MANURE, PHOSPHORUS, AND 125 SITE-YEARS OF EDGE-OF-FIELD RUNOFF MEASUREMENTS

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Abstract

Phosphorus export from agricultural fields continues to create water quality concerns in Wisconsin. The UW Discovery Farms program, along with Discovery Farms Minnesota have collected 125 site-years of edge-of-field monitoring data which can be used to better understand the relative effects of inherent soil properties (slope, drainage class, texture), management practices (manure application, tillage, crop rotation, cover cropping), and soil test P values on seasonal (frozen and non-frozen conditions) losses of dissolved P (DP) and total P (TP). The objectives of this study were to: (1) determine the seasonal controls of DP and TP loss, (2) determine the effect of manure application, tillage, and soil test P on DP and TP loss, and (3) evaluate the relative contribution of inherent soil properties and management practices on seasonal DP and TP loss. The relationship between DP and TP concentration was very strong during frozen conditions, but quite weak during non-frozen conditions. Manure application had a greater effect on DP and TP flow weighted mean concentration (FWMC) during frozen conditions compared to non-frozen. During non-frozen, pasture had greater FWMC compared to other manure applications. Tillage practices led to inconsistent effects, sometimes increasing and sometimes decreasing FWMC relative to no-till. The relationship between STP and FWMCs during frozen or non-frozen conditions was generally weak, with R^2 values less than 0.27. Regression tree analysis identified soil test P (0-2”) as the most influential factor for DP FWMC during non-frozen conditions and TP and DP FWMC during frozen conditions. Tillage was the most influential factor for TP FWMC for non-frozen conditions. Collectively, this work, along with future analysis can lead to a greater understanding of the relative influence of factors that drive P loss. This analysis would suggest that reducing soil test P would be the first step to reduce P loss for most conditions, although tillage reduction should be the first step to reduce TP during non-frozen conditions.

Justification

Controlling phosphorus loss from farm fields in Wisconsin continues to be a challenge. The Wisconsin Department of Natural Resources has identified more than 5,400 miles of streams and 230 lakes as “impaired” based on total concentrations (WDNR, 2015). However, improve-ments can be made at a watershed scale through targeted implementation on high-export fields (Carvin et al., 2018). Agricultural management practices such as no-tillage, conducting nutrient management plans reduce STP and manage manure, and increasing vegetative cover (of both managed lands and field boundaries) as well as engineering practices such as grade-stabilization structures and stream bank stabilization, have been promoted as conservation practices to help mitigated P loss. While P loss is estimated through process models or through

P indexes (e.g., Wisconsin phosphorus Index), what is often lacking is empirical data of edge-of-field losses. The UW Discovery Farms program. While classic experimental design limitations prevent direct comparison of individual management practices through reductionist research, other statistical approaches can be used to understand the relevance and the magnitude of inherent soil properties and management practices on P loss. The objectives of this study were to: (1) determine

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the seasonal controls of DP and TP loss, (2) determine the effect of manure application, tillage, and soil test P on DP and TP loss, and (3) evaluate the relative contribution of inherent soil properties and management practices on seasonal DP and TP loss.

Materials and Methods

UW Discovery Farms and Discovery Farm Minnesota Dataset

The field scale edge-of-field runoff monitoring data presented in this study were generated by UW Discovery Farms and Discovery Farms Minnesota (hereby collective referred to as Discovery Farms), which in partnership with agricultural producers has fostered this on-farm research. The producers within this dataset represent a broad spectrum of current farm management practices and environmental conditions across the Wisconsin and Minnesota. Edge-of-field runoff measurements were installed in collaboration with the USGS (USGS, 2008). The Discovery Farms annual edge-of-field runoff monitoring dataset was evaluated in a series of screening layers to ensure the validity of the resultant dataset and narrow its focus to represent common agricultural practices. The first screening layer omitted sites that were not in an agricultural land use or reflected a non-representative agricultural land use. The second layer removed sites or site years that contained incomplete data or data that could not be validated. The third layer evaluated the subsequent dataset for outlier sites or site years using a simple linear regression model. The linear regression evaluation was conducted in R and screened dependent nutrient variables against input variables known to have a significant relationship (runoff depth and precipitation) for normality. Sites and site years that were believed to be non-normal underwent further evaluation to determine the integrity of the data prior to retaining or omitting the data. The resultant dataset is comprised of 26 individual agricultural sites (Figure 1), in two states (MN, WI), and over the course of 14 water years spanning from 2004 to 2017.

The resultant dataset, was originally established on a hydrologic year set between (October 1st to September 30th). In order to narrow the focus of the study and investigate the effects of field-level management practice on edge-of-field phosphorus loses under frozen conditions the dataset was divided into two sub-datasets based on soils' thermal phase of (1) non-frozen soil and (2) frozen soil. The soil temperature used to separate the two sub-datasets was monitored on site at depths ranging from 2 to 80 cm in WI (USGS 2008-1015, 2008) and 5 to 60 cm in MN (Discovery Farms SOP, 2011). If the soil temperature profile contained any temperature below 32°F the soil was considered frozen.

The agricultural land use variable was comprised of two categories: annual cropping (including beans, beet, corn, mix, soy, wheat) and perennial cropping (alfalfa-based rotations and pasture). Crop rotation was also simplified into four categories: (1) continuous corn, (2) corn-soybean (which may contain other small grains), (3) pasture, and (4) perennial legumes (where alfalfa was the dominant crop in rotation. Tillage practices were narrowed into four categories: (1) pasture, (2) no-till, (3) minimal-till (including vertical and strip tillage) and (4) conventional (including disk, chisel, moldboard plow, cultivator, injection, and rip tillage). Manure practices were separated in five categories based on field practices and the soil thermal phases: (1) no manure, (2) applied non-frozen soil, (3) applied early frozen soil approximately December and January, (4) applied late frozen soil approximately February and March, and (5) pasture fields receiving manure year-round from grazing animals. The dependent variables TP and DP flow weighted mean concentrations (FWMC) were derived from the Discovery Farms edge-of-field monitoring stations. TP and DRP loads were calculated by multiplying the composite sample TP and DP concentration by their respective flow volume and reported on a per-hectare basis. TP and DP FWMC were determined by dividing loads, irrespective of unit area, by their respective flow volumes.

Statistical Analysis

Statistical data analysis and graphing were conducted in the R statistical environment version 3.5.1 (R Core Team, 2018). Univariate analysis of the input and dependent continuous variable was conducted with the "summary" function, while skewness and kurtosis were determined with the package "moments". Regression analyses were used to determine the relationships between TP FWMC and DP FWMC, as well as, TP FWMC or DP FWMC and soil test phosphorus with their respective soil thermal phase. Field-level manure and tillage management practices were separately analyzed for treatment effects on TP FWMC and DP FWMC using a Tukey Honest Significance Difference one-way ANOVA ($\alpha = 0.05$) with a general linear fit model using the package "agricolae". The relationships between field-level manure as well as tillage management practices and the dependent nutrients were determined to behave non-normal and potentially impact results, thus the data were log(x+1) transformed prior to analysis. The predictive models developed in this study were constructed from the regression tree analysis packages "rpart" and "rpart.plot." Regression tree analysis can evaluate relationships or make predictions based on a wide array of input variables and is utilized broadly across ecological, agronomic, and hydrologic scientific disciplines (e.g., Jakubowski et al., 2010; Smidt et al., 2016). A regression tree initiates with single root node that contains the entire data set. The root node is analyzed and partitioned by a predictor variable resulting in the greatest reduction in variability within the two descendant nodes. The process of node splitting continues until the tree reaches a limiting factor such as the complexity parameter (CP) or a minimum observation limit required to split a node is reached.

Surface runoff TP and DP FWMC or TP and DP loads were the primary response variables in the regression trees and the entire list categorical and continuous input variables is described in Zopp et al. (2019). Regression trees in this study were grown so that each node had at least 20 observations, each leaf had seven observations, and a CP = 0.001. The most parsimonious tree was selected through the application of the 1-SE rule as the smallest tree within one standard deviation of the minimum standard error. The 1-SE rule was applied in this study to locate the lowest number splits, by taking the sum of the smallest 10-fold cross validation error (xerror) and its corresponding standard error (xstd); the sum is then used to determine the cross-validation error and corresponding CP value via linear interpolation. The selected CP value is then used to prune the most parsimonious tree with the lowest number of splits. The variables of importance and top five completing splits for the primary node were reported by the "summary" function and the R^2 for the regression tree was determined the equation: $R^2 = 1 - \text{relative error}$.

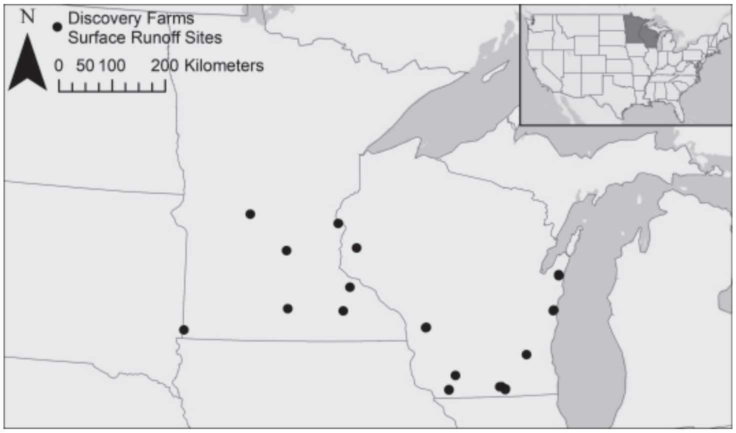


Figure 1. Location of the 26 farm fields used in this study.
Fields within 10 miles of each other are represented with one dot.

Results and Discussion

Flow-weighted Mean Concentrations

The TP and DP FWMC relationships for the non-frozen and frozen soil phases, seen in Figure 2, were both found to be significant ($P < 0.001$). However, only the frozen phase TP and DP FWMC relationship was determined to behave linearly with an adjusted $R^2 = 0.96$, while the non-frozen relationship was determined to behave non-linearly with an adjusted $R^2 = 0.11$.

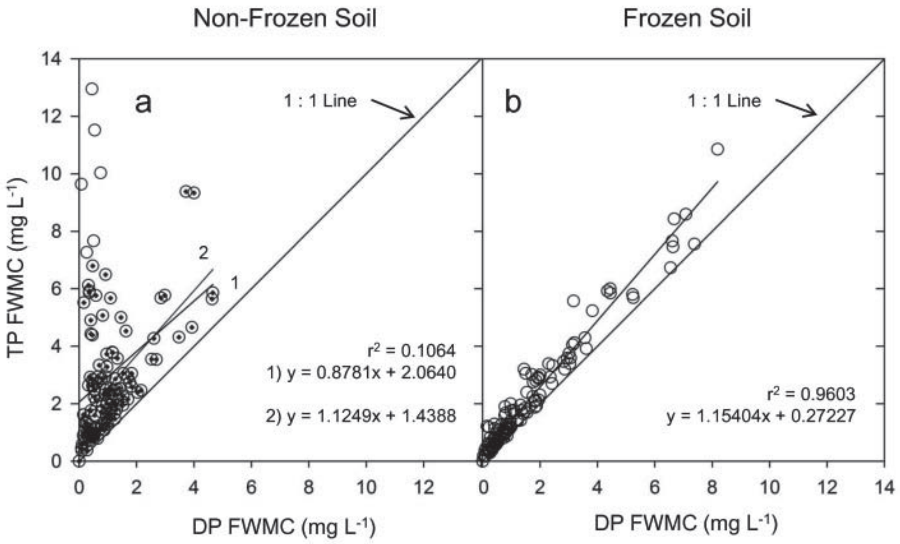


Figure 2. Relationships between total P (TP) flow weighted mean concentration (FWMC) and dissolved P (DP) FWMC during non-frozen soil conditions or frozen soil conditions (n = 125).

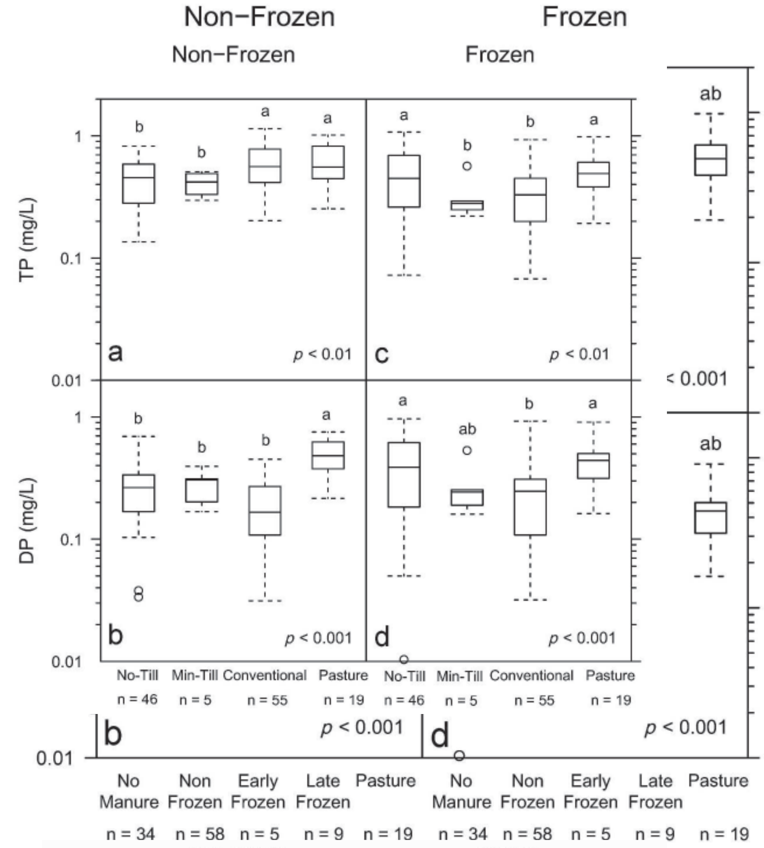
The slope ($b = 1.15$) of the frozen TP and DP FWMC linear regression indicates that potentially 87.7% of TP was comprised by DP; while the non-frozen was relationship too weak ($R^2 = 0.11$) to make such an estimate. Alternatively, the TP/DP ratio can also estimate the amount of TP comprised of DP. Based on the TP/DP ratio, DP FWMC on average accounted for 17.5% of TP during non-frozen phases and 60.1% of TP during frozen phases.

Management Practice Dynamics

Field-level manure practices, using a significance level ($\alpha = 0.05$) were shown to influence TP and DP FWMCs (Figure 3). The influence of field-level manure practices was predominately observed during the frozen soil phase. Seen in Figure 3c, the application of manure during the late frozen phase yields significantly ($P < 0.001$) higher TP FWMC as compared to a no manure or non-frozen manure application practices. The early frozen phase were similar to all other practices.

The application of manure during the late frozen phase was observed to result in significantly higher ($P < 0.001$) DP FWMC, as compared to the no manure and non-frozen manure application practices (Figure 3d). Pasture yielded significantly higher DP FWMC during frozen as compared to the no manure practice, but was similar to all other practices. The comparison of manure practices during the non-frozen soil phase showed no significant ($P < 0.05$) treatment difference in TP FWMC across all groups, even though individual comparisons of manure practices may have differed (Figure 3a). However, pastured fields produced significantly ($P < 0.001$) higher DP FWMC as compared to any other manure practice (Figure 3b).

Figure 3. Box plots of manure application timing and TP or DP flow weighted mean concentration (FWMC) during non-frozen (n = 125) or frozen soil condi-tions (n = 125). Relationships are log(x+1) – log(x+1) transformed. Results from a one-way ANOVA (Tukey) in R (α = 0.05) are indicated by letters above the 90th percentile whisker.



Field-level tillage practices, using a significance level (α = 0.05) were shown to impact log(x+1) transformed TP and DP FWMC for every soil phase (Figure 4).

Figure 4. Box plots of tillage practices TP or DP flow weighted mean concentration (FWMC) during non-frozen (n = 125) or frozen soil conditions (n = 125). Relationships are log(x+1) – log(x+1) transformed. Results from a one-way ANOVA (Tukey) in R (α = 0.05) are indicated by letters above the 90th percentile whisker.

The comparison of tillage practices during the non-frozen soil phase indicated that both conventional tillage and pasture "tillage" (bovine animals continuously roaming) practices yielded significantly ($P < 0.01$) higher TP FWMC as compared to no-till and minimum tillage practices (Figure 4a). Furthermore, pastured fields produced significantly ($P < 0.001$) greater DP FWMC as compared to any other tillage practice (Figure 4b).

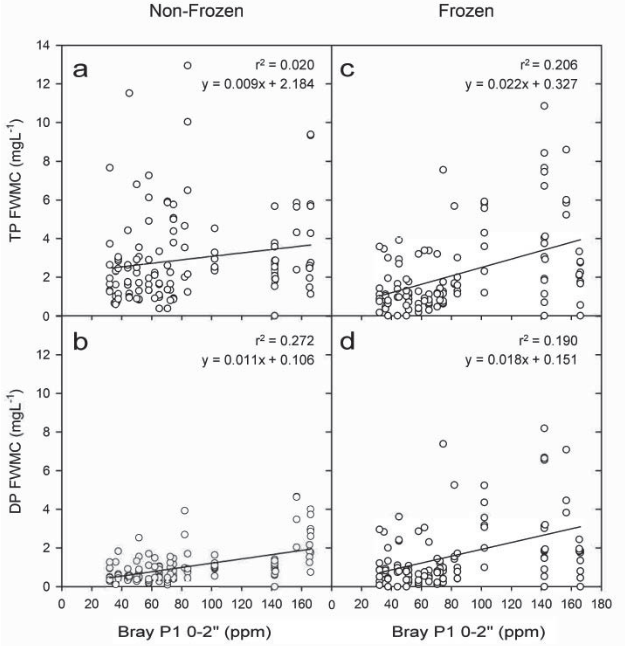


Figure 5. Relationships between 0 – 6 inch depth soil test Bray 1 phosphorus and total P (TP) or dissolved P (DP) flow weighted mean concentration (FWMC) during non-frozen or frozen soil conditions (n = 122).

Comparisons of tillage practices during the frozen soil phase reveal a slightly different set of influences. As seen in Figure 4c, both the no-till and pasture tillage practice yield significantly ($P < 0.01$) greater TP FWMC as compared to minimum tillage and conventional. No-till and pasture tillage practices again result in significantly ($P < 0.001$) higher DP FWMC as compared to conventional tillage, with minimum tillage being similar to all practices. In contrast to tillage and manure applica-tions, the relationship between TP or DP FWMC and soil test P (0-6") was weak with R^2 values less than 0.272, although positively associated (Figure 5).

Regression Tree Analysis

Regression tree analysis, within the bounds of the 1-SE rule, did result in reportable trees for TP and DP FWMC across the non-frozen and frozen soil phases. The TP FWMC non-frozen soil was only split by tillage practice (1.9 mg L^{-1} for minimum tillage and no-till; 3.6 mg L^{-1} for conventional and pasture) and only explained 11.6% of the variation. The DP FWMC non-frozen was only split by 2" soil test P (Bray-P) (0.76 mg L^{-1} if less than 150 ppm and 2.7 mg L^{-1} if greater than 150 ppm), but it explained 45.2% of the variation. The trees for TP frozen and DP frozen both had the 2" soil test P as the first split (Figure 6 and 7).

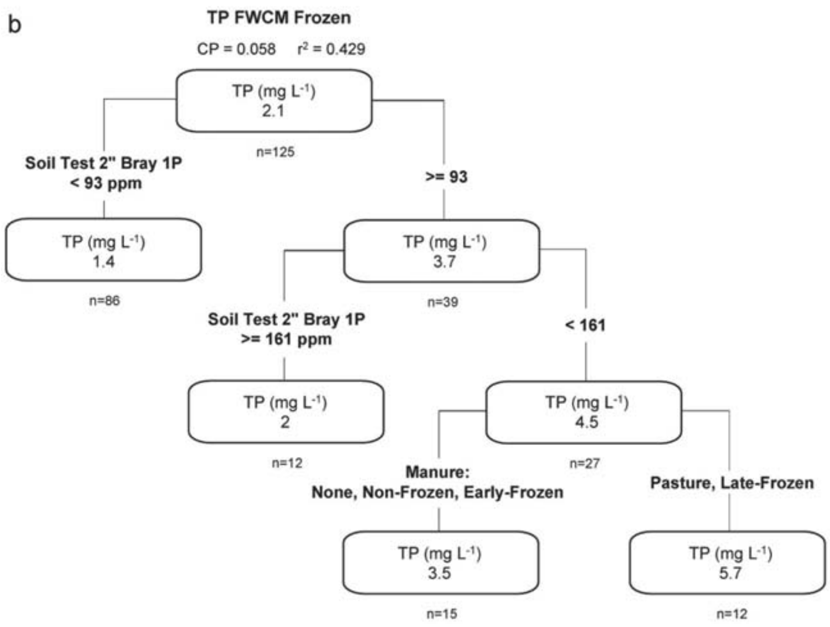


Figure 6. Regression tree results for TP FWMC under frozen conditions.

For TP frozen, additional splits under >93 ppm STP were an additional STP split of 161 ppm and manure application (with pasture and late-frozen having greater TP FWMC than other manure applications). For DP frozen, there was an additional split under >93 ppm STP of 161 ppm STP (Figure 7).

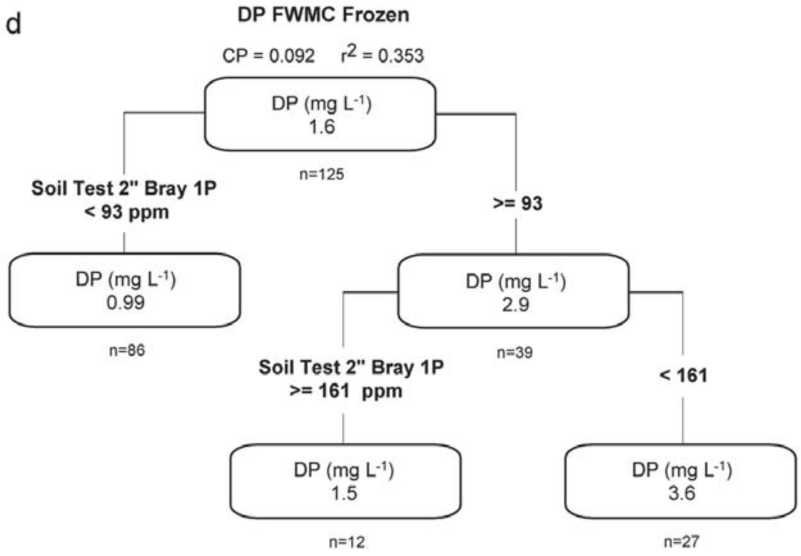


Figure 7. Regression tree results for DP FWMC under non-frozen conditions.

Conclusions

Clearly the relationship between TP and DP FWMC differs by environmental condition (frozen or unfrozen). Tillage, soil test P, and manure application were all influential aspects of TP and DP loss, but the magnitude of the influence differed between frozen and non-frozen conditions. Interestingly, inherent soil factors such as slope, texture, and drainage class were not influential based on regression tree analysis. These results confirm the conventional wisdom related to tillage, manure application, and soil test P, although no-till did not result in lower P losses during frozen conditions. Pasture also had much higher P losses than expected. More work is needed to understand that effect. But collectively, this work, along with further analysis, can lead to a greater understanding of the relative influence of factors that drive P loss. This analysis would suggest that reducing soil test P would be the first step to reduce P loss, followed by reduction in tillage.

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