.7	23	41	40	19	29	14	28	3
Me-4 Excessive	5.7	25	53	24	23	34	15	30	3

Table 2. Phosphorus properties of the 12 soils used in the incubation study

Soil and STP category	M3-P (mg kg^{-1})	WS-P (mg kg^{-1})	FeO-P (mg kg^{-1})	P_{ox} (mg kg^{-1})	M3-PSR
Evesboro					
Ev-1 Low	17	0.7	7	38	0.02
Ev-2 Excessive	128	4	30	218	0.11
Ev-3 Excessive	200	12	52	259	0.33
Ev-4 Excessive	372	14	64	616	0.32
Pocomoke					
Pm-1 Medium	39	0.1	0.9	65	0.03
Pm-2 Excessive	223	3	26	375	0.15
Pm-3 Excessive	260	5	33	399	0.17
Pm-4 Excessive	518	14	63	669	0.42
Matapeake					
Me-1 Low	23	1	9	134	0.03
Me-2 Optimum	89	4	26	228	0.09
Me-3 Excessive	268	25	100	478	0.28
Me-4 Excessive	391	45	160	602	0.38

evaluate the sensitivity of changes in STP to BL additions (Table 3, week 16 data shown). The relationships between M3-P and BL additions on all soils were positively correlated ($r^2 = 0.36^{*}-0.98^{***}$), with slopes ranging from 0.13 to 0.30. The greatest increase in M3-P from BL additions to the Ev soil was in Ev-1 and Ev-3, with the least response in the other two Ev soils. In the Pm soil, the greatest increase in M3-P was in Pm-1 and Pm-3, with the lowest response in Pm-4. In the Me soil, there were no significant differences among the soils. There was a significant positive relationship between M3-PSR and BL additions ($r^2 = 0.12-0.98^{***}$) on all except one soil (Me-4), with slopes ranging from 0.00007 to 0.00042. The only significant differences within the soil groups were in Ev-1 and Ev-3, which had a greater response than the other two soils in the group, and Pm-1, which had the greatest increase in M3-PSR within that soil group.

The change in FeO-P with BL additions was positively correlated on all soils ($r^2 = 0.47^{**}-0.93^{***}$) with slopes ranging from 0.033 to 0.11. The only significant differences within the soil groups were for Ev-3 and Pm-4, which had a greater response than the other soils within their groups. The increase in WS-P with BL additions was significant in all except one soil (Me-4) ($r^2 = 0.07-0.99^{***}$), with slopes ranging from 0.002 to 0.042. The greatest response within soil groups was Ev-3 and Ev-4; Pm-4; and Me-2 and Me-3.

The slopes of soil test P measurements (M3-P, M3-PSR, FeO-P, and WS-P) vs. BL-P for those regressions where the relationship was significant were analyzed to determine which soil parameters would best predict

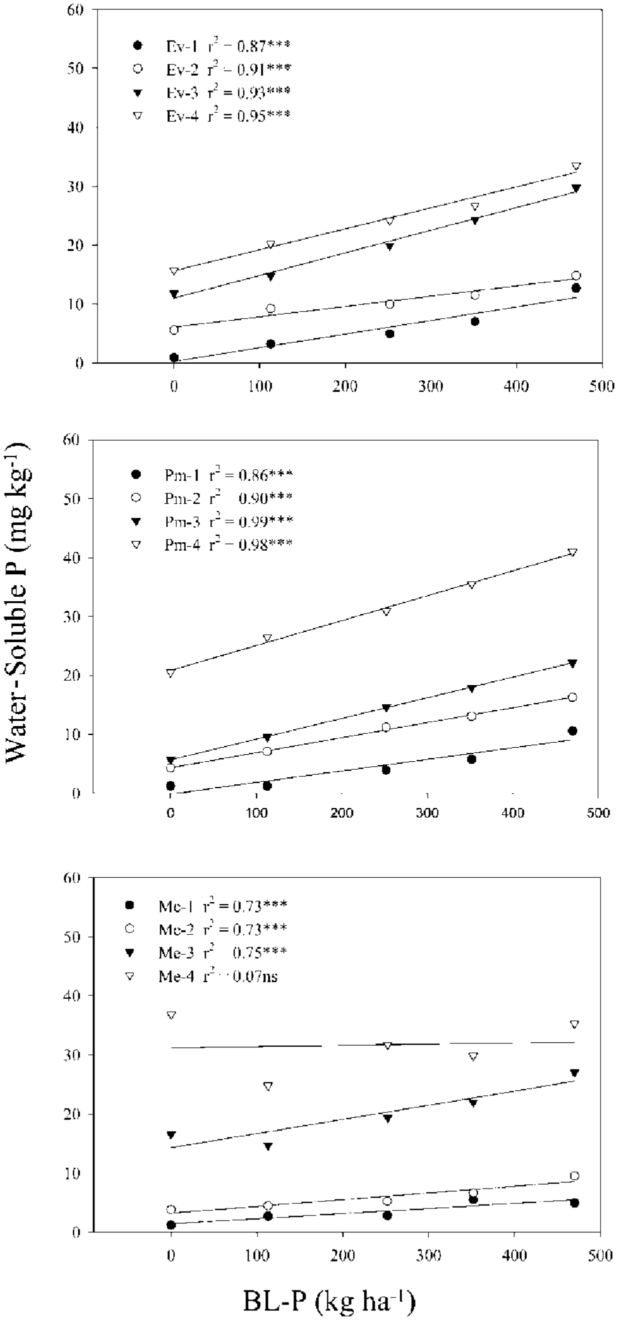

Figure 1. Relationship between broiler litter P additions and water-soluble P on the Evesboro, Pocomoke, and Matapeake soils. Data are for the 16-week sampling date of the incubation study.

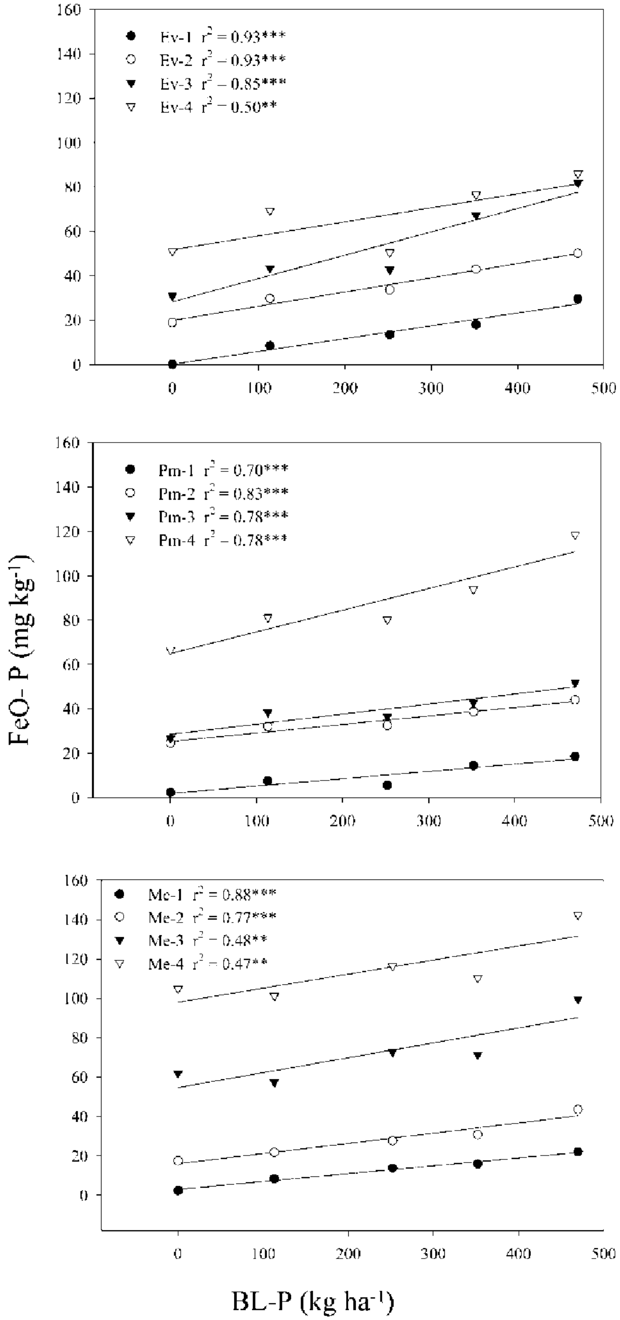

Figure 2. Relationship between broiler litter P additions and iron strip-extractable P on the Evesboro, Pocomoke, and Matapeake soils. Data are for the 16-week sampling date of the incubation study.

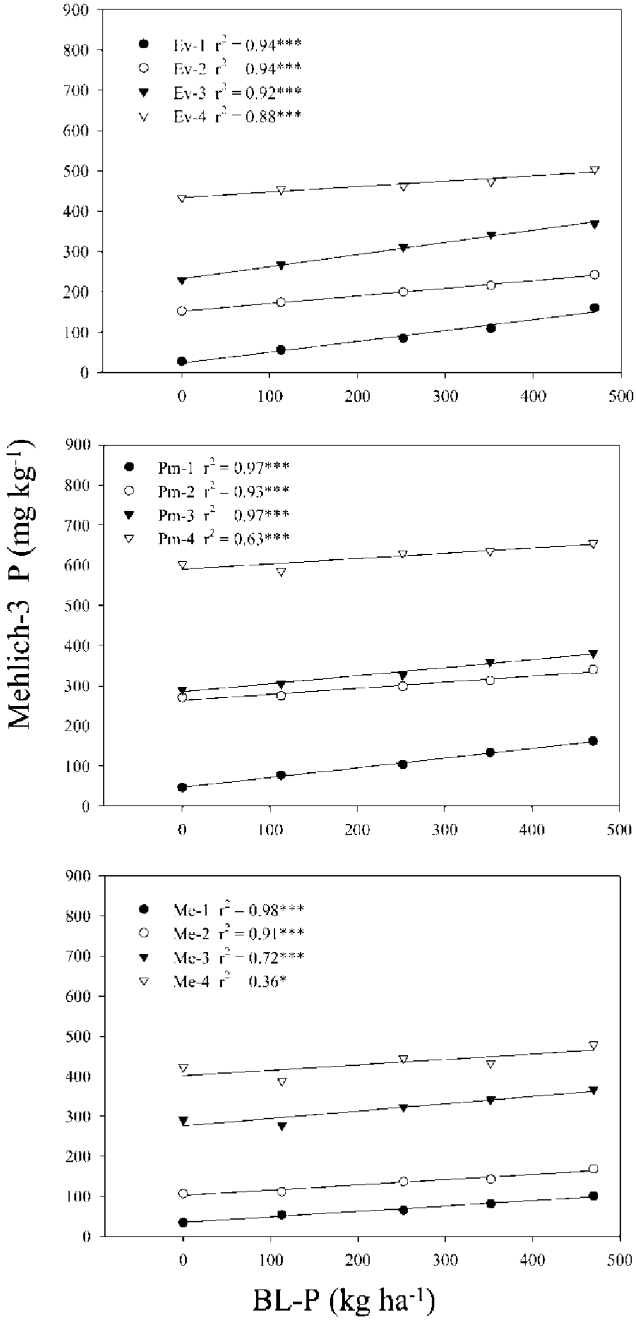

Figure 3. Relationship between broiler litter P additions and Mehlich-3 P on the Evesboro, Pocomoke, and Matapeake soils. Data are for the 16-week sampling date of the incubation study.

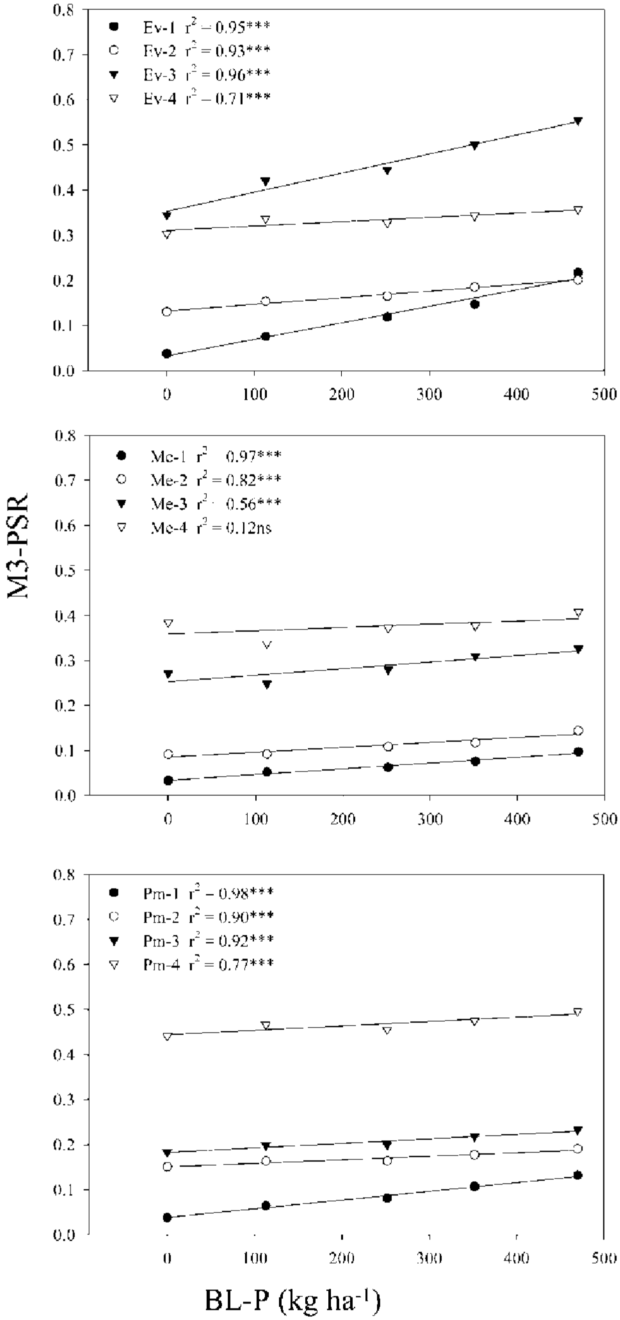

Figure 4. Relationship between broiler litter P additions and Mehlich-3 P saturation ratio on the Evesboro, Pocomoke, and Matapeake soils. Data are for the 16-week sampling date of the incubation study.

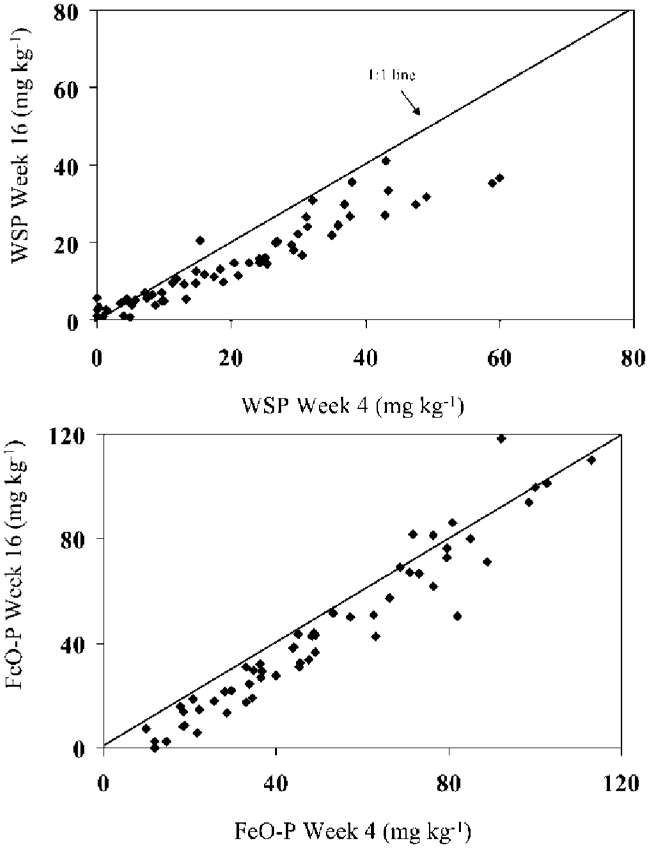

Figure 5. Relationship between extractable water-soluble and Fe strip P at the 4- and 16-week sampling dates.

increases in soil test P from BL additions. The M3-PSR of the initial soils (a measurement of soil P saturation) was highly correlated (Pearson correlation, $\alpha = 0.05$) to increases in both WS-P ($r = 0.83^{**}$) and FeO-P ($r = 0.76^{**}$) from BL additions. There was no significant correlation between measured soil parameters and increases in M3-P, whereas the increase in M3-PSR from BL additions was only correlated with the % silt (r = 0.65*).

Forward stepwise regressions ($\alpha = 0.05$) were performed for the slopes of WS-P and FeO-P vs. BL-P and all independent variables measured on the 12 soils (Table 4). The stepwise regressions selected the independent variables M3-PSR and Al_{M3} as being most important in predicting changes in WSP from BL additions. The variables M3-PSR, WS-P, % silt, and pH were selected for predicting changes in FeO-P from BL additions. The regression did select the variable % silt for predicting changes in M3-PSR,

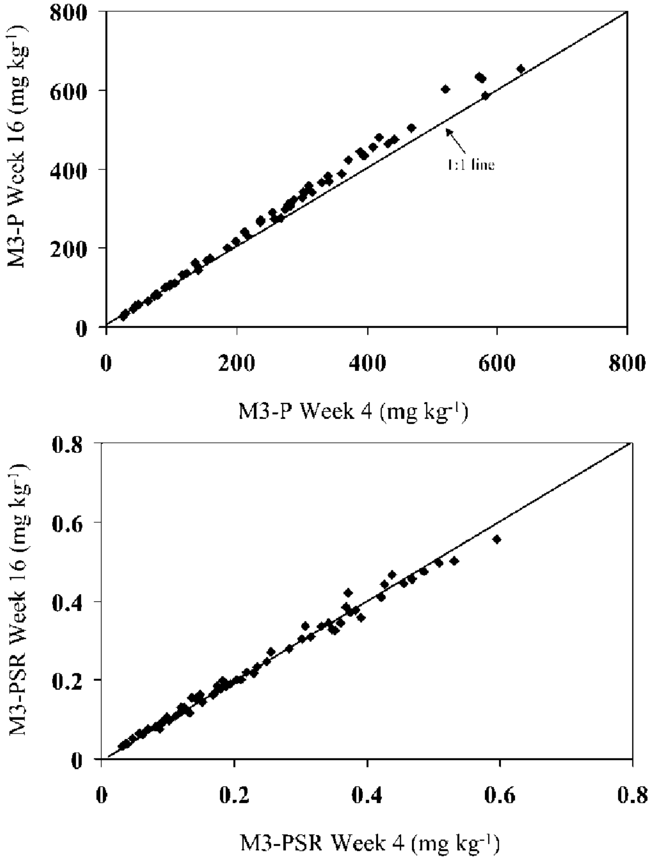

Figure 6. Relationship between Mehlich-3 P and Mehlich-3 P saturation ratio at the 4- and 16-week sampling dates.

but the relationship between the variables is poor. The regressions were rerun ($\alpha = 0.01$) and M3-PSR was the only variable selected for predicting changes in WS-P and FeO-P from BL additions, but the R^2 values dropped from 0.93*** to 0.66*** for WS-P and from 0.92*** to 0.53** for FeO-P. For comparison, forward stepwise regression ($\alpha = 0.05$) of the slopes of WS-P and FeO-P vs. BL using M3-P as the independent variable were performed to compare how well the two soil tests predicted these slope changes. The models had R^2 values of 0.42* and 0.33*, respectively, which indicate that M3-P is a poorer predictor of changes in WS-P and FeO-P with BL additions. Figure 7 shows a plot of the slopes (WS-P and FeO-P vs. BL-P) against M3-PSR, indicating that as a soil becomes increasingly saturated with P, the increase in extractable P becomes greater.

Table 3. Slopes of regression equations between the rate of broiler litter P added and forms of soil P in three Delaware soils. Slopes are based on Results from the 16-week sampling date

	Slope of BL-P vs.			
Soil	Mehlich 3	Mehlich-3 PSR	FeO-P	WS-P
Ev-1	0.27 a[a]	0.00037 a	0.058 b	0.023 b
Ev-2	0.19 b	0.00015 b	0.064 b	0.017 b
Ev-3	0.30 a	0.00042 a	0.110 a	0.039 a
Ev-4	0.14 b	0.00010 b	0.063 b	0.036 a
Pm-1	0.24 a	0.00019 a	0.033 b	0.020 c
Pm-2	0.15 bc	0.00008 b	0.038 b	0.025 c
Pm-3	0.20 ab	0.00010 b	0.045 b	0.035 b
Pm-4	0.13 c	0.00010 b	0.098 a	0.042 a
Me-1	0.14 a	0.00013 a	0.040 a	0.009 b
Me-2	0.13 a	0.00011 a	0.052 a	0.011 ab
Me-3	0.18 a	0.00015 a	0.080 a	0.024 a
Me-4	0.14 a	0.00007 a	0.072 a	0.002 b

[a]Mean values of slopes within a given column and soil group followed by the same letter are not different ($p < 0.01$).

DISCUSSION

A positive linear relationship between BL additions and soil test P measurements has been demonstrated in previous studies. Mozaffari and Sims (1996) found a linear increase in Mehlich-1 P (M1-P) from BL additions on both Ev and Pm soils. When their data are plotted by using the units kg BL-P ha^{-1}, the slope of BL-P vs. M1-P is 0.33 and 0.30 for the Ev and Pm soils, respectively, similar to those found in this study. Lucero et al. (1995) investigated the increase in M3-P on a Starr clay loam with five rates of BL.

Table 4. Stepwise regression independent variables selected for the relationship between the amount of BL-P added and the change in WS-P, FeO-P and M3-PSR

Slope of BL-P vs.[a]	Regression parameters	$R^{2\,b}$
WS-P	M3-PSR, M3-Al	0.93***
FeO-P	M3-PSR, WSP, % silt, pH	0.92***
M3-PSR	% silt	0.36*

[a]Abbreviation as in Table 1.
[b]Significant at $*p < 0.05$, $***p < 0.001$.

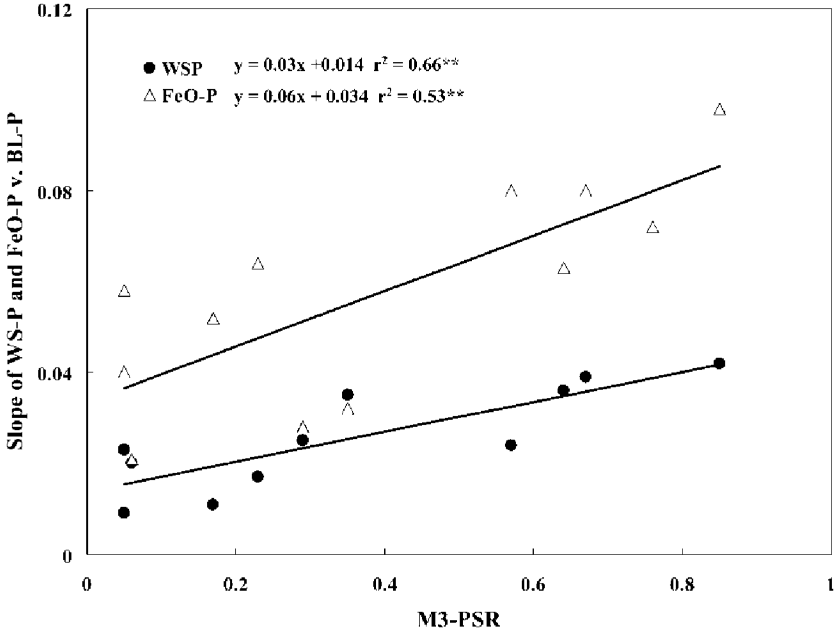

Figure 7. Relationship between the slopes of broiler litter P vs. water-soluble P and iron strip P and the Mehlich-3 P saturation ratio for the soils with significant linear correlations.

The calculated increase in M3-P from BL application in the topsoil (0–5 cm) had a linear relationship with a slope of 0.17, similar to those of the Me soils (0.15) used in this experiment. Cox and Hendricks (2000) saw a similar relationship with soils in the Atlantic Coastal Plain and Piedmont region of North Carolina. The calculated increases in M3-P due to additions of BL were linear, with slopes of 0.19 and 0.10 for the coastal plain and piedmont soils 18 months after BL application. Shepherd and Withers (1999) examined the effects of BL application on the soil P status and profile distribution in a sandy soil. There was a linear increase in WS-P with BL addition with a slope of 0.04, similar to that in this study where there was an average slope of 0.03 for the sandy soils.

Griffin et al. (2003) investigated the impacts of manure (beef, dairy, poultry, and swine) and KH_2PO_4 additions on changes in soil phosphorus. In all cases, the extractable soil P was a linear function of P application rate. When KH_2PO_4 was applied, there was an increase in the response of extractable soil P with increasing initial STP level, which they attributed to a higher P saturation in these soils. The effect of initial STP on the change in extractable P from BL additions did not follow the trends seen with KH_2PO_4 additions. The increase in M3-P and Morgan-P from BL additions did show the greatest increase in the soil with the highest initial STP value, although the increases in M3-P in the medium and low soils were not significantly different. When the increase in anion exchange membrane P was examined, the trend in response to BL additions was low > medium > high.

For the soils examined in this study, the increase in soil test P due to BL additions were not necessarily larger on soils having the highest initial soil test P values. Stepwise regression indicated that the variable most important in controlling changes in WS-P and FeO-P concentrations due to BL additions was M3-PSR. This soil measurement assesses the degree to which a soil is already saturated with P and, therefore, the potential for that soil to retain added P. The M3-PSR, an environmental assessment of the soils potential to retain added P, can be easily calculated with a soil test routinely used in soil testing laboratories in the region.

The degree of P saturation is also a good predictor of the amount of soluble P lost both in runoff and leaching. Sims et al. (2002) determined that the dissolved reactive P in runoff from soils (which included soils used in this study) via a simulated rainfall experiment was most accurately predicted by use of M3-PSR as opposed to using M3-P alone. Maguire and Sims (2002a, 2002b) found that M3-PSR was also a good predictor of leachate P concentrations from soil columns collected from the same area as those used in this study.

CONCLUSIONS

In summary, the nature of the increase in soil test P from BL additions was not directly related to the initial STP value of the soils. When BL was added to these soils, the response in measured STP (M3-P, M3-PSR, WS-P, and FeO-P) was not necessarily greatest on soils with the highest initial STP concentrations. The increase in soil test P from BL additions was better predicted by using the phosphorus saturation ratio of the soil instead of initial soil test P concentrations. In addition, the relationships between added BL and changes in STP were linear, suggesting that STP increases consistently with each additional manure application. There was also a linear relationship between the increase in STP from BL additions and the degree of P saturation of the soil. This relationship illustrates that the effect of BL additions on changes in STP increases as the degree of P saturation of a soil increases. This finding suggests that when conditions affecting P transport are very similar, soils with higher initial STP may not pose a greater risk of P loss from BL applications than soils with lower initial STP concentrations. Therefore, there may be little reason to restrict manure applications simply based on initial STP in areas with similar slopes, leaching and drainage characteristics, and soil/crop management practices that affect P transport (e.g., method and timing of manure application). These data suggest that other soil properties, such as the degree to which a soil is already saturated with P, will have a greater influence on the amount of extractable P following BL application than initial STP. Soil tests that predict the degree of P saturation may be better environmental soil test indicators for identifying sites suitable for BL application than traditional, agronomic soil test P measurements.

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