PLANT AVAILABILITY OF PHOSPHORUS IN SWINE SLURRY AND CATTLE FEEDLOT MANURE

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ABSTRACT

To utilize manure phosphorus (P) for crop production, the amount of P that is mineralized and subsequently becomes plant available needs to be determined. A laboratory incubation study was conducted to determine P release and availability from applied swine and cattle feedlot manure in three soils. Treatments included incubation temperature (11, 18, 25, and 32 ºC), P source (swine and beef cattle feedlot manure, synthetic fertilizer, and no manure or fertilizer), water regime [constant 60% water filled pore space, (WFPS), and variable water content which included four dry down cycles of 60% to 30% WFPS], time of incubation, and soils (Catlin silt loam, Sharpsburg silty clay loam, and Valentine fine sand). Incubation temperature was not a significant factor in manure P release in this study. Constant water regime resulted in more P mineralization from cattle feedlot manure than variable soil water content (P = 0.06). No significant effect of water regime was observed for the swine slurry. At the low synthetic P fertilizer application rate of 6 ug g^{-1}, about 12 kg P ha^{-1}, none of the applied P remained available in the Catlin soil while about 1/3 remained plant available in the Sharpsburg soil and 2/3 in the Valentine soil. Phosphorus availability was 81 to 100 % of applied cattle manure P (85% in field observation) and 62 to 100% of swine slurry P in the three soils. Phosphorus availability in the Sharpsburg soil was 100% of P in both manure types. Phosphorus availability from manure is high and manure can be used similar to inorganic P fertilizer (100% available) in soils with adequate P or in areas susceptible to P loss in runoff. In P deficient soils, a P availability of 70% should be used.

INTRODUCTION

To provide P needs of a crop, the amount of P mineralized following manure application needs to be determined. Phosphorus in manure is in various forms but is mostly inorganic (Sharpley and Moyer, 2000; Eghball, 2003) indicating that P availability following application should be high if the inorganic P converts to plant available form after application. Based on the soil test P changes and plant P uptake one year after application, P availability in the first year after application was 85% for beef cattle feedlot manure and 73% for composted feedlot manure (Eghball et al., 2002). Slightly lower P availability from composted than noncomposted manure indicates chemical reaction of P during composting which caused P to become less plant available. Motavalli et al. (1989) found that P availability from injected dairy manure ranged from 12 to 89% based on P uptake. The low P availability in this study was due to a small P response from applied manure P. In a field study, Wen et al. (1997) found that 69% of composted manure P was plant available. The objective of this study was to evaluate the effects of temperature and soil water regime on P mineralization and availability from cattle feedlot manure and swine slurry in three different soils.

MATERIALS AND METHODS

Variables included in this experiment were soil texture, P source (beef feedlot manure, swine manure slurry, and no P control), temperature (soils incubated at 11, 18, 25, and 32 °C for beef manure and 18, 25, and 32°C for swine slurry), and soil water regime (soil moisture maintained at 60% WFPS or soil cycled through four wet-dry cycles from 60% to 30% WFPS before being wetted again). Soils were incubated at the manure application rate equivalent to 350 kg N ha^{-1}. Phosphorus application rate was 67 kg P ha^{-1} for the cattle feedlot manure and was 116 kg P ha^{-1} for the swine slurry. The experimental design was a split-split plot in a completely randomized design with three replications. Incubation temperature was the main plot, soil was the subplot, and manure and water regime combinations were randomly assigned within each soil as the sub-subplots.

Three soils having different textures were used in this study. The Catlin loam had a C concentration of 28.6 g kg^{-1}, the Sharpsburg silty clay loam had a C concentration of 18.0 g kg^{-1}, and Valentine fine sand had a C concentration of 9.0 g kg^{-1}. Soils were air dried and passed through a 2mm sieve. Sand, silt, and clay contents were 160, 640, and 200 kg kg^{-1} for Catlin, 80, 620, and 300 kg kg^{-1} for Sharpsburg, and 940, 30, and 30 kg kg^{-1} for the Valentine soil, respectively. Soil (250 g) was placed into 2-liter jars. Manure was added to jars in the manure amendment treatment. Distilled water was added to all jars to wet the soil to 60% WFPS. The soil in each jar was than packed to the chosen bulk density (1.2 Mg m^{-3} for the Catlin soil, 1.3 Mg m^{-3} for the Sharpsburg soil, and 1.4 Mg m^{-3} for the Valentine soil). A lid having a 1.2 cm diameter hole (to allow aeration and evaporation) was placed on each jar. Jars were weighed every two or three days and distilled water was added as needed to jars in the constant moisture regime to maintain 60% WFPS. Jars in the wet-dry regime were allowed to dry to 30% WFPS before distilled water was added to return the soil moisture to 60% WFPS. Soil in each jar was sampled on the day the experiment was set up (T0) and at the end of each drying cycle (T1-T4) for a total of 5 samplings.

The term "phosphorus mineralization" used in this paper includes a combination of release of manure inorganic P and mineralization of organic P to plant available forms with time. Some of the mineralized P is expected to be adsorbed by the soil with time. In another laboratory incubation study, synthetic P fertilizer was used to determine the quantity of P that becomes unavailable with time. Phosphorus fertilizer (K_2HPO_4) was applied to soils in 27 two-liter jars (9 jars per soil) at rates of 0, 6, and 68 mg P kg^{-1} soil. The soils were incubated at 25 °C and constant water content of 60% WFPS. The soils were sampled approximately every two weeks. The percentages of P fertilizer remaining plant available were used to approximate the P availability from swine and cattle manure assuming similar amounts of P becoming unavailable from the manure treatments as from the 68 ug g^{-1} P fertilizer rate. The Bray and Kurtz No. 1 (BKP) increase of manure treated soil was deducted from that of the soil receiving no manure and the result was used to approximate manure P plant availability. Since no significant effect ($P > 0.05$) of temperature was observed for BKP for either manure type, calculations were made across all temperatures for each manure type at the constant soil water regime treatment.

Results are presented separately for each manure type since swine slurry did not have the 11 °C temperature treatment. Analysis of variance was performed for each manure type using the Mixed Models procedure of SAS. In these analyses, sampling times were considered as repeated measures. A probability level ≤ 0.05 was considered significant.

RESULTS AND DISCUSSION

Soil P Level

Swine Slurry

Incubation time, soil, and manure application influenced soil BKP concentrations (Table 1). Incubation times are defined as T0 to T4 where T0 is when soil samples were taken on the day the experiment started and T1 to T4 are sampling cycles when the soil in the varying water content treatment reached 30% WFPS. The BKP level remained the same for T0 to T2 but decreased for T3 and T4 suggesting adsorption of P by soil constituents with time of contact (Table 1). As expected, swine slurry application increased BKP concentration in the soil (Table 1). Water regime did not significantly influenced soil BKP concentration indicating that the range of soil water content (30 and 60% WFPS) was probably not wide enough to make a significant difference in P mineralization when swine slurry was applied. Also, incubation temperature was not a significant factor in P mineralization. The manure by soil interaction indicated that the soil BKP increase due to manure application was greatest for the Valentine soil and was least for the Catlin soil (Fig. 1) reflecting less P adsorption in the Valentine fine sand soil. The increase in soil BKP concentration due to manure application was least for the Catlin soil, even though it had the highest initial soil test P level (Table 2) indicating great P adsorption capacity in this soil.

Beef Cattle Feedlot Manure

Similar to swine slurry, incubation time, soil, and manure application influenced BKP concentration in the soil that received beef cattle feedlot manure (Table 1). The BKP values increased with incubation time up to T2 after which the soil P level decreased. Manure application increased soil BKP concentration. Constant water regime resulted in higher soil BKP concentration than variable water regime but the difference was significant at the 0.06 level. However, manure by water regime interaction indicated that there was a significant difference between constant and variable water regime for the manure treatment (68 vs. 63 mg kg^{-1} BKP, respectively) while the no manure control was unaffected by water regime (51 mg kg^{-1} for both). This indicated that P mineralization from cattle manure would be less under typical field conditions, where soil undergoes variable water content.

Temperature did not influence BKP concentration in the soil. However, temperature interacted with time for BKP level (Table 1 and Fig. 2a). The soil BKP concentrations increased with time for all temperatures up to T2, after which all temperatures resulted in similar soil BKP level. This once again indicated non-importance of temperature level on P mineralization after some contact time with the soil (Fig. 2a). This is probably because the increase in BKP is a function of a combination of P release from inorganic manure P pool and biological mineralization of manure organic P. Temperature was not a significant factor since the time by soil interaction for BKP pointed to differences among soils for P mineralization with time (Fig. 2b). The BKP level increased with time in the Catlin soil but remained constant for the Valentine soil. In the Sharpsburg soil, there was an increase in soil BKP level from T0 to T2 beyond which, the BKP level decreased (Fig. 2b).

Table 1. Least square means for the main effects of time, temperature, soil, manure, and water regime on Bray and Kurtz No. 1 P (BKP) in soil receiving beef cattle feedlot and swine slurry.

Variable	Swine	Beef Cattle
	-- mg kg^{-1} --------------------------------------	
Time[†]		
0	63.1	43.8
1	62.5	55.2
2	60.9	67.8
3	60.4	60.0
4	58.2	63.6
$LSD_{0.05}$	2.4	4.1
Soil		
Catlin	126.3	128.3
Sharpsburg	30.9	26.9
Valentine	25.8	19.1
$LSD_{0.05}$	2.8	3.7
Temperature (°C)		
11	not used	57.4
18	59.6	59.0
25	61.8	56.6
32	61.6	59.4
$LSD_{0.05}$	NS[‡]	NS
Manure treatment		
Manure	74.1	65.2
No manure	47.9	51.0
$LSD_{0.05}$	1.9	2.5
Water regime[#]		
Constant	61.6	59.3
Varying	60.4	56.9
$LSD_{0.05}$	NS	NS

[†]Time 0 is when soil samples were taken on the day the experiment started and 1 to 4 are sampling cycles when the soil in the varying water content treatment was reduced from 60% to 30% water filled pore space.

[‡]NS indicates an LSD with probability level > 0.05 level.

[#]Constant is when soil water content was kept at 60% water-filled pore space and varying is when water content was allowed to fluctuate between 30% and 60% water-filled pore space.

Phosphorus Availability

The percentages of applied P fertilizer remaining plant available with time of incubation are given in Table 2. At the low P application rate of 6 ug g^{-1}, only 4 and 34% of the added P in the Catlin and Sharpsburg soils remained plant available by the end of the incubation period (T4), respectively. This application rate is equivalent to 12 kg P ha^{-1} (typical sidedress P application rate) if applied to the surface 15 cm soil. If mixed well with the soil, only a small portion of the applied P at this low application rate will be plant available even shortly after application. In contrast, the percentage of applied P fertilizer remaining plant available in the

Valentine soil by T4 of the incubation period was 73% at the low rate of 6 ug P g^{-1} (Table 2). When P fertilizer application rate was increased to 68 ug g^{-1}, which is similar to typical manure P application, more than 61% and 79% of the applied P remained plant available in the Catlin and Valentine soils, respectively (Table 2). Only in the Sharpsburg soil, where the initial soil P level was 1/7 of the Catlin soil, the fraction of applied P fertilizer remaining plant available decreased with time to 38% by the end of the incubation period (T4).

Table 2. The percentages of applied synthetic P fertilizer remaining plant available in three soils following incubation at two application rates.

Soil	Initial soil P	P rate	T0†	T1	T2	T3	T4
	mg kg^{-1}	ug g^{-1}	------------------------------ % ------------------------------				
Catlin	119.1	6	45 ± 22‡	0 ± 68	0 ± 64	0 ± 48	4 ± 45
Catlin	119.1	68	49 ± 7	90 ± 9	80 ± 4	65 ± 11	61 ± 5
Sharpsburg	16.3	6	40 ± 10	44 ± 1	29 ± 4	25 ± 8	34 ± 6
Sharpsburg	16.3	68	55 ± 12	68 ± 9	48 ± 2	52 ± 4	38 ± 4
Valentine	9.3	6	71 ± 4	66 ± 4	68 ± 8	64 ± 2	73 ± 11
Valentine	9.3	68	75 ± 2	83 ± 1	82 ± 5	74 ± 1	79 ± 3

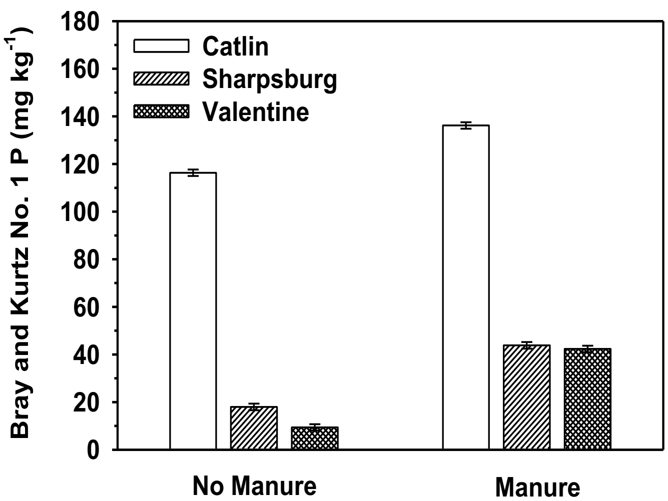
†Time T0 is when soil samples were taken on the day the experiment started and T1 to T4 are sampling about every two weeks.
‡The values after ± are standard errors.

Phosphorus availability from beef cattle feedlot manure was high (> 81%) for all three soils by the end of incubation period (Table 3). Eghball et al. (2002) found that P availability from applied cattle feedlot manure was 85% in the first year after application in a field experiment. The values determined in the laboratory incubation are consistent with these field observations for the cattle feedlot manure. Phosphorus availability from swine slurry was also high (> 62%) in all three soils.

Table 3. The percentages of applied manure P that becomes plant available in three soils following incubation for four wet-dry cycles.

	Beef cattle feedlot manure				Swine slurry			
Soil	T1†	T2	T3	T4	T1	T2	T3	T4
	------------------- % -------------------							
Catlin	53 ± 28	36 ± 16	94 ± 21	127 ± 63	36 ± 8	35 ± 10	52 ± 20	62 ± 6
Sharpsburg	121 ± 68	55 ± 14	113 ± 46	86 ± 24	63 ± 12	78 ± 15	83 ± 17	115 ± 20
Valentine	72 ± 15	69 ± 12	24 ± 11	81 ± 26	79 ± 5	67 ± 5	77 ± 5	75 ± 9

†Time T1 to T4 are sampling cycles when the soil in the varying water content treatment was reduced from 60% to 30% water filled pore space.
‡The values after ± are standard errors.



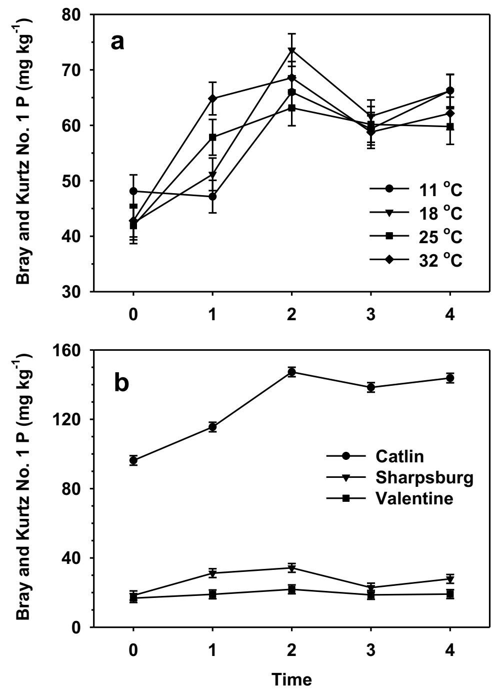


Fig. 1 (left). Phosphorus levels in three soils incubated with either swine slurry or no manure averaged across sampling times and water regimes.

Fig. 2 (right). Soil test P levels as influenced by incubation temperature and sampling times (a) and by soil and sampling time (b) for the beef cattle feedlot manure study. Time T0 is when soil samples were taken on the day the experiment started and T1 to T4 are sampling cycles when the soil in the varying water regime treatment reached 30% water filled pore space.

SUMMARY AND CONCLUSIONS

Temperature, soil moisture, soil properties, and manure characteristics influence mineralization of nutrients in manure. Temperature was not a significant factor in mineralization of P from cattle and swine slurry. Constant water regime resulted in greater cattle manure P mineralization in the soil than variable soil water content. No significant effect of water regime was observed for P mineralization from swine slurry. Phosphorus availability from beef cattle feedlot and swine slurry was 62 to 100% of total manure P. Phosphorus in manure can be used as an excellent P source for deficient soils. It seems that the high inorganic P fraction in manure (>70%) converts to plant available P in a short period after application. The P in manure can then be used similar to synthetic P fertilizer (100% available) in areas with adequate soil P for crop production to avoid soil P accumulation. In P deficient areas, an estimation of about 70% availability from manure should be used. The amount of P available in the second, third, and fourth year after application can be determined by testing soil for available P. The high plant availability of manure P can increase the economic hauling distance for manure application. In some circumstances it may be essential that P-based manure application be used to avoid excess P in runoff.

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