PHOSPHORUS AVAILABILITY FROM SWINE AND DAIRY SLURRIES

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Introduction

Compared to nitrogen (N), relatively little is known about the availability of phosphorus (P) from manure to crops. Many state extension bulletins recommend that 50-80% of total P in manure is available to crops the first year after application. This number is likely based on the fact that 35-90% of P in manures is in the inorganic form (Peperzak, et al., 1959; Barnett, 1994), which is immediately available to crops. The remaining P that is not credited in the first year is usually never credited. In addition, the same availability coefficient/index is usually given to all manure types, regardless of species, diets, or storage. Understanding manure P chemistry in soil and trying to predict P availability is an important component for making nutrient management plans that maximize economic benefits and minimize environmental risks.

Injection of liquid manures into the soil provides a unique soil chemical/biochemical environment because the manure injection bands are undisturbed by subsequent tillage and thus impact only about one-tenth of the soil in a field (Schmitt et al., 1992). Schmitt et al. (1992) studied the unique chemical environment within a band of injected beef manure with respect to nitrogen. The behavior of P in manure injection bands has received limited study (Comfort et al., 1987; Motavalli et al., 1989; Sutton et al., 1982).

Some past research suggests that manure P may be equally or more available than fertilizer P (Gale et al., 2000; Meek et al., 1979, Abbott and Tucker, 1973). This may be explained by the fact that several anions of organic acids have been found to prevent P fixation and are able to replace P bound to the soil resulting in greater concentrations of available P (Swenson et al., 1949; Nagarajah et al., 1970; Kafkafi et al., 1988). Swenson et al. (1949) found that the organic acid's effectiveness in decreasing P sorption was dependent upon the anion concentration. Struthers and Sieling (1950) discovered that at any pH found in agricultural soils, there were organic anions that could effectively prevent P sorption to iron and aluminum and they were the same organic acids that are produced in great quantity by microbial degradation of organic matter. Anderson et al. (1974) found that inositol hexaphosphate (an organic P compound found in manure) was preferentially sorbed to the soil compared to orthophosphate such that treatment of the soil with inositol hexaphosphate released orthophosphate bound to the soil and reduced later sorption of orthophosphate.

Manure-P has not always been found to be more available than fertilizer-P. Elias-Azar et al. (1980) found manure-P, from fresh and composted dairy manure, was as available as KH_2PO_4-P in alkaline sandy soils. The average relative P availability of fresh manure was 0.71 and for composted manure was 0.65, in the other soils studied (textures ranging from sandy loam to silty clay and pH 4.6 to 8.2). Additionally, Elias-Azar et al. (1980) reported that the relative availability of manure-P increased as pH and sand content increased. Overall, manure-P was less available than KH_2PO_4-P.

Gracey (1984) amended ryegrass turves with cattle (2.71 g L^{-1} P), pig (4.85 g L^{-1} P), and sheep (2.49 g L^{-1} P) manure and monoammonium phosphate (MAP) at the same rates of total P.

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After 168 days of incubation, the order of P availability was MAP > pig > cattle > sheep. Using the mean available soil P level for the greatest P application rate given by Gracey (1984), the relative availability of manure-P compared to MAP was 0.62, 0.47, and 0.36 for pig, cattle, and sheep, respectively. In another study, Sharpley and Sisak (1997) found that poultry litter leachate-P was less available than KH_2PO_4 when incubated with 193 soils for seven days. When soils were broken into 3 groups, calcareous, slightly weathered, and highly weathered, the relative availability of litter leachate-P compared to KH_2PO_4-P was 0.61, 0.58, and 0.52, respectively.

The objectives of these studies were designed to obtain a better understanding of manure-P availability in manure injection bands by 1) evaluating the relative availability of manure-P compared to fertilizer-P, 2) determining if differences in P availability exist between manure from different species, and 3) determining if previous manure applications impact the P availability of subsequent manure or fertilizer applications.

Materials and Methods

There are two different studies reported on in this paper. One that was performed on Minnesota soils and another performed on Michigan soils. Where appropriate, discussion of soils and results from both states will be intermingled. Soils from seven different soil mapping units, which are representative of soils commonly receiving manure applications in Minnesota, were used in this study. Two different locations were selected within each mapping unit based on manure application history. One location had no history of manure application while the second did. The exception was the Nicollet soil where three locations were sampled; one having no manure history (Ni1) and two having different manure application histories (Ni2 - moderate and Ni3 - heavy). Six soils were also collected from south central-Michigan. These soils were selected with a range in texture and having a Bray 1-P soil test level < 30 mg kg^{-1} and pH < 7. All soils were collected to a depth of 0.15 m, air-dried, and sieved to pass a 2mm sieve. Table 1 contains information regarding soil classification, characterization, and field manure application history of the selected soils.

For the Minnesota study, swine slurry was collected from an in-ground, anaerobic storage pit of a swine-finishing house that was being agitated. For the Michigan study, dairy slurry was collected from a short-term storage pit near a feedlot; while swine slurry was collected from a slotted floor feeder house at the time of cleaning. All manures were well mixed and sieved (2mm) to remove large residual particles. Manure was analyzed for percent moisture, percent solids, total N, total P, and K (Table 2). The manures were frozen in polyethylene jugs for long-term storage prior to use.

In the Minnesota study, swine slurry or fertilizer (KH_2PO_4) was applied at 0, 144, or 288 mg total P (P_T) kg^{-1} and incubated for 9 months at 25 °C. Samples were collected periodically throughout the incubation. Moisture in each soil was maintained at 70 to 90 % of field capacity. In the Michigan study, swine slurry was applied at a rate of 117 mg P_T kg^{-1}; while fertilizer and dairy slurry were applied at a rate of 100 mg P_T kg^{-1}. All mixtures were incubated at 22 °C for 6 weeks maintaining soil moisture between 70 and 85 % of field capacity. Soils in the Michigan study were packed to a bulk density of 1.2 Mg m^{-3}. These application rates are equivalent to vertical knife injection application rates of 3,600, 7,200, 5,600, and 2,800 gal $acre^{-1}$ for Minnesota swine lower rate, Minnesota swine higher rate, Michigan dairy, and Michigan swine slurries, respectively. The assumptions behind this are that knifed-in manure influences a volume of soil equivalent to 0.15 m in diameter and a knife spacing of 0.76 m.

For all data, the Bray P soil test of the control soil was subtracted from the soil test of the manure or fertilizer treated soils resulting in an increase in soil test due to manure or fertilizer application. The increase in soil test was then divided by the amount of P_T or P_I added to the soil. This provides a ratio of the increase in soil test per P added. The Minnesota study was analyzed using regression analysis; details can be found in Laboski and Lamb (2003). The Michigan study was analyzed using ANOVA and Fisher's LSD for means separation. Both studies were evaluated at the a = 0.05 level.

Results and Discussion

Minnesota Study

When swine slurry was added to soil at the same rate of total P as fertilizer, the increase in soil test P (STP) per P_T applied was greater for manure compared to fertilizer for all but one (Vd2) soil (Figures 1 and 2) after 1 month of incubation. The same relationship holds true after 9 months of incubation (data not shown) (Laboski and Lamb, 2003). This means that swine slurry was more effective in increasing soil test P than fertilizer and had a greater P availability relative to fertilizer.

The data in Figures 1 and 2 were also compared to evaluate the relative effectiveness of manure to increase STP on a given soil series when comparing a soil with a previous manure history to one without a previous manure history. For approximately one-half of the soils (PB, Sa, Ni2/Ni1, and Ba), there was no difference in the relative effectiveness of manure-P to increase STP on previously manured compared to unmanured soil. When differences did occur, in 75 % of the occurrences (Wa, Vd, Ni3/Ni1), the relative effectiveness of manure-P to increase STP on a previously manured soil was less than on a previously unmanured soil. This occurred over the range of soil textures and previous species of manure applied (Laboski and Lamb, 2003).

Michigan Study

The increase in STP per P_T applied varied between P sources, fertilizer, swine slurry, or dairy slurry. For Co1, Co2, and Pr soils, the increase in STP per P_T applied was significantly different between all sources in the order of fertilizer > swine slurry > dairy slurry (Figure 3). For the Os and Sk soils, swine slurry increased STP per P_T applied as much as fertilizer did. On these soils, dairy slurry increased STP significantly less than fertilizer or swine slurry. Overall, dairy slurry did not increase STP as much as fertilizer. However, on two of the five soils, swine slurry increased STP as much as fertilizer.

Inorganic P was also measured on the manure slurries. Thus, the increase in STP per P_I applied could be calculated. On a P_I basis, swine slurry increased STP per P_I applied more than fertilizer for the Co1, Os, and Sk soils (Figure 4). Swine slurry increased STP per P_I applied as much as fertilizer on the Co2 soil and less than fertilizer on the Pr soil. Dairy slurry increased STP per P_I applied as much as fertilizer on the Os and Sk soils, but increased STP less than fertilizer on the Co1, Co2, and Pr soils. Dairy slurry always increased STP less than swine slurry. This data shows that P_I from swine slurry can be more effective in increasing STP, and subsequently plant available P, than fertilizer over a range of soil textures. These data, on a P_I basis, are also supported by other research on these soils. Marshall and Laboski (2003) found that inorganic P from swine slurry sorbed to soil less than KH_2PO_4 but that inorganic P from dairy slurry sorbed to soil more than KH_2PO_4. Suggesting that application of swine and dairy manure could increase STP more or less, respectively, than fertilizer.

Both Studies

The differences in ability of P from manure to increase soil test are likely a result of the contents of the manure itself. For example, what percentage of P_T was P_I; animal diet, storage, forms of organic P in manure, and amount and type of organic acids in manure. The P_T in both swine slurries used generally had P availabilities similar to or greater than fertilizer, while the P_T in the dairy slurry had a P availability less than fertilizer. This suggests that there may be some inherent differences in manure output from monogastric vs. ruminant animals not to mention the impact of different dietary management strategies.

It must be acknowledged that in both studies, the amount of manure applied was based on a manure injection band. This would be equivalent to extremely large broadcast incorporated rates (greater than acre-inch of water). During the incubation, all of the manure applied remained in contact with the same volume of soil. These circumstances likely would not apply under field conditions where the manure is subject to movement in the soil due to water movement or tillage.

Conclusions

Phosphorus from swine slurry was found to increase STP more, equally, or less than fertilizer over the two studies, while P from dairy slurry was found to increase STP less than fertilizer. When manure is applied to soils with a previous manure history, the STP levels may increase differently than when manure is applied to soil for the first time. These data suggest that P availability coefficients (similar to N mineralization coefficients) for various manure sources should be developed to provide better guidance on how many P credits from manure can be taken when developing nutrient management plans.

Injection of liquid manures is considered a best management practice with regard to efficient N capture and reducing P loss to surface waters. These studies suggest that manure injection may create bands of soil with high P availability. Further studies need to be conducted in the field to determine the effect of manure injection on the spatial and temporal variability of available P in the soil and determine how manure application methods may impact plant uptake of P and P loss to runoff (Laboski and Lamb, 2003).

Acknowledgments

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Table 1. Soil classification, characterization, and manure history.

Soil ID	Soil Series	Classification	Field Manure History	pH 1:1 H_2O	OM	Sand	Silt	Clay	CEC	Bray P	Olsen P
					---------- g kg^{-1} ----------				$cmol_c\ kg^{-1}$	-- mg kg^{-1} --	
MINNESOTA											
PB1	Port Byron	Fine-silty, mixed, mesic Typic Hapludolls	None	5.2	53	97	634	269	21.5	34	24
PB2	Port Byron	Fine-silty, mixed, mesic Typic Hapludolls	Dairy + Swine	6.2	51	86	670	243	22.0	98	67
Wa1	Waukegan	Fine-silty over sandy or sandy skeletal, mixed, mesic Typic Hapludolls	None	7.1	43	148	581	271	21.0	26	19
Wa2	Waukegan	Fine-silty over sandy or sandy skeletal, mixed, mesic Typic Hapludolls	Swine	6.4	38	110	634	256	20.3	162	126
Sa1	Sanburn	Coarse-loamy, mixed, frigid Inceptic Hapludalfs	None	6.4	31	677	197	126	9.8	35	20
Sa2	Sanburn	Coarse-loamy, mixed, frigid Inceptic Hapludalfs	Beef	6.8	20	753	146	101	7.1	53	25
Vd1	Verndale	Coarse-loamy, mixed, frigid Typic Argiudolls	None	6.3	16	829	96	75	6.2	16	8
Vd2	Verndale	Coarse-loamy, mixed, frigid Typic Argiudolls	Turkey	6.5	18	804	96	101	7.5	67	41
Ni1	Nicollet	Fine-loamy, mixed, mesic Aquic Hapludolls	None	5.7	56	342	322	335	28.9	32	26
Ni2	Nicollet	Fine-loamy, mixed, mesic Aquic Hapludolls	Dairy + Swine	5.6	56	395	283	322	28.8	64	49
Ni3	Nicollet	Fine-loamy, mixed, mesic Aquic Hapludolls	Dairy + Swine	6.1	63	316	335	348	30.5	152	114
Vs1	Ves	Fine-loamy, mixed, mesic Calcic Hapludolls	None	6.9	42	257	426	317	25.2	3	3
Vs2	Ves	Fine-loamy, mixed, mesic Calcic Hapludolls	Beef + Swine	7.3	31	545	230	225	19.1	50	44
Ba1	Barnes	Fine-loamy, mixed, frigid Calcic Hapludolls	None	7.9	46	238	454	308	25.4	18	17
Ba2	Barnes	Fine-loamy, mixed, frigid Calcic Hapludolls	Dairy	7.4	48	439	293	268	21.3	138	97
MICHIGAN											
Co1	Colwood 1	Fine-loamy, mixed, active, mesic Typic Endoaquoll	None	6.0	5.4	42	36	22	16.4	15	14
Co2	Colwood 2	Fine-loamy, mixed, active, mesic Typic Endoaquoll	None	5.6	6.1	48	40	12	16.9	8	12
Os	Oshtemo	Course-loamy, mixed, active, mesic, Typic Hapludalf	None	5.6	2.5	68	23	9	8.3	11	12
Pr	Parkhill	Fine-loamy, mixed, semi -active, nonacid, mesic Mollic Endoaquepts	None	6.8	5.2	32	39	29	20.1	4	7
Sk	Spinks	Sandy, mixed, mesic Lamellic Hapludalfs	None	5.4	4.5	76	19	5	5.4	14	14

Table 2. Manure characteristics.

Manure	Moisture	Dry Matter	P_T *	P_I **	N_T ***	K
	---------- % ----------		------------------------ mg L^{-1} ------------------------			
MINNESOTA						
Swine	95.1	4.9	1196	--	5080	2489
MICHIGAN						
Dairy	95.3	4.7	532	421	3271	2228
Swine	94.8	5.2	1257	1105	6542	3810

* P_T = Total P, ** P_I = Inorganic P, *** N_T = Total N

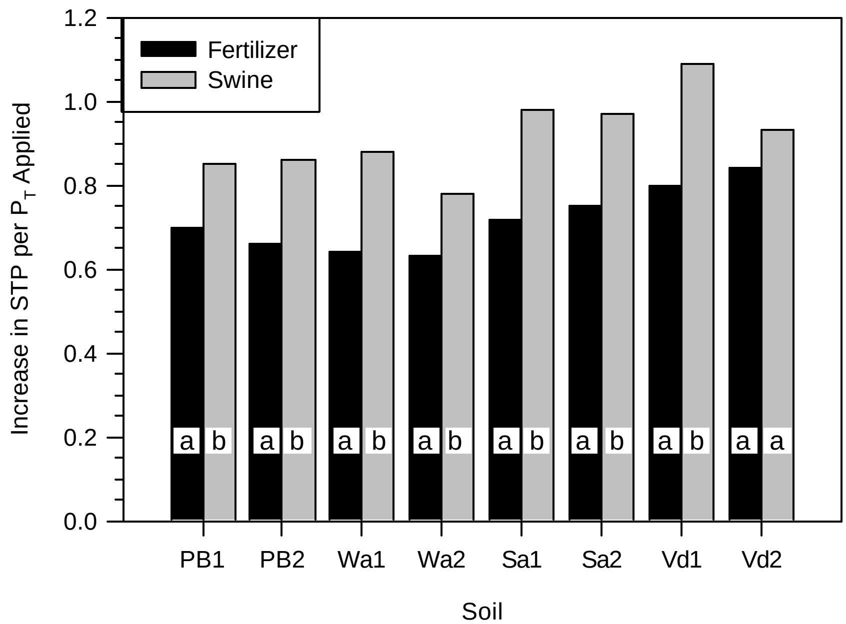

Figure 1. Increase in Bray-1 P (STP) per total P (P_T) applied over a 4-week incubation of selected Minnesota soils with fertilizer or swine slurry. For a given soil, P sources with different letters are significantly different at the a = 0.05 level.

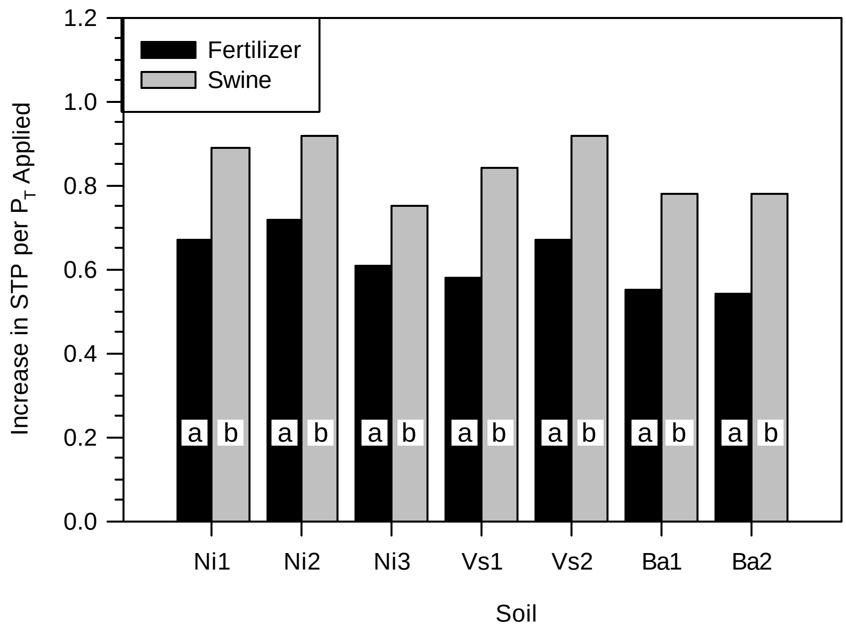

Figure 2. Increase in Bray-1 P (STP) per total P (P_T) applied over a 4-week incubation of selected Minnesota soils with fertilizer or swine slurry. For a given soil, P sources with different letters are significantly different at the a = 0.05 level.

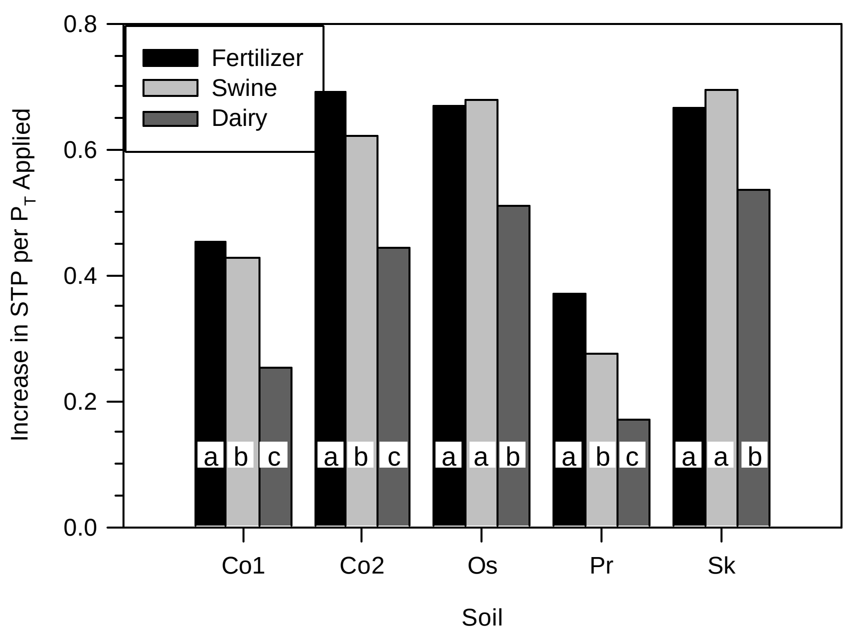

Figure 3. Increase in Bray-1 P (STP) per total P (P_T) applied over a 6-week incubation of selected Michigan soils with fertilizer, swine, or dairy slurries. For a given soil, P sources with different letters are significantly different at the a = 0.05 level.

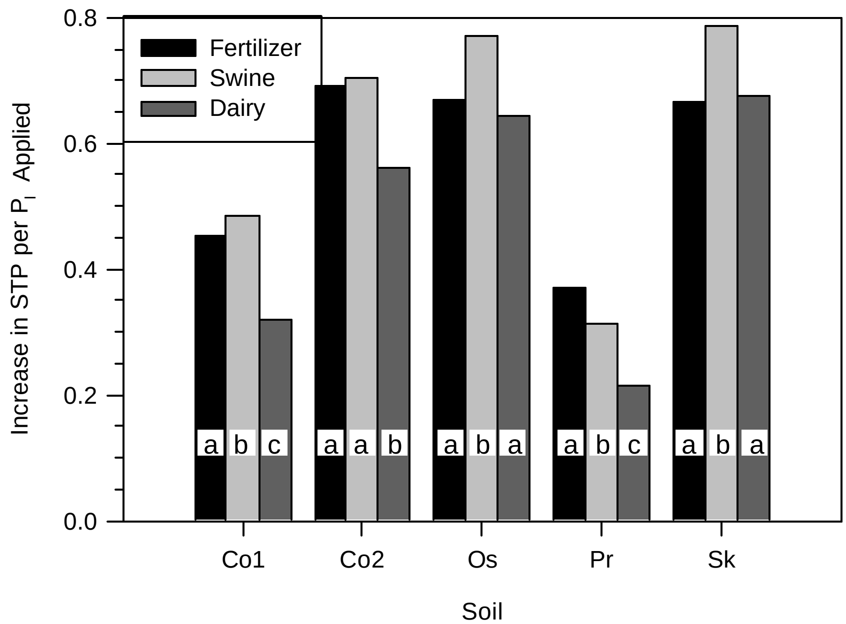

Figure 4. Increase in Bray-1 P (STP) per inorganic P (P_I) applied over a 6-week incubation of selected Michigan soils with fertilizer, swine, or dairy slurries. For a given soil, P sources with different letters are significantly different at the a = 0.05 level.