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Research Article

Soil Test Phosphorus Recovery from Livestock Manures Compared with Inorganic Fertilizer in Soil Incubations

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This paper compared dairy and hen manure P recovery relative to fertilizer P recovery for two Nova Scotia soils with different antecedent soil test P (STP), incubated for 5, 15, 30, 60, and 110 days. Fertilizer equivalence of manure P was expressed as P recovery ratio in percentage points (%PRR). Repeated measures analysis with soil pH covariate revealed: (1) manure %PRR averaged 72% (low-STP soil) and 80% (medium-STP soil), (2) there were no significant differences in %PRR between dairy and hen manure, and (3) manure %PRR decreased with incubation time for the low-STP soil but not for the medium-STP soil. The soil pH covariate was significant for both low- and medium-STP soils, and the relationship with %PRR was positive for low- but not for the medium-STP soil.

1. Introduction

The traditional approach of basing manure applications on N content leads to the buildup of soil P to levels that pose a pollution hazard. As a result, many jurisdictions have adopted P-based nutrient management planning regulations for intensive livestock operations. P-based nutrient management seeks to match P application to crop P requirements as indicated by soil testing. However, soil test P recommendations are based on crop response to inorganic fertilizer P and there is lack of agreement on the equivalence between manure P and fertilizer P.

While some studies have found that livestock manures were equivalent to inorganic fertilizer in P availability [1–4], others [5–8] have reported results that indicate that manure P was generally less available than inorganic fertilizer P. Laboski and Lamb [9] found that availability of soil P from injected swine manure was greater than that from fertilizer P for incubation periods of 1 to 9 months, with the difference between the two P sources increasing over time.

Some of the differences in results may be attributed to experimental conditions. Goss and Stewart [10] found that plants grown in superphosphate-amended soil removed a higher percentage of added P than in manure-amended

soil, partly because of luxury consumption. On the other hand, Sikora and Enkiri [11] found no significant overall differences between poultry litter compost and triple superphosphate fertilizer in plant cumulative P uptake; however, the soil used was already high to excessive in STP. The choice of fertilizer used for comparison can have an effect on the estimated fertilizer equivalence of manure P [12, 13]. Reagents used for soil extraction also differ in the amounts and forms of P they recover [12, 14].

Environmental conditions also play a role. For example, Blake et al. [15] suggested that manure P can be either less available or more available than superphosphate P, depending on climate, soil, and availability of other plant nutrients and advised careful consideration of environmental conditions when transferring conclusions about soil P availability from one environment to another. Others [6, 16] identified the effect of degree of soil P-saturation on release of soluble P where soils with higher initial STP and thus a greater degree of P saturation maintained a higher proportion of added P in available form.

The type of the manure, itself, can have a bearing on the availability of its P [6, 14, 17, 18], with manure Ca content identified as an important determinant of manure P availability [17, 18].

TABLE 1: Selected properties of Medium-Soil Test P (Med-STP) and Low-Soil Test P (Low-STP) soils used in the study. Lab analysis was performed on the bulked, dried, and sieved soil.

Soil	Soil Taxonomy		Soil Texture	pH	% SOM	Soil Test values (mg kg^{-1}) ^(a)		
	Canadian	U.S.D.A.				P (rating)	Ca (rating)	Fe
Med STP	Gleyed Humic Regosol	Humaquent	coarse loamy	6.7	2.7	38 (medium)	3828 (medium +)	336
Low STP	Gleyed Humic Regosol	Humaquent	coarse loamy	4.9	3.8	23 (low -)	2014 (low +)	430

^(a)Soil test values by Mehlich-3 extraction. Ratings shown in bracket indicate the magnitude of these values.

TABLE 2: Properties of Phosphorus sources.

Phosphorus Source	% P ^(a)	% dry matter	pH	% Ca
$\text{Ca}(\text{H}_2\text{PO}_4)_2 \cdot \text{H}_2\text{O}$ (MCP)	24.6%	—	—	15.9
Dairy Manure (DM)	0.046 to 0.058%	11.06 to 11.84	6.7 to 6.9	0.118
Layer Hen Manure (HM)	0.358 to 0.476%	28.66 to 30.08	6.8 to 8.4	1.84

^(a)Manure analysis on a wet weight basis.

The question of fertilizer equivalence of manure P sources is determined more definitively by crop responses in field trials using manure; however, such research requires large expenditures of time and labor. Sharpley and Sisak [8] suggested that rather than repeating field trials with manure P, equivalence could be determined more economically by laboratory comparisons with fertilizer P, and Zvomuya et al. [3] suggested that a few simple chemical measurements could predict manure P availability. Soil incubation studies offer a low-cost alternative to field studies, while allowing for better control over variables. Used in concert with data from existing field trials they can provide a basis for estimating manure P applications for optimum crop growth.

This study used soil incubations to try to establish fertilizer equivalence of two different sources of manure P based on Mehlich-3 (M3) STP in order that soil-test ratings may be used to more accurately determine the optimum manure P applications. It also attempts to address temporal differences in P availability by incubating the P-amended soil with repeated sampling over a period of 110 days. In order to assess the effects of antecedent soil P status on availability of added P, this study used similar soils with different antecedent STP ratings. The effects of soil pH on manure P fertilizer equivalence was also investigated.

Many of the studies cited herein used very high P levels associated with manure application rates required for disposal in intensive livestock operations, or even higher rates. Several researchers [2, 3, 6, 8–10, 16, 18, 19] applied manure P at levels as high as 1200, 800, 288, 154, 108, 100, 150, 280, and 200 mg P kg^{-1} soil, respectively. Because of changes in soil chemistry and biochemistry brought about by such high rates of amendments, their results may not be applicable for manure P application at rates equivalent to crop P removal. This study is different in that it used much lower P application rates, according to crop nutrient requirements based on soil testing.

The overall objective of this study was to determine the effect of source of manure and rate of application on P

recovery from manure relative to fertilizer over a growing season.

2. Materials and Methods

2.1. Soil Characteristics and Preparation. Two field soils from the Acadia association [20] located on dyked farmland (reclaimed salt marsh) near Truro, Nova Scotia ($45^\circ 14' \text{N}$, $63^\circ 19' \text{W}$), cropped to perennial mixed forages, were collected from 0–15 cm depth. Soil properties are shown in Table 1. Soils were selected for different STP ratings: low- and medium STP-soils. Bulked soil was dried at about 70°C for 1 week and sieved through 6 mm mesh prior to setting up the incubations.

2.2. Phosphorus Treatments. Nine different soil P treatments, each replicated three times, were applied to each soil: laboratory grade monocalcium phosphate (MCP), solid layer hen manure (HM), and liquid dairy manure (DM), each at 3 different rates. P application levels were approximately 1/2 \times , 1 \times , and 1.5 \times (representing low (1), medium (2), and high (3)) P requirements for spring feed barley for each soil, according to Nova Scotia Department of Agriculture STP ratings and plant nutrient requirement data. Properties of P sources are shown in Table 2 and P application rates are shown in Table 3.

Phosphorus treatments were dissolved or suspended in 350 to 400 mL water (to obtain soil moisture tension of about 20 kPa) which was sprinkled onto 1.25 kg dry soil in a shallow tray. The soil was then mixed for 10 minutes with a garden trowel until the soil was uniformly moist with aggregates less than about 2 cm diameter.

The treated soil samples were transferred into 2 L plastic tubs with perforated lids and incubated in a growth chamber in a completely randomized distribution for each soil at ambient room temperature (approximately 20°C) and soil moisture tension between 16 kPa and 24 kPa for the duration of the experiment (110 days). Gravimetric soil moisture

TABLE 3: Phosphorus application rates with low, medium, and high approximately equal to 1/2×, 1×, and 1.5× the recommended P rate for spring feed barley, respectively.

Soil	P source	Phosphorus application rates					
		mg P/kg soil			Equivalent kg P ₂ O ₅ /ha-fs		
		Low	Medium	High	Low	Medium	High
Medium STP	MCP	8	17	25	38	76	115
	DM	—	15	22	—	69	103
	HM	10	20	30	46	92	137
Low STP	MCP	10	21	31	47	94	142
	DM	—	22	33	—	100	150
	HM	14	28	42	64	128	191

TABLE 4: Soil Test P (ppm) values for the control, as well as the fertilizer, the dairy manure, and the hen manure sources and their application rates at the five incubation times. The shown values are averages of three replications.

Source	Rate	Low STP soil					Medium STP soil				
		Incubation time (days)					Incubation time (days)				
		5	15	30	60	110	5	15	30	60	110
Control	0	56	59	53	77	85	49	53	45	56	62
MCP	1	62	71	60	76	87	56	54	49	65	69
MCP	2	68	72	63	92	93	60	58	54	62	67
MCP	3	74	82	74	87	104	63	64	54	70	68
DM	2	67	72	60	80	90	57	55	49	58	69
DM	3	72	82	67	76	95	59	60	51	64	68
HM	1	65	68	59	78	89	53	51	47	60	66
HM	2	73	78	62	86	96	57	57	51	66	66
HM	3	80	83	68	91	96	64	62	55	70	73

content was monitored by weighing the soil pots before each sampling and adding water to keep incubations within soil moisture tension range, if necessary.

2.3. Repeated Sampling. After 5, 15, 30, 60, and 110 days of incubation, each container was emptied into a shallow tray and mixed thoroughly. A 150 to 200 g (moist weight) soil subsample was removed from the tray for analysis. The rest of the soil was returned to the container and incubator.

2.4. Manure Analysis. Manure mineral content was determined at Laboratory Services of the Nova Scotia Department of Agriculture in Truro, Nova Scotia, by modified AOAC method 968.08 [21]. Samples were prepared by first adjusting the pH to 2 with 50% H₂SO₄. The acidified samples were dried at 95°C and ground in a Wiley mill with 2 mm mesh, and a 0.75 g subsample was then ashed in a muffle furnace at 550°C for 5 hours. One mL concentrated HCl was added to the ash and after 5 minutes, the mixture was brought up to 75 mL with deionized water and shaken; and then allowed to sit for 30 minutes before determination of mineral content on a Jarrel-Ash Model 9000 Inductively Coupled Argon Plasma Optical Emission Spectrometer (ICAP).

2.5. Soil Analysis. The STP and soil pH were determined by the Laboratory Services of the Nova Scotia Department of Agriculture. A 2.5 mL subsample of dried (105°C) ground

(to pass 2 mm mesh) soil was mixed with 25 mL Mehlich-3 solution [22]. The mixture was shaken for 5 minutes on reciprocating shaker at 240 oscillations/min, and then filtered through no. 5 Watman filter paper. The filtrate was analyzed for P by ICAP. Mean values of STP at the different incubation times are shown in Table 4 to indicate the magnitude of differences among the treatments. However, percentages of Recovery Ratio values calculated as indicated in the following section are analyzed. It should be noted that STP values for control treatment were higher after incubation than those observed prior to the inception of the study, and that the relative STP values for the two soils changed following incubation.

Soil pH was determined with an Orion W-BNC combination electrode. Twenty mL of dry, sieved (2 mm) soil were mixed with 20 mL deionized water, stirred intermittently for 30 minutes, and allowed to settle for 30 minutes before pH determination in the supernatant.

2.6. Statistical Analyses. For each soil, incubation duration, P treatment, and replication, % P recovery was calculated as ((treatment STP – unamended control STP) ÷ added P) × 100%, and then the average of the 3 replications for each of MCP1, MCP2, and MCP3 was used to calculate the corresponding manure P recovery ratio (%PRR) response as: (% P recovery for manure treatment ÷ % Precovery) × 100% for equivalent P-fertilizer treatment. %PRR was converted

TABLE 5: ANOVA *P*-values that show the main and interaction effects of Source of P (Source), Rate of application (Rate), and Incubation time (Day) as well as the linear and quadratic coefficients of the covariate on %PRR. Significant effects that require further multiple means comparison are shown in bold.

Source of variation	Low-STP soil	Medium-STP soil
Source	0.857	0.609
Rate	0.285	0.303
Source * Rate	0.134	0.934
Day	0.001	0.033
Source * Day	0.004	0.002
Rate * Day	0.544	0.002
Source * Rate * Day	0.389	0.009
pH	0.003	0.001
pH squared	0.004	0.001

to mass basis using the bulk density of dried ground sieved soil subsamples. For each soil, %PRR response was analyzed as repeated measures analysis of unbalanced two-factor factorial design with two levels of Source of P (DM, HM) and three Rates of application (1, 2, and 3), and 5 durations (Day: 5, 15, 30, 60, and 110 days) with a second order polynomial of soil pH covariate (by using pH and pH-squared values as covariates). In this repeated measures analysis, the error terms were assumed to have a normal distribution with constant variance, but dependence among them expressed with the most appropriate covariance structure. For both soils, based on the Akaike's Information Criterion (AIC) and Schwarz's Bayesian Criterion (SBC), [23], the most appropriate covariance structure was determined to be Unstructured (UN). The normal distribution and constant variance assumptions on the error terms were verified by examining the residuals [24]. Since the covariates were significant (Table 5), the least squared means that are adjusted for the covariate were compared and letter groupings generated. The MIXED Procedure in SAS [25] was used to complete the analysis. The relationships between %PRR and the covariates were further explored to determine whether the relationship was positive or negative.

3. Results and Discussion

Overall, manure %PRR was 72% for the low-STP soil and 80% for the medium-STP soil (averaged over all manure treatments). However, the effect of the treatments varied with incubation period for the low STP, but not for the medium STP.

3.1. Effect of Source, Rate, and Incubation Time on %PRR. The interaction effect of source, rate, and incubation time was significant for medium STP soil; but only the interaction effect of source and incubation time was significant for the low STP soil (Table 5) suggesting that the effect of source (for the low STP soil) and source by rate combination (for the medium STP soil) changed during the incubation period. The %PRR showed dramatic change for the low STP soil compared to that for the medium STP soil (Figure 1).

However, there was no difference among the rates for the low STP soil, and the pattern of the differences among the rates in the medium STP soil was not discernible.

Redding et al. [26] identified a similar temporal effect on P sorption by soil incubated with pig manure effluent. They found that piggery effluent temporarily increased vulnerability of soil P to desorption, but that the effect was lost after 2 to 113 days of incubation. Guppy et al. [27] found a temporary suppression (lasting less than 6 days) of P sorption by fulvic acid components of plant leachates added to two Oxisols whereas [28] observed that maximum STP (Olsen extraction) from addition of pig manure compost occurred at 30 days incubation and declined rapidly thereafter in a moderately acid soil.

Laboski and Lamb [9] observed effects opposite to those seen in Figure 1. They found that fertilizer P availability decreased while swine manure P availability was unchanged over 1 to 9 months of incubation for 6 of the 7 Minnesota soils used in their study. This would result in increasing manure %PRR over time; however, comparisons with their results are tenuous because their P application rates averaged about one order of magnitude greater than those used in this study.

3.2. Effect of Soil pH on %PRR. Initial pH differences caused significant differences in the %PRR of manure P treatments for low- as well as medium-STP soils (Table 5). Second order polynomial regression of %PRR on soil pH (Figure 2) for the manure treatments in the low-STP soil indicated that fertilizer equivalence of manure P increased with soil pH that ranged between 4.2 and 5.4. Although manure P was mainly lower in availability than fertilizer P throughout the pH range found in this soil, the difference narrowed as soil pH increased. Tan et al. [29] found that the metal complexing capacity and stability of metal complexes formed by water extract of poultry manure increased with increasing pH. Increasing binding of soil Fe and Al in organometal complexes at higher pHs might explain the relationship between %PRR and soil pH in the low-STP soil as seen in Figure 2. The pH range for the medium STP soil (6.3 to 6.9) was rather narrow and falls in the range where P availability often rises and falls with increasing soil pH. It was not surprising to see a curved pattern depicted in Figure 2.

Lower molecular weight (MW) dissolved organic matter may be most effective in complexing metals [30]. Low MW organics released from manure by mineralization in the medium STP soil (with neutral pH) could be responsible for the suppressing P fixation in the manure treatments; whereas, in the low-STP soil, mineralization was retarded by the low pH (4.2–5.4), so that low-MW organics did not accumulate. This conclusion is also consistent with findings of Tan et al. [29]: that the metal complexing capacity and stability of complexes formed with manure extracts increased with increasing soil pH.

On the other hand, organometal complexes may also form new P-sorption sites, which is important because it was shifts in soil P-sorption isotherms that led Guppy et al. [27] to hypothesize that formation of metal chelates may have increased P adsorption in highly weathered soils. Although

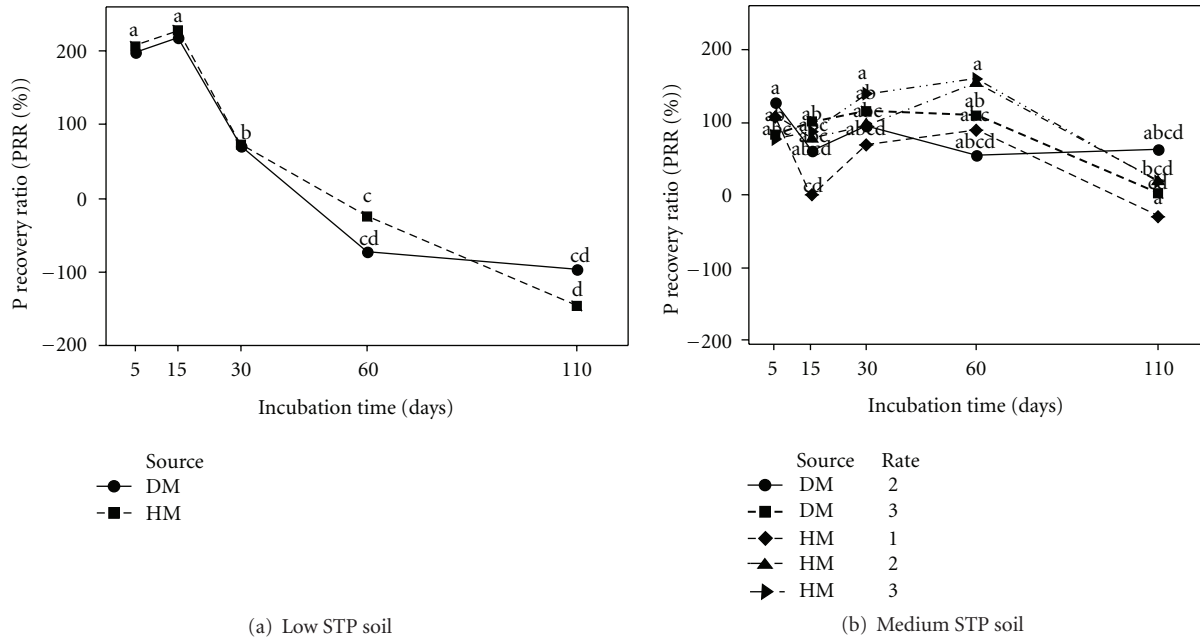


FIGURE 1: % P Recovery Ratio (%PPRR) for the two sources of manure (low-STP soil) and the five combination of source of manure and application rate (medium-STP soil) at the five incubation periods. Within each soil, means sharing the same letter are not significantly different.

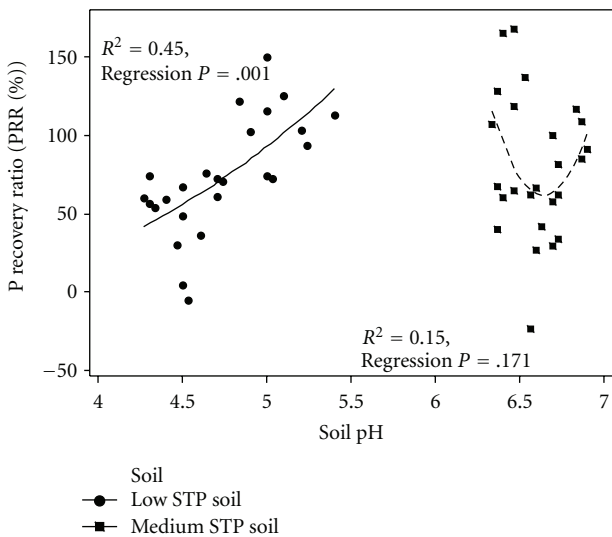


FIGURE 2: Plot of the percentage of P-Recovery Ratio versus Soil pH along with fitted second order polynomial regression line. The data points are averages of the three replication of the P treatment by incubation time combinations.

the soils in this study were relatively young, the low-STP soil results are consistent with this hypothesis.

4. Conclusions

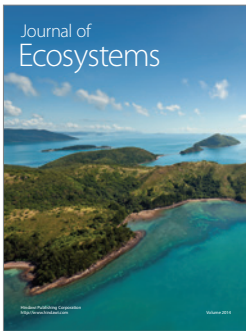
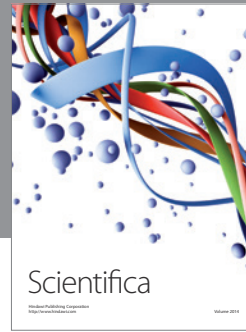
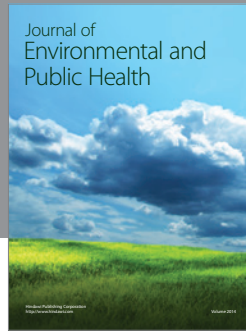
This paper indicated that based on M3 extraction, P from poultry and dairy manures was less available than MCP-P (%PPR less than 100%). The overall average %PPR for

the two sources of manure and the two soils was 75%, however, the fertilizer equivalence of manure P (%PPR) varied depending on resident time in soil and soil pH as well as the soil chemistry. Fertilizer available P increased with incubation period at a faster rate than manure available P in the low-STP soil, but not as fast in the medium-STP soil. Depending on the combination of factors and the nature of the soil, manure P may be much less available or even more available than MCP fertilizer. Soil P dynamics is very complex and warrants further research.

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