BioOne COMPLETE

Modelling dissolved phosphorus losses from accumulated soil phosphorus and applied fertilizer and manure for a national risk indicator

Authors: Reid, Keith, and Schneider, Kimberley

Source: Canadian Journal of Soil Science, 102(2) : 463-476

Published By: Canadian Science Publishing

URL: https://doi.org/10.1139/CJSS-2021-0049

BioOne Complete (complete.BioOne.org) is a full-text database of 200 subscribed and open-access titles in the biological, ecological, and environmental sciences published by nonprofit societies, associations, museums, institutions, and presses.

Your use of this PDF, the BioOne Complete website, and all posted and associated content indicates your acceptance of BioOne's Terms of Use, available at www.bioone.org/terms-of-use.

Usage of BioOne Complete content is strictly limited to personal, educational, and non - commercial use. Commercial inquiries or rights and permissions requests should be directed to the individual publisher as copyright holder.

BioOne sees sustainable scholarly publishing as an inherently collaborative enterprise connecting authors, nonprofit publishers, academic institutions, research libraries, and research funders in the common goal of maximizing access to critical research.

Downloaded From: https://complete.bioone.org/journals/Canadian-Journal-of-Soil-Science on 04 Nov 2024
Terms of Use: https://complete.bioone.org/terms-of-use

Canadian Science Publishing

ARTICLE

Modelling dissolved phosphorus losses from accumulated soil phosphorus and applied fertilizer and manure for a national risk indicator

Keith Reid and Kimberley Schneider

Abstract: Balancing the weighting of various components of phosphorus loss in models is a critical but often overlooked step in accurate estimation of risk of P loss under field conditions. This study compared the P loss coefficients used to predict dissolved P losses from desorption from accumulated P in the soil, and those incidental to applications of P as fertilizer or manure, with extraction coefficients determined from actual P losses reported in literature for sites in Canada, with the addition of some sites with similar soils and climate from some northern states. The extraction coefficients for dissolved P measured in runoff water were 6.5× greater in year-round edge-of-field (EoF) measurements than in runoff boxes, indicating that models using P extraction coefficients derived from runoff box experiments will be underestimating the magnitude of losses from P accumulation in soil. Differences among the measurement methods (runoff box, rainfall simulator, or EoF) were not evident for incidental losses from applied P, but current models appear to overpredict the losses of applied P. Good agreement between measured and predicted dissolved P (DP) concentrations using the equations in the Annual Phosphorous Loss Estimator model were achieved by applying coefficients of 0.275 to the fertilizer equations and 0.219 to the manure equations, implying that 72.5% of fertilizer P and 78% of manure P are not available for runoff. This study underlines the importance of considering the relative weights of the various components of P loss as new models are developed and validated.

Key words: soil, phosphorus, manure, fertilizer, water quality.

Résumé : Dans un modèle, il est impérieux d'équilibrer la pondération des diverses composantes de la perte de phosphore (P), mais on néglige souvent cette étape quand on s'efforce d'estimer avec précision les risques d'une telle perte sur le terrain. Les auteurs comparent les coefficients employés pour prédire les pertes de P dissous associées à la désorption du P accumulé dans le sol et les pertes découlant de l'application de P sous forme d'engrais ou de fumier aux coefficients d'extraction établis en fonction des pertes de P réelles rapportées dans la littérature, pour différents sites au Canada et certains endroits dans quelques États du nord, au sol et au climat similaires. Les coefficients d'extraction du P dissous dosé dans les eaux de ruissellement sont 6,5 fois plus élevés pour les relevés pris en bordure du champ durant l'année que pour ceux venant des récipients qui recueillent l'eau de ruissellement, signe que les modèles utilisant les coefficients calculés lors des expériences sur le ruissellement sous-estiment l'ampleur des pertes du P accumulé dans le sol. Les divergences des méthodes de mesure (boîte de ruissellement, simulateur de précipitations, relevés en bordure du champ) ne se reflètent pas dans les pertes secondaires issues de l'application de P, mais les modèles courants semblent surestimer les pertes de P. Les auteurs ont obtenu une bonne concordance entre la concentration réelle et la concentration prévue de P dissous en utilisant les équations du modèle APLE et en appliquant un coefficient de 0,275 aux équations se rapportant aux engrais ou de 0,219 à celles se rapportant au fumier, ce qui signifie que 72,5 % du P des engrais et 78 % du P du fumier ne peut se retrouver dans le ruissellement. Cette étude souligne combien il importe de prendre en compte les facteurs de pondération des composantes de la perte de P quand on élabore et valide un nouveau modèle. [Traduit par la Rédaction]

Mots-clés : sol, phosphore, fumier, engrais, qualité de l'eau.

Received 19 April 2021. Accepted 13 September 2021.

K. Reid. Science and Technology Branch, Agriculture and Agri Food Canada, 174 Stone Road W., Guelph, ON N1G 4S9, Canada.

K. Schneider. Department of Plant Agriculture, University of Guelph, Guelph, ON N1G 2W1, Canada.

Corresponding author: Keith Reid (email: dkeithreid10@gmail.com).

© 2021 Author Schneider and Agriculture and Agri-Food Canada as representative of Her Majesty the Queen in right of Canada. This work is licensed under a Creative Commons Attribution 4.0 International License (CC BY 4.0), which permits unrestricted use, distribution, and reproduction in any medium, provided the original author(s) and source are credited.

Downloaded From: https://complete.bioone.org/journals/Canadian-Journal-of-Soil-Science on 04 Nov 2024
Terms of Use: https://complete.bioone.org/terms-of-use

Introduction

Losses of both particulate and dissolved phosphorus (DP) from agricultural land have been identified as important drivers for surface water quality impairment by encouraging harmful (Steffen et al. 2014) and nuisance algae growth (Howell and Dove 2017) and hypoxic zones (Scavia et al. 2014). Recently, attention has focused on the disproportionate role of DP in algae blooms because of its high bioavailability and because the proportion of DP to total P exported from farmland appears to be increasing, particularly in the Lake Erie basin (Joosse and Baker 2011; Baker et al. 2014). This shift in the proportion of P fractions has been attributed to changes in agricultural management including a conversion to conservation tillage combined with surface broadcast of P fertilizers (Jarvie et al. 2017; Smith et al. 2017). DP losses from agricultural land are generally attributed to one of three sources: (*i*) desorption of a portion of the P that has accumulated on soil particles (from previous applications of mineral or organic fertilizers or native in the soil) into runoff water (desorbed P, DeP); (*ii*) incidental losses of DP from recent application of P fertilizer or manure while these remain on the surface of the soil (applied P, ApP) (Reid et al. 2018); or (*iii*) losses of P from the above-ground portion of overwintering vegetation (Liu et al. 2019). The third source has been identified as being important for prairie environments, but less so for parts of Canada with milder winters (Plach et al. 2019). This paper focuses on the P desorption from the soil and P loss incidental to fertilizer or manure application, as being important for the entire country. The third source (P losses from overwintering vegetation) has recently been thoroughly reviewed in Liu et al. (2019) and will not be discussed further in this paper.

Models are of critical importance in understanding the drivers for DP losses and for predicting the impacts of management practices on reducing DP exports (Bolster et al. 2012; Sharpley et al. 2012). There is a continuum of spatial and temporal scales for models of water and solute movement, but they can be classed very broadly into the bench-top or pedon scale mechanistic models, edge-of-field (EoF) models, and watershed-scale models. An example of a very detailed mechanistic model is Hydrus (Šimůnek et al. 2012), which requires many parameters at a high level of precision. It would be impractical to scale up to a field or regional scale and therefore, is out of scope for this study. At the opposite end of the scale are watershed models, such as SWAT (Radcliffe et al. 2009; Woodbury et al. 2014), SPARROW (Benoy et al. 2016), or CANWET (Singh et al. 2012). A common element in all of these models is the estimation of DP concentration and (or) loading in runoff water. Pferdmenges et al. (2020) have compiled a comprehensive review of the P source routines used in runoff models and point out that a large number of watershed models use the same conceptual model, initially developed for the EPIC model, for DP release into runoff and pore water. These quasi-mechanistic P routines assume partitioning between organic and mineral forms of P in classes of varying degrees of stability, with transfers between these pools controlled by zero- or first-order kinetics. Unfortunately, as Das et al. (2019) and Neumann et al. (2021) point out, the EPIC model (and, by extension, all of the models based on the EPIC P routine) does not accurately characterize P cycling across a wide range of soils, and better models of P release from soils are required. For a mechanistic model such as EPIC, this would require much greater detail regarding soil properties and initial soil P fractions, and at a much finer spatial scale, than is widely available. The P routines embedded in SWAT (Radcliffe et al. 2009) have also been shown to provide poor estimates of P losses from applications of concentrated P sources such as manure or fertilizer, in large part because these additions are assumed to immediately enter the soil pool with no allowance for any incidental losses from the applied materials (Collick et al. 2016; Menzies Pluer et al. 2019). The result is that most watershed models are much less sensitive to the impact of field-scale management decisions on dissolved P losses than on total P losses (that tend to be dominated by soil erosion and particulate P). This has been partially, but not completely, addressed in the Conservation Effects Assessment Program in the United States (CEAP 2011) by linking the Agricultural Policy Environmental Extender (APEX) Model (Williams and Izaurralde 2005; Gassman et al. 2009) to SWAT. This linkage allows better characterization of fertilizer and manure applications within the HRUs used in the SWAT model but does not correct the lack of accounting for incidental P losses within SWAT.

The third group of models focuses on P losses at the EoF and explicitly accounts for variability in soil characteristics and in soil, fertilizer, and manure management. The most common of these are the P Indexes (Sharpley et al. 2012; Sharpley et al. 2017), which have evolved over time from conceptual, additive models (Lemunyon and Gilbert 1993) to mixed empirical–mechanistic models with a component structure such as the N.C. P Loss Assessment Tool (N.C. PLAT Committee 2005). These indexes do not attempt to predict P losses from runoff events, but rather to indicate the relative risk of P loss from fields based on inherent soil and climate conditions combined with soil and nutrient management practices by farmers. Also included in the EoF group of models is the semiquantitative Annual Phosphorous Loss Estimator (APLE) (Vadas 2017), which has been proposed to be robust enough for use in validating other P loss models (Fiorellino et al. 2017).

Rather than a process-based model of DP release, the EoF models use empirical relationships between soil test P values (either an agronomic test or an environmental

Published by Canadian Science Publishing

Downloaded From: https://complete.bioone.org/journals/Canadian-Journal-of-Soil-Science on 04 Nov 2024
Terms of Use: https://complete.bioone.org/terms-of-use

indicator such as water extractable P (WEP)) and DP concentration in runoff. Additional coefficients are used to predict the incidental losses of DP from applied fertilizer or manure. Discussion of the derivation of these coefficients follows later in the paper. This approach has been used in the national Indicator of Risk of Water Contamination by Phosphorus (IROWC-P) to predict the spatial and temporal variation in the risk of P loss (Reid et al. 2018). The coefficients for DP loss from accumulated P in soil have been updated from the previous versions of IROWC-P (van Bochove et al. 2010), and factors for the incidental losses from applied P have been added.

A key part of model development is validation of the model outputs against measured data to assess the accuracy and precision of the model predictions (Bolster and Vadas 2013; Vadas et al. 2013). One challenge with this validation step is avoiding being misled by equifinality, where models with different weightings of coefficients can give very similar results, so simply accepting the model with the most precise fit may not necessarily give the best characterization of the underlying processes (Hollaway et al. 2018). This could occur, for example, where the validation dataset includes fields with elevated soil test values that are also receiving applications of manure; models that attribute different relative weightings to the soil test P and the applied P could give similar results, and the validation data would not be able to ascertain which model was correct. This takes on great importance if the models are going to be used in different geographies or are going to be used to predict the impact of management changes on P losses. The authors are not aware, however, of any studies that have attempted to validate the relative weighting of the components in predictions of P losses within a comprehensive model, to ensure that not only are the model totals accurate but that the values of the individual components can be used confidently to identify appropriate management responses. This study aims to overcome that deficiency.

Methods

IROWC-P is a national-scale indicator of the spatial and temporal variability in the risk of P loss from Canadian agricultural land, derived from publicly available data on land use, nutrient application, and on-farm practices. The spatial scale of the assessment is the Soil Landscape of Canada (SLC) polygon. It uses a component structure, where each source of P loss from agricultural land (desorption of DP from soil; DP losses incidental to application of fertilizer or manure; DP leached from overwintering vegetation; and bioavailable particulate P from water erosion) is multiplied by a transport modifier appropriate for that P source, and then the products of these calculations are summed to give an overall risk of P loss at the edge of the field. The transport modifiers are derived from the surface runoff and tile flow predictions in the hydrology module of the DNDC model, which accounts for soil type, crop cover, and local precipitation. Delivery modifiers based on topography and distance to streams then predict the risk of P from agricultural land reaching surface water. The details of this modelling approach are found in Reid et al. (2018), and a very similar structure is used in the provincial P Loss Assessment Tool for Ontario (PLATO) (Ontario Ministry of Agriculture, Food and Rural Affairs 2021).

The goals of the recent updates to the IROWC-P model were to incorporate recent advances in our understanding of P losses from agricultural land while maintaining parsimony in data inputs and model structure. To accomplish this, updated coefficients were derived from current literature to predict DeP (Wang et al. 2010) and ApP for fertilizer (Vadas et al. 2008) and manure (Vadas et al. 2004; Vadas et al. 2009). The DeP coefficient is multiplied by soil test P (STP, converted to WEP as described below) and runoff (surface, plus the proportion of subsurface runoff that reaches tile drains through preferential pathways) to estimate the mass of DP that could be exported under average weather conditions (Reid et al. 2018). The DeP coefficient from Wang et al. (2010) was chosen as it represented a broad range of Ontario soil types and STP values and produced values in a similar range to those found by Vadas et al. (2005). Both studies showed strong correlations between DeP and soil WEP that appeared to be independent of soil type. The DeP coefficient should be validated in future for soils across Canada, to confirm that it is independent of soil type, but it represents the best currently available data.

The ApP coefficients were used in the manner of Vadas (2017), where a P distribution factor (PDF) is multiplied by the runoff: precipitation ratio between and an estimate of the WEP applied to estimate the mass of applied P that could be exported. The theoretical basis for this is that the runoff concentration of DP desorbed from freshly applied fertilizer or manure will be more concentrated than any runoff that has only interacted with the soil, so infiltration into the soil will trap the P from the runoff and reduce potential losses. The PDF values are different for fertilizer and manure, reflecting the differing nature of these two materials (Vadas et al. 2004; Vadas et al. 2008). For all materials, these calculations apply only to what remains on the soil surface, as fertilizer or manure that has been placed below the soil surface is assumed to be protected from desorption to runoff (Daverede et al. 2004). Differences in manure characteristics between livestock species are accounted for by basing the calculations on the water-extractable portion of the P in the manure rather than the total P applied.

These predictions of incidental P losses were integrated into larger models to allow their use for assessment of water quality impacts from agricultural activities. The ApP coefficients were developed using

Downloaded From: https://complete.bioone.org/journals/Canadian-Journal-of-Soil-Science on 04 Nov 2024
Terms of Use: https://complete.bioone.org/terms-of-use

data from studies across the United States, as cited in Vadas et al. (2004, 2008, and 2009), and have been incorporated into the APLE model (Vadas 2017), which has been recognized as a suitable model for assessing the performance of P Indexes in the United States (Bolster et al. 2012; Bolster et al. 2014). Significant effort was expended in assessing the precision of each these coefficients during their development, so they were simply added together along with the soil desorption components when the APLE model was created. There have also been assessments of the accuracy of the APLE model that combines the predictions using these coefficients with other components to predict total P losses (e.g., Bolster and Vadas 2013; Kleinman et al. 2017; Sharpley et al. 2017).

A literature review was conducted to gather existing data on P runoff across a range of conditions. The geographic scope of this review was primarily Canada, but studies from some of the northern American States were included where, in the authors' opinion, the soil and climatic conditions were similar enough to the adjacent Canadian regions to be relevant to IROWC-P (See Table 1 for a full list). Criteria for study selection included data for DP concentrations in runoff from individual treatments (or included both P loading and mean runoff volume so DP concentrations could be calculated), STP, soil texture, and P application data (source, rate, timing, incorporation method, and timing), as well as the type of runoff study. Some papers were excluded because the data was presented in aggregate to derive P loss coefficients so individual values for DP losses could not be determined (e.g., Wang et al. 2010; Vadas et al. 2005) or because only tile or surface runoff was reported but not both (e.g., Zhang et al. 2015). Runoff DP concentration data was categorized according to four methods of sample collection:

- year-round EoF monitoring,
- rainfall simulator studies in-situ on each plot at various times of the year, usually following a P application (RS),
- measurements from individual rainfall events, and
- runoff box studies from samples collected from the field and repacked into boxes for rainfall simulator studies in the laboratory (RB).

Only one study reported measurements of DP concentrations from individual rainfall events, so it was excluded from further statistical analysis for DeP. Studies that included P applications were only considered if there was a check treatment without any added P, so that the runoff P incidental to applied manure or fertilizer could be separated from the inherent P losses from the soil. A total of 38 references had adequate data for inclusion in the assessment (Table 1).

The structure of a component P Index, like that used in IROWC-P and PLATO, calculates the contribution from DeP and ApP separately and then sums them. For consistency with this structure, the contribution from DeP was deducted from the total DP runoff by subtracting the P loading in runoff from check plots from the P loading in the corresponding amended plot, as follows:

$$ApP = DP_{Treated} - DP_{Check}$$

where $DP_{Treated}$ is the mass of DP from the plots amended with fertilizer or manure, and DP_{Check} is the mass of DP from the corresponding unamended plot. This avoided the double counting of the contribution of P losses from soil desorption that would otherwise occur.

WEP concentrations were calculated from the STP concentrations, and where appropriate, soil textural class and soil pH, according to the method used in IROWC-P (details of this method are included in the Supplementary Material). The coefficients used to convert STP to WEP varied from province to province because the standard soil tests vary between provinces (Mehlich-3 in Quebec and Atlantic Canada, Olsen in Ontario and Manitoba, and Modified Kelowna Saskatchewan, Alberta, and British Columbia); there are also cases of different measured conversion factors between provinces, e.g., Manitoba soils showed higher proportion of WEP in Olsen P than Ontario soils (Table 2 and Supplementary Fig. S1[1]). Standardizing the soil P concentrations as WEP allowed comparison of a single extraction coefficient to estimate DeP in runoff water across the country. Where WEP was not reported directly in the American studies, values for STP were converted to WEP using the methodology for the nearest province. Predicted values for runoff P concentrations were calculated from the WEP data, and the conversion factors from WEP to DeP were used in the IROWC-P model. Measured and predicted values for runoff P losses from soil desorption and applied P were compared graphically, and goodness-of-fit statistics (R^2, RMSE) were calculated using the Analysis Tool Pack add-in in Excel (Microsoft 2016).

Results and discussion

P loss from desorbed P

The results from the three different water quality sample collection methods (EoF, RS, and RB), where sufficient data was available in the literature, were compared to determine if they were predicting P losses in a similar manner, in terms of both total losses and relative to STP or applied P. When assessing losses of DeP, the measured values of DP in runoff appeared to fall into different populations with higher mean concentrations observed in EoF monitoring than in RB, although the differences were not statistically significant (Table 2).

[1]Supplementary data are available with the article at https://doi.org/10.1139/cjss-2021-0049.

Published by Canadian Science Publishing

Downloaded From: https://complete.bioone.org/journals/Canadian-Journal-of-Soil-Science on 04 Nov 2024
Terms of Use: https://complete.bioone.org/terms-of-use

Downloaded From: https://complete.bioone.org/journals/Canadian-Journal-of-Soil-Science on 04 Nov 2024
Terms of Use: https://complete.bioone.org/terms-of-use

Table 1. Summary of plots used for assessment of the IROWC-P and PLATO models.

Location	Soil Texture	STP Method	STP concentration ($mg \cdot kg^{-1}$)	Amendment Type	P rate ($kg\ P \cdot ha^{-1}$)	Runoff Type	Reference
Wisconsin	SiL	Bray-Kurtz P1	33–104	Dairy Manure	29–88	RS	Andraski et al. 2003
Pennsylvania	fine-loamy	Mehlich-3 P	93–109	Dairy Manure	80	RB	Bechmann et al. 2005
Wisconsin	SiL	Bray-Kurtz P1	1–135	Fertilizer, Dairy Manure, Biosolids	24–207.5	RS	Bundy et al. 2001
Saskatchewan	nr	Kelowna Extract	8.3–14.7	Fertilizer	31	EoF	Cade-Menun et al. 2013
Indiana	SiL	Mehlich-3 P	109	LDM	22	RB	Cherobim et al. 2017
Wisconsin	SiL	Bray-Kutrz P1	14	Dairy Manure	40–108	RS	Ebeling et al. 2002
Minnesota	L	Olsen-P	5.2–10.9	Liq Swine Manure	14	EoF	Gessel et al. 2004
Minnesota	L	Olsen-P	6–30	Cattle Manure	164	EoF	Ginting et al. 1998
Vermont	SiL	Mod. Morgan	4.6	Manure	30–62	RB	Hanrahan et al. 2009
New York	SiL	Morgan	1.45–20.2	SCM–Surface Applied	8.6	RS	Hively et al. 2005
Pennsylvania	SiL	Mehlich-3 P	12	Dairy manure slurry	84	RS	Johnson et al. 2011
Wisconsin	SiL	Bray-Kurtz P1	40.5	Dairy manure	48	RS	Jokela et al. 2012
Wisconsin	SiL	Bray-Kurtz P1	26.2–33.9	Dairy manure	20	RS	Jokela et al. 2016
Maryland	fine-silty	Mehlich-3 P	633	Poultry Manure	130	RS	Kibet et al. 2011
New York	L	Mehlich-3 P	26–78	Dairy Manure	75	RS	Kleinman et al. 2005*a*
New York	nr	Mehlich-3 P	117–190	Dairy, Poultry, Swine Manure	77	RB	Kleinman and Sharpley 2003
New York	nr	Mehlich-3 P	13–415	Dairy/Poultry/Swine, DAP	100	RB	Kleinman et al. 2002
Pennsylvania	SiL, CL	Mehlich-3 P	54–119	Dairy Manure	25	RS	Kleinman et al. 2009
Pennsylvania	SiL, L	Mehlich-3 P	16–215	Dairy, Poultry, Swine Manure	100	RB	Kleinman et al. 2004
Manitoba	CL, S	Olsen-P	19.6–29.8	None	0	RB	Kumaragamage et al. 2011
Alberta	CL	Kelowna Extract	34	None	0	RS	Little et al. 2005
Alberta	L, SiL, CL	Kelowna Extract	3–35	Fertilizer	15–20	EoF	Little et al. 2007
Manitoba	nr	Olsen-P	19.8	Fertilizer	7.1	EoF	Liu et al. 2014
Quebec	nr	Mehlich-3 P	51–189	Hog Manure	59	RS	Michaud and Laverdière 2004
Quebec	CL	Mehlich-3 P	33–45	None	0	Event	Michaud and Poirier 2009
Alberta	L	Kelowna Extract	32–64	Cattle Manure	12–24	RS	Miller et al. 2011
Saskatchewan	L	Kelowna Extract	15.4	None	0	EoF	Nicholaichuk and Read 1978
Pennsylvania	fine loam	Mehlich-3 P	44–72	Rock P and Swine manure	100	RS	Shigaki et al. 2006
Indiana	nr	Mehlich-3 P	20–39	DAP, MAP, and polyphosphate	9.6–24.4	RS	Smith et al. 2017
Wisconsin	SiL	Bray-Kurtz P1	32–45	Liquid DM	13	EoF	Stock et al. 2019
New York	Coarse-loamy	Mehlich-3 P	15–20	Spring and Fall Dairy Manure	75	RS	Srinivasan et al. 2007
New Hampshire	coarse-loamy	Mehlich-3 P	100	Fall Dairy Manure	24	RS	Srinivasan et al. 2007
Manitoba	CL	Olsen-P	10.3–21.3	Inorganic Fertilizer	14.8–17	EoF	Tiessen et al. 2010
Ontario	L, CL	Olsen-P	12–15	Poultry manure and MAP	44.5–64	EoF	Van Esbroeck et al. 2016
Pennsylvania	SiL	Mehlich-3 P	12	Liquid Dairy manure	34	EoF	Veith et al. 2011
Manitoba	CL	Olsen-P	5.4–21.2	MAP	0–18.4	EoF	Wilson et al. 2019
Wisconsin	SiL	Bray-Kurtz P1	75	Dairy Pit and Composted	0, 47, 95	RS	Yague et al. 2011
Ontario	CL	Olsen-P	27–36.1	Control	0	EoF	Zhang et al. 2015

Note: nr, not reported; EoF, year-round edge-of-field monitoring; event, monitoring of individual runoff events; RB, runoff boxes with rainfall simulation; RS, rainfall simulator in field.

Published by Canadian Science Publishing

Table 2. Summary statistics of regression between measured DP concentrations in runoff from different study types (EoF, year-round edge-of-field; RS, rainfall simulated field plots; RB, runoff boxes) and soil WEP concentrations (no applied P).

Study Type	n	Mean DP ($mg{\cdot}L^{-1}$)	Intercept	Slope	R^2 (%)	RMSE	Lower 95%	Upper 95%
EoF	22	0.245^{ns}	0.0027^{ns}	0.746^{**}	54.3	0.159	0.426	1.065
RS	51	0.282^{ns}	0.1625^{**}	0.418^{**}	21.7	0.235	0.190	0.647
RB	26	0.178^{ns}	0.0949^{**}	0.114^{**}	64.6	0.076	0.079	0.150

Note: *P* values for differences between means, and for intercept and slope of each regression. ns, not significant; **, $P < 0.001$.

The range of STP in each of the measurement categories also varied, so that when the DP concentrations were regressed against soil test (expressed as WEP), the extraction coefficients, indicated by the slopes of the lines, were significantly different (Table 2 and Fig. 1). Year-round EoF measurements were felt by the authors to be more relevant to environmental impacts of P losses from agricultural land, as they represent the spatial scale most likely to influence adjacent water bodies and the temporal scale, which represents the range of runoff events over the year, so this was the primary focus of comparisons between measured and modelled DeP. The extraction coefficients in the literature cited for all of the measurement systems were much higher than those reported by Wang et al. (2010) or Vadas et al. (2005), so to maintain consistency with the original dataset used in the IROWC-P model, the relative difference between extraction ratios was used rather than applying the extraction coefficients directly from the literature values.

The impact of the choice of extraction coefficients in predicted DP concentrations is significant, with much lower predictions from the coefficients derived from runoff box data than from year-round EoF studies (Fig. 2).

The initial estimates of P desorption for use in IROWC-P were based on extraction coefficients derived from runoff box experiments by Wang et al. (2010), which had shown similar relationships to STP as Vadas et al. (2005). The study by Wang et al. (2010) showed a linear relationship between DP concentration in runoff and STP, with a coefficient of 0.0183 $mg{\cdot}L^{-1}$ DP in runoff water per $mg{\cdot}kg^{-1}$ of WEP. Applying this coefficient to WEP values reported in the literature showed a strong linear correlation between STP and predicted DP concentrations (Fig. 2), but the model was significantly underestimating the DP losses from soil desorption at EoF. The slope of the correlation was lower than the measured DP concentrations from these plots by a factor of 6.5 (the slope of the regression of modelled to observed EoF plots was greater than the slope of the RB plots by this factor; Fig. 1 and Table 2). Multiplying the original coefficient by the observed difference between the RB and the EoF values (6.5) increased the coefficient to a value of 0.114 and brought the predicted and measured DP concentrations into nearly perfect alignment. When the revised coefficients are used, there is a very close correspondence between the measured and modelled DP values from DeP (Fig. 3), with a slope that does not differ significantly from one and an R^2 value of 75%.

The reasons for the discrepancy between year-round EoF measurements and measurements based on artificial rainfall are unclear. The studies for all three measurement systems included a broad range of soil types, covering similar ranges of soil texture and pH and with no obvious differences in past management where information was provided. The runoff box studies included soils with higher values for WEP than the EoF or RS, but there is no evidence that the slope of the correlation with runoff P concentrations changes at the higher WEP values. Kleinman et al. (2004) and Vadas et al. (2005) found only small differences between DP concentrations measured in runoff box and field plots using a rainfall simulator (with a trend toward higher concentrations from the rainfall simulator studies), but neither of these studies included year-round measurement of DP concentration in runoff from natural precipitation. In contrast, Doody et al. (2006) found that DP concentrations in runoff water increased as the length of flow path increased, which could partly explain the pattern of higher concentrations measured at the EoF compared with artificial runoff experiments with small areas. Little et al. (2007) also noted that P extraction coefficients for small Alberta watersheds were higher than those measured in runoff box experiments. Studies from Ontario (Lozier et al. 2017) and the Canadian prairie provinces (Tiessen et al. 2010) have suggested that longer contact time between runoff water and soil, as could occur in snowmelt, would increase soluble reactions between soil and water. The implication of this observation is that the direct application of runoff coefficients from runoff boxes or rainfall simulator studies to models of DP loss from agricultural fields can result in a significant underestimation of the actual risk of P loss.

P loss from applied manure and fertilizer

When losses incidental to the application of P fertilizer or manure were compared among the three sample collection methods, each appeared to fall into distinct

Downloaded From: https://complete.bioone.org/journals/Canadian-Journal-of-Soil-Science on 04 Nov 2024
Terms of Use: https://complete.bioone.org/terms-of-use

Fig. 1. Comparison of observed and modelled DP concentrations in annual surface runoff from check plots (no added P) to soil WEP values from different measurement systems. Statistical values for these correlations are in Table 2.

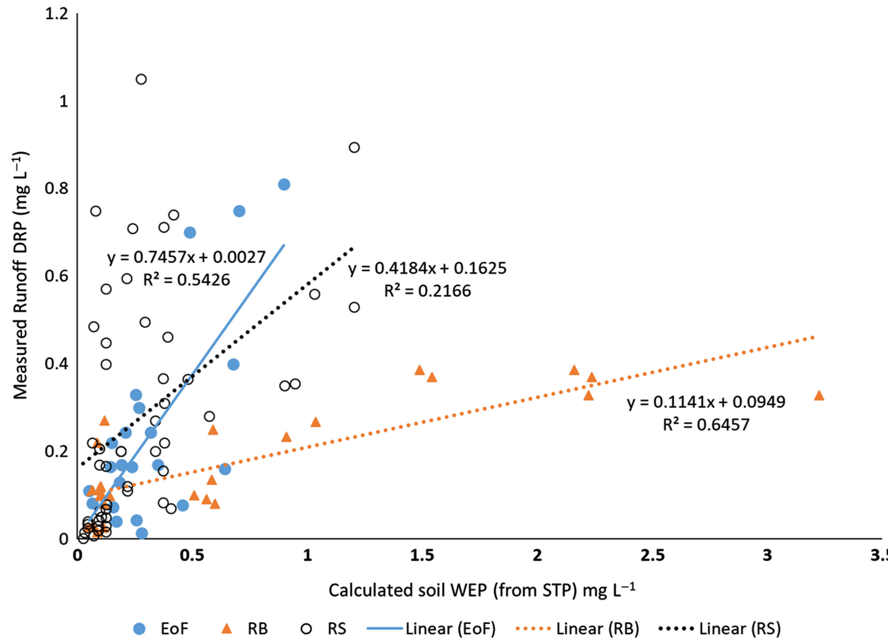
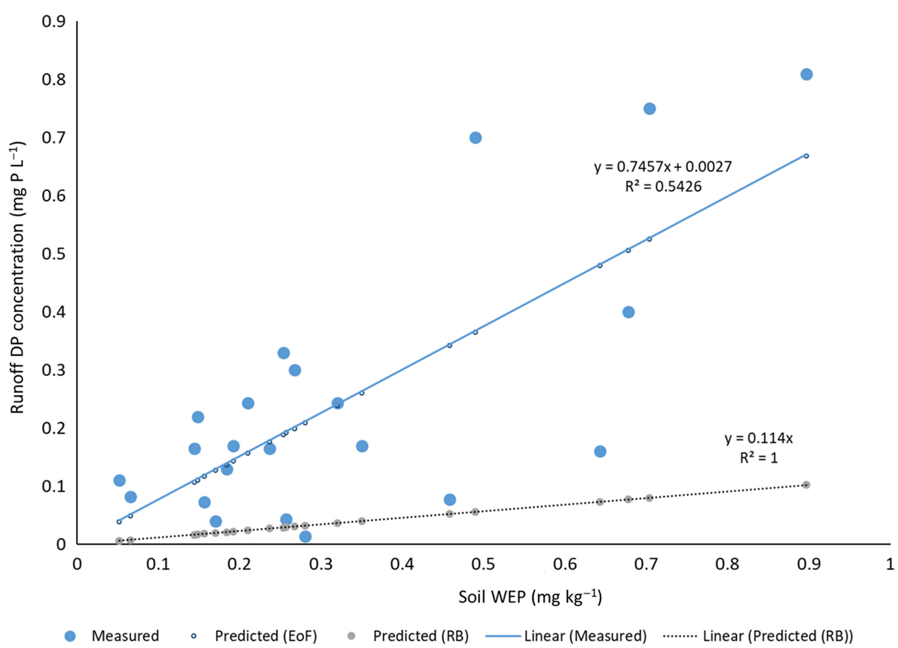


Fig. 2. Comparison of measured to modelled DP predictions from soil WEP using coefficients from year-round edge-of-field or runoff box experiments. Regression statistics are found in Table 2.



populations for both the amount of applied P and the measured ApP losses, in order of EoF < RS < RB (Table 3). The differences among the measurement methods in ApP, however, were not due to the measurement method but rather to the rate of P applied. When the ratio of P loss from ApP to mass of P applied as fertilizer or manure was calculated, there were no significant differences among the three sample collection methods for either fertilizer or manure, indicating that the proportion of applied P that was desorbed into runoff water was the same for all three methods. Since application rate is part of the prediction of ApP, the data from the sample collection methods was pooled for assessment of the model.

Downloaded From: https://complete.bioone.org/journals/Canadian-Journal-of-Soil-Science on 04 Nov 2024
Terms of Use: https://complete.bioone.org/terms-of-use

Fig. 3. Comparison of modelled to observed DP concentrations in surface runoff for the edge-of-field plots with no added fertilizer or manure.

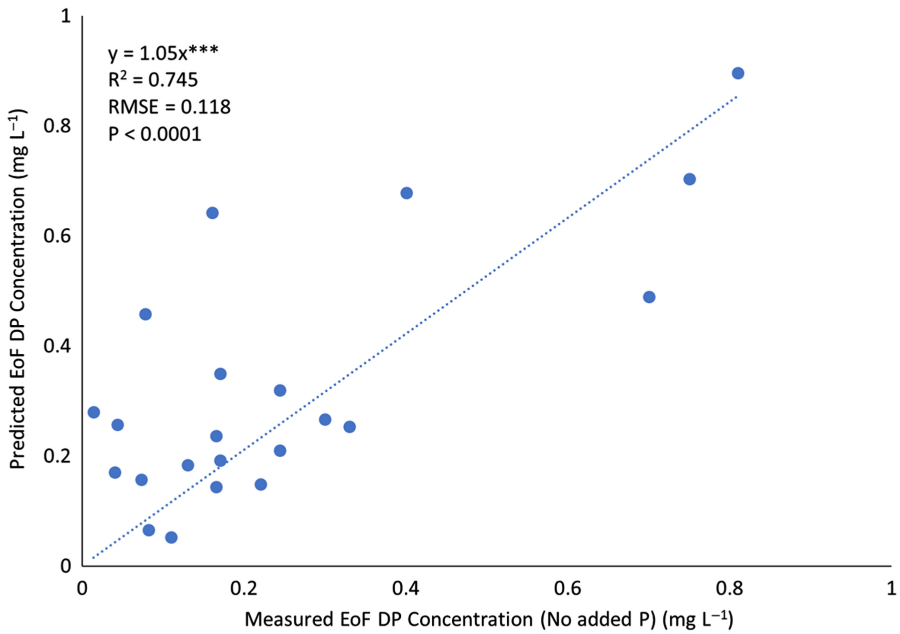


Table 3. Mean values for DP concentration in runoff incidental to P application (ApP), rates of applied P as fertilizer or manure, and the DP concentration as a proportion of applied P.

Sampling Methods	Manure			Fertilizer		
	ApP ($mg \cdot L^{-1}$)	Applied P ($kg \cdot ha^{-1}$)	ApP/Applied	ApP ($mg \cdot L^{-1}$)	Applied P	ApP/Applied
EoF	0.62	11.01	0.123	0.18	4.23	0.123
RS	2.04	15.28	0.140	2.67	15.28	0.265
RB	4.89	24.21	0.221	5.64	65.75	0.091
P value	***0.0013***	***0.0049***	*0.1597*	***0.0003***	***0.0000***	*0.0523*

Note: Bold values indicate that the difference between sampling methods is significant at $P < 0.05$.

Applying the coefficients derived by Vadas et al. (2009) to predict the proportion of applied P from both manure and fertilizer that was lost in runoff resulted in values that were significantly higher than those that were measured by any of the sampling methods. It should be noted that the derivation of the PDF values did not appear to segregate the DeP from ApP, as has been done here, which would result in higher apparent P loss from ApP. This effect would be largest in cases where the P applications were on soils that were already high in WEP (e.g., from historic manure applications in excess of crop P requirements). The PDFs from the APLE model (Vadas et al. 2009) have unique values for fertilizer and manure to account for the differences in the P release characteristics of the materials. These equations predicted that close to 100% of the available WEP would be lost in runoff at high runoff: precipitation ratios, but across all of the studies reported in the literature, WEP losses were less than one-third of this value.

The relative amount of P loss for both fertilizer and manure as the runoff: precipitation ratio increased appeared to be well characterized by the PDF equations, as indicated by statistically significant correlations between measured and predicted DP concentrations in runoff. Using the equations directly from the APLE model, however, resulted in significant overprediction of DP concentrations from applied P in runoff water (Figs. 4 and 5), by a factor of 3.63× for fertilizer and 4.57× for manure (Note: the assumption from the APLE model that 60% of liquid manure infiltrates immediately was not used in this analysis, so that solid manure was not assigned a 2.5× greater risk of P loss than liquid manure; this discrepancy in risk was not apparent in the data we examined). The relative amount of applied P that was lost in runoff water was very well predicted by the APLE equations, but the predicted results only matched the measured when the equations were multiplied by the inverse of the overprediction, resulting in

Downloaded From: https://complete.bioone.org/journals/Canadian-Journal-of-Soil-Science on 04 Nov 2024
Terms of Use: https://complete.bioone.org/terms-of-use

Fig. 4. Modelled DP concentrations from fertilizer applications compared with measured DP concentrations. Open circles and dashed line are predicted P losses incidental to fertilizer application using the equations in the APLE model, which overpredicted the P losses by 3.63×. The closed circles and solid line show the result of multiplying the APLE model equations by a factor of 0.275. Statistics are for the linear fit of the revised model.

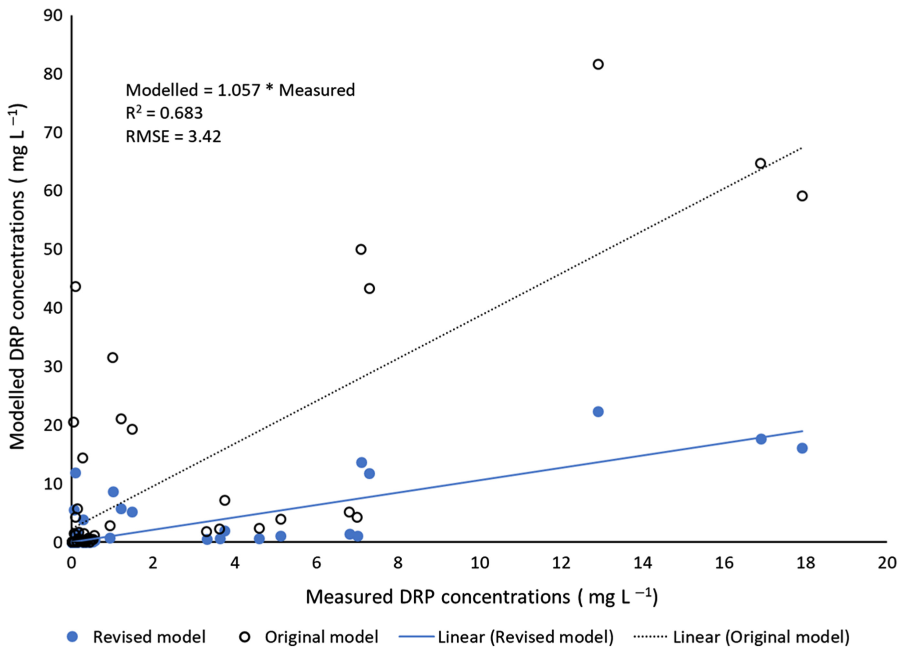
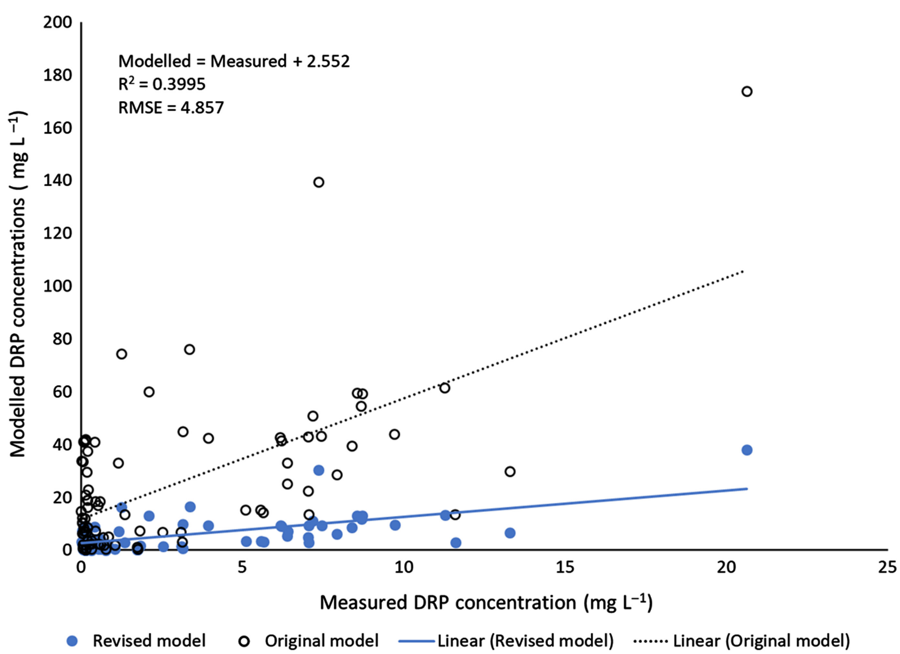


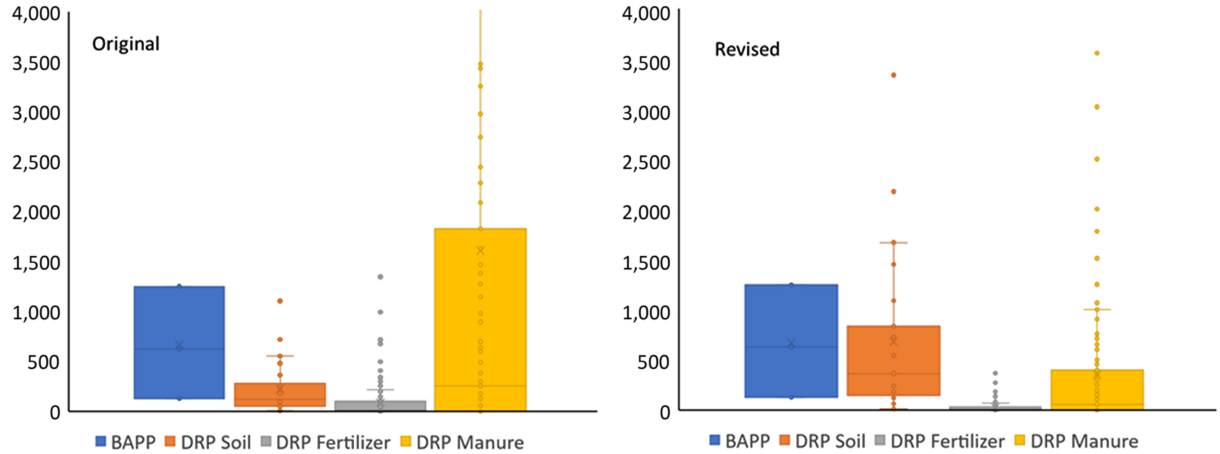
Fig. 5. Modelled DP concentrations from manure applications compared with measured DP concentrations. Open circles and dashed line are predicted P losses incidental to manure application using the equations in the APLE model, which overpredicted the P losses by 4.57×. The closed circles and solid line show the result of multiplying the APLE model equations by a factor of 0.219. Statistics are for the linear fit with the revised model.



factors of 0.275 for fertilizer and 0.219 for manure, implying that 72.5% of fertilizer P and 78% of manure P are not available for runoff. (Figs. 4 and 5). Regression analysis shows that the slope of the measured to modelled correlation was not different from 1. The intercept for the fertilizer prediction was not significantly different from 0,

Downloaded From: https://complete.bioone.org/journals/Canadian-Journal-of-Soil-Science on 04 Nov 2024
Terms of Use: https://complete.bioone.org/terms-of-use

Fig. 6. Relative weighting for components in the IROWC-P model before and after adjusting coefficients, based on a constructed database of 8900 combinations of erosion rate (expressed as Bioavailable Particulate P–BAPP), soil tests, and manure and fertilizer applications.



while for manure there was a significant positive intercept. This suggests that the model is predicting some risk of P loss inherent in manure application, although this value is small relative to the total risk. There was also greater variability in the measured P losses incidental to manure application. This is not unexpected given the inherently greater variability in manure P stemming from uncertainty regarding the precise proportion of both DP and total P in manure (Kleinman et al. 2005*b*) and variability in the amount remaining on the soil surface following incorporation due to the bulky nature of manure. Relations between measured and predicted DP concentrations for both fertilizer and manure were highly significant ($p<0.001$) with moderately high R^2 values and low RMSE (Figs. 4 and 5). Residuals were evenly distributed with average = 0 and no significant slope. The adjustment to the fertilizer availability for loss is consistent with the original model proposed by Vadas et al. (2007), which included a factor for P absorption by the soil between the time of fertilizer application and the first runoff event. In the literature investigated, it appears that the greatest fertilizer loss expected would be 27.5% of the total applied.

The APLE model includes a factor for infiltration of liquid manure into the soil, assuming that 60% of the applied liquid infiltrated and therefore protected the P from loss in runoff (Vadas et al. 2004). This had not been included in the original IROWC-P model, to treat the P from solid manure in a similar manner to liquid manure as a source of P runoff. If infiltration was the only mechanism reducing the loss of P from applied manure, we would expect to see relatively greater losses from solid manure applications than from liquid, but this difference was not observed in the literature results. It suggests there is another mechanism in place. Possibly the temporal pattern of runoff generation, which is accounted for in the SWCS Curve Number approach as the “initial abstraction” (SCS 1985; Rawat et al. 2010), is carrying a disproportionate amount of desorbable P into the soil during the early part of a rain event and therefore, limiting the amount available for runoff. There could also be different mechanisms operating with liquid and solid manure (infiltration of liquid manure and sequestration of P within solid manure either in organic forms or physically protected from diffusion out of clumps) that result in similar apparent availability for loss from the two forms. This is an area that requires further investigation to fully understand the underlying processes of manure and fertilizer P dissolution and transfer to runoff water.

In the APLE model, P runoff from fertilizer or manure is estimated through the use of a PDF based on the runoff:precipitation ratio to partition DP between runoff and infiltration, assuming that the P that infiltrates into the soil is then adsorbed to the soil (Vadas et al. 2009). To align the predictions of P loss with the measured P concentrations in the literature, we suggest that the equations for the PDF for incidental losses from applied P need to be multiplied by the upper limit of P available for loss: 0.275 in the case of fertilizer and 0.219 in the case of manure.

Impact of model revisions on relative weighting of P loss components

A set of synthetic values was constructed using various combinations of soil erosion (Bio Available Particulate P, BAPP), soil test values, and manure and fertilizer application rates to test the relative contributions of each component using the original and revised coefficients (Fig. 6). The relative importance of STP to the overall scores increased, while manure and fertilizer were reduced, providing a much more balanced weighting for these components. It would be beneficial to carry

Downloaded From: https://complete.bioone.org/journals/Canadian-Journal-of-Soil-Science on 04 Nov 2024
Terms of Use: https://complete.bioone.org/terms-of-use

out a sensitivity analysis to determine the impact of changes to individual components to the final P loss assessments, as well as to compare the overall scores to a range of water quality measurements from across the country to test the overall performance of the model, as these steps have not yet been completed.

Future work

Despite the broad range of conditions represented by the literature reviewed, further work is needed to increase confidence in the weightings of components of P loss. In particular, there needs to be emphasis on year-round EoF monitoring under a range of soil types, climatic conditions, P sources, and application rates. Performing these trials with a broad enough range of P management practices will increase confidence that the P losses are being partitioned correctly among the different components.

Conclusions

This paper compares the results of P runoff experiments relevant to Canadian soil and climatic conditions with modelled P concentrations, focusing in particular on the relative weights of P losses through desorption from the soil and incidental to P applications. The measurements of DeP varied significantly depending on what sampling methods were used. Within each sampling method, there were strong and consistent correlations between STP and DeP, but the DP concentrations measured in runoff boxes were significantly lower than in year-round EoF measurements. Models using DeP coefficients derived from runoff box studies are likely to be underestimating the contribution of elevated STP to risk of P loss from fields over the course of a year. Runoff box and rainfall simulator studies will continue to be valuable for understanding the underlying P release processes and the impacts of soil test P, soil texture and pH, and other soil parameters on the relative losses of DP in runoff. The controlled conditions of these studies are not reflective of EoF situations, and so scaling up their results to field scale models should be approached with caution.

Applying the same type of analysis to ApP showed much less variation between sampling methods, once the rate of P application had been considered. The amount of P desorption, however, did not approach that which would be expected if all of the applied P (or applied WEP in the case of manure) on the soil surface desorbed into runoff water. Models using the assumption of 100% availability for loss of P applied as manure or fertilizer appear to be overestimating the contribution of applied P to the risk of P loss within a component P index.

Ensuring correct balance among the components of P loss in any P index or P loss model will improve the overall accuracy of risk assessments and provide better guidance to land managers regarding the optimum choice of mitigation techniques if the risk of P loss is high. Further, it will improve the capacity of models to correctly predict the impact of applying various beneficial management practices on P loss reduction in both the short and long term, which is critical for meeting P reduction targets.

Acknowledgements

This project was funded as part of the Sustainability Metrics initiative of Agriculture and Agri Food Canada. Thanks to co-op student Alexander Nauta, who summarized the data from the literature sources and performed the initial data analysis. Thanks as well to the scientists who shared their data on the relations between STP and WEP (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 (Sainte-Foy, QC, Canada) and Tiequan Zhang and Yutao Wang for their assistance in data analysis.

References

Andraski, T.W., Bundy, L.G., and Kilian, K.C. 2003. Manure History and Long-Term Tillage Effects on Soil Properties and Phosphorus Losses in Runoff. J. Environ. Qual. **32**(5): 1782–1789. doi:10.2134/jeq2003.1782. PMID:14535321.

Baker, D.B., Confesor, R., Ewing, D.E., Johnson, L.T., Kramer, J.W., and Merryfield, B.J. 2014. Phosphorus loading to Lake Erie from the Maumee, Sandusky and Cuyahoga rivers: The importance of bioavailability. J. Great Lakes Res. **40**(3): 502–517. doi:10.1016/j.jglr.2014.05.001.

Bechmann, M.E., Kleinman, P.J.A., Sharpley, A.N., and Saporito, L.S. 2005. Freeze–Thaw Effects on Phosphorus Loss in Runoff from Manured and Catch-Cropped Soils. J. Environ. Qual. **34**(6): 2301–2309. doi:10.2134/jeq2004.0415. PMID:16275731.

Benoy, G.A., Jenkinson, R.W., Robertson, D.M., and Saad, D.A. 2016. Nutrient delivery to Lake Winnipeg from the Red—Assiniboine River Basin – A binational application of the SPARROW model. Canadian Water Resources Journal/ Revue canadienne des ressources hydriques **41**(3): 429–447. doi:10.1080/07011784.2016.1178601.

Bolster, C.H., and Vadas, P.A. 2013. Sensitivity and Uncertainty Analysis for the Annual Phosphorus Loss Estimator Model. J. Environ. Qual. **42**(4): 1109–1118. doi:10.2134/jeq2012.0418. PMID:24216362.

Bolster, C.H., Vadas, P.A., Sharpley, A.N., and Lory, J.A. 2012. Using a phosphorus loss model to evaluate and improve phosphorus indices. J. Environ. Qual. **41**(6): 1758–1766. doi:10.2134/jeq2011.0457. PMID:23128733.

Bolster, C.H., Horvath, T., Lee, B.D., Mehlhope, S., Higgins, S., and Delgado, J.A. 2014. Development and testing of a new phosphorus index for Kentucky. J. Soil Water Conserv. **69**(3): 183–196. doi:10.2489/jswc.69.3.183.

Bundy, L.G., Andraski, T.W., and Powell, J.M. 2001. Management practice effects on phosphorus losses in runoff in corn production systems. J. Environ. Qual. **30**(5): 1822–1828. doi:10.2134/jeq2001.3051822x. PMID:11577891.

Cade-Menun, B.J., Bell, G., Baker-Ismail, S., Fouli, Y., Hodder, K., McMartin, D.W., et al. 2013. Nutrient loss from Saskatchewan cropland and pasture in spring snowmelt runoff. Can. J. Soil Sci. **93**(4): 445–458. doi:10.4141/cjss2012-042.

Downloaded From: https://complete.bioone.org/journals/Canadian-Journal-of-Soil-Science on 04 Nov 2024
Terms of Use: https://complete.bioone.org/terms-of-use

CEAP. 2011. Assessment of the Effects of Conservation Practices on Cultivated Cropland in the Great Lakes Region. in USDA-NRCS, ed.

Cherobim, V.F., Huang, C.-H., and Favaretto, N. 2017. Tillage system and time post-liquid dairy manure: Effects on runoff, sediment and nutrients losses. Agric. Water Manage. **184**: 96–103. doi:10.1016/j.agwat.2017.01.004.

Collick, A.S., Veith, T.L., Fuka, D.R., Kleinman, P.J.A., Buda, A.R., Weld, J.L., et al. 2016. Improved Simulation of Edaphic and Manure Phosphorus Loss in SWAT. J. Environ. Qual. **45**(4): 1215–1225. doi:10.2134/jeq2015.03.0135. PMID:27380069.

Das, B., Huth, N., Probert, M., Condron, L., and Schmidt, S. 2019. Soil Phosphorus Modeling for Modern Agriculture Requires Balance of Science and Practicality: A Perspective. J. Environ. Qual. **48**(5): 1281–1294. doi:10.2134/jeq2019.05.0201. PMID:31589725.

Daverede, I.C., Kravchenko, A.N., Hoeft, R.G., Nafziger, E.D., Bullock, D.G., Warren, J.J., and Gonzini, L.C. 2004. Phosphorus Runoff from Incorporated and Surface-Applied Liquid Swine Manure and Phosphorus Fertilizer. J. Environ. Qual. **33**(4): 1535–1544. doi:10.2134/jeq2004.1535. PMID:15254136.

Doody, D., Moles, R., Tunney, H., Kurz, I., Bourke, D., Daly, K., and O'Regan, B. 2006. Impact of flow path length and flow rate on phosphorus loss in simulated overland flow from a humic gleysol grassland soil. Sci. Total Environ. **372**(1): 247–255. doi:10.1016/j.scitotenv.2006.08.029.

Ebeling, A.M., Bundy, L.G., Powell, J.M., and Andraski, T.W. 2002. Dairy Diet Phosphorus Effects on Phosphorus Losses in Runoff from Land-Applied Manure. Soil Sci. Soc. Am. J. **66**(1): 284–291. doi:10.2136/sssaj2002.2840.

Fiorellino, N.M., McGrath, J.M., Vadas, P.A., Bolster, C.H., and Coale, F.J. 2017. Use of Annual Phosphorus Loss Estimator (APLE) Model to Evaluate a Phosphorus Index. J. Environ. Qual. **46**(6): 1380–1387. doi:10.2134/jeq2016.05.0203. PMID:29293844.

Gassman, P.W., Williams, J.R., Wang, X., Saleh, A., Osei, E., Hauck, L.M., et al. 2009. The Agricultural Policy Environmental EXtender (APEX) Model: An Emerging Tool for Landscape and Watershed Environmental Analyses. Center for Agricultural and Rural Development, Iowa State University.

Gessel, P.D., Hansen, N.C., Moncrief, J.F., and Schmitt, M.A. 2004. Rate of Fall-Applied Liquid Swine Manure. J. Environ. Qual. **33**(5): 1839–1844. doi:10.2134/jeq2004.1839. PMID:15356245.

Ginting, D., Moncrief, J.F., Gupta, S.C., and Evans, S.D. 1998. Interaction between Manure and Tillage System on Phosphorus Uptake and Runoff Losses. J. Environ. Qual. **27**(6): 1403–1410. doi:10.2134/jeq1998.00472425002700060017x.

Hanrahan, L.P., Jokela, W.E., and Knapp, J.R. 2009. Dairy Diet Phosphorus and Rainfall Timing Effects on Runoff Phosphorus from Land-Applied Manure. J. Environ. Qual. **38**(1): 212–217. doi:10.2134/jeq2007.0672. PMID:19141811.

Hively, W.D., Bryant, R.B., and Fahey, T.J. 2005. Phosphorus Concentrations in Overland Flow from Diverse Locations on a New York Dairy Farm. J. Environ. Qual. **34**(4): 1224–1233. doi:10.2134/jeq2004.0116. PMID:15942041.

Hollaway, M.J., Beven, K.J., Benskin, C.M.H., Collins, A.L., Evans, R., Falloon, P.D., et al. 2018. The challenges of modelling phosphorus in a headwater catchment: Applying a 'limits of acceptability' uncertainty framework to a water quality model. J. Hydrol. **558**: 607–624. doi:10.1016/j.jhydrol.2018.01.063.

Howell, E.T., and Dove, A. 2017. Chronic nutrient loading from Lake Erie affecting water quality and nuisance algae on the St. Catharines shores of Lake Ontario. J. Great Lakes Res. **43**(5): 899–915. doi:10.1016/j.jglr.2017.06.006.

Jarvie, H.P., Johnson, L.T., Sharpley, A.N., Smith, D.R., Baker, D.B., Bruulsema, T.W., and Confesor, R. 2017. Increased Soluble Phosphorus Loads to Lake Erie: Unintended Consequences of Conservation Practices? J. Environ. Qual. **46**(1): 123–132. doi:10.2134/jeq2016.07.0248. PMID:28177409.

Johnson, K.N., Kleinman, P.J.A., Beegle, D.B., Elliott, H.A., and Saporito, L.S. 2011. Effect of dairy manure slurry application in a no-till system on phosphorus runoff. Nutr. Cycling Agroecosyst. **90**(2): 201–212. doi:10.1007/s10705-011-9422-8.

Jokela, W., Sherman, J., and Cavadini, J. 2016. Nutrient runoff losses from liquid dairy manure applied with low-disturbance methods. J. Environ. Qual. **45**(5): 1672–1679. doi:10.2134/jeq2015.09.0498. PMID:27695757.

Jokela, W.E., Coblentz, W.K., and Hoffman, P.C. 2012. Dairy heifer manure management, dietary phosphorus, and soil test p effects on runoff phosphorus. J. Environ. Qual. **41**(5): 1600–1611. doi:10.2134/jeq2012.0046. PMID:23099952.

Joosse, P.J., and Baker, D.B. 2011. Context for re-evaluating agricultural source phosphorus loadings to the Great Lakes. Can. J. Soil Sci. **91**(3): 317–327. doi:10.4141/cjss10005.

Kibet, L.C., Allen, A.L., Kleinman, P.J.A., Feyereisen, G.W., Church, C., Saporito, L.S., and Way, T.R. 2011. Phosphorus runoff losses from subsurface-applied poultry litter on coastal plain soils. J. Environ. Qual. **40**(2): 412–420. doi:10.2134/jeq2010.0161. PMID:21520748.

Kleinman, P.J.A., and Sharpley, A.N. 2003. Effect of broadcast manure on runoff phosphorus concentrations over successive rainfall events. J. Environ. Qual. **32**: 1072–1081. doi:10.2134/jeq2003.1072. PMID:12809308.

Kleinman, P.J.A., Sharpley, A.N., Moyer, B.G., and Elwinger, G.F. 2002. Effect of mineral and manure phosphorus sources on runoff phosphorus. J. Environ. Qual. **31**(6): 2026–2033. doi:10.2134/jeq2002.2026. PMID:12469853.

Kleinman, P.J.A., Sharpley, A.N., Veith, T.L., Maguire, R.O., and Vadas, P.A. 2004. Evaluation of phosphorus transport in surface runoff from packed soil boxes. J. Environ. Qual. **33**: 1413–1423. doi:10.2134/jeq2004.1413. PMID:15254124.

Kleinman, P.J.A., Salon, P., Sharpley, A.N., and Saporito, L.S. 2005*a*. Effect of cover crops established at time of corn planting on phosphorus runoff from soils before and after dairy manure application. J. Soil Water Conserv. **60**(6): 311–322.

Kleinman, P.J.A., Wolf, A.M., Sharpley, A.N., Beegle, D.B., and Saporito, L.S. 2005*b*. Survey of water-extractable phosphorus in livestock manures. Soil Sci. Soc. Am. J. **69**(3): 701–708. doi:10.2136/sssaj2004.0099.

Kleinman, P.J.A., Sharpley, A., Saporito, L., Buda, A., and Bryant, R. 2009. Application of manure to no-till soils: phosphorus losses by sub-surface and surface pathways. Nutr. Cycling Agroecosyst. **84**(3): 215–227. doi:10.1007/s10705-008-9238-3.

Kleinman, P.J.A., Sharpley, A.N., Buda, A.R., Easton, Z.M., Lory, J.A., Osmond, D.L., et al. 2017. The Promise, Practice, and State of Planning Tools to Assess Site Vulnerability to Runoff Phosphorus Loss. J. Environ. Qual. **46**(6): 1243–1249. doi:10.2134/jeq2017.10.0395. PMID:29293848.

Kumaragamage, D., Flaten, D., Akinremi, O.O., Sawka, C., and Zvomuya, F. 2011. Soil test phosphorus changes and phosphorus runoff losses in incubated soils treated with livestock manures and synthetic fertilizer. Can. J. Soil Sci. **91**(3): 375–384. doi:10.4141/cjss10004.

Lemunyon, J.L., and Gilbert, R.G. 1993. The concept and need for a phosphorus assessment tool. J. Prod. Agri. **6**(4): 483–486. doi:10.2134/jpa1993.0483.

Little, J.L., Bennett, D.R., and Miller, J.J. 2005. Nutrient and sediment losses under simulated rainfall following manure incorporation by different methods. J. Environ. Qual. **34**(5): 1883–1895. doi:10.2134/jeq2005.0056. PMID:16151240.

Little, J.L., Nolan, S.C., Casson, J.P., and Olson, B.M. 2007. relationships between soil and runoff phosphorus in small Alberta Watersheds. J. Environ. Qual. **36**: 1289–1300. doi:10.2134/jeq2006.0502. PMID:17636290.

Downloaded From: https://complete.bioone.org/journals/Canadian-Journal-of-Soil-Science on 04 Nov 2024
Terms of Use: https://complete.bioone.org/terms-of-use

Liu, K., Elliott, J.A., Lobb, D.A., Flaten, D.N., and Yarotski, J. 2014. Nutrient and sediment losses in snowmelt runoff from perennial forage and annual cropland in the canadian prairies. J. Environ. Qual. **43**(5): 1644–1655. doi:10.2134/jeq2014.01.0040. PMID:25603250.

Liu, J., Macrae, M.L., Elliott, J.A., Baulch, H.M., Wilson, H.F., and Kleinman, P.J.A. 2019. Impacts of cover crops and crop residues on phosphorus losses in cold climates: A review. J. Environ. Qual. **48**(4): 850–868. doi:10.2134/jeq2019.03.0119. PMID:31589697.

Lozier, T.M., Macrae, M.L., Brunke, R., and Van Eerd, L.L. 2017. Release of phosphorus from crop residue and cover crops over the non-growing season in a cool temperate region. Agric. Water Manage. **189**: 39–51. doi:10.1016/j.agwat.2017.04.015.

Menzies Pluer, E.G., Knighton, J.O., Archibald, J.A., and Walter, M.T. 2019. Comparing watershed scale p losses from manure spreading in temperate climates across mechanistic soil p models. J. Hydrol. Eng. **24**(5): 04019009. doi:10.1061/(ASCE)HE.1943-5584.0001774.

Michaud, A., and Poirier, S.-C. 2009. Évaluation des exportations de surface et souterraines de phosphore en sol drainé. Rapport final de projet. Institut de recherche et de développement en agroenvironnement (IRDA) et MAPAQ, Quebec. p 39.

Michaud, A.R., and Laverdière, M.R. 2004. Cropping, soil type and manure application effects on phosphorus export and bioavailability. Can. J. Soil Sci. **84**(3): 295–305. doi:10.4141/S03-014.

Miller, J.J., Chanasyk, D.S., Curtis, T.W., and Olson, B.M. 2011. Phosphorus and nitrogen in runoff after phosphorus - or nitrogen - based manure applications. J. Environ. Qual. **40**(3): 949–958. doi:10.2134/jeq2010.0279. PMID:21546681.

N.C. PLAT Committee. 2005. North Carolina Phosphorus Loss Assessment: I. Model Description and II. Scientific Basis and Supporting Literature. Department of Soil Science, North Carolina State University, Raleigh, NC. p. 95

Neumann, A., Dong, F., Shimoda, Y., Arnillas, C., Javed, A., Paredes, D., et al. 2021. A review of the current state of process-based and data-driven modelling: guidelines for Lake Erie managers and watershed modellers. Environ. Rev. (in press). doi:10.1139/er-2020-0070.

Nicholaichuk, W., and Read, D.W.L. 1978. Nutrient runoff from fertilized and unfertilized fields in Western Canada. J. Environ. Qual. **7**(4): 542–544. doi:10.2134/jeq1978.00472425000700040015x.

Ontario Ministry of Agriculture, Food and Rural Affairs. 2021. AgriSuite Software (webpage). [online]. Available from http://www.omafra.gov.on.ca/english/nm/nman/agrisuite.htm#top.

Pferdmenges, J., Breuer, L., Julich, S., and Kraft, P. 2020. Review of soil phosphorus routines in ecosystem models. Environ. Model. Software, **126**: 104639. doi:10.1016/j.envsoft.2020.104639.

Plach, J., Pluer, W., Macrae, M., Kompanizare, M., McKague, K., Carlow, R., and Brunke, R. 2019. Agricultural Edge-of-Field Phosphorus Losses in Ontario, Canada: Importance of the Nongrowing Season in Cold Regions. J. Environ. Qual. **48**(4): 813–821. doi:10.2134/jeq2018.11.0418. PMID:31589700.

Radcliffe, D.E., Freer, J., and Schoumans, O. 2009. Diffuse Phosphorus Models in the United States and Europe: Their Usages, Scales, and Uncertainties J. Environ. Qual. **38**(5): 1956–1967. doi:10.2134/jeq2008.0060. PMID:19704139.

Rawat, S.S., Mishra, S.K., Gaur, M.L., and Singh, P.K. 2010. An updated hydrological review on recent advancements in soil conservation service-curve number technique. J. Water Clim. Change, **1**(2): 118–134. doi:10.2166/wcc.2010.022.

Reid, K., Schneider, K., and McConkey, B. 2018. Components of Phosphorus Loss From Agricultural Landscapes, and How to Incorporate Them Into Risk Assessment Tools. Front. Earth Sci. **6**(135): 1–15. doi:10.3389/FEART.2018.00135.

Scavia, D., David Allan, J., Arend, K.K., Bartell, S., Beletsky, D., Bosch, N.S., et al. 2014. Assessing and addressing the re-eutrophication of Lake Erie: Central basin hypoxia. J. Great Lakes Res. **40**(2): 226–246. doi:10.1016/j.jglr.2014.02.004.

SCS 1985. National Engineering Handbook. Supplement A, Section 4, Chapter 10. Soil Conservation Service, USDA, Washington, DC.

Sharpley, A., Beegle, D., Bolster, C., Good, L., Joern, B., Ketterings, Q., et al. 2012. Phosphorus indices: Why we need to take stock of how we are doing. J. Environ. Qual. **41**(6): 1711–1719. doi:10.2134/jeq2012.0040. PMID:23128728.

Sharpley, A., Kleinman, P., Baffaut, C., Beegle, D., Bolster, C., Collick, A., et al. 2017. Evaluation of Phosphorus Site Assessment Tools: Lessons from the USA. J. Environ. Qual. **46**(6): 1250–1256. doi:10.2134/jeq2016.11.0427. PMID:29293829.

Shigaki, F., Sharpley, A., and Prochnow, L.I. 2006. Source-Related Transport of Phosphorus in Surface Runoff. J. Environ. Qual. **35**: 2229. doi:10.2134/jeq2006.0112. PMID:17071893.

Šimůnek, J., van Genuchten, M.T., and Šejna, M. 2012. The HYDRUS Software Package for Simulating the Two- and Three-Dimensional Movement of Water, Heat, and Multiple Solutes in Variably-Saturated Media - Technical Manual (Version 2.0). PC Progress, Prague, Czech Republic. p. 258.

Singh, A., Rudra, R.P., and Gharabaghi, B. 2012. Evaluation of CANWET model for hydrologic simulations for upper Canagagigue Creek watershed in southern Ontario. Can. Biosyst. Eng. **54**: 1.7–1.18. doi:10.7451/CBE.2012.54.1.7.

Smith, D.R., Huang, C., and Haney, R.L. 2017. Phosphorus fertilization, soil stratification, and potential water quality impacts. J. Soil Water Conserv. **72**(5): 417–424. doi:10.2489/jswc.72.5.417.

Srinivasan, M.S., Kleinman, P.J.A., Sharpley, A.N., Buob, T., and Gburek, W.J. 2007. Hydrology of Small Field Plots Used to Study Phosphorus Runoff under Simulated Rainfall. J. Environ. Qual. **36**(6): 1833–1842. doi:10.2134/jeq2007.0017. PMID:17965386.

Steffen, M.M., Belisle, B.S., Watson, S.B., Boyer, G.L., and Wilhelm, S.W. 2014. Status, causes and controls of cyanobacterial blooms in Lake Erie. J. Great Lakes Res. **40**(2): 215–225. doi:10.1016/j.jglr.2013.12.012.

Stock, M.N., Arriaga, F.J., Vadas, P.A., Good, L.W., Casler, M.D., Karthikeyan, K.G., and Zopp, Z. 2019. Fall Tillage Reduced Nutrient Loads from Liquid Manure Application during the Freezing Season. J. Environ. Qual. **48**(4): 889–898. doi:10.2134/jeq2018.11.0417. PMID:31589665.

Tiessen, K.H., Elliott, J.A., Yarotski, J., Lobb, D.A., Flaten, D.N., and Glozier, N.E. 2010. Conventional and conservation tillage: influence on seasonal runoff, sediment, and nutrient losses in the Canadian Prairies. J. Environ. Qual. **39**(3): 964–980. doi:10.2134/jeq2009.0219. PMID:20400592.

Vadas, P.A. 2017. Annual Phosphorus Loss Estimator Theoretical Documentation Version 2.5. in USDA-ARS, ed. U.S. Dairy Forage Research Center, Madison, WI.

Vadas, P.A., Kleinman, P.J.A., and Sharpley, A. 2004. A Simple Method to Predict Dissolved Phosphorus in Runoff from Surface - Applied Manures. J. Environ. Qual. **33**(2): 749. doi:10.2134/jeq2004.7490. PMID:15074829.

Vadas, P.A., Kleinman, P.J.A., Sharpley, A.N., and Turner, B.L. 2005. Relating Soil Phosphorus to Dissolved Phosphorus in Runoff. J. Environ. Qual. **34**(2): 572–580. doi:10.2134/jeq2005.0572. PMID:15758110.

Vadas, P.A., Harmel, R.D., and Kleinman, P.J.A. 2007. Transformations of soil and manure phosphorus after surface application of manure to field plots. Nut. Cycling Agroecosys. **77**(1): 83–99. doi:10.1007/s10705-006-9047-5.

Downloaded From: https://complete.bioone.org/journals/Canadian-Journal-of-Soil-Science on 04 Nov 2024
Terms of Use: https://complete.bioone.org/terms-of-use

Vadas, P.A., Owens, L.B., and Sharpley, A.N. 2008. An empirical model for dissolved phosphorus in runoff from surface-applied fertilizers. Agri. Ecosys. Environ. **127**(1–2): 59–65. doi:10.1016/j.agee.2008.03.001.

Vadas, P.A., Good, L.W., Moore, P.A.J., and Widman, N. 2009. Estimating Phosphorus Loss in Runoff from Manure and Fertilizer for a Phosphorus Loss Quantification Tool. J. Environ. Qual. **38**: 1645–1653. doi:10.2134/jeq2008.0337. PMID:19549941.

Vadas, P.A., Joern, B.C., and Moore, P.A. 2012. Simulating Soil Phosphorus Dynamics for a Phosphorus Loss Quantification Tool. J. Environ. Qual. **41**(6): 1750–1757. doi:10.2134/jeq2012.0003. PMID:23128732.

Vadas, P.A., Bolster, C.H., and Good, L.W. 2013. Critical evaluation of models used to study agricultural phosphorus and water quality. Soil Use Manage. **29**: 36–44. doi:10.1111/j.1475-2743.2012.00431.x.

van Bochove, E., Thériault, G., and Denault, J.-T. 2010. Indicator of Risk of Water Contamination by Phosphorus (IROWC_P). A Handbook for presenting the IROWC_P Algorithms. AAFC.

Van Esbroeck, C.J., Macrae, M.L., Brunke, R.I., and McKague, K. 2016. Annual and seasonal phosphorus export in surface runoff and tile drainage from agricultural fields with cold temperate climates. J. Great Lakes Res. **42**(6): 1271–1280. doi:10.1016/j.jglr.2015.12.014.

Veith, T.L., Kleinman, P.J.A., Shigaki, F., Saporito, L.S., and Beegle, D.B. 2011. Assessing the Impact of Manure Application Method on Runoff Phosphorus using Controlled and Natural Rainfall. Proc. International Symposium on Erosion and Landscape Evolution (ISELE), 18–21 Sept. 2011, Anchorage, Alaska, St. Joseph, MI.

Wang, Y.T., Zhang, T.Q., Hu, Q.C., Tan, C.S., Halloran, I.P.O., Drury, C.F., et al. 2010. Estimating Dissolved Reactive Phosphorus Concentration in Surface Runoff Water from Major Ontario Soils. J. Environ. Qual. **39**(5): 1771–1781. doi:10.2134/jeq2009.0504. PMID:21043282.

Williams, J.R., and Izaurralde, R.C. 2005. The APEX Model. nrcs143_013182. Natural Resources Conservation Service, United States Department of Agriculture.

Wilson, H., Elliott, J., Macrae, M., and Glenn, A. 2019. Near-Surface Soils as a Source of Phosphorus in Snowmelt Runoff from Cropland. J. Environ. Qual. **48**(4): 921–930. doi:10.2134/jeq2019.04.0155. PMID:31589699.

Woodbury, J.D., Shoemaker, C.A., Easton, Z.M., and Cowan, D.M. 2014. Application of SWAT with and without Variable Source Area Hydrology to a Large Watershed. JAWRA J. Am. Water Resour. Assoc. **50**(1): 42–56. doi:10.1111/jawr.12116.

Yague, M.R., Andraski, T.W., and Laboski, C.A. 2011. Manure composition and incorporation effects on phosphorus in runoff following corn biomass removal. J. Environ. Qual. **40**(6): 1963–71. PMID:22031580.

Zhang, T.Q., Tan, C.S., Zheng, Z.M., and Drury, C.F. 2015. Tile Drainage Phosphorus Loss with Long-Term Consistent Cropping Systems and Fertilization. J. Environ. Qual. **44**(2): 503–511. doi:10.2134/jeq2014.04.0188. PMID:26023969.

Downloaded From: https://complete.bioone.org/journals/Canadian-Journal-of-Soil-Science on 04 Nov 2024
Terms of Use: https://complete.bioone.org/terms-of-use