SOURCE EFFECTS ON PHOSPHORUS AVAILABILITY

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Introduction

Phosphorus (P) availability differences among sources, especially those between commercial fertilizer and manure or other organic P sources, are of increasing interest to farmers, agronomists, and nutrient management planners. While the traditional interest in maintaining adequate P supplies for crop production continues, P availability effects on the risk of P loss in runoff and the environmental implications of these losses are receiving increasing attention. This is particularly true since soil test P and the characteristics of P in manures and organic materials are important factors in P-based nutrient management planning.

The purpose of this paper is to review potential P source differences in the following areas.

- P availability to plants
- Effects on soil test P
- Effects on productivity and soil characteristics
- Effects on P losses in runoff

Since most studies of differences between P sources involve comparisons between commercial fertilizers and manures or between manures from different animal species or management systems, it is important to recognize that characteristics of manures and other organic P sources are quite variable. Some of the manure characteristics that could influence P availability relative to other P sources include: (1) animal species and management; (2) water soluble P content; (3) mineralization rates of organic P components; and (4) manure constituents that may react with soil or with inorganic P.

Phosphorus Availability to Plants

Numerous comparisons of plant availability of P from fertilizers relative to manures have yielded results showing both higher and lower availability of manure P compared to fertilizer P. Manure P is generally assumed to be 60 to 90% as available as fertilizer P, since the inorganic P in manures is viewed as having availability equal to fertilizer P while the organic P component of manures must be mineralized before plant use. Goss and Stewart (1979) compared manure and superphosphate fertilizer as P sources for alfalfa in greenhouse and field studies. Alfalfa grown with fertilizer P removed a higher percentage of added P than where manure was used as the P source. However, alfalfa grown with manure P had a greater yield increase per unit of P uptake (efficiency) than with fertilizer P. Greenhouse yields were higher with fertilizer P, but no yield differences were observed between P sources in field experiments.

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Sharpley and Sisak (1997) reported higher P availability from fertilizer P than from poultry manure leachate (Table 1). Phosphorus availability assessed in a 7-day incubation with 193 soils was inversely related to the ratio of soil clay/organic carbon content which provides an estimate of reactive surface area involved in P sorption and availability. The availability index reported was calculated from the relationship between a soil P test value and the amount of P added. The difference in P availability between the fertilizer and poultry leachate sources was attributed to reaction of P with calcium or with soluble organic compounds in the poultry leachate.

Table 1. Comparison of P availability from fertilizer and poultry litter leachate (Sharpley and Sisak, 1997).

P source	Calcareous soils n = 56	Slightly weathered n = 74	Highly weathered n = 63
	---------- availability index ----------		
Fertilizer (KH_2PO_4)	0.56	0.57	0.36
Poultry leachate	0.34	0.33	0.19

Several studies have shown greater P availability with manure than with fertilizer P. During and Weeda (1973) found that manure P applied at equivalent rates with fertilizer P decreased P sorption by soil and increased recovery in pastures. Similarly, Abbott and Tucker (1973) compared the residual effects of manure and fertilizer P on calcareous soils and found higher availability where P was applied as manure. They attributed this higher availability to P association with organic compounds possibly involving organic acid production during manure decomposition resulting in reduced P sorption. In an incubation study, Laboski and Lamb (2003) found that P in swine manure was more available than fertilizer P. They suggested that manure P availability was enhanced by organic acid formation during manure decomposition which reduced P sorption to the soil. In subsequent work, Marshall and Laboski (2003; 2004) found that P in dairy manure was less available than fertilizer P, but swine manure P was more available than fertilizer P. These animal species effects on manure P availability were attributed to: 1) differences in P sorption by soil due to differences in organic/inorganic distribution of P in the manures; 2) preferential blocking of sorption sites or displacement of sorbed P by organic acids; and 3) reactions of desorbed iron (Fe) or aluminum (Al) with soil or manure constituents to increase P sorption.

Effects on Soil Test P

The influence of various P sources on change in soil test P (STP) was determined in a 64-week laboratory incubation study using a Ringwood silt loam soil from Arlington, WI (Ebeling et al, 2003). In this work, several dairy manures differing in animal diet and manure handling were applied to soil along with an inorganic P fertilizer and biosolids from the Madison Metropolitan Sewerage District. All P sources were applied at rates of

90, 180, and 360 lb P/acre based on the total P content of the P source, and mixed with the soil. The influence of these treatments on Bray P-1 soil test values after 64 weeks of incubation are shown in Table 2. The soil test values reported are the averages of the three P application rates. All of the P sources increased STP compared to the unfertilized soil. Soil test P with the fertilizer P source was higher than for the other sources suggesting greater availability form the fertilizer. The influence of the dairy manures on STP suggests that their effects are related to the water soluble P content of the manures. For example, STP was increased most by the high P diet manures with higher water soluble P contents, while the fiber fraction from a manure separation process had the smallest increase in STP. Although biosolids had a relatively high total P content, this source increased STP less than fertilizer P or the manures from high P diets. This suggests that biosolids P may react differently than the other P sources when added to soil.

Table 2. Effect of dairy manures, biosolids, and fertilizer P on soil test P after 64-wk incubation (Ebeling et al., 2003).

P source	Manure P content (%)		Bray P-1 (ppm)[1/]
	Total P	Water soluble	
Manure –high P diet	1.31	0.37	59b
Manure medium P diet	1.09	0.21	55bc
Manure low P diet	0.66	0.13	46d
Fiber fraction	0.28	0.03	34e
Whole manure	0.85	0.25	58b
Biosolids	3.97	0.22	52c
Fertilizer – $CaHPO_4$	--	--	70a
Control (no P added)	--	--	22

[1/] Bray P-1 soil test P values are averages from 3 P rates (90,180, 360 lb P/acre)

Effects on Productivity and Soil Characteristics

Edmeades (2003) reviewed results from 14 long-term field trials (20 to 120 years) that compared the effects of fertilizers and manures on crop productivity and soil properties. The experiments examined in this study included many of the well-known long-term field experiments such as Morrow (IL), Sanborn (MO), Magruder (OK), Breton (Canada), Broadbalk-Rothansted (England), and Askov (Denmark). Edmeades (2003) concluded that although long-term manure applications increased many of the parameters (eg., organic matter content, soil biological activity, porosity, hydraulic conductivity, and aggregate stability) typically used as indicators of soil quality relative to fertilizer treatments, productivity as measured by crop yields was not significantly different between fertilizer or manure treatments. Manured treatments had higher levels of nutrients including N and P in the topsoil, and thus may have greater potential for losses of P in runoff or nitrate by leaching. Only when manures applied at high rates for many years resulted in large accumulations of organic matter, such as in the Rothamsted experiments, did the manured treatment have significant productivity advantages.

Motavalli and Miles (2002) compared long-term (111 years) fertilizer and manure treatments in continuous corn plots at the University of Missouri Sanborn Field for their effects on soil P fractions. Using a sequential soil extraction procedure, they found that the two P sources clearly affected the amounts and forms of soil P compared with the initial native prairie soil and the cropped control treatment (Table 3). Both P sources increased soil P content in all fractions. The manure treatment increased the labile (active) and slowly available inorganic P fractions compared with the fertilizer treatment. Manure treatments also increased organic P incorporated in soil aggregates (occluded) compared with plots receiving fertilizer P. The authors concluded that conventional soil test P methods such as the Bray P-1 procedure provide an assessment of P availability that is at least equal to measurements of individual P fractions.

Table 3. Long-term P source effects on soil inorganic P fractions from Sanborn Field continuous corn plots (Motavalli and Miles, 2002).

Treatment	Available	Labile	Slow	Occluded	Weatherable
	---------- ppm P ----------				
None	3	18	19	14	1
Fertilizer	54	55	76	39	25
Manure	56	181	149	41	23
Prairie	4	7	22	10	7

Effects on P Losses in Runoff

Kleinman et al. (2002) compared runoff P losses from surface-applied and incorporated fertilizer (DAP) and manures using simulated rainfall and runoff boxes packed with representative soils (Table 4). Results showed that all surface-applied P sources (90 lb P/acre) increased soluble P (DRP) and total P concentrations in runoff relative to the control and that DAP had similar runoff P concentrations as poultry and swine manures. Dairy manure had lower runoff P concentrations that the other P sources. When P sources were incorporated before rainfall, DAP, and poultry and swine manures had no effect on runoff total P concentrations, and only dairy manure had a higher total P concentration than the control.

Phosphorus source effects on runoff P losses were also evaluated by Withers et al. (2001). They found that P loads (total amount of P lost), total P concentrations, and soluble P as a percentage of total P concentration in natural runoff from plots with surface-applied fertilizer and organic P sources were higher where P was applied as triplesuperphosphate (TSP) and liquid cattle manure compared with the control and dewatered sewage sludge (Table 5). In this study, P sources were applied at 54 to 80 lb P/acre, depending on the nitrogen content of the P source. Particulate P losses were not affected by application of the P sources. Incorporating the P sources into the soil lowered soluble P concentrations in runoff from all sources and particulate P was the dominant contributor to losses.

Table 4. Runoff P concentrations from surface-applied and incorporated P sources on a high-P soil (Kleinman et al., 2002).

Treatment	Surface-applied		Incorporated
	Soluble P (DRP)	Total P	Total P
	---------- ppm ----------		
Control	0.2a	4a	5a
Fertilizer (DAP)	13b	20b	5a
Dairy manure	2c	3.5a	9b
Poultry manure	11b	21b	7ab
Swine manure	14b	16b	7ab

Table 5. Effect of surface-applied P sources on P in natural runoff (Withers et al., 2001).

Treatment	Cumulative load		Total P (TP)	DRP as a % of TP
	Soluble P (DRP)	Particulate P		
	---------- mg/plot ----------		ppm	
Control	5	19	0.89	24
Fertilizer (TSP)	63	19	4.79	74
Cattle Manure	62	26	3.99	62
Dewatered	8	25	1.19	28

In both of the studies summarized above, Kleinman et al. (2002) and Withers et al. (2001) noted that P runoff losses were related to the water-soluble P content of the P source applied. Similar observations emerged from a recent simulated rainfall runoff study with three manures conducted at the University of Wisconsin Arlington Research Station in 2004 (Andraski and Bundy, 2004, unpublished data). In this study, poultry manure from an egg laying operation, and liquid and semi-solid dairy manures were surface-applied to corn residue at a uniform rate of 60 lb P_2O_5/acre (first-year available P) and runoff from simulated rainfall was collected and analyzed. Results showed that runoff volumes and soluble P concentrations with semi-solid and liquid dairy manures were higher than with the poultry manure (Table 6), and that all P sources increased P concentrations compared to the control. Runoff soluble P concentrations ranged from 0.22 to 4.72 ppm and followed the order: no manure < poultry < dairy slurry < dairy semi-solid. Runoff total P concentrations ranged from 1.36 to 8.51 ppm and followed the order: no manure = poultry < dairy slurry = dairy semi-solid. Treatment effects were the same for soluble and total P loads and followed the same order as runoff total P concentrations. Water extractable P application rates in the three manures were significantly different and were well correlated with soluble P concentrations in runoff. These results suggest that water extractable P content of manures may provide an

improved method of assessing the risk of P losses from various P sources especially manures from different animal species and handling practices.

Table 6. Phosphorus in simulated rainfall runoff from various manures and manure handling practices, Arlington WI, 2004.

Manure	Runoff volume	P applied		Soluble P		Total P	
		Avail. P_2O_5	WEP[1/]	Conc.	Load	Conc.	Load
	mm	------- lb/acre --------		ppm	g/ha	ppm	g/ha
Control	9b	0	0	0.22d	19b	1.36b	130b
Poultry 2.7 t/acre	7b	60	9	1.24c	88b	2.60b	181b
Dairy semi-sol. 31.1 t/acre	20ab	60	27	4.72a	1031a	8.51a	2086a
Dairy liquid 17,340 gal/acre	35a	60	24	3.42b	1260a	6.88a	2463a

[1/] WEP = water extractable P

Summary

Phosphorus in manures can have either greater or lower plant availability than fertilizer P. Dairy manures usually have lower availability than fertilizer P while swine manures may have greater availability. The relative availability of P in manures depends on several factors including soluble or water extractable P content, organic P mineralization rates, and reaction of manure constituents with soil or P. Results from long term comparisons of fertilizer or manure P sources show no clear differences in terms of crop productivity. However, the amounts and forms of P in soils can be influenced by long-term additions of various P sources. Experiments with dairy manure, fertilizer, and biosolids indicates that soil test P is increased more by fertilizer than by dairy manure or biosolids, and the increase may be related to the water soluble P content of the various P sources. Observed differences in P runoff losses with various P sources are often due to placement method, dry matter content of the P source, and water extractable P application rate. Substantial differences in runoff P losses can occur due to animal species and manure handling variables. Water extractable P appears to provide useful information for assessing P runoff losses from land-applied manures.

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