**Supplementary Information to Modelling Dissolved Phosphorus Losses from Accumulated Soil Phosphorus and Applied Fertilizer and Manure for a National Risk Indicator**

STP was converted to WEP for each of the Canadian provinces using the following methods:

**Soil data collection**

Agriculture and Agri-Food Scientists that had worked on the IROWC-P model in the past (Van Bochove et al. 2012) had assembled data from soil scientists across Canada containing both STP and WEP data, along with data on soil type, texture, and pH. A literature search was conducted to find additional data to update this database and soil scientists were again contacted to obtain additional data. The goal was to obtain a dataset with soils from a diverse range of agricultural soils within the provinces and across the country. We restricted our data search to those studies that conducted the WEP procedure according to the method of Self-Davis et al. (2000), with a water: soil ratio of 10: 1 and an extraction time of 1 hr. A description of the data collected is found in Table S1.

**Statistical Analysis**

Statistical analyses were performed using the statistical software program SAS ver. 9.4 for Windows (SAS Institute Inc., Cary, NC, USA). Using the Proc glm procedure, regression statistical methods were used to evaluate relationships between STP and WEP. All regression equations were developed in-house with the exception of the province of British Columbia, where regression equations had already been developed by Kowalenko (2010). For other provinces, if soil texture was found to have a significant effect on the model, and sample size was adequate, the samples were grouped into textural groups (Fine: Soil classified as heavy clay, clay, clay loam, silty clay loam, silty clay or sandy clay; Medium: Soil classified as loam, silt loam, silt, and sandy clay loam; Coarse: Soil classified as sandy loam, loamy sand, and sand)

for regression analyses. Where sample size allowed, the inclusion of the effect of pH was also included in the regression analysis. Using the Proc Univariate procedure, homogeneity of error (residuals) was tested for each model and the residuals were tested for normality as determined by the Shapiro-Wilk statistic. Proc mixed was used to determine significant differences among Ontario and Manitoba soils for differences in basic soil properties. A type I error rate of p = 0.05 was used for all statistical comparisons.

Results and Discussion

For all provinces, significant (p<0.0001) regression equations were determined describing the relationship between STP and WEP (Table S2). For Manitoba and Ontario, where sufficient sample sizes existed, the interaction between pH and STP was found to be a significant factor in the regression, so equations have been shown which included pH as a factor. However, the differences in the R2 values between the two equations were very small. Ige et al. (2007) showed that for Manitoba soils, the impact of pH on soil P retention was due to its collinearity with other soil properties, and that may also be the case here. It should be noted that for Ontario fine and medium textured soils, the regression equation may occasionally yield a negative result (if STP is low enough (~ < 6 mg kg-1), especially if pH is high (> 7).

The linear regression coefficients for converting Mehlich-3 and Kelowna STP to WEP are generally lower than those for Olsen STP (Table S2); this is to be expected because Olsen STP generally extracts a lower proportion of labile P than Mehlich-3 or Kelowna if run on the same soil sample, particularly for neutral-alkaline soils (e.g. Kowalenko 2010; Wang et al. 2010). For Prince Edward Island however, the coefficient was found to be particularly low. This may be in part a result of our low sample size (n=11), however, the soils from PEI are generally sandy acidic podzolic soils that are high in aluminum (Benjannet et al. 2018). Aluminum is linked with greater P retention and so this may explain why less WEP would be measured at a given STP (and have a lower regression coefficient). Moreover, Pellerin et al. (2006) tested 275 Quebec surface soils and found that for a given P saturation index (using Mehlich-3 extractable P and Al), WEP increased with increasing clay content. Since PEI soils are sandy, this may additionally explain why an apparently low regression coefficient converting STP to WEP was derived. Interestingly, the opposite trend is observed for the more alkaline soils of Ontario and Manitoba, where, higher coefficients are obtained for coarser textured soils (Table S2); this may be due to occlusion of P by clay in these soils.

Overall, our equations predict that for an equivalent soil STP and pH, Manitoba soils have a greater WEP than Ontario soils (see linear regression coefficients, Table S2, and Fig. S1). The raw data supports this with Ontario soils having a mean (se) of 25.1 (1.2) mg kg-1 Olsen STP and a mean (se) WEP of 2.86 (0.26) mg kg-1, while Manitoba soils had a lower (p = 0.02) mean (se) Olsen STP of 20.6 mg kg.-1, but higher (p< 0.0001) mean (se) WEP of 5.11 (0.32). This has implications in that typical Manitoba soils may release more P in agricultural runoff water than Ontario soils. The reason for this is unclear and warrants further verification with edge of field runoff water quality data.

These regression equations (Table S2) will be used in the Agriculture and Agri-Food Canada’s IROWC-P model in order to convert various STP concentrations across the country into a consistent unit of measurement, WEP. Other applications for the regression equations presented here may assist modelling researchers who desire an estimation of WEP (or alternatively STP from WEP). For smaller plot or field scale work, where both of these datasets are desired, it is still recommended to run both of these analyses directly, as ultimately this will still be the most accurate. This analysis also provides insight into how soil properties by region may affect the availability of P to be lost from the soil to adjacent waterways.

Acknowledgements

We gratefully acknowledge the sharing of data from the following scientists: Wayne Pettipiece, Alvin Anderson, Norma Sweetland, Bob Eilers, Steve and Maria Sheppard, Wole Akinremi, Craig Drury, Tiequan Zhang, Gordon Barnett, Nicolas Tremblay, Denise Desrosiers, Pierre Audesse, Ken Webb, Delmar Holmstrom, as well as the Laboratoire de pédologie et d’agriculture de précision (Laboratory of pedology and precision agriculture), Sainte-Foy, QC. Tiequan Zhang and Yutao Wang are gratefully acknowledged for their assistance in data analysis and providing editorial comment. Cooperative education student, Katelyn Mackay, is also kindly acknowledged for her work organizing and analyzing the collected data.

References

Benjannet, R., Khiari, L., Nyiraneza, J., Thompson, B., He, J., X. Geng, K. Stiles, Y. Jiang, and Fillmore, S. 2018. Identifying environmental phosphorus risk classes at the scale of Prince Edward Island, Canada. Can. J. Soil Sci. 98: 317-329. doi:10.1139/cjss-2017-0076.

Ige, D. V., Akinremi, O. O., and Flaten, D. N. 2005. Environmental index for estimating the risk of phosphorus loss in calcareous soils of Manitoba. J. Env. Qual. 34:1944-1951.

Ige, D. V., Akinremi, O. O. and Flaten, D. N. 2007. Direct and Indirect Effects of Soil Properties on Phosphorus Retention Capacity. Soil Science Society of America Journal 71(1):95-100.

Kowalenko, C. G. (2010). Relationships between extraction methods for soil nutrient testing in British Columbia. pp 1-25.

Pellerin, A., Parent, L.-É., Fortin, J., Tremblay, C., Khiari, L., and Giroux, M. 2006. Environmental Mehlich-III soil phosphorus saturation indices for Quebec acid to near neutral mineral soils varying in texture and genesis. Can. J. Soil Sci. 86: 711–723. doi:10.4141/S05-070.

Self-Davis, M. L., Moore, P. A., Jr., and Joern, B. C. 2000. Determination of water or dilute salt extractable phosphorus in soils. Pages 24–26 in G. M. Pierzynski, ed. Methods of phosphorus analysis for soils, sediments, residuals and waters. Kansas State University, Manhttan, KS.

van Bochove, E., Thériault, G., Denault, J.-T., Dechmi, F., Allaire, S. E. and Rousseau, A. N. 2012. Risk of Phosphorus Desorption from Canadian Agricultural Land: 25-Year Temporal Trend. J. Env. Qual. 41:1402-1412.

Wang, Y. T., Zhang, T. Q., Hu, Q. C., Tan, C. S., Halloran, I. P. O., Drury, C. F., Reid, D. K., Ma, B. L., Ball-Coelho, B., Lauzon, J. D. et al. 2010. Estimating dissolved reactive phosphorus concentration in surface runoff water from major Ontario soils. J. Env. Qual. 39: 1771-1781.

Tables

Table S1: Representative soil samples collected from across Canada (with the exception of British Columbia) analyzed in the laboratory for soil test phosphorus (soil test phosphorus; either Olsen, Mehlich-3 or Kelowna), water extractable phosphorus (WEP), as well as pH and texture. The n indicates the number of soil samples analysed.

|  |  |  |  |
| --- | --- | --- | --- |
| **Province** | **n** | **Contact name** | **Organization** |
| Alberta | 17 | Wayne Pettipiece (retired) | AAFC, Edmonton |
| Saskatchewan | 13 | Alvin Anderson | AAFC, Saskatoon |
| Manitoba | 173 | Norma Sweetland and Bob Eilers (retired) (n= 58) | AAFC, Winnipeg |
|  |  | Steve and Maria Sheppard (n= 2) | Ecomatters Inc., Pinawa |
|  |  | Wole Akinremi*a*(n= 113) | University of Manitoba, Winnipeg |
| Ontario | 259 | Craig Drury (n= 205) | AAFC, Harrow |
|  |  | Tiequan Zhang*b*(n= 60) | AAFC, Harrow |
| Quebec | 63 | Laboratoire de pédologie et d’agriculture de précision | AAFC, Québec |
|  |  | Gordon Barnett (retired) | AAFC, Lennoxville |
|  |  | Nicolas Tremblay | AAFC, St-Jean-sur-Richelieu |
|  |  | Denise Desrosiers | ITA, La Pocatière |
|  |  | Pierre Audesse (retired) | IRDA, Quebec |
| New Brunswick | No soil collected |  |  |
| Nova Scotia | 1 | Ken Webb | AAFC, Truro |
| Prince Edward Island | 11 | Delmar Holmstrom | AAFC, Charlottetown |
| Newfoundland and Labrador | No soil collected |  |  |

Notes:

*a*Data obtained pertain to the paper Ige et al. (2005).

*b*Data obtained pertain to the paper Wang et al. (2010).

Table S2: Regression equations established to convert soil test phosphorus for Olsen (STPolsen), Mehlich 3 (STPm3) and Kelowna (STPkelowna) (mg kg-1) to soil water-extractable phosphorus (WEP) (mg kg-1). Soil WEP was determined using a water: soil ratio of 10: 1 and an extraction time of 1 hr (Self-Davis et al. 2000) on a given number (n) of samples. Multiple regression was done only when sample numbers made this statistically feasible. All regression equations were significant with a p value < 0.001.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Province and Description | *n* | Simple linear Equation | R2 | If pH is available | R2 |
| British Columbiaa | 330 |  |  |  |  |
| *pH < 7.2* | 242 | y = - 0.41 + 0.10(STPkelowna) | 0.47 |  |  |
| *pH > 7.2* | 88 | y = 1.06 + 0.14(STPkelowna) | 0.85 |  |  |
| Alberta and Saskatchewan | 30 | y = 0.105(STPkelowna) | 0.95 |  |  |
| Manitoba | 173 |  |  |  |  |
| *Fine textured soils* | 72 | y = 0.216(STPolsen) | 0.87 | y = 0.436(STPolsen) + 0.031(pH) - 0.032(STPolsen\*pH) | 0.88 |
| *Medium and coarse textured soils* | 101 | y = 0.263(STPolsen) | 0.85 | y = 0.549(STPolsen) + 0.058(pH) - 0.0431(STPolsen\*pH) | 0.86 |
| Ontario | 259 |  |  |  |  |
| *Fine and medium textured soils* | 219 | y = 0.106(STPolsen) | 0.78 | y = 0.369(STPolsen) – 0.056(pH) – 0.036(STPolsen\*pH) | 0.81 |
| *Coarse textured soils* | 40 | y = 0.157\*STPolsen | 0.90 |  |  |
| Quebec, New Brunswick, Nova scotia, Newfoundland and Labrador | 64 |  |  |  |  |
| *Fine textured soils* | 18 | y = 0.047(STPm3) | 0.92 |  |  |
| *Medium textured soils* | 21 | y = 0.033(STPm3) | 0.71 |  |  |
| *Coarse textured soils* | 24 | y = 0.029(STPm3) | 0.64 |  |  |
| Prince Edward Island | 11 | y = 0.016(STPm3) | 0.75 |  |  |

|  |  |  |  |
| --- | --- | --- | --- |
| Notes: |  |  |  |

aFor British Columbia, the regression equations were not derived in-house but were obtained from Kowalenko (2010), from soil samples in the Lower Fraser Valley and the Okanagan-Similkameen.



Figure S1: Water-extractable phosphorus (WEP) versus Olsen soil test phosphorus (STP) for Manitoba (shaded circles) and Ontario (open circles) soils.