Forage, Phosphorus and Soil on Dairy Farms

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Take Home Message

- Phosphorus (P) is an important nutrient and an important contaminant of fresh water.
- P fertilizer is a diminishing resource and improved practices are needed, especially on livestock farms, to conserve P and minimize pollution.
- Manure application can contribute to P loading of soils and it is suggested that solid liquid separation produces two products that can be managed more effectively than whole manure.
- The liquid fraction can be used as a primary N source with relatively little P loading.
- The solid fraction can be used to replace fertilizer P.
- Controlling runoff for reducing P contamination into surface waters is less effective on the prairies where most contamination is from snow melt compared to hilly land where rainfall is often most important.
- In all landscapes, but even more so on the flat prairie landscape, it is important to keep soil P levels low to prevent contamination of surface waters. This fact points to the importance of avoiding farm P surpluses.

Introduction

While the importance of nitrogen (N) to food supplies and its multifaceted role in environmental contamination is receiving a lot of international attention, the role of phosphorus (P) is no less important. There can be no life without P as it is involved in fundamental energy processes, in DNA and in animal bone formation. For crop farming, the challenge is usually to manage P inputs effectively, because P is reactive in many soils and P is less mobile than the other major nutrients. But on livestock operations, the emphasis has recently been on the problem of surplus P inputs and excess P in farm soils. Unlike N, P does not cause global warming or air pollution, but loss of P from farms is a major threat to fresh water bodies causing algal accumulation, oxygen depletion and fish death, a process referred to as eutrophication. The problem of P contamination is of greatest concern wherever there is a concentration of animal production or where there is a lot of runoff and soil erosion. While P is being lost from farms to the environment, the global reserves of fertilizer are dwindling. About 75% of all mined P is used in agriculture and most of this for fertilizer. The known world P resources are concentrated in just a dozen countries and the vast majority located in just two countries, China and Morocco. The most reasonable predictions suggest that half of all existing reserves will have been consumed in about 50 years and large increases in biofuel production would hasten the depletion (Figure 1). The goal of our research work, and of this presentation, is to investigate ways to improve the utilization of P on dairy farms and to reduce losses to the environment.

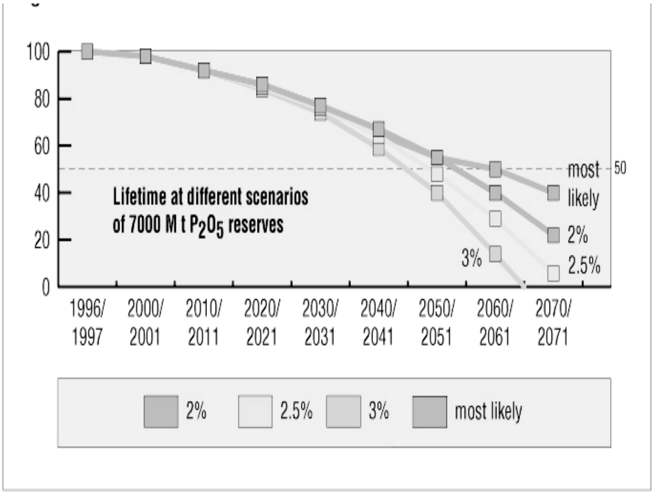

Figure 1. Predicted life expectancy of existing P reserves based on 4 scenarios. http://www.nhm.ac.uk/research-curation/research/projects/phosphate-recovery/p&k217/steen.htm

■ A Phosphorus Primer

Plants require P for all energy processes and P is a component of DNA (Table 1). Animals need P for the same reasons but also for bone formation so P is commonly supplemented to livestock. Uptake of P by crops is hampered by two key factors. First, P tends to be chemically bound up in soils, by Al and Fe in very acid soils and by Ca and Mg in basic soils, so P is most available around pH 6-7. The second factor is the low solubility and slow movement of P in soils. This means that P uptake is a function of root length and uptake may be difficult for juvenile plants with small root systems. As plant uptake is a diffusion process which is strongly temperature and moisture dependent, P uptake is slowest in cold and in dry soils. The result is that the P level in crops is often deficient in early season when roots are small and soils cold, and P must be supplied to address this deficiency. Indeed, plants are most likely to appear P deficient in the juvenile stage after seed P supplies are exhausted; in corn this is at the 3-6 leaf stage. P deficiency in crops is difficult to overcome during the current season. If plants are allowed to be deficient in early season, their development may be delayed, so even if P concentrations catch up later on, development may not. Most crop (and weed) species benefit in early season by the association with a soil fungus called 'arbuscular mycorrhizal fungi' (AMF). These fungi are symbiotic in that they trade energy from the crop for transferring P (also Zn and Cu) from the soil to the crop alleviating the early season shortages. The fungi in effect increase the root volume of the plant. Members of the cabbage family (including canola, mustard and several weed species) and sugar beets do not associate with AMF so when these crops are planted (or when there is fallow) population of AMF in the soil declines and the subsequent crop is more likely to be P deficient in early season. Tillage breaks or buries the fungal filaments, thus reducing the early season efficacy of AMF. By mid-season, colonization of host crop plants does bounce back, even after 2 years with no host plants.

It is evident that predicting P demand with a soil test is difficult because of complex soil chemistry, and the interaction of soil transport, crop development and microbial associations. So while P has complex chemical forms that vary from soluble reactive to highly insoluble, there is also an organic P component which is subject to mineralization and leaching (i.e. behaves more like soil N). Whereas for soil test N there is typically one extractant used in most labs, for P there are numerous extractants (Table 1) that give contrasting estimates of the amount of P available to plants or amount of P that is an environmental hazard, and great care must be used in comparing lab results. It should also be underlined that soil N is generally reported as elemental N, but soil P analysis may be reported as elemental P or P_2O_5 (which is equal to P x 2.29). P analysis in fertilizer is generally P_2O_5 while P in plants and manure is expressed as elemental P. Therefore, special care is needed for comparing manure and fertilizer rates and in doing farm balances.

▪ P Surpluses and Hotpots on Dairy farms

Whether or not there is a P surplus on a dairy farm depends mostly on the land area available for crop production and the proportion of imported feedstuffs relative to homegrown feeds. For all farms there is a need to balance crop production in order to provide for the nutritional requirement of the cow. On farms with abundant land there is the possibility of spreading manure onto crops that are to be exported off the farm to compensate for imported feedstuffs. But for farms that have a limited land base, the problem is more challenging.

Table 2 compares a typical Dutch dairy farm with a model farm whose goal was to maintain equivalent productivity but reducing losses to the environment of both N and P (only P shown). Both farms have a limited land base. The key to the success for the model farm was to reduce imports of concentrates by producing a more complete diet (including protein) on the farm, limiting excessive feeding, and reducing fertilizer imports by effectively recycling manure nutrients. The overall milk production of the model and typical farm is similar.

Even if a farm has an overall P balance thanks to management or available land resource, there may be fields on the farms with excess P. This is because manure, especially liquid manure, is very costly to transport so there is a tendency to apply more manure on nearby fields. In addition, there may be issues with runoff from barns, holding areas and feed storage areas to nearby ditches. Furthermore, access by grazing animals to water courses can add to P contamination.

While there may be spatial P ‘hotspots’ on dairy farms, there may also be temporal hotspots. Farmers with insufficient storage may be forced to spread manure during periods of high runoff risk or on frozen soils. There is evidence that runoff, which is associated with sloped land and rain events, transports a disproportionately large amount of solid particles that contain P. In contrast, on very flat prairie landscape such as the Red River Valley, P is transported much more by snowmelt than by rain water, and snowmelt seems to carry more highly reactive dissolved P which may be released from freezing and thawing of living cells and tissues. Living cells may be in soil microbes, crop residue, cover crops or even forage crops (see control measure below).

Table 1. A Phosphorus Primer: Comparison of P and N in soils and crops.

General	P	N
Source	Mined -finite resource; see Fig.1.	From atmosphere (Unlimited supply but an 'Energy Hog')
Soil		
Soil	Chemical binding to Al, Fe (low pH); Ca, Mg (high pH) pH 6-7 best	Biological immobilization, ammonium adsorption
Soil transport	-Diffusion (slow) -Controlled by root length and soil temperature	-Mass transport (fast) -Controlled by transpiration
Soil tests	Kelowna/ Bray /Mellich /Olson/ water etc.	KCl extract
Microbial assist	Increase availability: AM Fungi increase root reach; Bacteria solubilization	Increase amount: N fixation by *Rhizobium* and free-living bacteria
Crop		
Plant function	Energy processing, DNA (mainly non structural)	Protein: structural and non-structural
Plant transport	Mobile	Less mobile
Plant content	0.2-0.5%	2-4%
Plant uptake	15-40 kg P/ha	50-300 kg N/ha
N:P ratio- Crops	Corn, Wheat 6-7 : 1 Grass 10:1	
Manure		
N:P ratio- Manure Excreted	5:1	
Concentration, slurry	0.06%	2.0%
N:P ratio, slurry	3:1	
Environment		
Environmental impact water	Fresh water eutrophication	Nitrate in ground water, ammonium surface water
Atmospheric levels and deposition	Very little	Ammonia, NO_x, N_2O

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Table 2. Farm P balances on typical Dutch dairy farm and model farm with equivalent milk production. (From Oenema, J. and Verloop, J. 2004 Whole Farm Nutrient Management *in* Bittman, S. and Kowalenko, C.G. (eds) Advanced Silage Corn Management, Pacific Field Corn association, Agassiz BC.)

	Typical Dutch Farm	Model Farm
	Kg P/ha	
Inputs		
Concentrates	49	29
Roughages	2	0
Chemical fertilizer	41	0
Organic manure	29	0
Atmospheric deposition	2	2
Total input	*124*	*32*
Output		
Milk	24	23
animals	9	5
Total output	*34*	*28*
Surplus	**90**	**3**

■ Managing Manure P

Improving the N:P Balance on Dairy Farms

The ultimate goal of managing manure is to replace chemical fertilizer so that imports can be reduced, reducing the cost of the imports and of managing the surpluses. Unfortunately the nutrient balance in manure does not match crop requirements. Crops take up and hence livestock consume feeds with N:P ratios of about 7:1 to 10:1 depending mostly on the N (or crude protein) concentration of the crop. Dairy cattle excrete manure with a ratio of about 5:1 due to the more efficient utilization of N than P by the cow and to supplementation of mineral P in the ration. However, the N:P ratio narrows further as N is lost from manure building and storages, mostly through volatilization of ammonia (Table 3) and to a lesser extent denitrification. More N will be lost as ammonia when manure is spread on the land, and crop-available N in the soil may also be lost by denitrification, leaching and runoff. Very little P is lost into the atmosphere and in most cases P also does not leach. Thus there is a tendency throughout the farm system for P to concentrate relative to N. The primary loss pathway for P is via runoff and erosion, mostly into fresh surface water, and this becomes more prevalent as P accumulates in soils.

Table 3. Proportion of excreted N lost by ammonia volatilization on dairy farms in Canada. Calculation is based on average Canadian conditions and farming practices. (from Sheppard and Bittman, manuscript in preparation)

	% of excreted N
Housing	11
Storage	3
Spreading	14
Total loss	**26**

Figure 2 shows results from a study of slurries collected from dairy farms in the Lower Fraser Valley in BC. For slurry with DM content of over 3%, most samples had N:P ratios of 4:1 to 6:1. These would likely have after-spreading N:P ratios of about 3.5:1 to 5:1. With these ratios, crop N requirements cannot be met without over-application of P. The imbalance of N:P in manure relative to crop needs is a problem that needs to be addressed if manure is to be the predominant source of nutrients for crops.

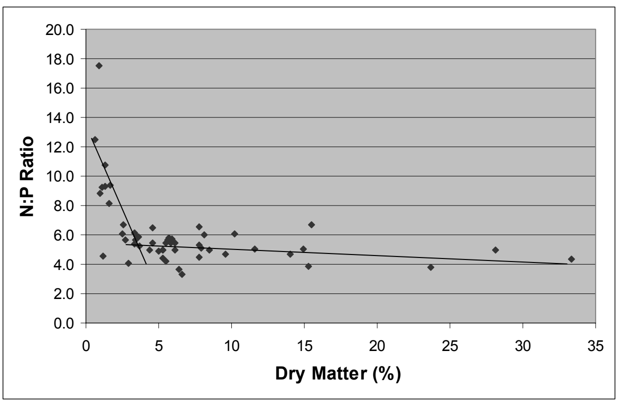


Figure 2. Relationship between ration of N:P and dry matter in dairy manure samples collected from about 30 dairy farms in the lower Fraser Valley of BC.

There are a number of strategies for farmers to reduce the N:P imbalance. The most obvious approach is to match the P imports onto farms to P exports in milk and meat, while maximizing the recycling of P within the farm. This requires that import of P onto the farm in feedstuffs, supplements and fertilizer is carefully monitored and that over-feeding P and over-fertilizing with P is avoided.

The N:P ratio in manure is also increased by reducing N losses through the entire farming operation, including land spreading, which is the largest loss pathway (Table 3). Manure applicators have been developed to reduce both odour and ammonia loss. For perennial grasses where injection may not be possible, surface banding implements using the drag hose (drop hose) or drag shoe (or sleigh-foot) concept have been shown to reduce ammonia losses by 30-60%. The AERWAY SSD which combines banding with soil aeration consistently reduced emissions by 45%. We have shown in long term trials that the low-emission applicators enabled consistent crop response relative to chemical N fertilizer, but that high yields with only manure inevitably lead to rising concentrations of P (and organic N) in the soil. Accumulation of soil P was reduced if applications of manure were alternated with chemical N fertilizer. While effective, this strategy is possible only on farms that have an abundant land base (i.e. do not have an N surplus).

Where there is a limited land base, farmers need to move a portion of the excess P away from the barns. Movement of dairy slurry manure, which contains 93% water and only about 2% N and 0.4% P, is very costly. To lower the transportation cost, the P can be concentrated by separating the solid and liquid fractions of the manure, since most manure P is in the solid (feces as opposed to urine) fraction. Filters or screens are least expensive but are ineffective for removing P because the P-rich particles are too fine. These particles can be removed by flocculating with a resin prior to screening, or by centrifugation. Both techniques are available commercially but considered costly. We have found that for slurry with less than 7% dry matter, simple settling is a low cost method for removing some of the P in the manure. The manure samples with high N:P ratios in Fig. 2 also had low dry matter content because they were obtained from farms with settling ponds and weeping walls.

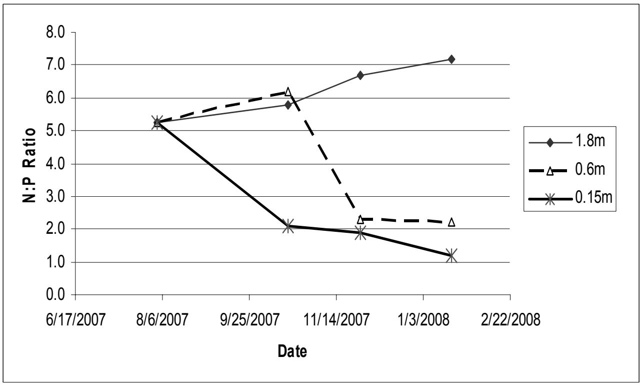


Figure 3. Change of N:P ratios during storage of dairy slurry as affected by depth (measured from bottom of the storage vessel).

Figure 3 shows the change of N:P ratios of dairy slurry at different levels in a

2.5 m deep vessel over about 4 months. By the end of the storage period, the N:P ratio supernatant had increased from about 5:1 to 7:1 while the ratio for the sludge decreased to about 2:1. Note that the particle-size distribution varied with height in the vessel (Figure 4). The very small particles were evenly distributed (they did not settle) and had a relatively low P concentration. The intermediate sized particles also did not settle but had a relatively high P concentration, and it would be beneficial to facilitate settling of this fraction. The fractions that settled were over 1mm in screen size and also had a relatively high P concentration. We are currently investigating factors that affect settling efficiency.

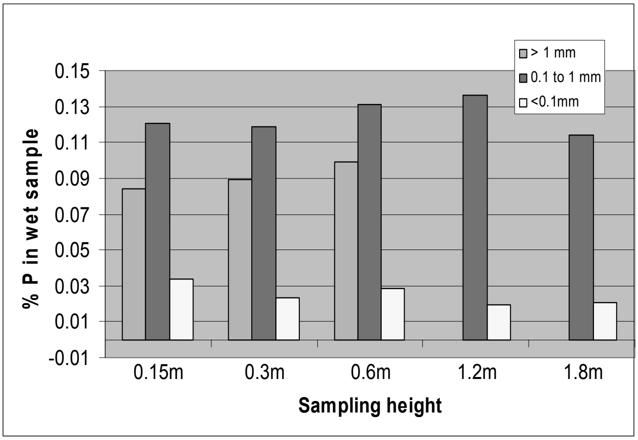


Figure 4. P concentration in dairy slurry after 4 months of storage as affected by depth and particle size.

We tested the effectiveness of the separated liquid fraction on grass in a field trial at Agassiz, BC. The slurries were collected from a commercial dairy farm. We found that the liquid fraction promoted more grass growth for the same level of N (inorganic plus organic) input because more N was in the available inorganic form (see curves on Figure 5). Also, we found in associated trials that less ammonia was lost from the liquid slurry fraction than whole slurry, because the separated fraction was thinner and infiltrated the soil more rapidly. This effect was most pronounced in cool weather. Clearly with the lower P concentration in the thin fraction, the ratio of crop yield to soil P loading (bars in Figure 4) was much more favourable for the separated slurry fraction than the whole manure. Thus using the supernatant appears to be a more sustainable practice for grass production than using the whole manure. We are currently investigating the long term effects of using separated slurry.

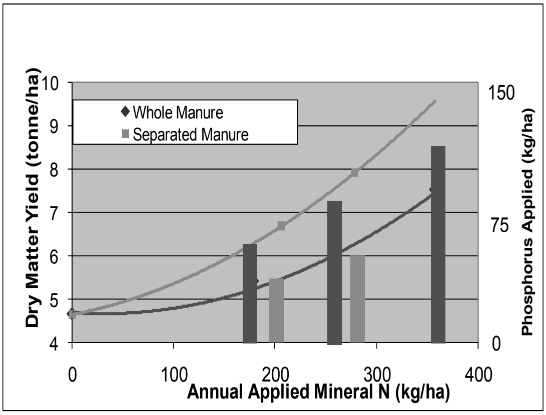


Figure 5. Effect of applications of whole and separated dairy slurry liquid on yield of grass (curves) and loading of P in the soil (bars) in south coastal BC.

How Effective is Separated Manure P?

The separated solid fraction should also be used to support crop growth. How effective is the P in separated manure solids? Manure analysis provides information on total P in the manure sample but up to 30% of dairy manure P is in the organic form which may be less available. The organic fraction requires mineralization to become available. In whole manure, P is alternatively assumed to be either fully or half available in the year of application. The efficacy of P in the solid fraction of manure has not been widely tested but recent work in Quebec on hog manure shows that for both crop (corn) yield and P uptake there is little difference between P in the solid fraction and fertilizer P(M. Chantigny, personal communication).This test was conducted in the field on contrasting soils. Interestingly, the manure P could be less prone than fertilizer P to leaching and runoff, depending on soil. These results suggest that separated solids can replace P fertilizer on non-manured soils that are typically low in P. Crops and soils that would also benefit from the organic matter, micronutrients and organic N in the sludge (and where risk of microbial contamination is contained), may be the most suitable recipients of the separated solid fraction.

Optimizing Solid Fraction P

As mentioned above, crops are most sensitive to P deficiency during their juvenile stage. This is because typically soils are cold and root development is limited early in the season. Deficiency of P in early stages often delays crop development. Figure 6 shows that % grain in corn crops at harvest is very strongly related to P uptake by corn to the 6-leaf stage. Note that P uptake at this critical period is just 0.3 to 1.2 kg/ha.

Because access to soil P in juvenile corn plants is limited, fertilizer P is generally most effective when placed in bands near the seed during the seeding operation. We tested to see if settled dairy manure fraction placed near seed rows would provide P as efficiently as chemical fertilizer. We were concerned about crop injury that might occur from high concentrations of ammonium or salt in the manure.

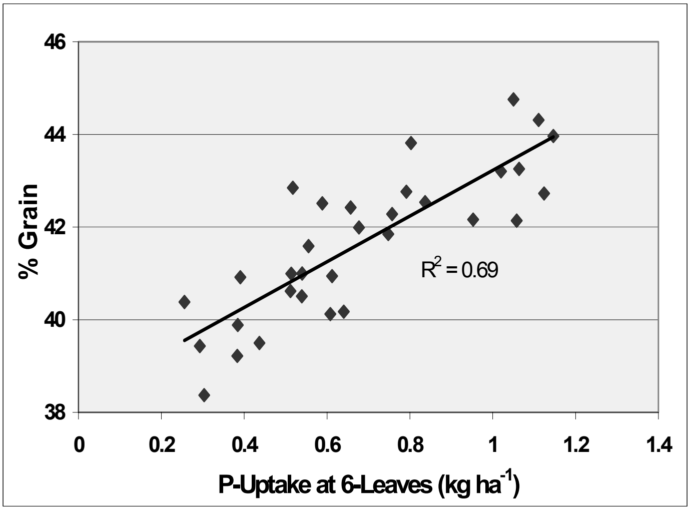
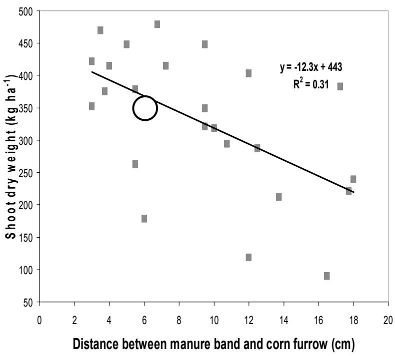


Figure 6. The relationship between P uptake at 6-leaf stage and % grain at harvest. The data is from commercial dairy farms in the Lower Fraser Valley.

Settled manure sludge (very fluid at around 8% DM) was injected at 30 kg P/ha in 12 cm deep furrows spaced 75 cm apart. The corn was planted at the same row spacing a few days later, with the corn rows located at various distances from the injection furrow. Results from this trial showed that the manure worked best when it was close to the corn row and that the response to mineral fertilizer was fully matched by the manure. This trial also showed that the colonization of the roots by mycorrhizal fungi (AMF) helped corn take up P and that the manure did not appear to harm root colonization (Figure 7). Thus it appears that injected dairy solids can fully replace seed-placed chemical fertilizer for corn on dairy farms.

AMF colonization = 56%



AMF colonization = 39%

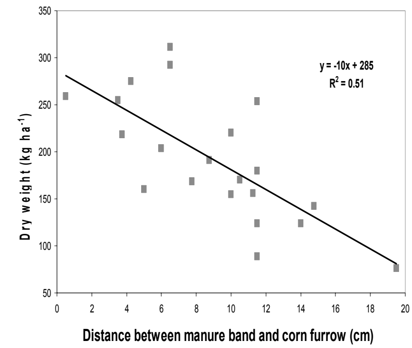


Figure 7. Narrow spacing between corn row and manure injection furrow improves growth at the 6-leaf stage. The injected manure was solid-rich fraction from settled dairy slurry. Mineral fertilizer is indicated by the large circle. Note that yield is lower and spacing has more effect when corn roots are poorly colonized by AMF fungi (right).

Reducing Surface Runoff: Soil Aeration.

Injecting manure has the combined benefits of reducing ammonia emissions (hence improving the N:P balance) and reducing surface runoff. However, full injection into forage stands is not always possible due to crop damage and soil conditions, while shallow injection leaves manure in open channels that may actually facilitate runoff. We tested using soil aeration to reduce manure runoff from a sloped field in coastal BC. We found that soil aeration across the slope prior to manure application reduced runoff of solids and reactive P over the rainy winter months (Table 4). Note that there was very little snow and the soils were generally not frozen. It is evident from Figure 8 that most of the runoff resulted from intense rainfall events relatively soon after manure spreading.

Table 4. Effect of soil aeration on runoff and loadings of suspended solids and reactive P after application of manure in fall in coastal BC. The driest and wettest of 4 winters are shown.

	1998-1999 (high rain)		2001-2002 (low rain)	
Parameter	Control	Aeration	Control	Aeration
Runoff amount (L)	10460	1990	3550	1890
Suspended solids load (kg ha^{-1})	130	40	400	210b
Dissolved reactive P load (kg ha^{-1})	0.71	0.03	0.65	0.11

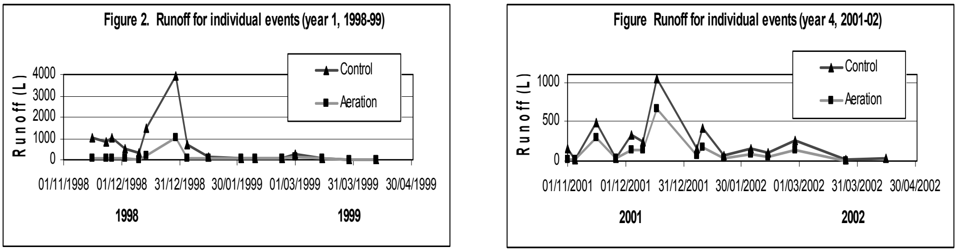
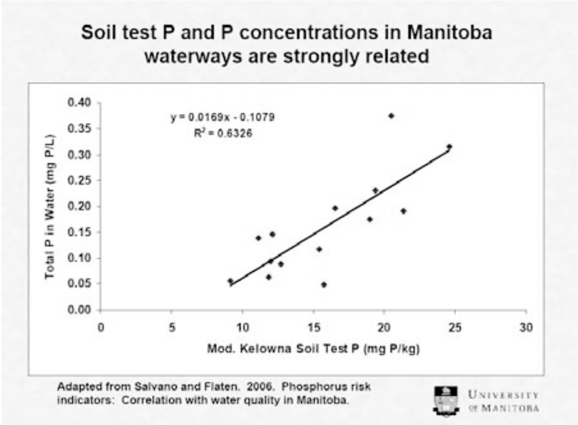


Figure 8. Effect of soil aeration on runoff events in coastal BC. The driest and wettest of 4 winters are shown.

Do Forages Reduce P Contamination Of Water?

It is well know that forages reduce erosion and thus sediment loading from fields into waterways. Surface runoff and erosion occurs on sloped land which would be reduced by cover crops, filter strips, contour farming, soil aeration and buffer strips on the field margins. However, on the prairie landscape, movement of P into surface waters occurs mostly from snow melt, and the transported P is in the form of dissolved reactive P rather than particulate P. Recent work in Manitoba and Alberta has shown that there is a strong relationship between the concentration of reactive P in soil and concentration of P in waterways (Figure 9). http://www.lakewinnipeg.org/web/downloads/P_Managment_on_CdnPrairies_by_Flaten_2007_09_22.pdf The significance of this work is that the conventional strategy for reducing movement of P into water that has been developed for sloped land (such as the well known P index) is less effective for much of the prairie landscape.



http://www.lakewinnipeg.org/web/downloads/P_Managment_on_CdnPrairies_by_Flaten_2007_09_22.pdf

Figure 9. Total P in waterways is closely related to soil test P in surrounding fields in Manitoba.

For example, in the prairie landscape, freezing and thawing cycles release soluble nutrients from vegetation contributing directly to soluble P which reaches waterways during snowmelt. Thus vegetation cover cannot be used to reduce loss of P in these landscapes. Similarly, buffer strips which are often recommended for protecting waterways from nutrient loadings may be less effective than often assumed for preventing P loadings associated with snow melts on flat land.

■ Conclusions

Phosphorus fertilizer is a dwindling resource yet accumulation of P in soils of intensive livestock farms threatens the health of water bodies. Uptake of P by crops is complex and deficiency is often marked by delayed crop development, so farmers need to carefully manage this nutrient to avoid excessive buildup in soils. For dairy operations, this means avoiding importing more P in feeds and fertilizer than is exported as milk and meat. Also, all P on the farm needs to be used efficiently. Managing the imbalance of N:P in manure relative to crop needs is a particular problem facing operations with a limited land base. Solid liquid separation enables better control over nutrient inputs on soils. Our research shows that the liquid fraction is an excellent N source for grass while the solid fraction can be used as a primary P source for corn. While ‘end-of pipe’ techniques are available for preventing loss of soil P into waterways, these techniques are not completely effective so it is important to keep P levels in the soil as low as possible.

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