

Effect of Hog Manure on Soil Phosphorus Forms

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INTRODUCTION

Application of livestock manure can benefit crop production as a valuable source of nitrogen (Bandel and Fox 1984; Campbell et al. 1986; Chase et al. 1991). However, phosphorus is not a negligible factor as phosphorus in livestock manure may be readily used by crops (Tunney, 1981; Stewart, 1992). Generally, the rate of manure applied to the field to meet the crop nitrogen requirement in the year of application is often the first consideration. Under semi-arid conditions in the prairies, rates in excess of the crop's nutrient demand in the year of application may result in nutrients in manure in both organic and inorganic forms left over after harvest, which may pose environmental concern if nutrients escape the soil system before they are used by subsequent crops (Schoenau et al., 1999). In a scenario of repeated high rates of manure added every year, excess P is a concern as N:P ratio in manure may be lower than N:P ratio required by crop uptake. However, in the first year of application, the manure addition may not significantly increase extractable P in soils. The fate of manure P in the soil P cycle deserves attention in Saskatchewan soils.

Manure addition changes different pools of soil P, especially at higher P rates as fertilizer or manure (Campbell et al., 1986; O'Halloran, 1993). However, most of the previous studies have only reported long-term effects of several years of manure addition (Dormaar and Sommerfeldt, 1986; N'dayegamiye and Angers, 1990; McKenzie et al., 1992a; Dormaar and Chang, 1995). Information on short-term effect is needed to help understand P availability and potential P mobility in soils receiving manure for the first time, an important consideration as the swine industry expands in Western Canada. Thus, we designed an incubation experiment and used a sequential extraction technique to identify changes in P forms and assess manure P dynamics two and sixteen weeks after addition of liquid swine effluents. Urea was added at the same rate of manure N for comparative purposes.

MATERIALS AND METHODS

Soil and fertilizer sources

Soil type (association) of this study was a Cudworth loam that was selected from manure field trials near Dixon, Saskatchewan (Schoenau et al., 1999). The soil collected was from control plots that had never received manure. Soils were collected from the field (0-15 cm), air-dried, crushed, passed through 2-mm sieve and stored at room temperature. Texture was

determined by hand. Electrical conductivity (EC) and pH were measured using a 1:1 soil:water suspension (Janzen, 1993; Hendershot et al., 1993). Organic C was measured by dry combustion method using Leco carbon analyzer (LECO[®] Corporation, 1987). CEC measurement was made using 1 M NH₄OAc at pH 7.0 (Sumner & Miller, 1996). The amount of available P was determined by a modified Kelowna (KM) method (Qian et al., 1994). The selected soil characteristics are summarized in Table 1.

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

Soil Association	Texture	pH	EC dS m ⁻¹	CEC cmol kg ⁻¹	Organic C %	Extractable Available P mg kg ⁻¹
Cudworth (Black Chernozem)	Clay loam	7.3	0.51	23.4	3.66	34

The swine manure used in this study was liquid effluent obtained from a single-cell earthen storage unit near the location where the soils were collected. Total N and P in the swine manure were measured by sulfuric acid-hydrogen peroxide digestion using a temperature-controlled digestion block (Thomas et al., 1987), followed by determination of the phosphate concentration in the digest using automated colorimetry (Wall et al., 1975; Watanabe and Olsen, 1965). To calculate the proportion of organic N in the manure, inorganic N (ammonium-N and nitrate-N) were measured colorimetrically in filtered samples extracted by KCl solution (Keeney and Nelson, 1982). Available P in the manure was assessed by shaking ion exchange resin membrane in a diluted liquid manure sample for one hour followed by colorimetric measurement (Qian et al., 1992). About 74% of the total P in the manure was extracted using the membrane technique and considered readily soluble phosphate (Table 2). Urea was used as an inorganic N source. To compare with the manure, the rates of urea N used were matched to the amounts of total N added as manure.

Table 2. Nitrogen and phosphorus contents and pH of liquid hog manure (fresh weight basis)*

Analysis	Total N	Organic N		Total P	Available P		pH
	mg kg ⁻¹	mg kg ⁻¹	% of total N	mg kg ⁻¹	mg kg ⁻¹	% of total P	

Mean	2406	1288	53.5	239	177	74	8.6
CV	8.8	16.7		49.6	4.6		

*Average of triplicate analyses

Incubation

We designed the experiment with 2 treatments (manure and urea) and 3 application rates (0, 100 and 400 mg of total N per kg of soil) with 3 replicates. The large range in rates was used to provide a large contrast in N load by manure or fertilizer addition as reported by Charles (1999) in his field trials, with 100 mg N kg⁻¹ rate representing a typical soil available N concentration in the surface layer after application at recommended rates while 400 mg N kg⁻¹ represents excessive application. Amounts of total P added as manure for the 100 N rate were 10 mg P kg⁻¹ and 40 mg kg⁻¹ for the 400 N rate. In the incubation, 40 g air-dried soil was weighed and placed in a plastic petric dish (100 x 20 mm), and pre-mixed solution of manure or urea was added into the soil to 70% of field capacity. The dishes were loosely covered with paraffin and incubated at 20°C for a total of 16 weeks. Additional water was added to compensate for any loss of moisture as required by biweekly weighing. Sequential P extraction was performed twice, once at 2 weeks and again at 16 weeks after manure addition. At each incubation time, soil samples were randomly collected, air-dried and mixed thoroughly. Moisture contents were determined and results are expressed on an oven dry basis.

Fractionation Scheme

The fractionation scheme used to determine discrete pools of soil P is the one described by Tiessen and Moir (1993). A diagrammatic representation of this scheme is given in Fig. 1. In the fractionation 0.5 g of air-dried soil was first extracted with 30 ml of deionized water and a strip of anion exchange membrane, followed sequentially by 0.5 M NaHCO₃ (pH 8.5), 0.1 M NaOH, 1 M HCl, and conc. HCl. For each extraction, the time was 16 hours in a rotation shaker. After each extraction, the extracting solution was centrifuged for 10 min at 10,000 x g at 0°C and filtered through a 0.45-µm filter. For resin extraction, the resin membrane was removed from soil suspension and shaken with 20 ml 0.5 M HCl for 16 hours in rotation shaker. Residual P was determined using acid (H₂SO₄ + H₂O₂) digestion (Thomas et al., 1967).

Inorganic P (orthophosphate) in the various soil extracts was determined colorimetrically using an ascorbic acid reduction method (Murphy and Riley, 1962). In NaHCO₃, NaOH and conc. HCl extractions, two measurements were conducted. One was to directly determine total P (P_t) contents in the soil extracts. The other was to measure P contents after soil extracts were acidified to precipitate organic matter and P contents in this acidified solution was considered as inorganic P (P_i) in this extraction. Organic P (P_o) in each extraction was calculated by the

difference between P_i and P_t in each extraction. Absorbance was determined on Beckman DU-65 spectrophotometer at a wavelength of 712 nm.

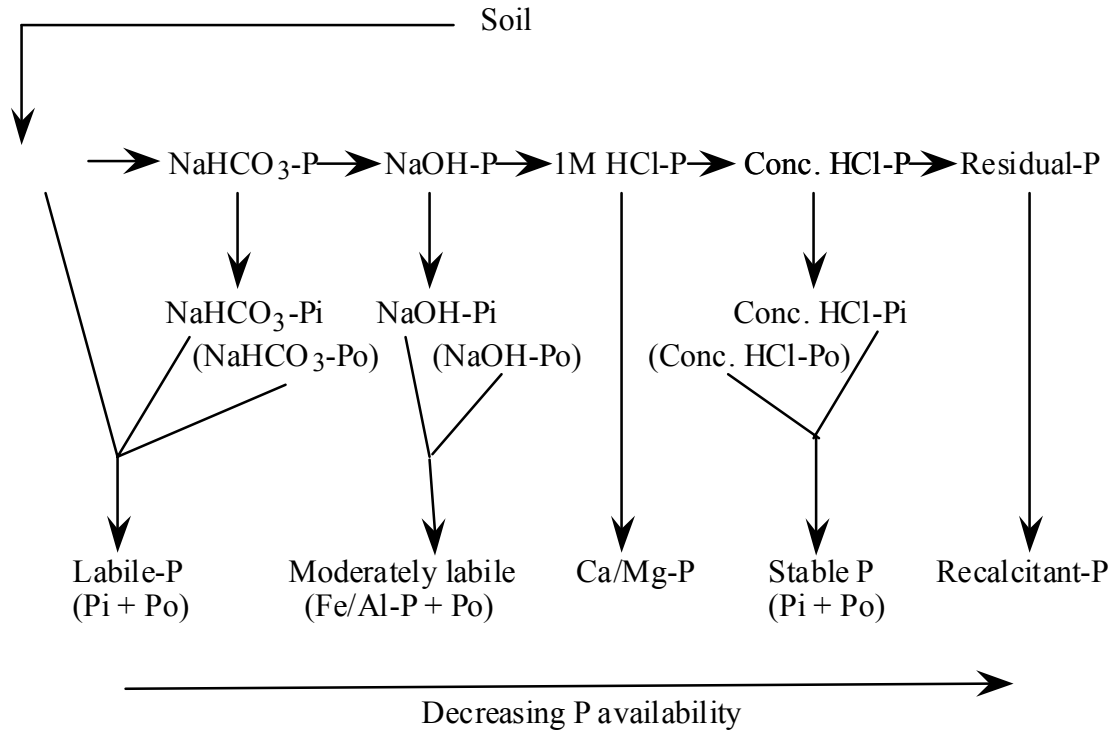


Fig.1. Fractionation scheme for characterization of P forms in soil. P_o (organic P) in each fraction is calculated by subtracting P_i (inorganic P) from P_t (total P) of the fraction.

We define resin P_i , $\text{HCO}_3\text{-P}$ (P_i and P_o) as easily removable 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., 1992b), 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 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 .

Additional analysis

Soil total P was determined using acid digestion (Thomas et al., 1967), which was used to calculate total P recovery from sequential extraction (Table 3). After the 16 weeks of incubation, extractable available P in treated soils was also determined by the KM method (Qian et al., 1994).

To measure effect of manure and urea on P supply rates in soils, ion exchange resin placement in soil was performed on soil collected at 2 and 16 weeks of incubation. Five g of soil was used each time for a "sandwich" burial for 24 hours. This was performed as follows: 5 g of soil was placed in two 7 cm² plastic caps; deionized water was added to the soil to achieve 70% of field capacity; a strip of AEM (A2000, Electra-Pure Inc., CA, USA) of 12.2 cm² was placed between the two caps; and then the "sandwiched" caps were covered with two layers of parafilm.

RESULTS AND DISCUSSION

Effect of Manure and Urea on Total P and P Fractions in Soil

Soil total P, as expected, was increased by the addition of manure, but not by addition of urea (Table 3). However, P fractions responded differently to the addition of manure and urea (Table 3 and 4). In general, there is no significant effect of urea addition on each of P fractions in either inorganic or organic forms. However, small but significant changes in P concentration were observed in some of the inorganic and organic P fractions related to manure addition (Table 4).

Table 3. Distribution of total labile, moderately labile, and stable P in a Cudworth soil two weeks and sixteen weeks after addition of manure and urea

Treatment	Labile P	Moderately Labile P	Stable P	Total P	Recovery
	----- mg P kg ⁻¹ soil -----				%
<i>Two weeks incubation</i>					
Control	63	158	471	692	97.4
Urea 100N	61	161	466	688	95.6
Urea 400N	62	164	451	677	95.4
Manure 100N-10P	63	178	455	695	96.1
Manure 400N-40P	62	169	486	717	97.2
<i>Sixteen weeks incubation</i>					
Control	65	135	489	688	97.1
Urea 100N	66	136	489	690	96.2
Urea 400N	64	145	478	687	95.9

Manure 100N-10P	65	148	482	695	96.1
Manure 400N-40P	67	153	491	711	96.5

Manure addition did not increase the most labile resin extractable P (inorganic form) after 2 and 16 weeks of incubation, but led to an increase in NaHCO₃ extractable P over the control and urea treatment at both 2 weeks and 16 weeks (Table 4). Both manure and urea led to decreases in NaHCO₃ P_o initially. This may reflect enhanced decomposition of labile organic matter by microorganisms stimulated by the added N (Eiland, 1980). This effect diminished after 16 weeks, possible due to replenishment of labile P_o from decomposition of other fractions. Overall, addition of manure P to the soil did not lead to an increase in total labile P, the sum of resin-P and NaHCO₃-P (Table 3). Other measures of available P we employed, including KM extractant (Qian et al., 1994) and ion exchange membrane *in situ* extraction for 24 hours (Qian and Schoenau, 1997), also showed that P availability was not increased by manure addition measured after 2 weeks and 16 weeks (data not shown). A similar result was found by Charles (1999) that a single manure addition had little effect on extractable inorganic P. In a recent study by Qian and Schoenau (2000), continuous extraction of soil P by membrane over 84 days in manured soils showed significantly higher cumulative P supply and plant P uptake over the period than the control. This is because continuous burial of the membrane will result in continuous membrane sorption of phosphate mobilized from organic P mineralization and mineral solubilization.

Table 4. Distribution of inorganic P (Pi) and organic P (Po) fractions in a Cudworth soil two weeks and sixteen weeks after addition of manure and urea.

Treatment	Resin	NaHCO ₃		NaOH		Dil. HCl	Conc. HCl		Residual
	P _i	P _i	P _o	P _i	P _o	P _i	P _i	P _o	P _o
----- mg P kg ⁻¹ soil -----									
<i>Two week incubation</i>									
Control	37b	20a	6.0c	39cd	120bc	217c	50c	132a	72b
Urea 100N	36ab	21ab	4.1ab	39cd	123bc	210bc	45b	131a	80bc
Urea 400N	36ab	22ab	4.3ab	42d	122bc	200bc	47bc	127a	77bc
Manure 100N-10P	36ab	25c	1.7a	39cd	139d	226cd	46bc	135a	48a
Manure 400N-40P	36ab	24bc	2.4a	36bc	133d	229d	44ab	141a	72b

Sixteen incubation

Control	36ab	21a	7.6c	32a	103a	196b	42a	165b	86c
Urea 100N	35ab	24bc	6.1c	33ab	103a	192b	46bc	167b	84c
Urea 400N	34a	23bc	7.0c	32ab	113b	185ab	44ab	167b	82bc
Manure 100N-10P	35ab	25c	5.1bc	32ab	116bc	190b	46bc	171b	75b
Manure 400N-40P	36ab	25c	6.2c	33ab	120bc	193b	46bc	173b	79bc

Mean (n=3) values followed by the same letter in the same column are not significantly different (P=0.05) according to Duncan's new multiple range test.

For moderately labile P extracted by NaOH, an increase is observed in its organic form only, both 2 weeks and 16 weeks after manure addition. The high rate of manure addition also significantly increase the dilute HCl extractable P compared to the control and urea 2 weeks after addition of manure, but not after 16 weeks. The concentrated HCl extractable P in the manure treatment was slightly but significantly higher than control after 16 weeks. Manure had no impact on all the other forms of P_i and P_o , except that manure application at the low rate significantly lowered the residual P 2 weeks and 16 weeks after incubation (Table 4). Concentrated HCl P_o increased significantly from 2 weeks to 16 weeks for all treatments as did residual P_o which may reflect humification by microorganisms over the 14 weeks of incubation. Hedley et al (1982) also showed higher residual P with incubation. These increases appeared to take place at the expense of the dilute HCl extractable P_i and moderately labile NaOH P_o .

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 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 available phosphate in the liquid swine manure used was about 70% of the total P in the manure, which means most of P from manure was labile. However, there was no increase in labile P form (resin- P_i plus NaHCO_3 P_i and P_o) in the manured soil, indicating P added from manure has entered into relatively more stable forms (moderately labile or stable P) even after only 2 weeks of incubation. Transformation of added P (phosphate) from labile to stable P fractions is commonly observed (Hooker et al., 1980; Ryan et al., 1985ab; Afif et al., 1993; Castro and Torrent, 1995). Application of P into the soil may lead to surface adsorption and precipitation of P which depress the availability of applied P (Samadi and Gikes, 1999).

In studies evaluating use of manure over the long-term, the stable P_i and P_o fractions were not significantly influenced by manure application (MnKen and MacKenzie, 1985; McKenzie et al., 1992ab; Campbell et al., 1986), suggesting the stable fractions become saturated with manure P due to long-term application, and thus added P has no place to "store" but stays in its labile form, which increases potential P mobility and environmental concerns. Changes in the distribution of P_i and P_o due to addition of P into the soil through either P fertilizer or P-containing organic by-products, e.g. swine manure, are likely to occur over a long time rather than over a short term (Richards et al., 1995). Our study suggests that potential P pollution concerns are not great in the early years of application or when the added manure P can be utilized by a crop. Potential P pollution concerns arise when large amounts of manure are applied repeatedly for several years, leading 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

Phosphorus in the liquid swine manure had no large impact on increasing labile P forms measured in soil following a single application of manure at low and high rates. Manure P, either in available or non-available form, was mostly stored in relative stable fractions in the soil. Incubation led to an increase in relative stable P fractions, especially in the organic forms. Overall, the soil examined, which has no previous history of use of manure, appears to have a relatively high capacity to fix manure P instantly. However, repeated application of manure may contribute to saturation of the fixed pool, leading to increase in labile P. Further studies are needed to determine how much P loading is required for saturation of the fixed pool of phosphorus.

ACKNOWLEDGMENT

The financial support of the Canada-Saskatchewan Agri-Food Innovation Fund is gratefully acknowledged

REFERENCES

Afit, E., A. Matar, and J. Torrent. 1993. Availability of phosphate applied to calcareous soils of West Asia and North Africa. *Soil Sci. Soc. Am. J.* 57: 756-760.

Bandel, V. A., and R. H. Fox. 1984. Management of nitrogen in New England and Middle Atlantic states. p. 677-689. In R. D. Hauck (ed.) Nitrogen in crop production. ASS, CSSA, and SSSA, Madison, WI.

Bowman, R.A. and C.V. Cole. 1978. An exploratory method for fractionation of organic phosphorus from grassland soils. *Soil Sci.* 125: 95-101.

Campbell, C. A., M. Schnitzer, J. W. B. Stewart, V. O. Biederbeck and F. Selles. 1986. Effect of manure and P fertilizer on properties of a Black Chernozem in southern Saskatchewan. *Can. J. Soil Sci.* 66: 601-613.

Castro, B. and J. Torrent. 1995. Phosphate availability in calcareous Vertisols and Inceptisols in relation to fertilizer type and soil properties. *Fert. Res.* 40: 109-119.

Charles, J. L. 1999. Soil and crop response to hog and cattle manure additions in east central Saskatchewan, MS thesis, University of Saskatchewan, Saskatoon, Saskatchewan, Canada.

Chase, C., Duffy, M. and Lotz, W. 1991. Economic impact of varying swine manure application rates on continuous corn. *J. Soil and Water Conservation.* 46: 460-464.

Dormaar, J. F. and C. Chang. 1995. Effect of 20 annual applications of excess feedlot manure on labile soil phosphorus. *Can. J. Soil Sci.* 75: 507-512.

Dormaar, J. F. and T. G. Sommerfeldt. 1986. Effect of excess feedlot manure on chemical constituents of soil under nonirrigated and irrigated management. *Can. J. Soil Sci.* 66: 303-313.

Eiland, F. 1980. The effect of manure and N, P and K fertilizers on the soil microorganisms in a Danish long-term field experiment. *Danish J. Plant Soil Sci.* 84: 447-454.

Hedley, M.J., J.W.B. Stewart, and B.S. Chauhan. 1982. Changes in inorganic and organic soil phosphorus fractions induced by cultivation practices and by laboratory incubations. *Soil Sci. Soc. Am. J.* 46: 970-976.

Hendershot, W. H., H. Lalonde and M. Duquette. 1993. Soil reaction and exchangeable acidity. In: Martin R. Carter (ed) *Soil Sampling and Methods of Analysis*. Canadian Society of Soil Science, CRC Press Inc., FL. pp. 141-146.

Hooker, M.L., G.A. Peterson, D.H. Sander, and L.A. Daigger. 1980. Phosphate fractions in calcareous soils as altered by time and amounts of added phosphate. *Soil Sci. Soc. Am. J.* 44: 269-277.

Janzen, H. H. 1993. Soluble salts. In: Martin R. Carter (ed) *Soil Sampling and Methods of Analysis*. Canadian Society of Soil Science, CRC Press Inc., FL. pp. 161-166.

Keeney, D. R. and D. W. Nelson. 1982. Nitrogen-inorganic form. In: C. A. Black et al. (ed) *Methods of Soil Analysis, Part 2. Agronomy 9:643-698*. Am. Soc. Agron. Inc. Madison, WI.

LECO[®] Corporation. 1987. Instruction manual for CR-12 carbon system. St. Joseph, MI. USA. 59p.

MacLaughlin, J.R., J.C. Reyden and G.K. Syers. 1977. Development and evaluation of a kinetic model to describe phosphate sorption by hydrous ferric oxide gels. *Geoderma* 18: 295-307.

McKenzie, R. H., J. W. B. Stewart, J. F. Dormaar and G. B. Schaalje. 1992a. Long-term crop rotation and fertilizer effects on phosphorus transformations: I. In a Chernozemic soil. *Can. J. Soil Sci.* 72: 569-579.

McKenzie, R. H., J. W. B. Stewart, J. F. Dormaar and G. B. Schaalje. 1992b. Long-term crop rotation and fertilizer effects on phosphorus transformations: I. In a Luvisolic soil. *Can. J. Soil Sci.* 72: 569-579.

MnKeni, P.N.S. and A. F. MacKenzie. 1985. Retention of ortho- and polyphosphates in some Quebec soils as affected by added organic residues and calcium carbonate. *Can. J. Soil Sci.* 65: 575-585.

Murphy, J. and J.P. Riley. 1962. A modified single solution method for determination of phosphate in natural waters. *Anal. Chim. Acta* 27: 31-36.

N'dayegamiye, A. and D. A. Angers. 1990. Effects de l'apport prolonge de fumier de bovins sur quelques proprietes physiques et biologiques de'un loam limoneux Neubois sous culture de mais. *Can. J. Soil Sci.* 70: 259-262.

O'Halloran, I. P., J. W. B. Stewart and R. G. Kachanoski. 1987. Influence of texture and management practices on the forms and distribution of soil phosphorus. *Can. J. Soil Sci.* 67: 147-163.

Qian, P. and J.J. Schoenau. 1997. Recent developments in use of ion exchange membranes in agricultural and environmental research. *Recent Res. Devel. in Soil Sci.* 1: 43-54.

Qian, P. and J.J. Schoenau. 2000. Effect of swine manure and urea on soil phosphorus to canola. *J. Plant Nutr.* (in press)

Qian, P., J. J. Schoenau and W. Z. Huang. 1992. Use of ion exchange membrane in routine soil testing. *Commun. Soil Sci. Plant Anal* 23: 1791-1804.

Qian, P. J. J. Schoenau and R. E. Karamanos. 1994. Simultaneous extraction of available phosphorus and potassium with a new test: A modification of Kelowna extraction. *Commun. Soil Sci. Plant Anal.* 25: 627-636.

Ryan, J., D. Curtin, and M.A. Cheema. 1985a. Significance of iron oxides and calcium carbonate particle size in phosphorus sorption by calcareous soils. *Soil Sci. Soc. Am. J.* 49: 74-76.

Ryan, J., H.M. Hasan, M. Bassiri, and H.S. Tabbara. 1985b. Availability and transformation of applied phosphorus in calcareous soils. *Soil Sci. Soc. Am. J.* 49: 1215-1220.

Richards, J.E., T.E. Bates, and S.C. Sheppard. 1995. Changes in the forms and distribution of soil phosphorus due to long-term corn production. *Can. J. Soil Sci.* 75: 311-318.

Samadi, A. and R.J. Gikes. 1999. Phosphorus transformations and their relationships with calcareous soil properties of Southern Western Australia. *Soil Sci. Soc. Am. J.* 63: 809-815.

Schoenau, J.J., J. Charles, R. Wen, P. Qian and G. Hulgren. 1999. Swine effluent versus cattle manure: effects on plant nutrition and growth. pp. 59-70 in *Proceeding 1999 Soil and Crops Workshop* University of Saskatchewan, Saskatoon, Saskatchewan

Schoenau, J.J., J.W B. Stewart and J.R. Bettany. 1989. Forms and cycling of phosphorus in prairie and boreal forest soils. *Biogeochemistry* 8: 223-237.

Stewart, B. A. 1992. Effect of animal manure on soil physical and chemical properties. In: National livestock, Poultry, and Aquaculture waste Management, Proceedings of the National Workshop. J. Blake, J. Donald, and W. Magette (eds). USDA Extension Service, Water Quality Initiative Team: ASAE Publication 03-92. pp.149-154.

Sumner, M. E. and W. P. Miller. 1996. Cation exchange capacity and exchange coefficients. pp. 1201-1229. In D. L. Sparks (ed). Methods of Soil Analysis, Part 3 - Chemical Methods. SSA. Madison. WI

Thomas, R., R. W. Sheard and I. P. Moyer. 1967. Comparison of conventional and automated procedures for nitrogen, phosphorus and potassium analysis of plant material using a single digest. Agron. J. 99: 240-243.

Tiessen, H. and J.O. Moir. 1993. Characterization of available P by sequential extraction. pp.75-86. In M.R. Cater Ed., Soil Sampling and Methods of Analysis. Lewis Publishers. Boca Raton, FL.

Tiessen, H., J.W.B. Stewart, C.V. Cole. 1984. Pathways of phosphorus transformations in soils of differing pedogenesis. Soil Sci. Soc. Am. J. 48: 853-858.

Tran, T. S. and A. N'dayegamiye. 1995. Long-term effects of fertilizers and manure application on the forms and availability of soil phosphorus. Can. J. Soil Sci. 75: 281-285.

Tunney, H. 1981. An overview of the fertilizer value of livestock wastes. In: Livestock Wastes: A Renewable Resource. The Proceedings of the 4th International Symposium on Livestock Wastes. Amer. Soc. Agric. Engineers: St Joseph, MI. pp.181-184.

Wall, L. L., C. W. Gehrke, T. E. Neuner, R. D. Cathey and P. R. Rexnord. 1975. Cereal protein nitrogen: Evaluation and comparison of four different methods. J. Assoc. Off. Anal. Chem. 58: 811-817.

Watanabe, F. S. and S. R. Olson. 1965. Test of an ascorbic acid method for determining phosphorus in water and NaHCO₃ extracts from soil. Soil Sci. Soc. Am. Proc. 29: 677-678.

Williams, J.D.H., J.K. Syers, R.F. Harris and D. E. Armstrong. 1971. Fractionation of inorganic phosphate in calcareous lake sediments. *Soil Sci. Soc. Am. J.* 35: 250-255.