Long-Term Manure Impact on Soil Nutrient Status and Surface Water Quality

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Abstract

Manure increases the solubility of P in soils, whether applied once or repeatedly. Long-term application of manure often results in the build-up of soil P to the point that a critical degree of soil P saturation is reached. Although this is good in terms of crop yield potential, the risk of P transfer from soil to water bodies may increase. Areas characterized by a high density of confined livestock operations are more at risk than others. Several modes of transport can result in P transfer from soils to waters. Results from studies conducted in the Prairies indicate that the calcareous nature of the soils does not preclude the downward movement of P deep into the soil profile. Movement of P will probably be accentuated by irrigation or incidental flooding. Overland transport by wind and water probably dominates in the Prairies, but subsurface transfer by lateral flow or seepage may also contribute to the load of P reaching water bodies. Areas most at risk can be identified by the Phosphorus Index (PI). However, the PI's presently in use in Quebec and Ontario should be adapted to the reality of Prairie soils. A multiplicative index composed of transport, charge, and site management components may be useful to identify the areas most at risk and to identify practices that may be detrimental or positive to water quality.

Introduction

Phosphorus is known to accumulate in soils when applied in excess of crop exports, especially in areas of high density livestock confinement operations (Mozaffari and Sims, 1994, Simard et al. 1995, Whalen and Chang 2001). This accumulation is accompanied by increases in soil-test P and degree of soil P saturation (Simard et al. 1995, Zheng et al. 2001). Significant contributions of soil P to surface water P contamination by surface (Sharpley et al. 2000) and subsurface pathways (Breeuwsma and Silva 1992) have been observed in such areas. This results in eutrophication and impaired water quality, thereby decreasing water quality for fisheries, recreation, the farm industry, and drinking (USEPA 1996).

A large proportion of the studies on the long-term impact of manure on soil P accumulation and the risk of transfer to surface waters have been conducted on acidic soils (Beauchemin and Simard 1999). The soils of the Prairies tend to be more alkaline than acidic since they are mostly developed from calcareous parent materials (Clayton et al. 1977). Nevertheless, a few studies are available on the impact of repeated manure application on calcareous soils (Campbell et al. 1986, Eghball et al. 1996, Haygarth et al. 1998, Whalen and Chang 2001, McDowell et al. 2001). This manuscript will report some work conducted on calcareous soils.

The use of multiple factor index procedures to assess the risk of contamination of surface waters by soil P has generated a lot of interest in North America. "*This index is intended as a tool for field personnel to easily identify agricultural areas or practices that have the greatest potential to export P and allow farmers more flexibility in developing remedial strategies*" (Sharpley and Tunney, 2000). Some of the Canadian approaches will be presented (Bolinder et al. 1998, OMAFRA 2000) along with a validation of the P index with data from a long-term experiment on the impact of hog liquid manure (Simard et al. 2001).

Some definitions

Soil P reaches surface waters by either surface or subsurface pathways (Ryden et al. 1973, Haygarth and Sharpley 2000). The modes of transfer may be either dissolution (e.g. leaching), incidental (e.g. storm flow) or physical (e.g. erosion). The overland flow is the part of the total rainwater or snowmelt which flows over the land surface to stream channels. The subsurface pathways comprise the by-pass flow (preferential flow, the vertical movement along larger subsoil pathways, e.g. wormholes and fissures, often occurring in unsaturated conditions), the *interflow* (lateral flow below the soil surface) and the matrix flow (uniform vertical movement downward, common in very porous media such as sandy textured soils). All of these modes are linked with water and do not include the transfer by wind erosion which is another type of overland transfer common to Prairie environments. Wind-erosion P is in the particulate form and may not be algal-available. This is the proportion of P available to algae which may subsequently result in water eutrophication.

All of these processes can transport dissolved P (DP, that is, P in the filtrate passing through a 0.45 µm filter) or particulate P (PP, P retained by a 0.45 µm filter). The DP is normally measured with the Mo-Blue reaction (Murphy and Riley, 1962). The fraction so-determined is called reactive P (RP, <0.45), and should not necessarily be interpreted as being inorganic P or orthophosphate-P. When the unfiltered, raw sample is analyzed, the designation RP (unf) is used . The unreactive P (UP, <0.45) is comprised of dissolved organic P (DOP), soluble organic P (SOP), and dissolved unreactive P (DNRP).

pH influences the reactivity of P with the soil solid phase

It is often assumed that P movement in calcareous soils will be limited because of their large sorption capacity. Furthermore, the behaviour of fertilizer P is assumed to be different for acidic and calcareous soils. Groupings based on this criteria have been proposed to link soil-test P to fertilizer needs (Tran and Giroux 1985, 1987; Simard et al. 1991) or in the prediction of P concentration in drainage waters (Beauchemin 1996). Tran and Giroux (1987) indicated that although Ca-P compounds dominated in calcareous soils, the reactive Al and Fe as extracted by ammonium oxalate were still most closely related to the soil P sorption and maximum P buffer capacities. Studies carried out on Prairie soils indicated that Ca-P compounds dominate (O'Halloran et al. 1987, Selles et al. 1999). Leclerc et al. (2001), in a study which grouped 277 soils of the Montreal Lowlands based on their P sorption and desorption characteristics, found that soil pH was an important variable. A dendogram was produced which clearly indicated that soil pH, soil texture, and genesis were the main classification criteria (Figure 1).

Short-term impact of manure on soils which have not received manure before

Qian and Schoenau (2000) reported that a single application of liquid hog manure had little impact on labile P, because its' P precipitated as calcium phosphate or was re-organized as organic P in the soil. This differs with the results of a study carried out on a St-Urbain Clay, a calcareous gleysolic soil from Québec (Simard et al. 2001). The application of liquid hog manure produced a very rapid increase in anion-exchange membrane extractable P. Larney et al. (2000) observed increased soil-test P in an artificially eroded soil after a single application of cattle manure. Zheng et al. (2001) reported a significant increase in labile inorganic and organic P fractions after 4 years of liquid dairy manure to a silty clay. These results indicate that, in most cases, manure has a very rapid impact on the very labile P fractions in soils.

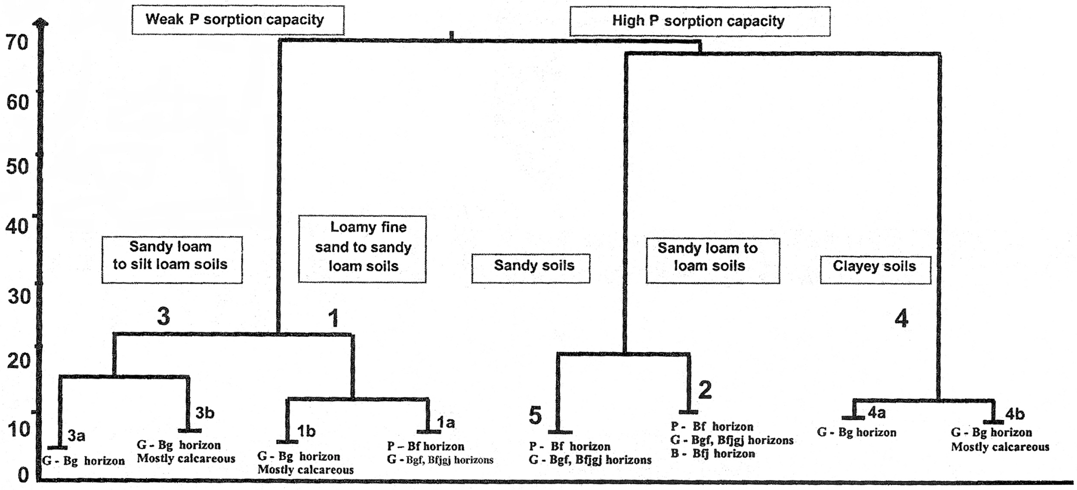

Figure 1. Dendogram of soil fertility groups (1 to 5) generated by Ward's clustering method using the first two principal components of soil attributes from 277 soil Ap horizons from the St-Lawrence lowlands. P=Podzol, G=Gleysol, B=Brunisol, a=non calcareous soils b=mostly calcareous soils (Leclerc et al. 2001).

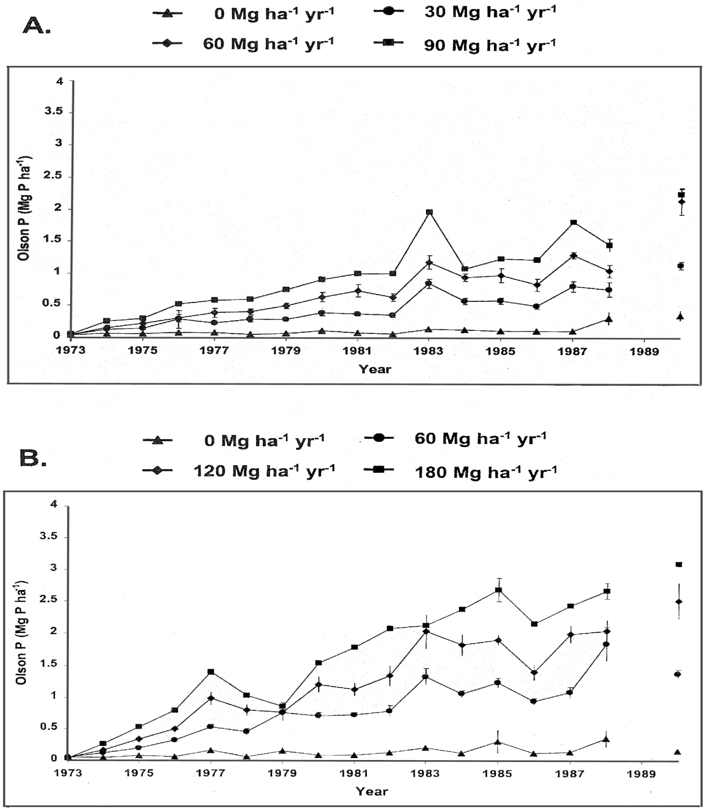

Figure 2. Annual changes in Olsen-P in the 0-150 cm layer of an Orthic Dark Brown Chernozem under (A) dry land and B (irrigation) as affected by annual inputs of feedlot manure (after Whalen and Chang, 2001).

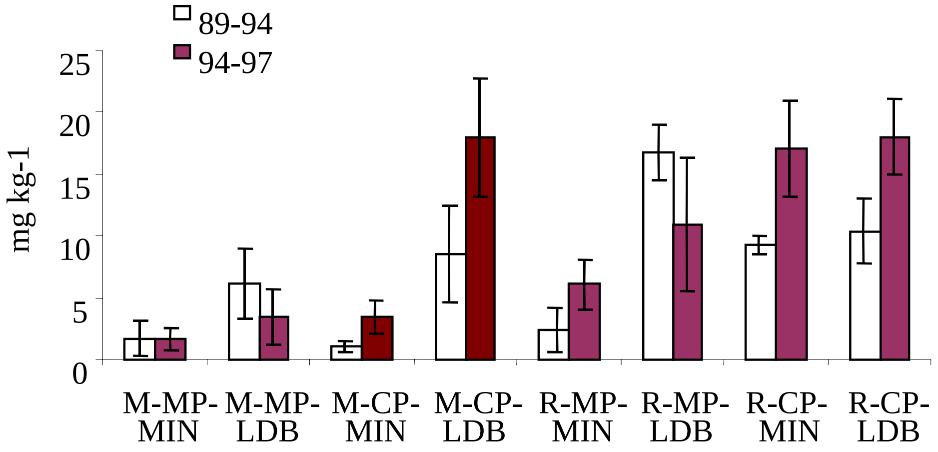

Figure 3. Changes in labile P of the 0-15 cm of a Labarre silty clay (Humic Gleysol) as affected by combinations of cropping sequences, primary tillage and nutrient sources. M=monoculture, R= rotation MP=mouldboard plow, CP= chisel plow, MIN=mineral fertilizers, LDM=liquid dairy manure (after Zheng et al. 2001).

Manure composition impact on the change in soil-test P and P transfer

Manure composition depends on the type of animal involved and manure management (Gagnon and Simard 1999). The change in soil-test P of an acidic soil with the addition of 30 different manure and industrial composts was closely related to the compost total P content and C/P ratio. Sharpley and Moyer (2000) have studied the impact of manure and composts on the simulated rainfall leaching of P. The amount of P leached was very strongly correlated with the amount of water soluble inorganic or organic P of each material.

Poultry manure, because of its high P content, may have a larger impact of soil-test P content and P transfer than other manure types. Baziramakenga et al. (2001) studied the impact of de-inking paper sludge and poultry manure compost on the soil P content of an acidic gleysolic soil near Québec City. The amount of Mehlich 3-P was significantly increased by the addition of this compost and the soil-test P was increased below the plough layer. Comparable results were reported by Warman and Cooper (2000) in a study on the impact of compost and manure additions to forage stands on acidic soils in Nova Scotia. The relative mobility of P was much higher for composted chicken manure than from raw manure. This happened even though the P content of the raw manure was higher than that of the compost. The type of organic amendment may also influence the physical properties of soils and thus have a large impact on the water infiltration capacity of the soils, aggregate stability, and potential for wind and water erosion. These results clearly indicate that manure type and management will influence the change in soil P, on the overland and vertical movement of water and particles, and thus on the potential risk of surface water contamination by soil P.

Repeated manure applications increase soil P fertility

Manure is often used (and regulated) as a source of N for crops rather than as a source of P (Government of Quebec 1997). Since the N:P ratio of manure is less than that of the crops exported , P tends to accumulate in soils. Soils have a strong buffering power for P (Barber 1995), and the efficiency of uptake of added P by plants is rarely larger than 20 %. Since 80 % of added P is not taken up by plants and shows “limited” mobility in soils, long-term manure addition will result in accumulations of labile (Dormaar and Chang 1995, Tran and N'dayegamiye, 1995, Simard et al. 2001, Whalen and Chang 2001) and non-labile P forms (Sharpley et al. 1984, Simard et al. 1995, Whalen and Chang 2001) in soils. These accumulations may be restricted to the Ap horizon (Sharpley et al. 1993, Mozaffari and Sims 1994, Zheng et al. 2001) but may reach the C horizon (Campbell and Racz 1975, Chang et al. 1991, Simard et al. 1995, Whalen and Chang 2001). . The long-term applications of feedlot manure had a very large impact on the water-soluble P and labile P fractions tremendously increasing the proportion of the total soil P in inorganic P forms while decreasing labile organic P (Dormaar and Chang 1995). The increase in soil-test P is larger in soils receiving more water (irrigation) than under dry land conditions (Whalen and Chang 2001, Figure 2). Zheng et al. (2001) reported that liquid dairy manure applied to the plough layer of a gleysolic silt clay produced three times as much labile P increase per unit of P added in surplus to plant exports than did mineral fertilizer (Figure 3). Although the exact reason for this increase needs to be explored, it was closely related to changes in soil C.

The accumulations of soil P in the plough layer and in the subsoil have been associated with increased in P solubility in water (Simard et al. 1995, Dormaar and Chang 1995) and decreased P retention capacity (Sharpley et al. 1984, Mozaffari and Sims 1994, Simard et al. 1995). The concentration of P in drainage water has been related to the soil-test P in the subsoil (Hanway and Laflen 1974, Sharpley et al. 1977, Simard et al. 1998).

Long-term addition of manure and P transfer

In their study on the long-term input (16 years) of feedlot-cattle manure in dry land conditions at Lethbridge, Alberta, Whalen and Chang (2001) reported that there was an apparent balance between P added in manure and P recovered in soil (0-150 cm layer) and crop pools. They concluded that P transfer by surface or subsurface pathways was negligible. They also indicated that P could be leached past the 150 cm depth if manure applications are continued.

The situation was different in irrigated conditions where up to 15 % of the total amount of P added was not accounted for. They suggested that this P could have been transferred outside of the soil profile and that some of this P could be transported by groundwater. This raises the question of possible transfer of P from these soils to adjacent surface waters by *lateral flow* or by *seepage*. Eghball et al. (1996) reported that beef manure could move through soil layers with high calcium carbonate contents and could eventually reach groundwater, especially in areas of shallow water tables. These results and those from Whalen and Chang (2001) clearly indicate that downward P movement is a definite possibility in calcareous soil profiles in the Prairies.

Although the climate of the Prairies tends to be drier than that of Eastern Canada, large rainfall events and occasional spring floods such as observed in Southern Manitoba in 2000 may result in soils becoming saturated with water. Saturated conditions may increase the concentration of water soluble P in soils. An experiment was conducted in Sainte-Foy to investigate the impact of flooding on P release in a gleysolic soil that had received either mineral fertilizers or 16 repeated applications of liquid hog manure (Marsan and Simard, unpublished results). The decrease in Eh was more pronounced for long-term manure amended soils than for soil receiving mineral fertilizers (data not shown). This reduction process released a much larger amount of P in the subsoil from liquid hog manure amended soils (60 SS and 120 SS) than from those receiving mineral fertilizer (0SS, Figure 4). These results clearly indicate that soils which have had a long history of manure application and which are subject to occasional flooding conditions , can result in P transfer via subsurface pathways, and thus may be more at risk than soils that receive mineral fertilizers.

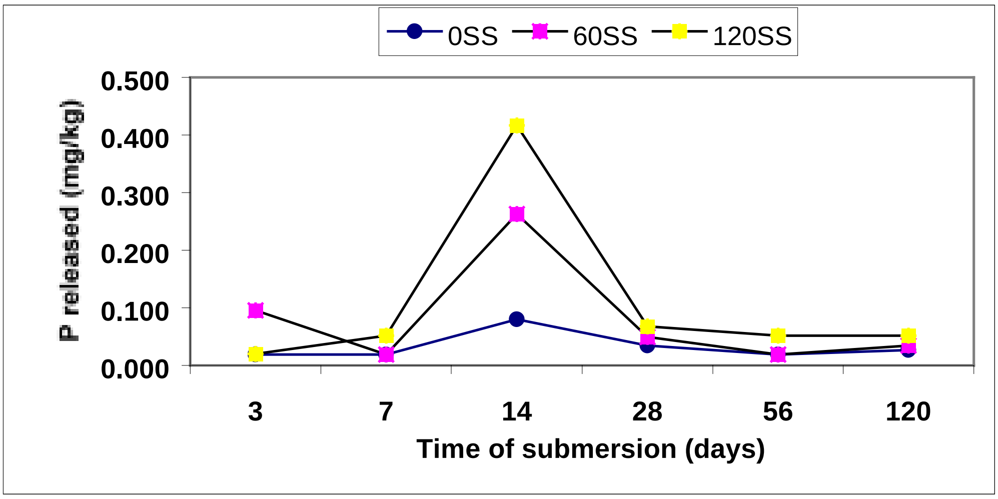

Figure 4. P released from a gleysol as influenced by yearly applications of two rates of liquid hog manure (SS, Mg ha^{-1}).

The indicator of risk of phosphorus contamination

The assessment of the P contamination risk of surface water by agricultural soils has been addressed by indicators such as the PI index, developed by US soil scientists (Lemuyon and Gilbert, 1993; USDA-NRS, 1997), or its' adaptations in Canada (IROWC-P:Bolinder et al., 1998, OMAFRA 2000). "*These indexes integrate agronomic soil test P and other criteria that quantify erosion, surface runoff as well as P fertilizer and/or organic P source application rate, timing and methods in a simple, weighted matrix system to identify soils, landforms, and management practices with the potential for unfavourable impacts on water bodies because of P losses from agricultural soils*" (Sims et al. 2000). The original PI index was modified to be used in a pilot project for Quebec to describe the risk of P contamination of surface waters by P as a part of the indicators program of Agriculture and Agri-Food Canada (Bolinder et al. 2000). Components relative to the degree of soil P saturation (DSPS) as predicted by the Mehlich 3 extraction and a P balance component were added to the original indicator. The indicator was calculated at the landscape of Canada polygon levels and indicated a high risk of P contamination for a large proportion of the intensive agricultural areas, particularly those with concentrated livestock production (Figure 5, Bolinder et al. 2000).

The risk factors can be grouped according to site characteristics, P status, and P input management. Classes of risk are given for each component of the indicator from very low (1) to very high (16). The product of the weighting factors and of the classes associated with each factor can be summed up to derive the site cumulative index.

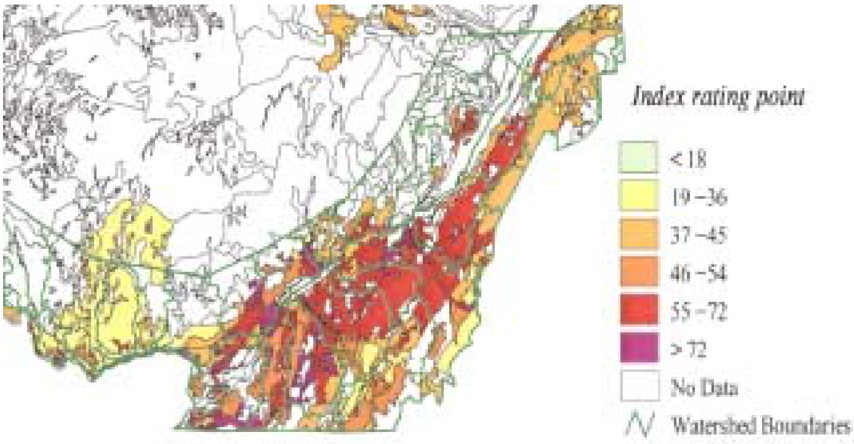

Figure 5. Indicator of risk of water contamination by P for Soil Landscapes of Canada Polygons for the Province of Quebec (Bolinder et al. 2000).

The Quebec Index. The risk of preferential flow, as predicted by soil texture and the distance between tile drains, was included in a modified Quebec version applicable at the farm level (Table 1, Ministère de l’Environnement du Québec, 1998). In the modified index, weighting factors (1.0 to 7.0) are assigned as multipliers of the risk factors (Table 1). A detailed risk component pertaining to manure type, application period, and incorporation mode is also provided to account for some of the risk of incidental transfer (Table 2).

The Ontario P Index. The P index was also adapted to Ontario (Table 3, OMAFRA 2000) to be used as a management tool for yearly manure applications at the farm level (NMAN2000 software). The P index rating is then combined with the distance to watercourse to regulate the amount of P added (Table 4). This version of the index does not directly consider the transfer of P via subsurface pathways (inter-flow and preferential flow) or by incidental processes. Incidental processes are however partly taken into account by the distance to watercourse component. The subsurface processes may dominate in certain soils which do not have high slope components and are artificially drained (Gaynor and Findlay 1995, Uusitalo et al. 2001). Incidental transfer may happen when a large rainfall event removes P from fertilizer, manure or animal dung soon after their application (Haygarth and Sharpley, 2000).

Table 1. Assessment of the risk of P losses adapted from PI and IROWC-P for the Province of Quebec (Ministère de l'Environnement du Québec 1998).

				Classes		
		Very Low	Low	Moderate	High	Very High
Parameter	Wt index	(1)	(2)	(4)	(8)	(16)
Site Characteristics						
Erosion (T/ha.yr)	(4)	0-3	3-6	6-12	12-18	>18
Surface Runoff	(4)	[3]See Table	[3]See Table	[3]See Table	[3]See Table	[3]See Table
Risk of preferential flow						
Texture	(1,5)	sandy loam	loam, silt loam	Clay loam, silty clay loam	medium sandy loam, clay	Coarse sands, heavy clay
Distance between tile drains (m)	(1,5)	nil	> 35 m	25-35 m	15-25 m	> 15 m
Soil P Status						
DPSS[1] (%)	(6)	0-2.5	2.5-5	5-10	10-20	>20
Mehlich-3 extractable P (kg/ha)	(6)	0-60	60-150	150-250	250-500	>500
P inputs management[2]						
Total P added (kg P_2O_5/ha.yr)	(3)	<-20	-20-0	0-20	20-40	> 40
P added in manure or organic form (% of crop exports)	(2)	<50	50-100	100-150	150-200	>200
Mineral fertilizer P (% of crop exports)	(1)	<50	50-100	100-150	150-200	>200
Manure type and incorporation mode	(7)	see Table 2	see Table 2	see Table 2	see Table 2	see Table 2
Cumulative Index		36-54	55-108	109-221	222-432	433-576

[1] as calculated by the ratio of Mehlich-3 P (mg/kg) over Mehlich-3 Al (mg/kg)

[2] The balance at the soil surface (as expressed relative to off-site crop exports)

[3] The factors refer to more detailed tables regarding hydrology of the site and manure management not given here in the sake of saving space.

Table 2. Manure type, application period and incorporation mode criteria of the modified Phosphorus Index in Québec (Ministère de l'Environnement du Québec 1998).

Application period	**Incorporated**	**Tillage before application**	**Solid manure or mineral fertilizer[1]**	**Liquid manure (< 10 % dry matter)[1,2]**
Pre-seeding[3]	low	low	high	medium
In the growing season	very low	very low	medium	high
Post-harvest in late fall	medium	medium	very high	very high

Table 3. Calculation of the Ontario Phosphorus Index.

	LOW	**MEDIUM**	**HIGH**	**VERY HIGH**	**EXTREME**
1. Soil Erosion (USLE in t/ha/year)	< 12 **2**	12 - 25 **4**	25 - 37 **8**	> 37 **16**	
2. Water Runoff Class (slope and soil texture)	< 0.5% loam **1**	0.5-2.0% loam **2**	2-5% clay loam **4**	> 5% clay **8**	
3. Soil test P (Olsen, mg/L)	< 15 **2**	15-30 **4**	31-60 **8**	61-100 **16**	> 100 **32**
4. Fertilizer P_2O_5 application rate (kg/ha)	< 25 **0.5**	25-50 **1**	50-75 **2**	> 75 **4**	
5. Fertilizer placement	band-applied **1.5**	incorporated < 2 weeks **3**	incorporated > 2 weeks **6**	not incorporated **12**	
6. Manure P_2O_5 application rate (kg/ha)	< 12 **0.5**	12-36 **1**	36-60 **2**	> 60 **4**	
7. Manure/Biosolid Application Method	injected in season	incorporated in < 5 days	pretillage, crop residue, or standing crop	bare soil; not incorporated	
	1.5	**3**	**6**	**12**	

The P Index is calculated as the sum of the above seven components.

Table 4 . Phosphorus guidelines in NMAN2000, for annual manure applications.

	Distance to Watercourse (m)			
P Index	**< 3**	**3-30**	**30-60**	**> 60**
< 30	0	CR	CR+78	CR+78
30-50	0	CR	CR	CR+78
>50	0	0	CR	CR

CR = crop removal; amount of P_2O_5 removed by crop (kg/ha)

Further refinements internationally

Magette et al. (1998) proposed adding watershed factors (condition of receiving water, and ratio of land/water and farm factors (proximity to receiving water) to better represent the sensitivity of the surface waters to P inputs. Part of it is included in the Ontario phosphorus guidelines. It was also proposed that the indicator be multiplicative to included processes that are operative at the watershed level (Gburek et al. 2000, Heathwaite et al. 2000).

PI = (erosion rating x runoff rating x return period rating) x sum of (source characteristic x weight)

Nash et al. (2000) indicated that the number of days since P inputs was a key factor to predict runoff concentration from grazed grasslands. Such an indicator is helpful to evaluate the risk *per se* but does not provide actual indications of the P loads or P losses. This approach provides some flexibility to the agronomist and the producer to identify the management changes to be implemented to reduce the risk of diffuse contamination of surface waters by P. It has been proposed that this approach be used for producers where there is a high water contamination risk by soil P (Ministère de l'Environnement du Québec, 1998, OMAFRA 2000).

The approach may have to be refined to include other factors such as, grazing, water balance, mean water table or depth of the tile line, soil cracking, type of crop, etc (Sims et al. 1998, Bolinder et al. 1998). A validation step is required to clearly assess the efficiency of this tool to accurately estimate the risk of contamination at the farm level. These PI's will be adapted regionally and undoubtedly, an approach which is valid for the wet conditions of Eastern Canada may not be adequate for the irrigated areas of Alberta.

The soil test component of the index is also an issue. A soil-test developed for acidic soils may not be adapted for calcareous conditions since Ca would play as important a role in P sorption/desorption as does Al which has a dominant role in acidic soils. Soil-tests such as the water and 0.01 M $CaCl_2$ extraction methods may be useful (McDowell et al. 2001, McDowell and Sharpley 2001). However, these methods may not be as adequate as soil-tests in use, such as Olsen (Olsen et al. 1954), to predict the potentially plant-available P from calcareous soils (Tran and Giroux 1987, Simard et al. 1991).

The PI may however prove useful for irrigated areas, such as those found near Lethbridge, Alberta. Addition of a wind erosion component may also be very important in the Prairies, since it may be a major transport pathway for P in particulate form from agricultural soils to surface waters. The results of an experiment conducted in Lennoxville, Québec, will be used to provide further evidence of the need to consider soil P attributes and soil hydrologic features in predicting the risk of P contamination from heavily manured soils.

The Lennoxville Case Study

This experiment was conducted on a site initiated in 1989 near Lennoxville, Québec, at the Agriculture and Agri-Food Canada Research Centre on a Coaticook silt loam (Humic Gleysol). The soil (0-20 cm) had a pH of 5.8, 5.3 % organic matter and a Mehlich-3 extractable P content of 81 mg kg^{-1}. This soil P level is considered to be rich for grain corn and hay (Conseil des Productions Végétales du Québec 1996). The site has a 6 % slope and is equipped to collect surface runoff and drainage waters.

Two crop species were studied, grain corn (*Zea mays* L.) and a mixture of timothy (*Phleum pratense L.*), white and red clovers (*Trifolium sp.*). The experiment included five treatments for each species : (C) control; (M) inorganic fertilizers according to soil test and local fertilizer recommendations (180 kg N, 7 kg P, 12 kg K ha^{-1} to corn); liquid hog (*Sus scrofa*) manure (HLM) at 360 kg total N ha^{-1} + inorganic fertilizers applied either all in spring at pre-seeding (S), 50 % in the spring and 50 % in the fall after harvest (SF) and all in the fall after harvest (F). Amounts of 55 kg N and 9 kg P and 16 kg K ha^{-1} were added as inorganic fertilizers in forages and 110 kg total N as HLM. The corn residues were chisel-ploughed in the fall.

The risk index of water contamination by P was calculated according to the procedure of the Ministry of the Environment of Québec (1998). The surface runoff, sediments and drainage were collected from 1996 and 1997 events. The drainage water was analyzed for its molybdate reactive P (MRP, Murphy and Riley 1962). The water and sediments were also analyzed for total P content (Rowland and Haygarth 1997).

Index of risk of water contamination by soil P

The risk of water contamination was estimated from P balance, P soil test, degree of P saturation, type and mode of application of manure data (Simard et al. 2001). The index under corn is much lower with mineral fertilizer (moderate risk) than for manure (high risk) and is slightly less for the spring than for fall applications (Table 5). This difference is related to the type of manure coefficient which is less for spring applications (Ministère de l'Environnement du Québec 1998). The values of the index were in general lower for forages than for corn. The differences between the manure treatments were again related to the type and mode of manure application coefficients. The lower values associated with the inorganic fertilizer treatment are related to lower soil-test P, degree of soil P saturation, amount of P added and to the smaller values of the coefficient for mineral P than for manure P.

Table 5. Values of the P index (Ministère de l'Environnement du Québec 1998) as influenced by crop type and nutrient management (after Simard et al. 2001) .

	Corn	**Forages**
Mineral fertilizers	126	113
HLM-100 % spring	341	295
HLM-50-50	355	275
HLM-100 % fall	355	330

P transfer in surface runoff and drainage

Data for the first years of the study (1989-1992) clearly indicated that transfer of P from these plots was larger for the LHM-F application treatment than for the others and that most of the transfer occurred in the fall and winter (Gangbazo et al. 1997). Summer P transfer tended to be lower for manure treatments than for mineral fertilizers. The data from the fist years tended to confirm the ratings provided by the 1998 Quebec PI index.

The P transfer was larger for corn than for forages mostly because of a much more important surface runoff component (Figures 6 and 7). The mineral fertilizer treatment resulted in the largest amount of P transfer under both crops. Under corn, the spring application of manure resulted in the smallest transfer amongst manure treatments whereas the fall application is close to values of the mineral fertilizer treatment. Under forage, the TP loads associated with the manure treatments were comparable between fall and spring applications whereas the split application resulted in a smaller transfer. There is also a significant variation in P transfer between years, the fall manure application treatment was comparable to the mineral fertilizer in 1996 whereas it showed the smallest losses in 1997.

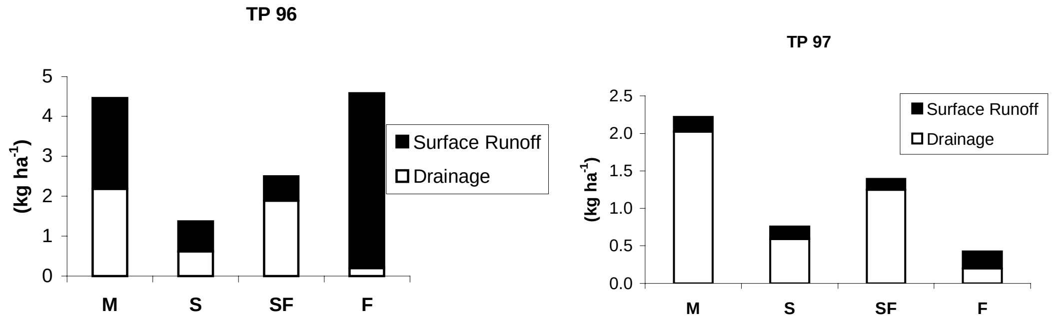

Figure 6. Total Phosphorus loads in surface runoff and drainage water under corn in 1996 and 1997.

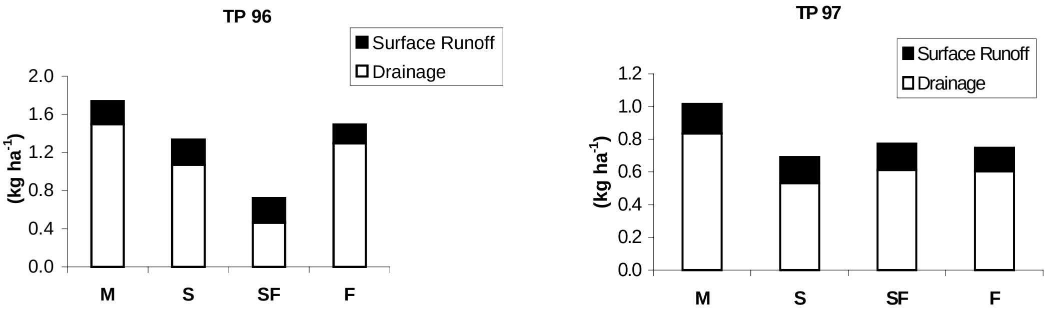

Figure 7. TP Loads in surface runoff and drainage water under forages in 1996 and 1997.

Discussion

This site study clearly indicates that under reduced or in the absence of tillage, P accumulates very fast near the surface of soils (Simard et al. 2001). This results in a very high degree of saturation of the soil P fixation capacity which suggests a high risk of P contamination of surface waters. The data on total P transfer by surface and subsurface pathways indicate however a very poor relationship between soil-test P and/or degree of soil P saturation and the P transfer in water. The main disagreement is with the mineral fertilizer plots which show a higher relative transfer than predicted by the PI index. This contrasts with the data of the first years. Withers et al. (2001) suggest that fertilizer rates applied to meet the P requirements of an individual crop would result in lower P transfer by surface runoff than N-driven manure rates. The results of the present study suggest that this would not apply to the studied soil. Improvements in surface soil physical properties might explain the lower transfer for the plots receiving manure than the mineral ones (Sommerfeldt and Chang 1985, N'dayegamiye and Angers, 1990). The impact of manure on soil physical properties is not always present in calcareous soils (Campbell et al. 1986). However, improvement of the properties of soils prone to erosion is very dependent on the organic C content of the recipient soil (Larney et al. 2000).

The observed difference in P transfer from the forage plots is more difficult to explain. The P index was shown to be closely related to the total P loss from 30 unit-source watersheds of about 2 ha in Texas and Oklahoma (Sharpley 1995). The results of the present study challenge the assumptions that formed the basis for the various versions of the P index which suggested that a higher weight be accorded to manure P than to fertilizer P (Lemunyon and Gilbert 1993, Bolinder et al. 2000, Gburek et al. 2000). This clearly indicates that assessments based only on short-term experiments may be misleading. The amount of P transfer under corn from the mineral fertilizer and liquid manure treatments applied in the fall are in the high range of those reported by Sharpley (1995). The relative risk ratings would be medium for the mineral fertilizer treatment and high for the fall application of manure. The risk of erosion component was not quantified in the present study. However, even if it was rated as very high, a medium ranking for the mineral fertilizer plots would still be found. The use of a multiplicative index, as suggested by Gburek et al. (2000), may help to address some of the concerns since it would better integrate the surface runoff component than earlier versions of the PI (Lemunyon and Gilbert 1993, Bolinder et al. 2000).

The predicted risk rankings from the P index for soil-P transfer were generally higher for corn than for forages and were less for spring applications for both crops (Table 5). The measured loads of P suggest that this assumption was valid in most cases. The split application between spring and fall produced lower P losses under forages. However, there is no provision in the PI index for split application of manure (Ministry of the Environment of Québec 1998, Gburek et al. 2000). The data of the present study suggest that this may be a management practice that should be incorporated in future iterations of the P index. Split application is an interesting practice for manure management on forages in high density areas of confinement livestock operations.

A modified P transfer index for the Prairies

New versions of the indicators could be adapted from the current model (Ministère de l'Environnement du Québec 1998) to reflect the particularities of the Prairies areas. The main modifications would be to separate mode of transport, charge , and management components (Table 6). The risk of wind erosion could be adapted from the indicator developed in the Prairie provinces (Padbury and Stushnoff, 2000). The distance to a waterbody would also be included. The overall index would be a multiplication of these three components (Gburek et al. 2000). The weight related to each sub-component would have to be adjusted regionally and the risk classes that were used in the previous model could be used.

Table 6. Components of a new indicator of risk of soil P contamination of surface waters.

Modes of transport components :
Risk of erosion
Risk of surface runoff
Risk of wind erosion
Risk of incidental transfer : Surface transfer of manure/fertilizer particles
Preferential flow
Distance to a waterbody
Charge components :
Soil-test P
Degree of soil P saturation
Management components :
Fertilizer Padded (kg/ha)
Manure P added (kg/ha)
Manure and Fertlizer application mode
Grazing intensity

Conclusions

In most areas of Canada, manure management based on a disposal philosophy to the available land base or on the N needs of crops results in P accumulation and increased P saturation in areas of concentrated livestock production. The increase of livestock production in many of the Prairies provinces will certainly accentuate these effects. The prediction of the risk of P contamination of surface waters by surface transport (erosion and runoff) from the soil test of the first cm of soil is often successful. This is probably the most probable source of transfer in the Prairies. Enriched surface soils may be transferred by wind erosion if plant cover is not maintained. An evaluation should be made to determine if land that receives manure frequently will transfer P by this process. The assumptions that P does not move in calcareous soils is not supported by the results of the available research. The enrichment of the water in the soil profile may increase the risk of transfer by lateral flow or seepage. This would particularly be the case in areas where flooding is frequent or where irrigation is used to increase crop yield potential.

The data from an experiment in Lennoxville clearly indicate that transport factors also need to be incorporated to improve the prediction of the risk of surface water contamination by soil P. The prediction of P loss by drainage from contrasting soils is much more difficult. This may apply to areas of the Prairies under irrigation. However, the use of the degree of P saturation rather than soil-test P alone is an improvement. Soils need to be grouped according to their inherent characteristics since those with calcareous substratum do not behave like acidic soils. More comprehensive assessment tools such as the P index may help to better identify the sites most at risk but need to be adapted to the reality of the area. They are more versatile since they integrate the notions of hydrology, agronomy, and soil science.

Long term manure application has had a large impact on the quality of surface waters in Eastern Canada. The economic reality favours intensification of confinement livestock operations in the Prairies since less grain is transported to the eastern Canada markets. Sound manure management strategies will certainly be key factors for a sustainable agricultural industry.

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