Phosphorus Loading Effects on Water Quality in Alberta

A literature review was carried out by Howard et al. (2006) to examine the science-based evidence for the relationship between soil phosphorus and water pollution risk (Figure 6), and to present options for the development of a phosphorus management strategy in Alberta. The literature review was carried out in 1999. The main conclusions from the review are as follows.

- Research has increasingly identified excess phosphorus from municipal, industrial, and agricultural sources as a major threat to water quality.
- Potential risk to water quality increases with higher levels of soil phosphorus. However, site-specific soil, hydrologic, and management characteristics also have considerable influence on water pollution risk.
- Surface waters in Alberta are extremely sensitive to further phosphorus enrichment. Further enrichment of surface waters can have significant economic and environmental implications.
- A desirable long-range goal for Alberta is a balanced nutrient management approach to land application of nutrient-bearing materials.

Assessment of Other Jurisdictions

Jurisdictions in North America and elsewhere in the world have either faced or are facing similar challenges of managing soil phosphorus to prevent or remediate water contamination. The catalyst for action by other jurisdictions has often been related to the application of livestock manure. A detailed assessment study on how other jurisdictions have approached agricultural phosphorus issues was carried out in 2000 and 2001. Based on experiences in other jurisdictions, the objectives of the study were: (1) to evaluate the economic and environmental implications of implementing phosphorus standards in Alberta; (2) to evaluate mechanisms and time frames for the implementation of phosphorus standards in Alberta; and (3) to identify management options to assist producers to meet phosphorus standards (Soil Phosphorus Limits Committee and LandWise Inc. 2006).

An internet and literature search of 16 jurisdictions throughout the world was carried out. Four case-study jurisdictions were then selected based on program history, applicability, and adaptation to Alberta conditions. The case-study jurisdictions selected were Texas, Michigan, Wisconsin, and The Netherlands. A project team member and an industry or government

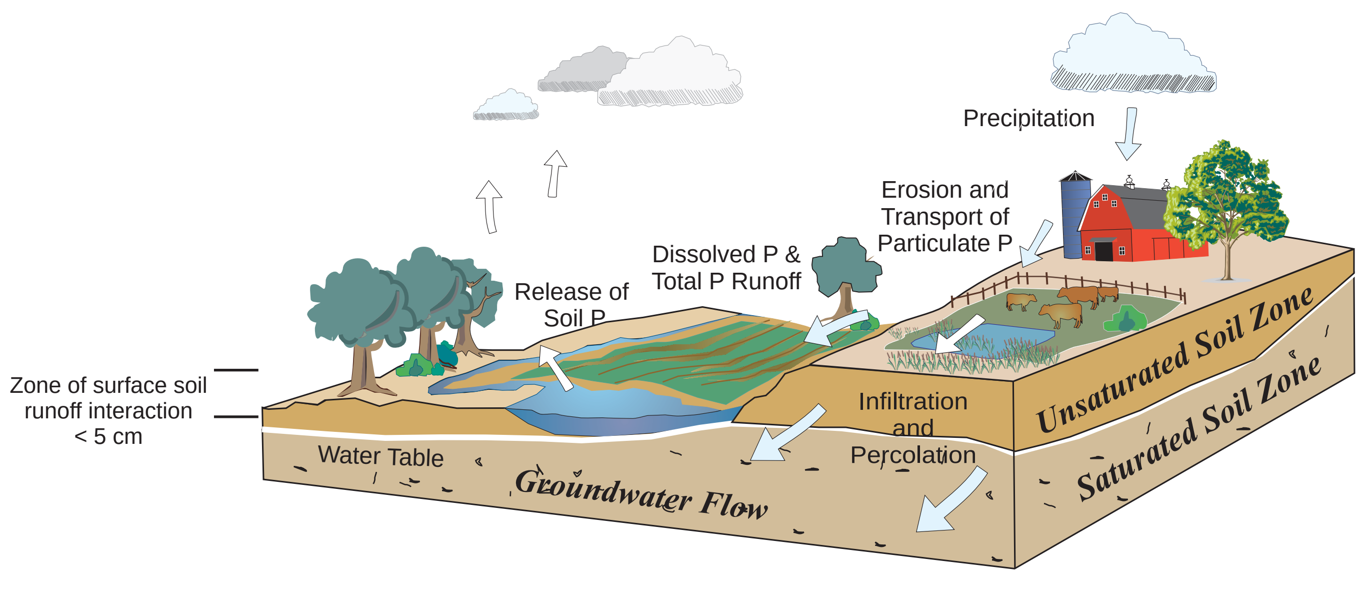
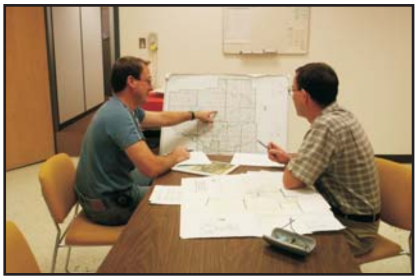


Figure 6. Phosphorus (P) transport processes (adapted from Sharpley et al. 1996).

representative travelled to each jurisdiction and collected more detailed information. Based on the results of the case studies, the following five recommendations were presented.

- ***Implementing soil phosphorus limits should include a voluntary education program within a regulatory framework.*** The case studies show that voluntary compliance through adoption of nutrient management plans was most successful in meeting environmental objectives. However, there must be a regulatory backup to achieve nutrient management objectives and to discourage violations. The case studies show that reliance on regulation alone is cost prohibitive, intrusive, and ineffective.



Producer training

- ***Phosphorus limits should be variable, depending on soil, climate, and topographic conditions.*** Phosphorus limits should be regionally varied and take into consideration differences in soil characteristics, climate, and topography. Case studies have shown that one limit across a political jurisdiction is not practical or credible.
- ***Implementation of phosphorus limits should be staged.*** For areas where soil phosphorus is in a deficit or balanced state, phosphorus limits should be implemented immediately. This could represent 80 to 85% of the land in Alberta. In areas of phosphorus surplus, phosphorus limits should be phased in to allow producers time to comply with the standards.
- ***Monitoring should be required to ensure phosphorus standards are met.*** Producers would be required to carry out a regular soil monitoring program and keep records to prove that soil phosphorus limits are not exceeded. In addition, the Alberta Government would be required to continue with long-term monitoring of representative watersheds to determine if environmental objectives are being met.
- ***Implementation of soil phosphorus limits should be combined with a coordinated nutrient management strategy.*** A provincial nutrient management strategy is required to provide producers and the agricultural industry with the necessary information and tools to manage soil phosphorus. This will require the selection and testing of beneficial management practices that are effective at a regional and local level throughout the province. Education, awareness, and demonstration of effective technologies need to be coordinated and implemented. Where effective technologies do not exist, applied research programs will be required.

Agronomic Phosphorus Thresholds

Phosphorus is an important nutrient for crop production and is often applied to soil to achieve optimum yield. A key tool for managing soil nutrients for optimum crop production is soil testing. A soil test and interpretation of the results determines whether or not a given soil is deficient in phosphorus, and if it is deficient, how much phosphorus should be added. For soils that are not deficient, there is no reason to apply phosphorus in terms of crop growth. An agronomic threshold of soil phosphorus is defined as the STP level beyond which there is no crop yield response to added phosphorus from either inorganic or organic fertilizer sources (Howard 2006). It was recognized that agronomic requirements of phosphorus in agricultural soil relative to environmental protection needed to be considered. Therefore, a literature review was carried out and addressed three areas: (1) a review of the basis for STP recommendations in Alberta; (2) a review of the agronomic thresholds for phosphorus that apply to different crops and soil types in Alberta;

> ***An agronomic threshold of 60 ppm in the top 15 cm of soil is the upper level for most crops. Applying additional phosphorus to the soil will not result in yield increases for most crops.***

and (3) a review of the implications for the application of non-commercial nutrient sources of phosphorus (Howard 2006).

Producers in Alberta soil test to obtain recommendations for the application of soil nutrients that are lacking for crop production. Two versions of the modified Kelowna extraction are commonly used for determining STP levels in Alberta. Based on data from field trials in the major soil groups of Alberta, an agronomic threshold of 60 ppm (modified Kelowna extractable phosphorus) in the top 15 cm of soil is the upper level for most crops. Applying additional phosphorus to the soil will not result in yield increases for most crops. The 60 ppm STP concentration represents about 120 kg/ha, depending on the soil bulk density.

Most of Alberta's soils are deficient in plant-available phosphorus. A province-wide study by Manunta et al. (2000) examined more than 56,000 soil analysis records for the 1993 to 1997 period, and found that the majority of Alberta soils had a mean STP value between 25 and 30 ppm in the top 15 cm. (Figure 7), which is below the agronomic threshold value of 60 ppm. These phosphorus levels mean that most producers can apply additional phosphorus to their soils to attain optimum yields. Manunta et al. (2000) also examined plant-available phosphorus levels for the 1963 to 1967 period, and found that levels had not changed significantly during the 30-year period. A detailed soil survey in a small, agricultural watershed in central Alberta showed that most of the land had 60 mg/kg STP or less in the top 15 cm of soil, and a large part of the land had 20 mg/kg STP or less (Svederus et al. 2006).

Soil-test phosphorus levels have not changed significantly between the 1960s and 1990s.

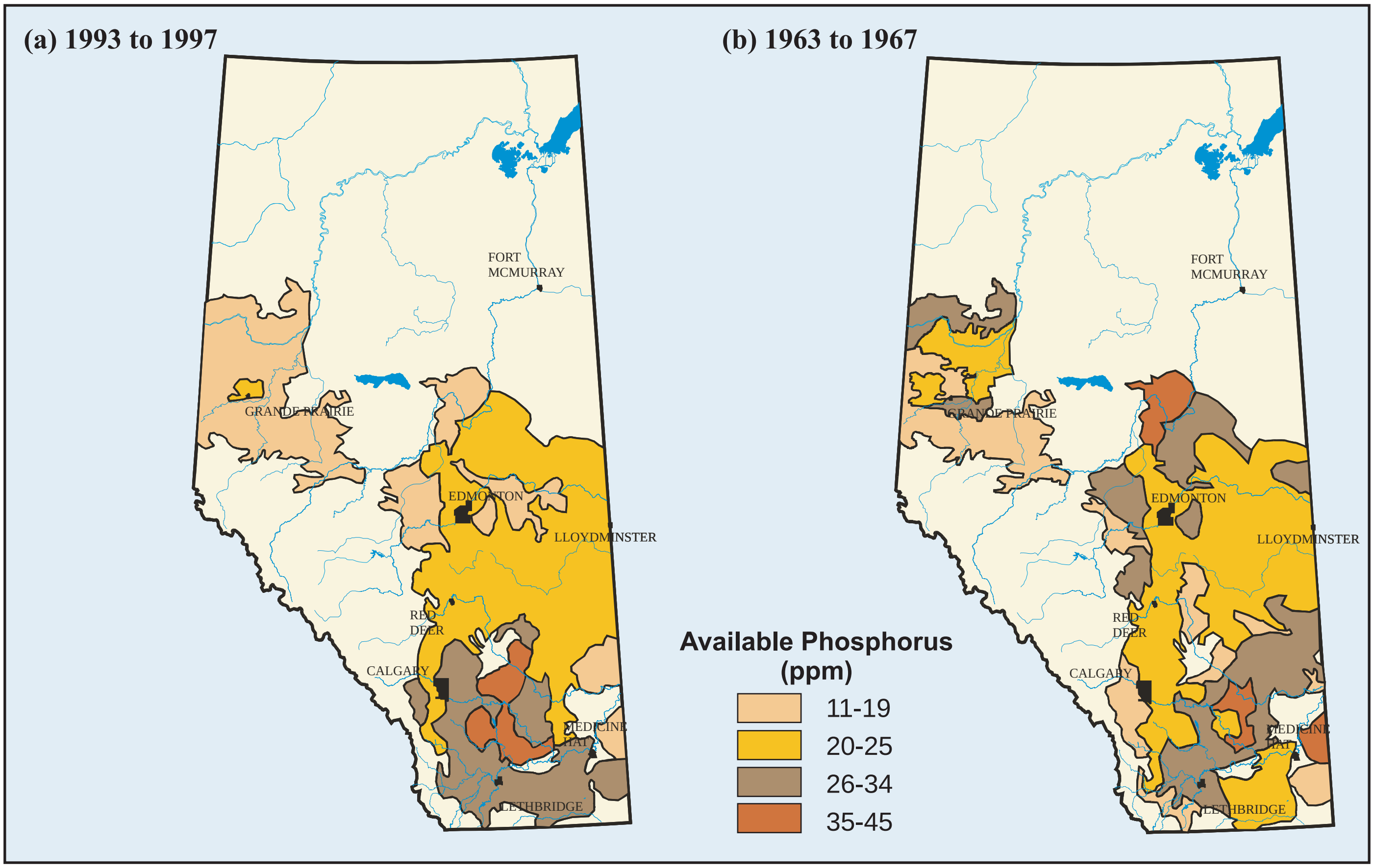


Figure 7. Available phosphorus for dryland annual crops in (a) 1993 to 1997 and (b) 1963 to 1967.

Phosphorus Export to Streams

The purpose for soil phosphorus limits is to minimize the amount of phosphorus that leaves agricultural watersheds and enters surface waters. The ultimate goal is to minimize anthropogenic causes and acceleration of eutrophication in surface water. An important part of the process of determining soil phosphorus limits is to select appropriate phosphorus concentrations in water. The purpose of this study was to assess options that may help define phosphorus limits in overland runoff so that the water quality of receiving water bodies is protected (Anderson 2006). This information may provide some guidance for selecting runoff water quality limits that may be used to calculate proposed soil phosphorus limits.

Small stream

Stream phosphorus data from 52 small streams, which were influenced by agricultural non-point sources, were used to illustrate how regional water quality limits could be derived. Stream data were grouped according to broad ecological areas in Alberta (boreal forest, parkland, and grassland) and agricultural intensity in the watershed (low, medium, and high). Six assumptions were made in assessing the data.

1. For each stream group, the data used to generate median dissolved phosphorus (DP) flow-weighted mean concentration (FWMC) were representative.
2. The 50^{th} percentile was the best measure to use as a reference for no further deterioration.
3. Dissolved phosphorus was considered the best marker for agricultural losses of phosphorus.
4. All land within a watershed contributed equally.
5. All phosphorus transported by the stream was derived from terrestrial origin.
6. Flow-weighted mean concentrations and export coefficients were applied to the entire annual flow period.

Depending on the ecological area and the level of agricultural intensity, DP FWMC limits ranged from 0.02 to 0.56 ppm and export coefficients ranged from 0.001 to 0.090 kg/ha DP (Anderson 2006).

Phosphorus Sources and Sinks in Watersheds

A literature review was carried out by Riemersma et al. (2006) on phosphorus sources and sinks in watersheds. The purpose of this review was to:

- Identify phosphorus sources and sinks that may impact water resources;
- Identify their individual contributions;
- Assess attempts to integrate phosphorus fluxes on a watershed scale; and
- Identify implications of the information on the Soil Phosphorus Limits Project.

The following are some highlights from the review.

- A common aspect to all studies was the inherent variability of phosphorus flux and its dependence on local conditions.
- Each land-use activity has a variety of factors that can affect the availability and transport of phosphorus.
- The phosphorus cycle in receiving water bodies is complex, and aquatic systems can act as a source and as a sink for phosphorus.
- Because of the inherent variability in watersheds, the phosphorus in runoff water is site-specific, and results in a large range of export coefficients for each source.
- Few studies have attempted to link small-scale plot work with large-scale watersheds. Researchers that have attempted this linkage of different scales found that a large proportion of soluble phosphorus from land is attenuated in-stream through adsorption or dilution.
- Researchers that have conducted large, multiple-land-use watershed studies found it difficult to

account for phosphorus from specific sources.

- There is some evidence that internal loading may contribute more to phosphorus concentrations in surface water, especially in lakes, than runoff from surrounding land.
- Soil-test phosphorus and the relationship between STP and DP in runoff, alone, will not provide an adequate basis for developing soil phosphorus limits in Alberta. Particulate phosphorus (PP) must also be included in the assessment of phosphorus losses from land to water.
- Targeting management practices within critical source areas may be the most effective way to reduce phosphorus losses.
- A better understanding of in-stream processes may help to identify the contributions of phosphorus from terrestrial or aquatic environments.
- Groundwater and surface water interactions, as well as atmospheric deposition, are other potential sources of phosphorus.

Considering all the variables, it is not surprising that each watershed seems to have a unique phosphorus budget. Export coefficients of phosphorus in runoff are site-specific, and heavily influenced by factors such as vegetation, soil structure, topography, precipitation, and watershed size. Combining those variables with various land use and management practices on tracts of land, a watershed-scale study will only produce phosphorus budgets that are suitable for the watershed that is being evaluated (Riemersma et al. 2006).

Soil Phosphorus Limits Project
Research Studies

Soil and Runoff Phosphorus in Eight Microwatersheds

Introduction

The main objective of this study was to determine the field-scale relationship between STP and runoff TP and dissolved reactive phosphorus (DRP) from field-sized watersheds (microwatersheds) under conditions in Alberta (Little et al. 2006).

Methodology

Eight microwatershed sites (2 to 248 ha) were selected throughout the agricultural zone of Alberta (Figure 8). The sites included one ungrazed grassland site west of Stavely (STV); five cultivated, non-manured sites near Crowfoot Creek (CFT), Grande Prairie Creek (GPC), Renwick Creek (REN), Threehills Creek (THC), and Wabash Creek (WAB); and two cultivated, manured sites near Ponoka (PON, heavy applications of cattle manure) and Lower Little Bow River (LLB, moderate applications of cattle manure). The microwatershed sites represented a range of precipitation and runoff potential within the agricultural area of Alberta.

Soil samples were collected from each site in the fall of 2002, 2003, and 2004, and from each site, except the STV site, in the spring of 2003, 2004, and 2005. The number of soil sampling points per site ranged from 22 to 48, except for the STV site, which had three sampling points. The sampling points were selected based on landform position and were arranged in a series of transects with upper, mid, and lower landform position sampling points. Soil samples were taken by laying an 11 by 60 cm steel frame on the soil surface and excavating the soil to the 15-cm depth in three incremental layers (0 to 2.5 cm, 2.5 to 5 cm, and 5 to 15 cm). Soil samples were air dried, ground, and analyzed for STP content using the modified Kelowna extraction method of Qian et al. (1991). Soil-test phosphorus values were calculated for the 0 to 2.5 cm, 0 to 5 cm, and 0 to15 cm soil layers. The fall STP values were related to the phosphorus concentration in the following spring runoff (i.e., snowmelt-generated runoff). The spring STP values were related to summer runoff events in the same year (i.e., rainfall- or irrigation-generated runoff). The STP results were used to calculate mean values for five different STP landform representations: simple average of all sampling

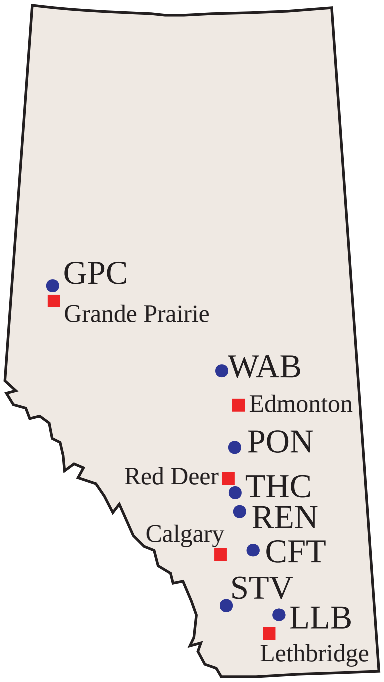


Figure 8. Microwatershed sites.

Figure 9. Instrumentation at the Lower Little Bow River site (left) and close-up of the circular flume (right).

points; landform-area weighted mean; runoff contributing area; representative random (typically used for agronomic sampling); and random subsamples. In addition, the degree of phosphorus saturation (DPS) was calculated for a subset of 0 to 2.5 cm soil samples using the STP values and phosphorus sorption index (PSI) values.

The outlet of each microwatershed was instrumented with a circular flume and a float potentiometer to measure flow volume (Figure 9). The exception was the STV site, which had an existing 0.15-m trapezoidal flume. Each site was equipped with a float potentiometer placed within the vertical column of the flume (Figure 9) to measure the head of water. Sites were also equipped with Lakewood TP10K5 thermistors and tipping bucket rain gauges. Backup float potentiometers and dataloggers were installed at most sites in 2004. Each site was equipped with ROM Communications Microcom units, which were integrated dataloggers with cellular communications technology that allowed for real-time monitoring of site conditions through the Internet.

Water samples were taken by ISCO 6700 automated water sampling devices. The ISCO samplers were programmed to take a 150 mL sample every 15 minutes for a total volume of 900 mL, or six samples per bottle. Changes in head were used to trigger the ISCO via the ROM Communications Microcom unit whenever flow volumes reached the minimum criteria set for each watershed. Water samples were collected daily during runoff events and immediately transported to the laboratory for analysis.

Water subsamples were filtered upon arrival at the laboratory and analyzed within 24 hours for pH and electrical conductivity, within 48 hours for DRP and within 30 days for TP. Runoff phosphorus was calculated as a flow-weighted mean concentration (FWMC) expressed as parts per million (ppm).

Results

Soil-test phosphorus values ranged from 3 to 512 ppm in the top 15 cm of soil among the eight microwatersheds (Little et al. 2006). The lowest STP concentration was at the grassland site (3 to 5 ppm), followed by the five non-manured crop land sites (20 to 39 ppm). The highest levels of STP were at the two manured crop land sites (236 to 512 ppm).

Strong linear relationships were found between STP and phosphorus in runoff.

Soil-test phosphorus decreased as the sampling depth increased from 0 to 2.5 cm to 0 to 5 cm, to 0 to 15 cm. However, there were no significant differences between the two shallower layers, and STP in the 0 to 15 cm layer was only significantly lower compared to the other two layers at three of the eight sites. There were few differences in STP concentrations among landform positions (upper, mid, and lower slope) at the microwatershed sites. The DPS ranged from 5 to 91%. The grassland and nonmanured cultivated sites had lower DPS values (less than 30%) compared to the two manured sites (greater than 50%).

Snowmelt runoff accounted for 90% of the runoff volume from the eight sites during the 3 years of the study (Figure 10). Seasonal FWMCs ranged from 0.01 to 7.4 ppm DRP and 0.1 to 8.0 ppm TP. Phosphorus concentration was higher in runoff from the two manured sites compared to the nonmanured sites.

Figure 10. About 90% of the total annual runoff occurred during spring snowmelt.

Strong linear relationships were found between STP and phosphorus in runoff (Little et al. 2006). Relationships were developed for DRP and TP FWMC. Although a number of different STP representations were examined, a simple average of all soil sampling points was as good a predictor of runoff phosphorus concentrations as the other STP representations tested. The relationships were also comparable among the three soil layers (0 to 2.5 cm, 0 to 5 cm, and 0 to 15 cm). The simple average of any soil layer was the best predictor because there were essentially no differences among STP values of the representations, and the STP was highly correlated among the three soil layers. The latter point is particularly useful since the standard soil sampling depth is 15 cm for agronomic sampling for STP analysis. This means that soils sampled for agronomic purposes to the 15-cm depth, using recommended sampling strategies, can be used to predict phosphorus losses in runoff water (Figure 11).

This means that soils sampled for agronomic purposes can be used to predict phosphorus losses in runoff water.

Strong relationships were also found between DPS and the DRP and TP FWMC; however, the relationships were not linear. Predictive abilities were similar to those observed for STP. Change point values corresponded to STP values that were around the agronomic threshold of 60 ppm. Although the DPS holds promise for predicting runoff and leaching losses of phosphorus, the modified Kelowna STP is the standard for agronomic sampling in Alberta and the results suggest that there is no strong reason to move toward another soil test.

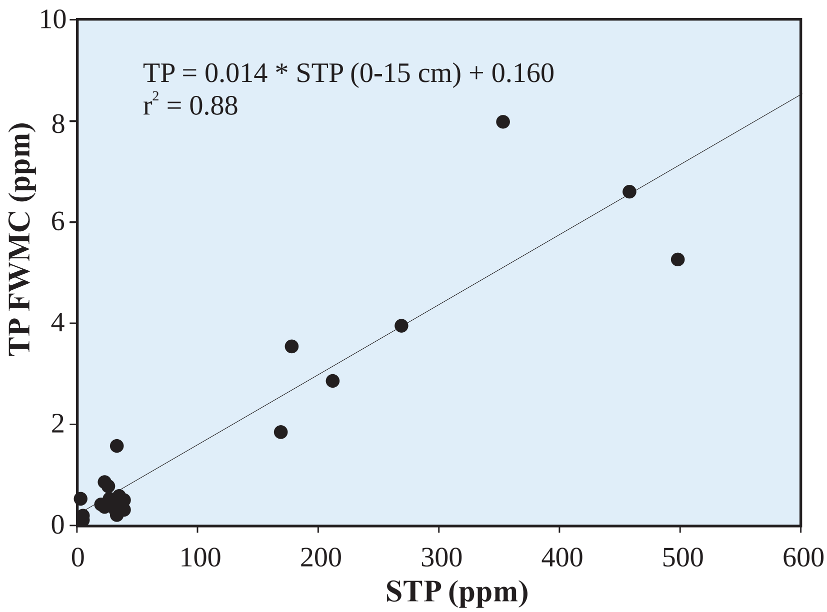


Figure 11. Relationship between soil-test phosphorus (STP) in the 0 to 15 cm soil layer and total phosphorus (TP) flow-weighted mean concentration (FWMC) in runoff water.

Phosphorus Losses in Simulated Rainfall Runoff From Manured Soils

Introduction

The main objective of this study was to determine the effects of manure application rate and incorporation on phosphorus concentrations in runoff from cropped agricultural land (Ontkean et al. 2006). These effects were studied immediately after manure application as well as 1 year later, allowing phosphorus in the manure and soil to equilibrate.

Methodology

Three sites were selected for this study: one near Wilson (southeast of Lethbridge), one near Lacombe, and one near Beaverlodge. The Wilson site had Orthic Dark Brown Chernozemic clay-loam to clay soil and a 6% slope, the Lacombe site had Orthic Black Chernozemic loam to sandy-clay-loam soil and a 10% slope, and the Beaverlodge site had Dark Gray Luvisolic clay-loam soil and a 5% slope. All three sites were under cereal production.

Experimental treatments included four cattle manure application rates and two levels of incorporation (incorporated and non-incorporated) for a total of eight treatments. The plots were 7 by 10 m in size and the treatments were arranged in a randomized complete block design with four replicates. Manure application rates were based on TP. The application rates were approximately 0, 100, 200, and 400 kg/ha TP at the Wilson site; 0, 50, 100, and 200 kg/ha TP at the Lacombe site; and 0, 25, 50, and 100 kg/ha TP at the Beaverlodge site.

Soil samples (0 to 2.5 cm) were collected from each plot prior to manure application. Soils were sampled again after manure application, but prior to rainfall simulations. Soil samples were air dried, ground, and analyzed for STP content using the modified Kelowna extraction method of Qian et al. (1991). Manure samples collected at the time of application were analyzed for TP and water-extractable phosphorus (WEP).

Rainfall simulations were carried out immediately after manure application and 1 year after application. Simulated rainfall was generated from a single Fulljet ½HH-SS50WSQ nozzle held 3 m above a 1.5 by 2 m area delineated on three sides by a steel frame. The rainfall rate was 70 mm per hour. This apparatus is the standard system utilized throughout North America, and this allows comparison of results by researchers in Canada and the United States (Figure 12).

Composite samples of runoff water were collected during consecutive intervals ending 5, 10, 20, and 30 minutes after the commencement of runoff. The total volume of water collected during each timed interval was recorded. Samples from each time interval sampled were analyzed for TP, DRP, and total suspended solids (TSS). The DRP and TP FWMC and mass load values were determined in the total runoff period of 30 minutes.

Results

Soil-test phosphorus measured on freshly applied and residual manured soils increased with manure rate, but was generally lower for the residual manured soils at all sites (Ontkean et al. 2006). Some treatments had higher STP values 1 year after application, but these were associated with the unmanured and the lowest manure application rates. Generally, as the manure application rate increased, the greater the decrease in STP 1 year after application.

There were clear relationships observed between manure application rate and phosphorus concentration in the runoff from the rainfall simulation sites. The concentrations of TP in the runoff increased as the manure rate and associated STP increased from freshly manured soil (Figure 13). The same relationship was observed for the manured soils 1 year later, though at a lower rate. The TP concentration in runoff generally decreased more than the STP 1 year after manure application. Manure application rate had no effect on runoff volumes from either freshly manured or residual (1 year later) manured soils.

Soil-test phosphorus values were similar between incorporated and non-incorporated fresh and residual manured treatments, indicating an insignificant amount of phosphorus burial below the 0 to 2.5 cm layer (Ontkean et al. 2006). Runoff volumes and concentrations of TP and DRP in runoff decreased with manure incorporation for the freshly manured Beaverlodge simulations. However, incorporation did not impact runoff volumes and phosphorus concentrations at the other two sites, nor at the Beaverlodge site 1 year after manure incorporation. The effects of

Figure 12. Rainfall simulator, runoff frame and collection tray.

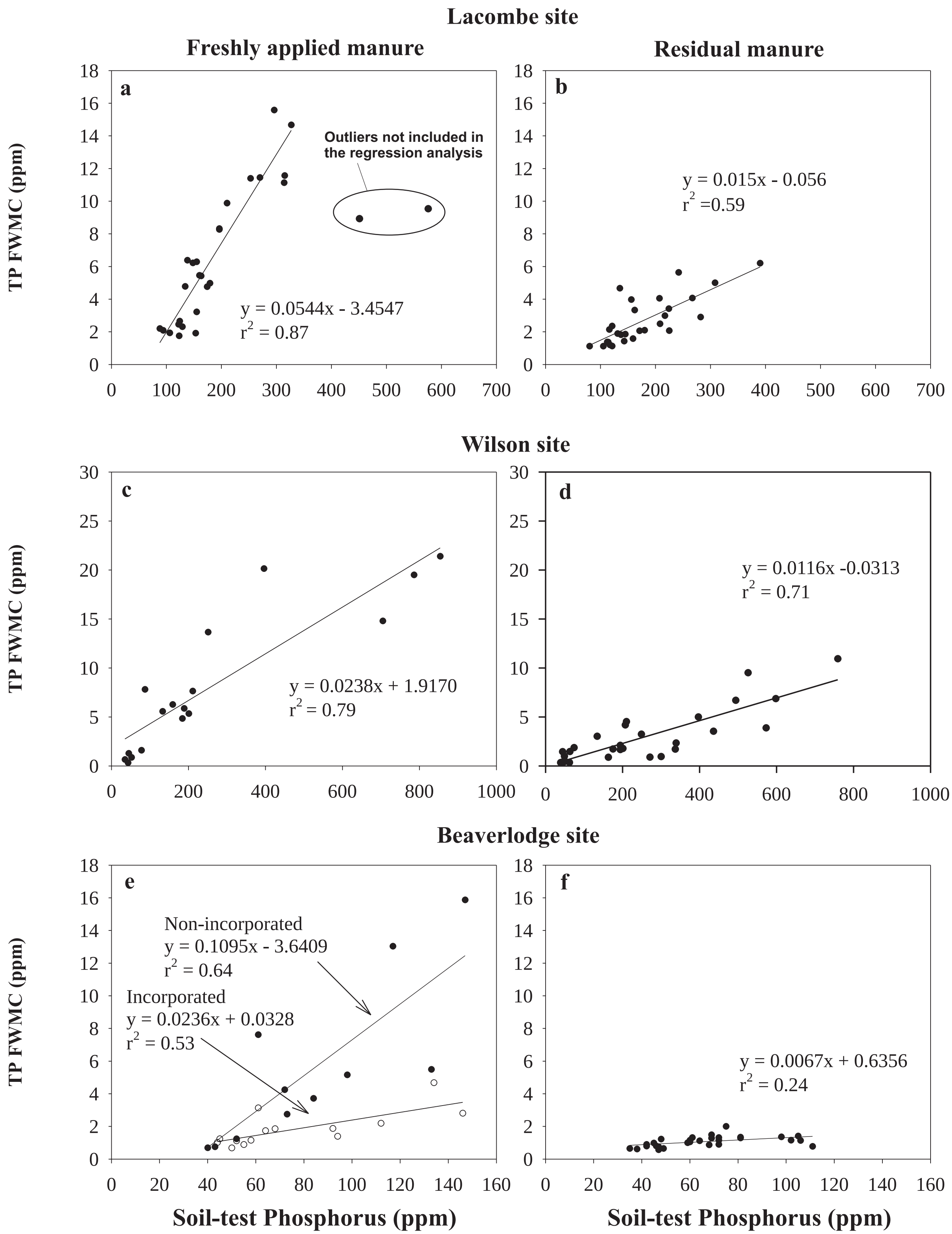


Figure 13. Relationship between soil-test phosphorus, after manure application and total phosphorus (TP) flow-weighted mean concentration (FWMC) in runoff at the rainfall simulator sites.

immediate incorporation at the Beaverlodge site were likely due to impeded infiltration of the non-incorporated treatments caused by soil surface sealing.

Of the parameters evaluated to predict TP and DRP concentration in runoff from freshly manured soils, the strongest relationships were found with applied manure TP. Strong relationships were also observed with STP after manure application.

Phosphorus loads in runoff from rainfall simulations conducted on freshly manured and residual manured soils exhibited similar trends relative to phosphorus concentrations. A relatively small portion (< 3%) of the phosphorus applied with manure was removed by runoff from the freshly manured soils, and less than 1% was removed 1 year after manure application. This indicates a large amount of applied phosphorus remains in the soil for potential transport during subsequent runoff events.

In general, the relationships between manure phosphorus in the soil profile and phosphorus concentrations in the runoff in the rainfall simulations were similar to the relationships observed for the microwatershed studies (Figure 14). As the amount of phosphorus in the upper soil profile increased, the concentration of phosphorus in runoff water increased. This relationship holds true regardless of whether the phosphorus is from non-manured or manured soil. When manure has time to equilibrate with the soil (6 to 12 months), as shown by the residual manure treatments (Figure 14), the relationship between STP and phosphorus concentrations in the runoff water are similar to the microwatershed values.

Phosphorus Sorption and Saturation Thresholds in Soil

Introduction

Two studies were conducted. The objective of the first study was to validate and adapt a single-point phosphorus sorption index (PSI) method for Alberta soils. The objectives of the second study were: to examine the phosphorus sorption characteristics of 13 soils; to determine if water-extractable phosphorus and calcium chloride-extractable phosphorus ($CaCl_2$-P) are good proxies for runoff phosphorus in these soils; and to determine the site-specific environmental thresholds of soil phosphorus (change points) in these soils (Casson et al. 2006).

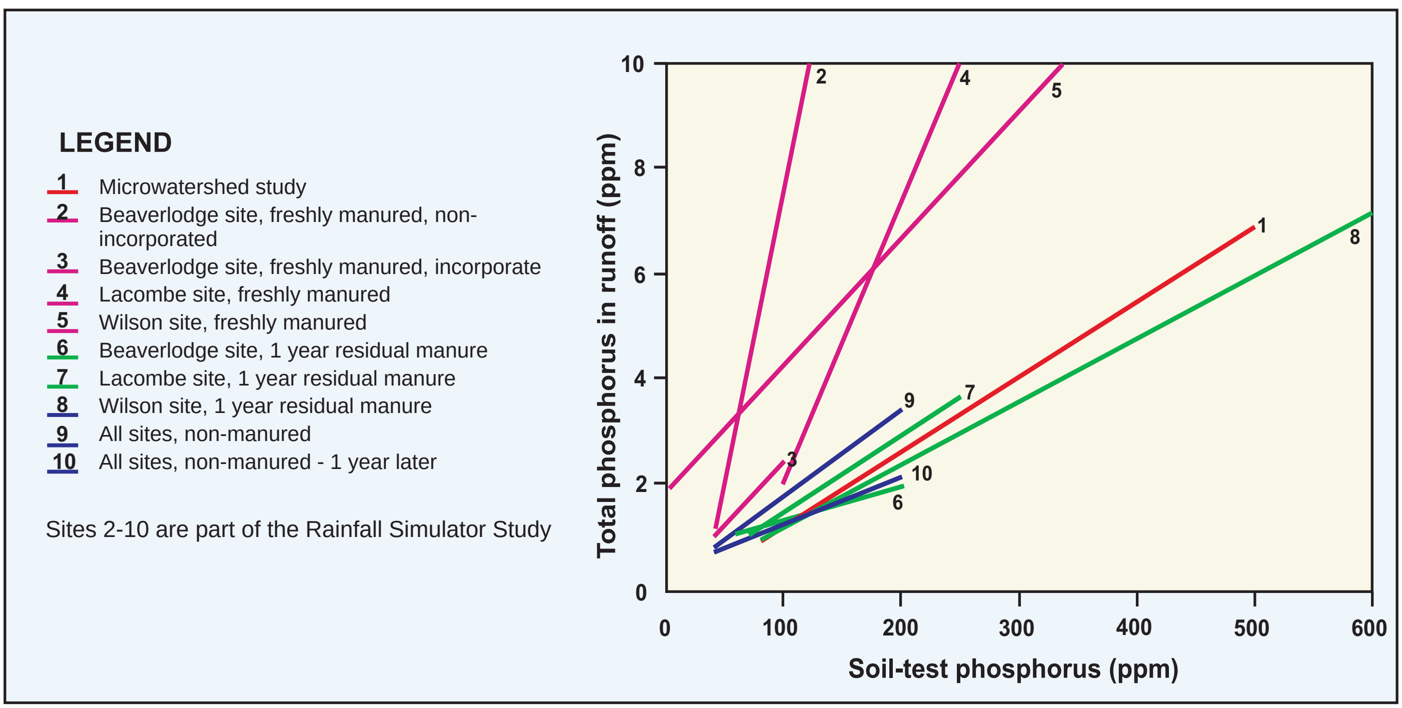


Figure 14. Relationships between soil-test phosphorus concentration and total phosphorus concentration in runoff water.

Methodology

For the first study, 47 archived soil samples from a previous study (Wright et al. 2003) were used to compare two single-point PSI methods (KCl-PSI and $CaCl_2$-PSI) to phosphorus sorption capacity (PSC) values determined using adsorption isotherms. These were surface soils (0 to 10 cm) collected throughout Alberta with STP values that ranged from 15 to 628 ppm. The PSI methods involve shaking the soil with a solution of KCl or $CaCl_2$ containing a known amount of phosphorus. The PSI values were calculated as the amount of phosphorus (mg) removed from solution by the soil divided by the soil weight (kg).

As the amount of phosphorus in the upper soil profile increases, so does the concentration of phosphorus in runoff water. This relationship holds true regardless of whether the soil phosphorus is from non-manured or manured soil.

For the second study, the degree of phosphorus saturation (DPS) of 13 Alberta soils was assessed using archived soil samples obtained from three field studies: a manure rate study where solid cattle manure was applied annually to irrigated soils for 8 years (1993 to 2000) at two sites near Picture Butte (Olson et al. 2003; Figure 15); a manure rate and tillage rainfall simulation study where solid cattle manure was applied once at various rates of TP at three sites (Ontkean et al. 2006); and a microwatershed study at eight sites that were part of a 3-year study to determine the relationship between STP and phosphorus in runoff (Little et al. 2006). The 8-year manure study involved a replicated plot study where cattle manure was applied at 0, 20, 40, 60, and 120 tonnes/ha (wet weight) each year. Soil samples used from this study were the samples collected at the end of the 8-year study. Single-point PSI values were determined on all of the samples using the $CaCl_2$-PSI method. The DPS values were calculated by dividing STP by STP plus PSI multiplied by 100. The soil samples were also analyzed for WEP content and 0.01M $CaCl_2$-extractable phosphorus ($CaCl_2$-P). The WEP and $CaCl_2$-P values were used as proxies for phosphorus that could be lost in runoff from these 13 soils. Actual runoff phosphorus concentration values obtained from the microwatershed study (Little et al. 2006) and

Figure 15. Small-plot study where cattle manure was applied annually at various rates for 8 years (Olson et al. 2003).

manure and tillage study (Ontkean et al. 2006) were also examined in relation to DPS values. Runoff studies were not carried out in the 8-year manure application rate study.

Results

A single-point $CaCl_2$-PSI method was validated by comparing to adsorption isotherm data from a wide range of Alberta soils (Casson et al. 2006). This method was subsequently used to determine the phosphorus sorption status of 13 Alberta soils.

Strong linear relationships were determined between STP and desorbed phosphorus (WEP and $CaCl_2$-P) in 13 Alberta soils (Casson et al. 2006). The WEP method generally resulted in higher concentrations of desorbed phosphorus than the $CaCl_2$-P method. Change points for DPS were identified in 12 of the 13 soils at values between 3 to 47% for WEP and 11 to 59% for $CaCl_2$-P using DPS-desorbed phosphorus relationships determined in the laboratory. Weak linear relationships were also found between STP and runoff DRP for the three soils used for the manure rate and tillage study. Change points for DPS and runoff DRP were not evident in the manure rate and tillage and microwatershed study soils.

Desorbed phosphorus concentrations (WEP or $CaCl_2$-P) determined in the laboratory were generally higher, in relation to STP or DPS, than runoff DRP concentrations measured in the three manure rate and tillage soils and eight microwatershed soils. However, the relative amounts of runoff DRP that could be lost from these soils were similar to the desorbed phosphorus values for the range of WEP and $CaCl_2$-P values observed. Both proxies overestimated phosphorus losses in runoff from the microwatershed sites, but relative amounts lost among sites were similar. These results suggest that WEP and $CaCl_2$-P may be good indicators of the relative amounts of DRP that can be lost from agricultural soils.

Analysis of all 13 soils combined resulted in DPS change points that were similar to the agronomic STP threshold of 50 to 60 ppm for crops grown on Alberta soils (Casson et al. 2006). The overall DPS threshold for these 13 soils was 35% for WEP and 54% for $CaCl_2$-P (Figure 16). These critical DPS thresholds correspond to modified Kelowna

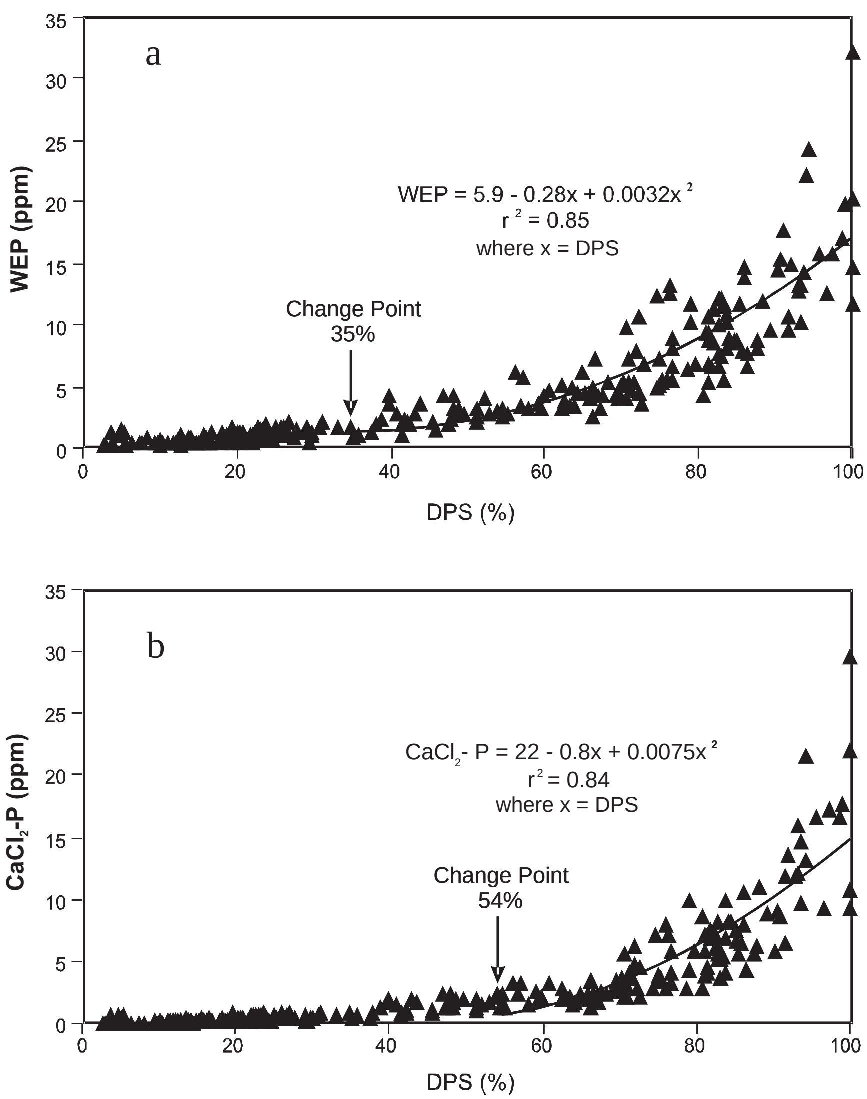


Figure 16. Relationships between degree of phosphorus saturation (DPS) and (a) water-extractable phosphorus (WEP), and (b) calcium chloride-extractable phosphorus ($CaCl_2$-P) in 13 Alberta soils.

STP values of approximately 51 ppm and 86 ppm, respectively, which are close to the agronomic threshold. Soils with DPS values that exceed these thresholds may be more susceptible to soluble phosphorus losses in overland flow and leaching.

Soil Sampling for Phosphorus

Introduction

A new soil-excavation method using a steel frame excavation method to collect soil samples within the 0 to 15 cm layer was developed for the microwatershed study (Little et al. 2006). The objective of this soil sampling study was to determine whether the frame-excavation method of sampling decreased STP variability, and thus improved the accuracy of STP measurements, compared to a variety of coring methods (Nolan et al. 2006; Figure 17). This is particularly relevant when phosphorus sources are banded in soil.

Methodology

The comparison of methods was carried out at four, small-plot sites: Wainwright manure site, Lethbridge manure site, Lethbridge fertilizer site, and Calgary biosolids site (Table 3). The Wainwright manure site included three 30 by 30 m plots, which were injected with 90,000 L/ha of liquid hog manure (60 kg/ha TP). Soil samples were collected about 1 month after manure injection. The two Lethbridge sites consisted of two treatments (with and without added phosphorus) arranged in a randomized complete block design replicated four times for a total of eight plots per site. Each plot was 7.5 by 10 m in size. The phosphorus source for the Lethbridge manure site was injected liquid hog manure (90,000 L/ha; 53 kg/ha TP), and the phosphorus source for the Lethbridge fertilizer site was banded inorganic fertilizer (176 kg/ha as elemental phosphorus). The phosphorus sources were applied in October and soil samples were taken the following May. The Calgary biosolids site consisted of four, 15 by 20 m plots: two plots received no biosolids and the other two plots received 10 tonnes/ha biosolids. Soil samples were taken 2 weeks after the biosolids were injected. The frame-excavation method was compared to three or five core sampling methods (Table 3).

The frame-excavation and 10-core methods also were compared at seven of the Microwatershed Study sites (Little et al. 2006): Crowfoot Creek (CFT), Grand Prairie Creek (GPC), Renwick Creek (REN), Three Hills Creek (THC), Wabash Creek (WAB), Lower Little Bow (LLB), and Ponoka (PON).

Soil samples were analyzed for STP content using the modified Kelowna method (Qian et al.

Figure 17. Frame-excavation method (left) versus core method (right).

Table 3. Small-plot sites used to compare soil sampling methods.

Site	Type	Plot size	Treatment[z]	No. of replicates	Methods compared
Wainwright manure	small plot	30 x 30	hog manure	3	frame, 5 core, 10 core, 20 core
Lethbridge manure	small plot	7.5 x 10	control, hog manure	4	frame, 5 core, 10 core, 20 core, 10 core/4 cm, directed cores
Lethbridge fertilizer	small plot	7.5 x 10	control, fertilizer	4	frame, 5 core, 10 core, 20 core, 10 core/4 cm, directed cores
Calgary biosolids	small plot	15 x 20	control, biosolid	2	frame, 5 core, 10 core, 20 core, 10 core/4 cm, directed cores
Microwatershed	field scale	–	none	note[y]	frame, 10 core

[z] Hog manure injected at 90,000 L/ha (53 to 60 kg/ha TP); fertilizer banded at 176 kg/ha P; biosolids injected at 10 tonnes/ha, wet weight.

[y] Included seven agricultural microwatershed sites with 5 to 12 sampling points per site during 2 years.

1991). A four gram subsample was weighed for the laboratory extraction procedure for all samples, except for the 10-core method used at the Microwatershed Study sites for which 4-cm^3 volume subsamples were used instead.

Results

Comparison of the frame-excavation method with several methods of core sampling showed that all of the sampling methods provided similar STP values at the Wainwright manure and Lethbridge fertilizer sites (Nolan et al. 2006). This was also generally true for the Lethbridge manure site. At the Calgary biosolids site, where only two replicates were used, significantly higher STP levels were measured using the 20-core method relative to the 5-core or the frame-excavation methods in all soil layers. Standard deviations did not differ significantly among the sampling methods at any of the sites, regardless of soil layer, except in the 0 to 2.5 cm and 0 to 5 cm layers at the Calgary Biosolids site (Nolan et al. 2006). However, where high levels of phosphorus (greater than 176 ppm) were applied in targeted layers, the standard deviations for the frame-excavation samples were the lowest. The time required to use the frame-excavation method was comparable to the 10-core composite sample method. The number of samples needed to measure STP within 10% of the mean in the soil layer where STP increases were greatest was reduced with the frame-excavation method for three of the four study sites (Table 4). It was concluded that a minimum of five core composite samples per sampling point were adequate for soils with low levels of banded phosphorus. For soils with higher and more variable phosphorus content, the frame-type method of sampling was comparable to other coring methods for determination of STP, but with reduced requirements for sampling time, and reduced requirements for the number of replicates needed to measure an accurate mean.

The STP in the 0 to 15 cm soil layer measured using the 10-core (subsampled by volume in the lab) method was well correlated with STP measured using the frame-excavation (subsampled by weight in the lab) method for a range of site conditions ($r^2 = 0.93$) in the Microwatershed Study. On average, the 10-core method STP values were about 28% less than STP values using the frame-excavation method. The same difference in STP values between the two methods was observed when the non-manured and manured site data were separated. The study design for the Microwatershed Study did not allow for separation of the sampling method (frame versus core) and

Table 4. Results of Stein's two-stage approach (Stein 1945) to estimate the number of soil sampling points required to accurately measure STP levels in the 0 to 15 cm soil layer.

Treatment	**Site**			
	Wainwright manure[z]	Lethbridge manure[z]	Lethbridge fertilizer[z]	Calgary biosolids[z]
5 cores	22	187	47	5
Directed[x]	-	12	24	17
10 cores	16	30	25	26
10 cores/4cm	-	15	125	29
20 cores	4	55	20	3
Frame	2	30	9	1

[z] Hog manure injected at 90,000 L/ha (53 to 60 kg/ha TP); fertilizer banded at 176 kg/ha P; biosolids injected at 10 tonnes/ha, wet weight.

[x] One within-band to eight between-band cores at manure site (30-cm spacing), and one within-band core to six between-band cores at fertilizer and biosolids sites (23-cm spacing).

analytical method effects (weight versus volume subsamples for analysis), or their interactions. Additional work is needed to clarify these effects. However, a more precise measure of STP would be obtained by weighing sub-samples for laboratory analysis because of the uncertainty of the bulk densities of sub-samples removed by volume.

Economic Assessment of Soil Phosphorus Limits

Introduction

The application of livestock manure based on crop phosphorus requirements generally requires a larger land base for application and increased transportation distances of the manure. These factors often have significant economic implications. The objectives of this study were: (1) to assess the current Alberta livestock industry with respect to manure and related phosphorus production; (2) to identify the current benefits and costs associated with livestock manure management; (3) to assess the costs, limitations, and benefits of livestock manure management if phosphorus limits are implemented; and (4) to identify the potential impacts to the Alberta agriculture industry if phosphorus limits are implemented (Toma and Bouma Management Consultants 2006).

Methodology

Nine case studies were examined; three hog, three dairy, and three beef feedlot operations. The cost of hauling manure different distances was based on estimated prices provided by custom applicators. The economic breakeven points for the distances that manure could be transported before it became more economical to purchase commercial fertilizers was calculated for each case study by varying a number of factors. These factors included: phosphorus availability in manure; the cost of commercial nitrogen and phosphorus fertilizers; and the nitrogen and phosphorus content of manure. A more in-depth analysis was carried out using a cattle feedlot operation and a farrow-to-finish hog operation and various scenarios. The purpose of this analysis was to determine the cost at the farm level if a phosphorus limit policy was implemented. In addition, the analysis identified any further limitations and/or benefits that might arise. The following four scenarios were applied to the two case studies.

- Scenario 4P – manure is spread at four times the annual phosphorus requirement of the crop. This is a 4-year rotation (manure applied on a given parcel of land once every 4 years).
- Scenario 2P – manure is spread at twice the annual phosphorus requirement of the crop. This is a 2-year rotation (manure applied on a given parcel of land once every 2 years).
- Scenario 1P – manure is spread to meet the annual phosphorus requirement of the crop. This requires manure to be spread on the same land every year.
- Scenario 2N – manure is spread at twice the annual nitrogen requirement of the crop. This is a 4-year rotation (manure applied on a given parcel of land once every 4 years).

Results

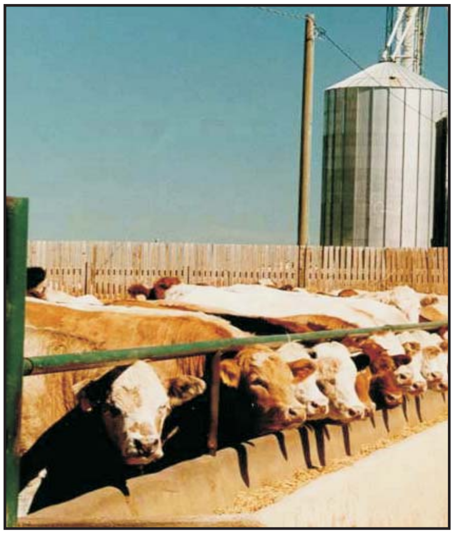
The literature review revealed that cost impacts at the farm level are highly variable and depend on several factors (Toma and Bouma Management Consultants 2006). Also, regional cost impacts are also highly variable, such that net cost impacts can range from levels that threaten the economic viability of farms to actually providing a net economic benefit resulting from better manure utilization as a source of nutrients. The willingness of cropland operators to accept manure is an important determinant of the ultimate costs associated with disposal of manure in regions with high animal concentrations.

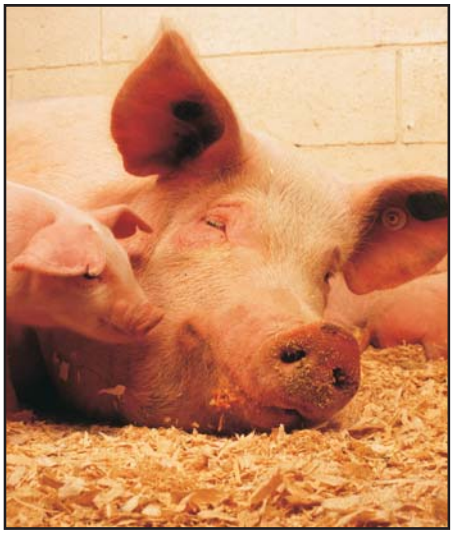
Provincial livestock populations are highly concentrated on relatively few farm operations. The statistical analysis illustrates that 1.2% of farms account for approximately 50% of all livestock. Livestock populations are skewed regionally and by municipality.

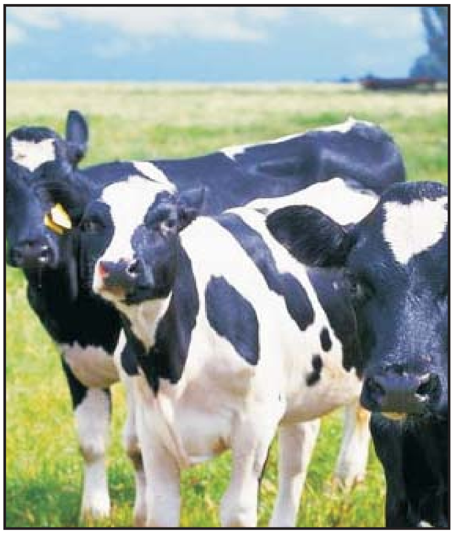
While the aggregate calculations illustrate that phosphorus loads do not appear problematic at the provincial level, a different picture emerges at the local level.

The most significant cost associated with manure management is loading and hauling. The transportation ranges that were considered economically feasible were: 2.4 to 9.7 km for liquid dairy manure; 2.4 to 10.2 km for liquid hog manure; and 5.0 to 18.8 km for solid beef feedlot manure.

Phosphorus loads are a concern in localities where large-scale individual livestock operations are situated. The findings from nine case studies (three hog operations, three dairy operations, and three beef feedlots) suggest that beef feedlots are most likely to have the highest concentrations of manure per hectare on associated land. This is followed by hog







operations. Dairy operations appear to have fewer concerns.

The most significant cost associated with manure management is loading and hauling. This varies widely from case to case and ranged from $1.45/tonne to $13.33/tonne (Toma and Bouma Management Consultants 2006). The transportation ranges that were considered economically feasible were: 2.4 to 9.7 km for liquid dairy manure; 2.4 to 10.2 km for liquid hog manure; and 5.0 to 18.8 km for solid beef feedlot manure (Toma and Bouma Management Consultants 2006). The actual economic range will vary from farm to farm and depends upon nutrient content, nutrient availability, and the cost of haulage. Operators using custom haulers appear to have lower and more consistent costs. Figure 18 shows the economic distance that solid beef manure, and liquid hog and dairy manure can be hauled, assuming that 80% of the phosphorus in the manure was available to the crop in the first year. The economic distance to haul beef manure is about 11 km, while liquid hog and dairy manure is about 4 km.

The detailed farm level analysis for the beef feedlot showed that a phosphorus-limit regime will require substantial increases in land for spreading manure (Toma and Bouma Management Consultants 2006). Feedlots will experience increased costs due to increased distances that manure will need to be hauled and decreased application rates to comply with the required phosphorus standards. Overall transportation and spreading costs could increase by as much as 24 to 128% depending on the average increase in distance that the manure will need to be hauled. The 4P scenario, which involves the application of manure on a parcel of land every 4 years, was less costly compared to the 2P and 1P scenarios. The 4P scenario works for land that has soil phosphorus levels that are significantly less than the phosphorus limit. While the nitrogen-limit scenario (2N) was the least costly alternative, phosphorus levels in the soil continue to build at an average rate of 29.6 kg/ha of phosphorus every year.

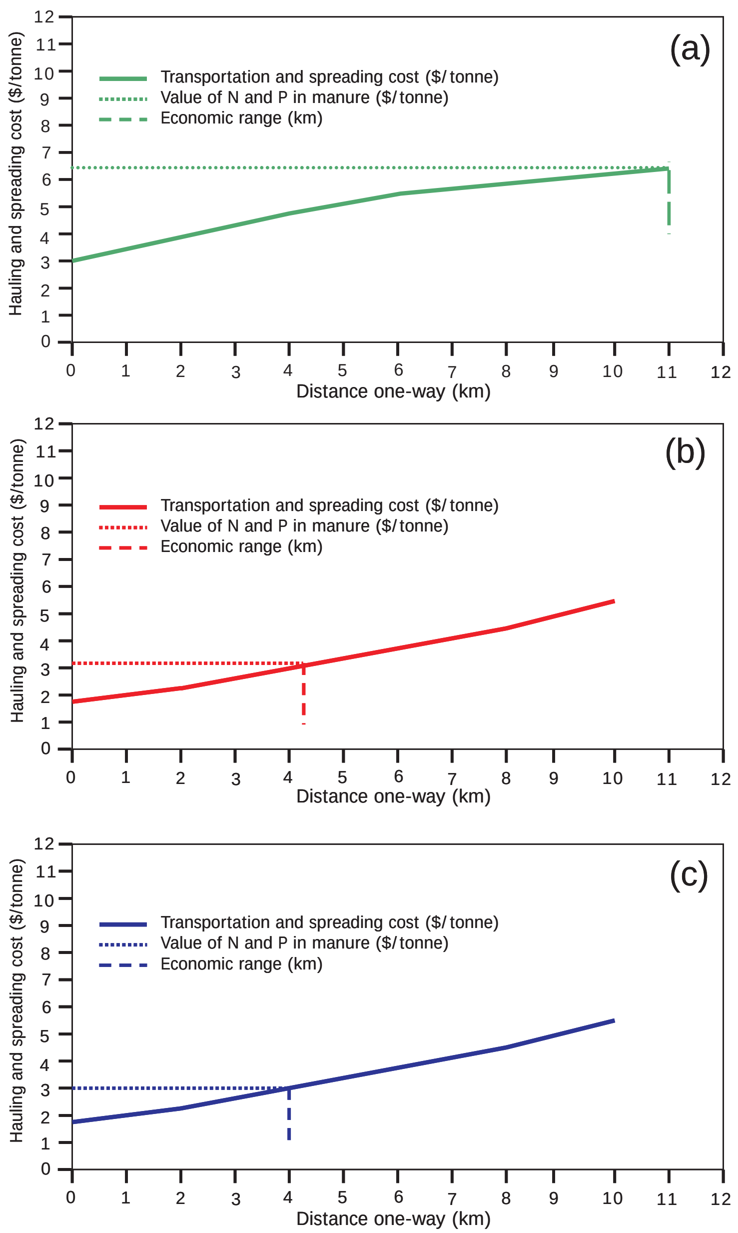


Figure 18. Economic range for hauling and spreading manure for (a) beef, (b) hogs, and (c) dairy, assuming that 80% of the phosphorus in manure is available to the crop.

The detailed analysis for the hog farrow-to-finish operation showed that a phosphorus-limit regime had a relatively small cost impact, provided sufficient land was available in the vicinity to receive the manure. Land requirements for manure application were estimated to increase by 23%. The cost impact on a per sow basis ranged from a low of $4.88 (Scenario 4P) to a high of $26.77 per sow (Scenario 1P).

Overall, it was concluded that the application of phosphorus limits will increase manure management costs to all livestock producers. However, the major impacts will occur on individual farms with large livestock concentrations and in localities where confined feeding operations are in close proximity to each other.

The application of phosphorus limits will increase manure management costs to all livestock producers.

The following recommendations provide guidance for planning further actions as well as for development of policy.

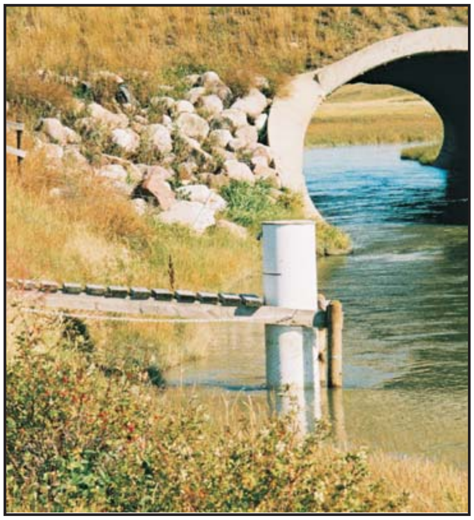
- Assess the environmental sustainability of applying relatively high levels of manure every 3 to 4 years.
- Optimize manure utilization in terms of nutrient value and economic considerations.
- Develop a set of analytical tools for better economic analysis of manure management.
- Encourage crop producers to accept manure as an alternative to commercial fertilizer.
- Explore options and/or special measures for regions in the province with high soil phosphorus and limited nearby land for manure application.

Hog feeding operation

Development of Soil Phosphorus Limits

Introduction

A method was developed to calculate soil phosphorus limits for agricultural land in Alberta (Jedrych et al. 2006). The proposed method involves calculation of total phosphorus (TP) export coefficients based on hypothetical TP runoff water quality limits (TPRWQLs) of 0.5 or 1.0 ppm and on calculated runoff flow volumes at the watershed scale. Runoff flow volumes were estimated for each watershed using 40 years of Water Survey of Canada data measured at 144 hydrometric stations throughout the agricultural area of Alberta. Within each watershed, the medians of estimated flow volumes were partitioned among the Agricultural Region of Alberta Soil Inventory Database (AGRASID) soil polygons (MacMillan and Pettapiece 2000) according to the runoff potential simulated by the Water Erosion Prediction Project model (Flanagan and Livingston 1995) using continuous barley production scenario. The allowable TP concentrations were then calculated for the surface runoff from each soil polygon and for the estimated watershed TP export coefficient. The allowable TP concentrations were then substituted into the soil-test phosphorus (STP) and runoff TP relationships measured in Alberta (Little et al. 2006) for two soil depths (0 to 2.5 cm and 0 to 15 cm). The STP limits were then calculated for each soil polygon.



Monitoring station

Two major assumptions were applied in the development of the method. First, it was assumed that there was no base flow in the receiving stream; therefore, surface runoff comprised the total flow volume from a watershed. Second, it was assumed that all polygons within a watershed are allowed to export the same amount of phosphorus on a per unit area basis (Jedrych et al. 2006). To meet this target, the TPRWQLs were applied to the total runoff volume in the watershed prior to runoff entering the stream, and then the soil-polygon allowable TP concentrations were adjusted according to its runoff potential.

Results

The STP limits calculated at the watershed and microwatershed scales were variable among soil and hillslope polygons. The variability was directly related to the runoff potential among polygons, the selected TPRWQL, and the STP-TP relationship used. There was little difference between STP limits calculated using the 0 to 2.5 cm STP-TP relationship compared to STP limits calculated using the 0 to 15 cm STP-TP relationship. As runoff potential from polygons within a watershed or microwatershed decreased, the allowable TP concentration in the runoff increased, which in turn resulted in higher STP limits. The TPRWQL value of 0.5 ppm resulted in STP limits of 60 ppm or less in the top 15 cm of soil for most of the land within the selected watersheds (Figure 19). However,

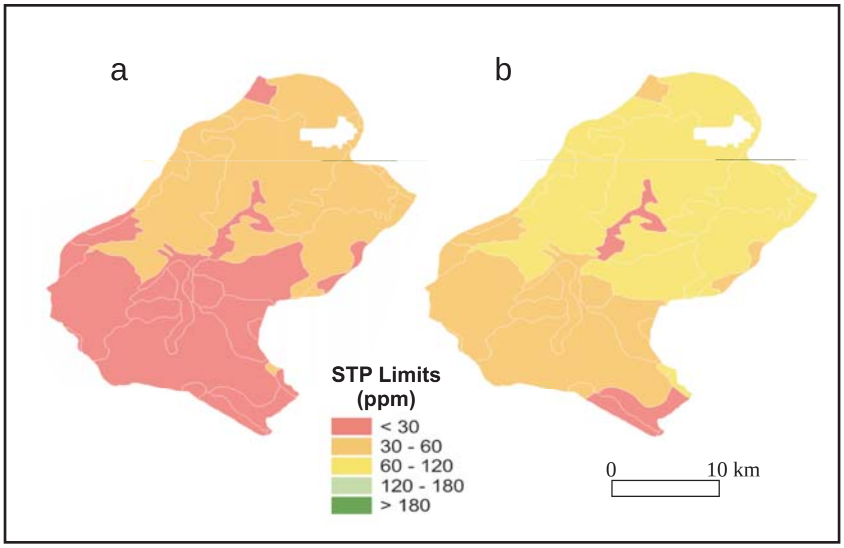


Figure 19. Examples of calculated soil-test phosphorus (STP) limits for total phosphorus runoff water quality limits of (a) 0.5 ppm and (b) 1.0 ppm in the Wabash watershed.

Table 5. Distribution of calculated soil-test phosphorus (STP) limits in the 0 to 15 cm layer for all AGRASID soil polygons in the agricultural zone of Alberta using two hypothetical total phosphorus runoff water quality limits (TPRWQLs).

STP limit categories (ppm)	0.5 ppm TPRWQL			1.0 ppm TPRWQL		
	AGRASID soil polygon area[z] (%)	Mean TP in runoff (ppm)	Mean STP limit [y] (ppm)	AGRASID soil polygon area[z] (%)	Mean TP in runoff (ppm)	Mean STP limit [y] (ppm)
<30	55.7	0.41	18	7.7	0.45	21
≥ 30 to <60	27.9	0.73	41	35.6	0.80	46
≥ 60 to 120	11.3	1.29	81	37.8	1.31	82
≥ 120 to 180	2.7	2.17	143	9.9	2.18	145
≥ 180	2.4	14.40	na[x]	9.0	10.60	na[x]

[z] Total agricultural area of soil polygons in AGRASID database = 24,768,750 ha.
[y] Calculated using the STP and runoff TP relationship for a soil depth of 0 to15 cm developed by Little et al. (2006).
[x] na = not available because "Mean TP" values were beyond the range of the STP-TP relationship.

when a TPRWQL value of 1.0 ppm was used, the majority of the area had STP limits from 30 to 120 ppm.

On a provincial scale, the TPRWQL value of 0.5 ppm resulted in STP limits (0 to 15 cm) of less than 60 ppm for 84% of the agricultural land base, 60 to less than 180 ppm for 14% of the land base, and 180 ppm or greater for 2% of the land base (Table 5; Figure 20). However, when a TPRWQL value of 1.0 ppm was used, STP limits were less

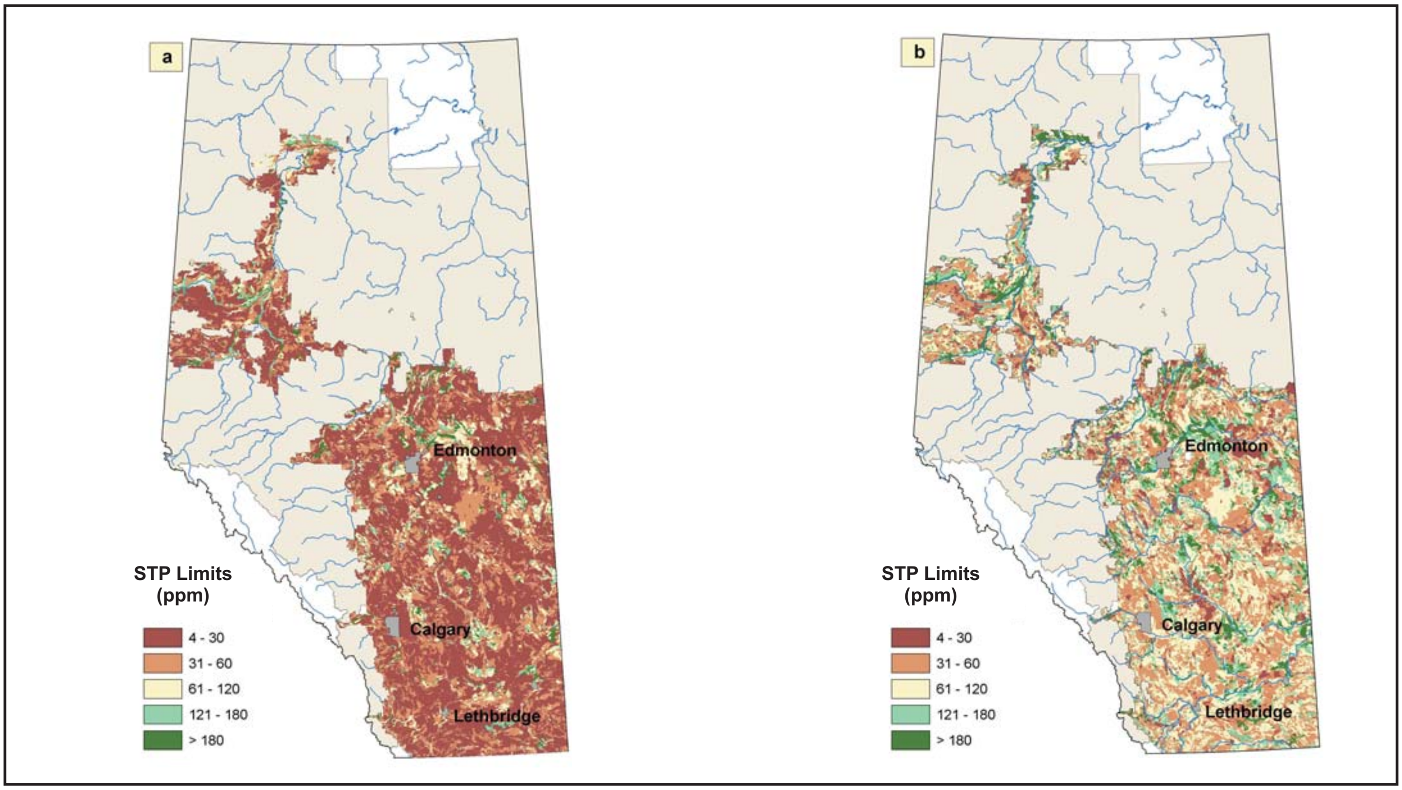


Figure 20. Calculated soil-test phosphorus (STP) limits in the 0 to 15 cm layer for the agricultural regions in Alberta using total phosphorus runoff water quality limits of (a) 0.5 ppm and (b) 1.0 ppm.

than 60 ppm for 43% of the agricultural land base, 60 to less than 180 ppm for 48% of the land base, and 180 ppm or greater for 9% of the land base.

However, when a TPRWQL value of 1.0 ppm was used, STP limits were less than 60 ppm for 43% of the agricultural land base, 60 to less than 180 ppm for 48% of the land base, and 180 ppm or greater for 9% of the land base.

The proposed method uses a quantitative approach for determining STP limits, based on data collected under Alberta conditions, and can be used to assign STP limits to agricultural land in Alberta. The method can be refined by further investigation of watershed-scale runoff water quality limits for Alberta, by application of digital elevation model data in runoff modelling, and by calculating the contribution of base flow to the total flow volume.

Key Research Project Findings

The following key findings are based on the review and research studies carried out during the Soil Phosphorus Limits Project.

1. **A soil-test phosphorus level greater than 60 ppm (agronomic threshold) in the top 15 cm of the soil profile will not result in a yield response from added phosphorus for most agricultural crops grown in Alberta.**

Phosphorus is an essential nutrient in agricultural systems and is important in nutrient management to achieve optimum crop production. Much of the agricultural land base in Alberta is deficient in phosphorus; therefore, phosphorus fertilizer is often applied to achieve optimum crop growth. However, research has shown little yield response when soil-test phosphorus levels exceed 60 ppm in the top 15 cm of soil. The actual amount of phosphorus required for optimum production of each crop should be determined through soil testing and development of appropriate fertilizer recommendations. There are limited areas where excessive soil phosphorus levels exist. Soil-test records indicate that these areas are generally associated with land that has a history of repeated manure applications.

2. **Phosphorus losses from agricultural land are a significant contributor to surface water quality degradation in Alberta.**

Snowmelt runoff accounts for most of the runoff volume from the agricultural land in Alberta. Stream water quality monitoring in Alberta has shown that as the intensity of agriculture increases in watersheds the amount of phosphorus also increases in surface water.

Surface water in Alberta tends to be naturally productive, with many streams exceeding phosphorus water quality guidelines under natural conditions. Many streams are therefore sensitive to phosphorus loading. The amount of phosphorus lost from land is usually quite small compared to the phosphorus level in the soil, and phosphorus amendments applied to land, such as commercial fertilizer or livestock manure. However, a small amount of phosphorus lost from the soil translates to a large amount relative to phosphorus levels in aquatic systems, and this can trigger accelerated growth of algae and aquatic vegetation.

3. **A direct relationship was found between soil-test phosphorus levels in the soil and phosphorus levels in runoff water from agricultural soils.**

There is a direct, linear relationship between soil-phosphorus levels and phosphorus concentration in runoff water in the agricultural areas of Alberta. As the amount of phosphorus in the upper soil profile increased, so did the concentration of phosphorus in runoff water (Figure 21). This relationship holds true regardless of whether the phosphorus in the soil is from fertilizer or livestock manure.

A direct relationship between soil-test phosphorus levels and phosphorus in runoff water was still observed 1 year after manure application, although values of both variables were less with

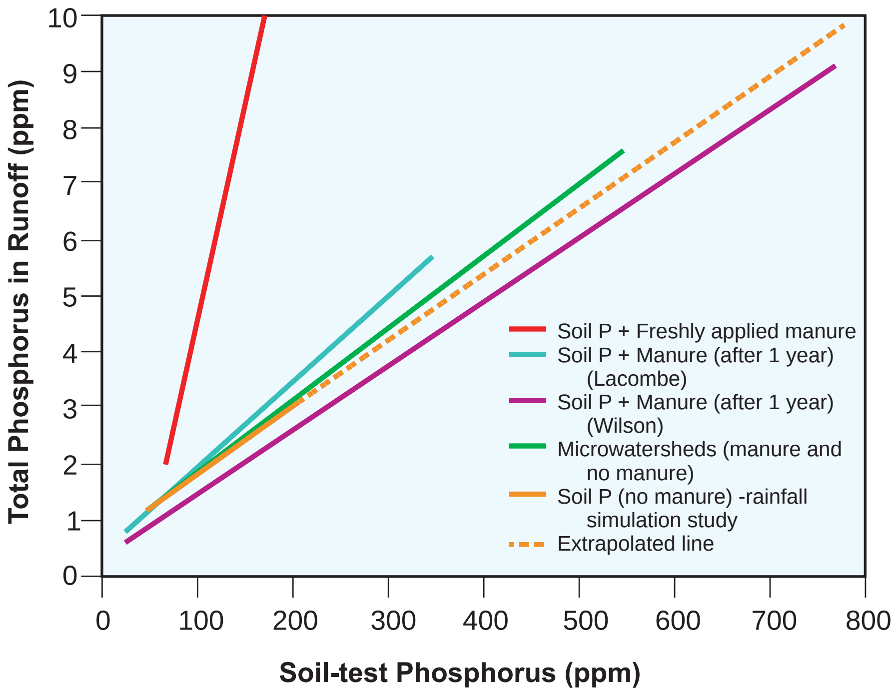


Figure 21. Relationship between soil-test phosphorus and total phosphorus in runoff water.

time. Runoff volumes and concentrations of phosphorus in runoff water decreased with manure incorporation for the freshly-manured soils at a site near Beaverlodge. However, manure incorporation did not have a significant effect on runoff volumes and phosphorus concentrations in runoff water at two other sites near Lacombe and Wilson. A relatively small portion (less than 3%) of the phosphorus applied with manure was removed by runoff from the freshly-manured soils and even less was removed 1 year after manure application.

4. **Agronomic soil samples from the top 15-cm depth commonly used to determine commercial fertilizer requirements for optimum crop production can also be used to predict phosphorus losses in runoff water.**

Comparison of a new frame-excavation soil sampling method with several core-sampling methods showed that all of the sampling methods provided similar soil-test phosphorus values, and that variability did not differ significantly among sampling methods, regardless of the soil layer used (0 to 2.5 cm, 0 to 5 cm, or 0 to 15 cm). A minimum of five core composite samples per sampling point are adequate for soils with low levels of banded phosphorus. For soils with higher and more variable phosphorus content, the frame-type method of sampling was comparable to coring methods for determination of soil-test phosphorus.

5. **Soils with soil-test phosphorus levels greater than the agronomic threshold (60 ppm in the top 15 cm) are generally more susceptible to phosphorus losses in runoff water than soils with lower soil-test phosphorus levels. Therefore, maintaining soil-test phosphorus levels at or below the agronomic threshold is recommended to minimize phosphorus losses from agricultural land.**

The phosphorus sorption capacity of a soil is a finite characteristic that varies widely according to a number of soil properties. Sorption of applied phosphorus is determined by the current sorption status and the phosphorus sorption capacity of a given soil, which determines the amount of phosphorus that is available for crop uptake or is susceptible to loss in runoff or leaching. The risk of phosphorus losses from agricultural land to surface and ground water generally increases as the degree of soil phosphorus saturation increases. Thresholds for the degree of phosphorus saturation for 13 soils generally corresponded to the agronomic threshold of 60 ppm for crops grown on Alberta soils. Phosphorus losses in overland flow and leaching may be greater in soils with soil-test phosphorus values that exceed the agronomic threshold than in soils with lower soil-test phosphorus values.

6. **Soil-test phosphorus limits were determined for all agricultural land in Alberta (Figure 22; Appendix 1), using: soil-test phosphorus and runoff phosphorus relationships; long-term climatic and hydrometric data; provincial soil and landform information; and hydrological modelling.**

The soil phosphorus limits were determined to not exceed selected hypothetical water quality limits for phosphorus in runoff water (0.5 and 1.0 ppm). A hypothetical water quality limit of 1.0 ppm of total phosphorus under continuous barley production resulted in soil-test phosphorus limits in the 0 to 15 cm layer that were:

- Less than 60 ppm for about 43% of the agricultural land base;
- 60 to 180 ppm for about 48% of the land base; and
- Greater than 180 ppm for about 9% of the land base.

Under these conditions, a large percentage of the agricultural land base had soil phosphorus limits near or below the agronomic threshold for phosphorus in soil. This implies that phosphorus generally needs to be managed based on crop phosphorus requirements.

7. **Economic impacts are greatest on farms with large livestock concentrations and within a short distance from neighbouring confined feeding operations.**

Economic impacts associated with phosphorus limits are highly variable at the farm level as well as at the regional level. Economic impact can

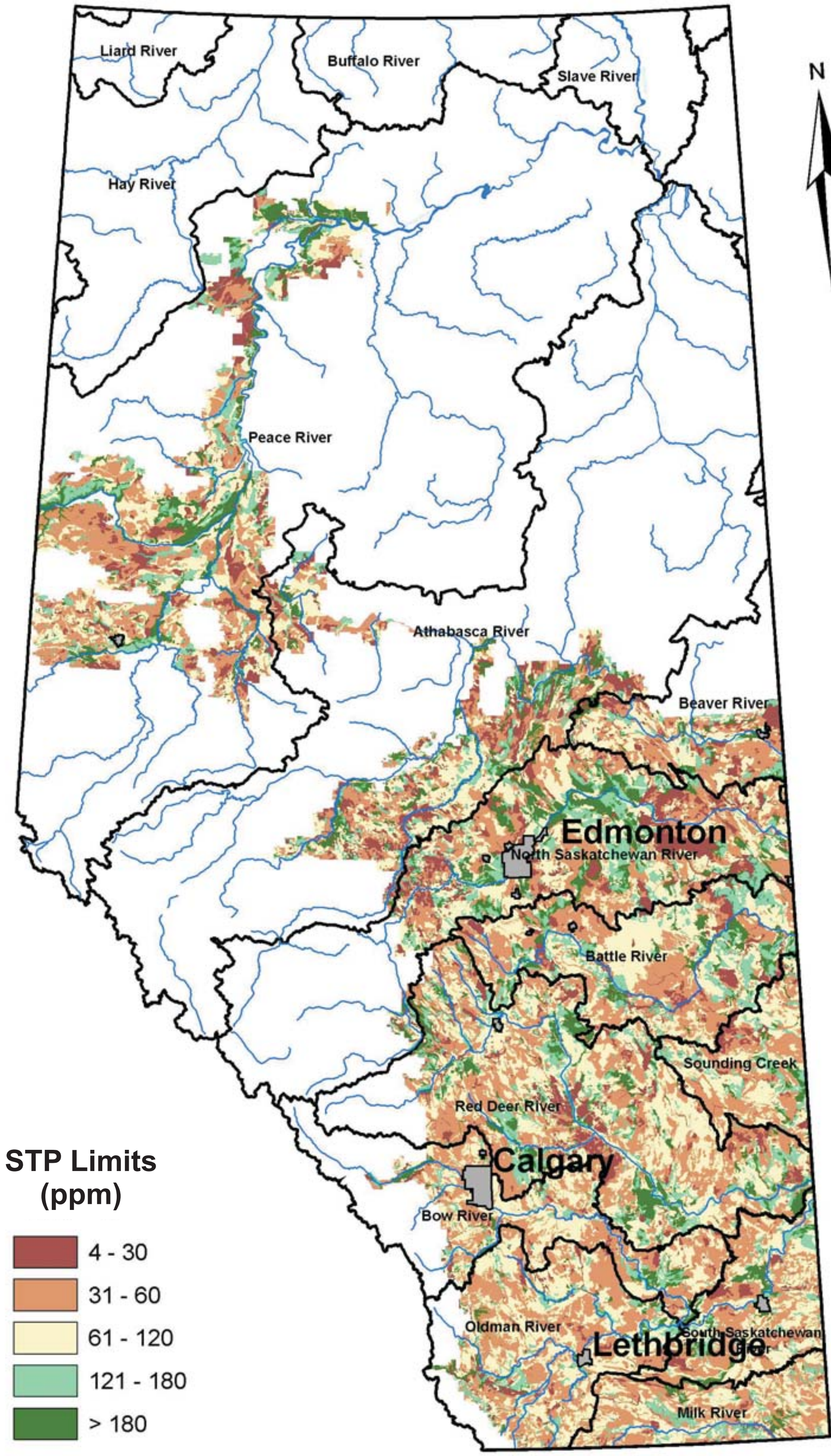


Figure 22. Calculated soil-test phosphorus (STP) limits for Alberta's agricultural land based on a runoff water quality limit of 1.0 ppm total phosphorus.

range from a net economic benefit, resulting from better manure utilization as a source of nutrients, to threatening the economic viability of farms. The most significant cost associated with manure is transportation. There is more than enough cultivated land available to agronomically manage all of the manure generated by Alberta's confined feeding industry, and more importantly, would benefit from the additional nutrients and organic matter contained in manure. However, there are often large distances between the receiving land and the confined feeding operations, which can pose significant financial challenges to livestock operators. The economic distance, where the value of nutrients is equal to or greater than the transportation costs, ranged from 2.4 to 18.8 km.

Economic assessments determined that beef feedlots are most likely to have the highest concentrations of manure per hectare on associated land. This was followed by hog operations, then dairy operations. Farm-level analysis of beef feedlots showed that a soil-phosphorus-limit regime will require a substantial increase (2.6 times) in land for spreading manure, and overall transportation and spreading costs could increase by 24 to128 %. Based on case study assessments, the increased land requirement for hog operations is about 1.2 times, resulting in a lower overall cost impact. The willingness of cropland operators to accept manure is the most critical determinant of the ultimate costs associated with disposal of manure in regions with high animal concentrations.