Phosphorus Amounts and Distribution in Soil as Influenced by Five Years of Repeated Addition of Liquid Swine Manure and Solid Cattle Manure in East-Central Saskatchewan

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INTRODUCTION

Land application of livestock manure is usually considered for N needs of crops (Gburek et al. 2000). Although the N:P ratio in animal manures and effluent exhibit wide variations due to different sources and stockpiling, the manure N:P ratio is often smaller than the N:P uptake ratio of most crops (Gburek et al. 2000). It is reported that the average N:P ratio in manure from various cattle feedlots was around 2.7 (Watts et al., 1994; Eghball et al., 1997), while N:P grain uptake ratios in winter wheat, corn, and grain sorghum were 4.5, 5.9, and 4.5 respectively (Gilbertson et al., 1979). Thus, accumulation of P in soils may increase the risk of P escape from the soil system before it is used by subsequent crops (Sharpley et al., 1994; Lennox et al., 1997; Schoenau et al., 1999; Sims et al. 2000).

A single application of swine manure at either low and high rates in Saskatchewan was found to have no significant impacts on increasing labile P forms in a Black Chernozemic soil (Qian and Scheonau. 2000a). However, after several years of application of animal manures, especially cattle manure, concerns over P loading have been brought to the attention of the livestock industry in Western Canada. Numerous reports show that long-term use of cattle manures and fertilizer P sources alter the amounts and distribution of P in the various pools of soil P, especially at higher P rates (Dormaar and Sommerfeldt, 1986; McKenzie et al., 1992a; Dormaar and Chang, 1995; Zheng et al, 2001). However, few studues have examined the effects of liquid swine manure addition on P distribution in prairie soils. The objective of this study was to evaluate and compare the effects of repeated applications of solid cattle manure and liquid swine manure on the amounts and distribution of P among various chemically distinguishable labile and stable P fractions in a Black Chernozemic soil in East-Central Saskatchewan.

MATERIALS AND METHODS

Soil and manure used

Soils used in this study were collected from swine and cattle manure field trials in east-central Saskatchewan near Dixon, where the soil type is a Black Chernozem (Cudworth Association) of loamy texture (Mooleki et al. 2001). In the field trials, described in detail by Mooleki et al. (2001), swine and cattle manures have been applied at low, medium and high rates every year since the fall of 1996 (Schoenau et al., 1999). Treatments sampled for the P distribution study included the control and manure applied at three different rates (low, medium and high) equivalent to approximately 100, 200 and 400 kg total N ha^{-1}, and urea application at 50, 100 and 200 kg N ha^{-1} as comparisons.

Table 1. Some characteristics of soil used in the experiment.

Soil Association	Sand	Clay	pH	Total C	Extractable N	Extractable P
	--- % ---			%	--- mg kg^{-1}---	
Cudworth (Black Chernozem)	31	24	7.3	2.9	12.8	6.9

Soil were sampled from each plot (0-15 cm) after crop harvest in the fall of 2001. Three cores from each plot were taken randomly and mixed thoroughly to get a composite sample. Visible crop residues were removed. After being shipped to the lab, soil samples were further air-dried, crushed, passed through 2-mm sieve, mixed, and stored at room temperature before analysis. Basic soil characteristics were measured on soil samples from the control plots that had never received manure. Texture was determined using particle-size analysis with pipette method (Gee and Bauder, 1986). The pH was measured using saturated paste of the soil samples (Rhoades, 1982). Total C was measured by dry combustion method using Leco carbon analyzer (LECO Corporation, 1987). Available N (NH_4- and NO_3-N) was extracted with 2 *M* KCl and measured colorimetrically using a Technicon Autoanalyzer II (Keeney and Nelson, 1982). The amount of available P was determined by a modified Kelowna (KM) method (Qian at al., 1994). The selected soil characteristics are summarized in Table 1.

Table 2. Rates of total N and P added as liquid swine manure and solid cattle manure at the low, medium and high application rates from 1997 to 2001 growing seasons on Cudworth soil

Treatment	1997 N	1997 P	1998 N	1998 P	1999 N	1999 P	2000 N	2000 P	2001 N	2001 P
	---- kg ha^{-1} ----									
Swine Manure										
Low	74	7	51	3	97	7	94	3	87	3
Medium	147	14	102	6	195	14	188	6	174	6
High	295	28	204	12	390	28	376	12	348	12
N:P	11		17		14		31		29	
Cattle Manure										
Low	121	39	104	30	69	20	113	37	76	29
Medium	242	79	208	60	138	40	226	74	152	58
High	484	158	416	120	276	80	452	148	304	116
N:P	3.1		3.5		3.5		3.1		2.6	

The swine manure applied in the field was liquid effluent obtained from an agitated single-cell earthen storage unit, and cattle manure was stockpiled, homogenized cattle feedlot penning manure. Rates of nutrients applied were calculated based on nutrient content of manure measured in samples collected during application. Total N and P in the manures were measured by sulfuric acid-hydrogen peroxide digestion using a temperature-controlled digestion block (Thomas et al., 1967), followed by determination of the N and P concentration in the digest using automated colorimetry (Wall et al., 1975; Watanabe and Olsen, 1965). Rates of phosphorus applied as manure for the 1997 to 2001 growing seasons were calculated based on the concentration of manure-P measured and the application rate of manure product. The rates of total N and P as liquid swine manure and solid cattle manure at the low, medium and high application rates from 1997 to 2001 growing seasons are reported in Table 2.

Crops grown in this experiment were Argentine canola (*Brassica napus, L.*) in 1997, hard red spring wheat (*Triticum aestivum, L.*) in 1998, Hulless barley (*Hordeum vulgare, L.*) in 1999, and again Argentine canola (*Brassica napus, L.*) in 2000 and hard red spring wheat (*Triticum aestivum, L.*) in 2001.

Phosphorus Fractionation

Soil samples were sequentially extracted using a procedure described by Tiessen and Moir (1993) and depicted in Fig. 1.

We define resin P_i, $NaHCO_3$-P (P_i and P_o) as easily desorbable or labile P (Schoenau et al., 1989), NaOH-extractable P (P_i and P_o) as Fe-Al-associated P (McLaughlin., 1977; Bowman and Cole, 1978) which is considered as moderately labile P (Hedley et al., 1982) and can contribute to plant-available P (Tiessen et al., 1984), 1 *M* HCl-extractable P_i as Ca-Mg-associated P_i (Williams et al., 1971) which is primary mineral P (Tiessen et al., 1984) and generally assumed to be low availability to plants (McKenzie et al., 1992a). The conc. HCl-extractable P_i and residual P is the P that is not readily removed by dilute alkaline or acidic extracting solution and is considered a recalcitrant P form of very low solubility and availability with the residual P as the most resistant (Tiessen and Moir, 1993). Conc. HCl-P_o may simply come from particulate organic matter that is not alkali extractable and is occluded. Total P is the sum of all the above forms of P_i and P_o. Soil total P was determined using acid digestion (Thomas et al., 1967).

Statistical Analyses

Differences in P fractions among components were examined statistically based on the least significant difference (LSD) using standard analysis of variance techniques and multiple comparison via the Walter-Duncan k-ratio procedure. Computations were performed by the GLM procedure (SAS 1985).

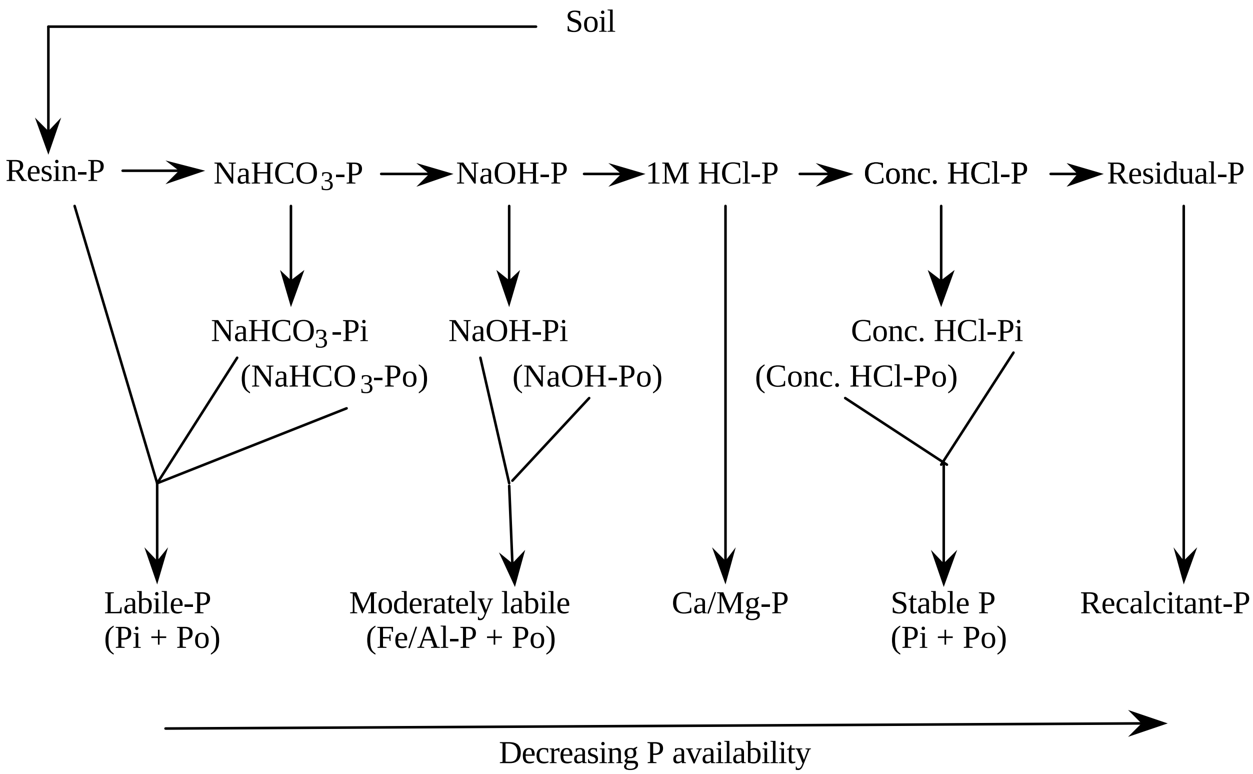

Fig. 1. Fractionation scheme for characterization of P forms in soil. Po (organic P) in each fraction is calculated by substracting Pi (inorganic P from Pt (total P) of the fraction.

RESULTS AND DISCUSSION

Phosphorus Forms

The amount of labile inorganic P extracted (resin P + $NaHCO_3$-P_i) varied from 12 to 94 mg kg^{-1} and represented, on average, 6% of total P. A significant increase in the proportion of total P made up by labile P was observed in cattle manure treatments (Table 3). Labile P accounted for 15% of total soil P in the high rate of cattle manure. These labile inorganic P pools (resin-P and $NaHCO_3$-P_i) correspond to the P forms loosely sorbed on the soil surface and in the case of $NaHCO_3$-P_o to the easily mineralizable organic P (Chauhan et al. 1981).

NaOH-P, especially in its inorganic form (P_i), is considered moderately labile and can contribute to plant-available P (Tiessen et al. 1984; Ivarsson 1990). Moderately labile P (NaOH-P_i and -P_o) contents were high, varying from 92 to 132 mg kg^{-1}, representing, on average, 22% of total P. However, the inorganic form only accounted for 13 to 22 mg kg^{-1} with the majority in the organic form, ranging from 79 to 116 mg kg^{-1}. NaOH-P_o represented 85% of NaOH-P_t on average, which is similar to our previous study (Qian and Schoenau 2000a) where the NaOH-P_o accounted for 77% of NaOH-P_t on average.

Table 3. Distribution of inorganic P (Pi) and organic P^z (Po) fractions in a Cudworth soil after 5 years of annual manure applications.

Treatment	Resin	$NaHCO_3$		NaOH		HCl	Conc. HCl		Residue	Total
	P_i	P_i	P_o	P_i	Po	P_i	P_i	P_o	P	P dg^y
	mg P kg^{-1} soil									
Swine manure										
Control	12	8	6	21	109	174	55	63	80	610
SM^x low	11	7	8	19	106	114	53	82	83	563
SM medium	6	6	8	14	97	143	60	88	85	565
SM high	9	8	7	16	95	158	62	97	84	621
Urea low	8	7	6	15	105	155	55	96	89	568
Urea medium	7	7	9	17	114	162	56	103	86	633
Urea high	7	6	8	15	116	136	56	101	93	570
LSD 0.05	4	2		7		44	7		10	74
Pr. > F	0.06	0.19		0.42		0.17	0.23		0.51	0.28
Cattle manure										
Control	1612	7	14	103	149	59	73	87	610	
CM^w low	35	15	8	21	105	154	65	56	92	607
CM medium	49	19	9	22	109	182	67	62	86	673
CM high	67	27	9	22	84	216	67	66	85	698
Urea low	10	10	9	15	102	193	65	64	81	618
Urea medium	9	10	9	13	79	208	65	70	84	623
Urea high	19	11	11	18	84	170	64	67	88	607
LSD 0.05	14	3		9		40	7		10	41
Pr. > F	<0.01	<0.01		0.25		0.02	0.31		0.20	<0.01

[Z]No statistics were conducted as the values of P_o are not measured directly but calculated as P_t - P_i.
[y]P dg = total P determined by acid digestion.
[x]SM = Swine manure, [w]CM = Cattle manure, [v]Ctr. = Control, and [u]U = Urea.

More stable P (dilute HCl-, concentrated HCl- and residual-P) represented, on average, 71% of the total P. The total P recovery from sequential extraction ranged from 86 to 95%.

Effect of Manure and Urea on Total P in Soil

Soil total P was not significantly increased by the addition of urea or by the additions of swine manure (Table 3). The reason for limited response of total P concentration to swine manure addition is because of the low amount of P added as swine manure as shown in Table 2. Soil total P was increased by the addition of cattle manure after 5 years of repeated application; however, significant increases in total P were only observed in the medium and high rate treatments (Table 3). Long-term application of cattle manure leads to accumulation of P in the soil. In a study in which cattle manure (wet) was applied every year at a rate of 30 Mg ha^{-1} yr^{-1} for 16 years, Whalen and Chang (2001) reported a total of 1.6 Mg ha^{-1} P from manure was added to the soil, and 1.2 Mg P ha^{-1} accumulated in the soil to a 150 cm depth. In our study, the 3 application rates were based on dry weights of manure added at 10 (low), 20 (medium) and 40 (high) Mg ha^{-1}, which is equal to 23, 47 and 93 Mg ha^{-1} (wet wt). Our results showed that at the low rate, a cumulative input of 155 kg P over 5 years did not lead to measurable increases in total P in the soil. With the medium rate, the cumulative input increased to 311 kg P, and thus an apparent increase in total P of 72 kg P ha^{-1} was observed in the surface soil. When cattle manure rate increased to 40 Mg ha^{-1} (dry wt), the cumulative P input reached 622 kg and led to an apparent 99 kg P ha^{-1} increase in total P in the 0-15 cm depth. Although the proportion of manure P accumulated in the soil is much smaller than that observed after 16 years of consecutive use of cattle manure (Whalen and Chang, 2001), the trend of accumulating P in soil in this study is not insignificant as the application was over only 5 years.

Effect of Manure and Urea on P Fractions in Soil

Phosphorus fractions responded differently to the addition of manure and urea (Table 3). In general, urea addition caused a slight depletion in labile P (resin-P and $NaHCO_3$-P_i) possibly due to plant uptake and removal, and slight increase in P in recalcitrant fractions. The effect of swine manure addition was similar to urea, with a possible trend of decrease in soil P availability if swine manure with large N:P ratio continued to be used repeatedly. On the contrary, cattle manure treatments revealed significant changes in P concentration in some of the inorganic and organic P fractions as a result of repeated manure application (Table 3).

Cattle manure addition significantly increased the most labile resin extractable P, and $NaHCO_3$ extractable P (inorganic forms) over the control and urea treatment (Table 3). Such increases were enhanced by increasing the rates of application (Table 3). Among the various P fractions, the most available P (Resin-P plus $NaHCO_3$-P_i) was increased by 23, 40, and 66 mg kg^{-1}, accounting for 75, 52 and 54 % of total P accumulated in the soil, calculated as available P incremental increase per unit P surplus after repeated manure application. Zheng et al. (2001) reported smaller P accumulation in the soil after 8 years of repeated use of liquid dairy manure as compared to mineral fertilizers, but higher labile P incremental increase per unit P surplus from liquid dairy manure than from mineral fertilizers. The cattle manures used in their research had a N:P ratio ranging from 2.7 to 8.1 with an average of 4.9. In our study, the average N:P ratio is 3.2 (Table 2), which indicates why a significant increase in labile P was observed in just 5 years.

Moderately labile P (NaOH-P_i and P_o) had little change after 5 years of annual cattle manure application compared to urea fertilizer treatment and the unfertilized control. Tran and N'dayegamiye (1995) found that manure application maintained high soil NaOH-P_o forms compared with fertilizer, which was not the case in our study. This could be explained by a higher proportion of manure P in available inorganic P forms and high mineralization rates of organic P to inorganic forms in these soils (Qian and Schoenau, 2000b).

In cattle manure treatments, stable P fractions (HCl-P, conc. HCl-P_i and P_o and residual-P) were not influenced by manure application, indicating a limited proportion of manure was added or transferred to these fractions. A similar observation was also reported by McKenzie et al. (1992ab) and Tran and N'dayegamiye (1995). These results suggest the stable fractions are not significant short-term storehouses of manure P, and thus added P stays or is transferred to labile forms, which increases potential P mobility and environmental concerns. In our study, among the fractions of stable P, there is a trend of increasing P present in dilute HCl extractable P after 5 years of repeated use of manure. Overall, the total P increase in cattle manure treatments after 5 years is mainly attributed to the dilute HCl and labile P (resin and $NaHCO_3$-P) fractions. Long-term manure addition has been known to increase the P_i forms in the labile and moderately labile fractions and also increased total P content (MnKeni and MacKenzie, 1985; Dormaar and Chang, 1995; Tran and N'dayegamiye, 1995). Dormaar and Chang (1995) reported 15 to 46% of total P was present as water-extractable P_i + P_o and resin-extractable P_i after 20 years of cattle manure addition. MnKeni and MacKenzie (1985) suggested that this is due to an important cumulative effect of manure additions and a decrease in the soil P adsorption as fixation sites become saturated. In our study, the most available P (resin-P and $NaHCO_3$-P_i) accounted for more than 50% of total cattle manure P accumulated in the soil. However, this is not the case for liquid swine manure. The available phosphate measured in the liquid swine manure used in this study comprised about 70% of the total P in the manure. The swine manure had a large N:P ratio, which means that almost all the manure P could be removed by the crop, suggesting that addition of swine manure of the composition used in this study is not a concern for potential P pollution. In fact, the decreasing trend in total P implies that additional P fertilizers may be needed with continued use of swine manure in the following years. On the other hand, repeated application of large amounts of cattle manure for several years could lead to an excess amount of labile P stored in soil after crop uptake. Risk from high labile P would mainly be associated with transfer by erosion and runoff.

CONCLUSION

Repeated application of cattle manure contributes to increases in labile P. This impact is enhanced when large amounts of cattle manure are applied. However, liquid swine manure had a limited effect on increasing labile P forms measured in soil following 5 consecutive annual application at similar rates of N. Due to the large N:P ratio in the swine manure we used, a potential decrease in plant available P in soil might be observed if swine manure is applied continuously on a N requirement basis in the same field.

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