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Characterizing phosphorus dynamics in tile-drained agricultural fields of eastern Wisconsin

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SUMMARY

Artificial subsurface drainage provides an avenue for the rapid transfer of phosphorus (P) from agricultural fields to surface waters. This is of particular interest in eastern Wisconsin, where there is a concentrated population of dairy farms and high clay content soils prone to macropore development. Through collaboration with private landowners, surface and tile drainage was measured and analyzed for dissolved reactive P (DRP) and total P (TP) losses at four field sites in eastern Wisconsin between 2005 and 2009. These sites, which received frequent manure applications, represent a range of crop management practices which include: two chisel plowed corn fields (CP1, CP2), a no-till corn–soybean field (NT), and a grazed pasture (GP). Subsurface drainage was the dominant pathway of water loss at each site accounting for 66–96% of total water discharge. Average annual flow-weighted (FW) TP concentrations were 0.88, 0.57, 0.21, and 1.32 mg L^{-1} for sites CP1, CP2, NT, and GP, respectively. Low TP concentrations at the NT site were due to tile drain interception of groundwater flow where large volumes of tile drainage water diluted the FW-TP concentrations. Subsurface pathways contributed between 17% and 41% of the TP loss across sites. On a drainage event basis, total drainage explained between 36% and 72% of the event DRP loads across CP1, CP2, and GP; there was no relationship between event drainflow and event DRP load at the NT site. Manure applications did not consistently increase P concentrations in drainflow, but annual FW-P concentrations were greater in years receiving manure applications compared to years without manure application. Based on these field measures, P losses from tile drainage must be integrated into field level P budgets and P loss calculations on heavily manured soils, while also acknowledging the unique drainage patterns observed in eastern Wisconsin.

1. Introduction

Eutrophication, the accelerated nutrient enrichment of surface waters, impairs freshwater ecosystems in Wisconsin and around the world by causing unfavorable odors, algal blooms, and fish kills. Agricultural phosphorus (P) loss is the dominant driver of accelerated eutrophication in many freshwater lakes and streams (Carpenter et al., 1998a, b; Sharpley et al., 1994). A given field's susceptibility to P loss is influenced by soil properties, landscape position, management history, and current practices. There is also a disproportionality of P loss within a watershed; it has been estimated that 80% of losses come from 20% of the watershed (Sharpley et al., 2009).

Phosphorus leaching losses have been historically discounted because orthophosphate, the biologically active form of P, rapidly adsorbs onto soil surfaces. Furthermore, recent studies have concluded that tile drains are not main contributors to watershed P fluxes (e.g. Domagalski and Johnson, 2011; Sprague and Gronberg, 2012), although results from Gentry et al. (2007) indicate that tile drainage is a major contributor in specific watersheds. It is likely that P contribution from tiles can vary on a watershed-by-watershed basis and Ulén et al. (2011) make the case for the need for tile drains to be considered in P risk assessment. Other research highlights the risk of P loss from tile drains. Algoazany et al. (2007) determined that at four out of five continuously monitored sites in Illinois, tile drains exported more P than surface

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pathways due to large tile drainage volumes. There have also been numerous studies which suggest that preferential flow plays a role in leaching of P (e.g. Djodjic et al., 2000; Geohring et al., 2001; Hansen et al., 1999; Jensen et al., 2006; Kleinman et al., 2003, 2005; Simard et al., 2000), which would also play a key role in P export from tile drains. It is also clear that manure applications can lead to an increase in P loss from tile drains (Hernandez-Ramirez et al., 2011).

Beauchemin et al. (1998) concluded that P rich, flat, and clayey soils could contribute P to surface waters if tile drained. Eastern Wisconsin farmland fits these criteria. Soil tests conducted between 2005 and 2009 indicate that the average soil P levels in eastern Wisconsin counties are in the high to excessively high soil test category for most crops (University of Wisconsin Soil and Plant Analysis Laboratory (UW-SPAL), 2009). The lowest county average in Wisconsin is 33 mg kg^{-1}, which would be in the high soil test category for forage crops and excessively high soil test category for grain crops (Laboski et al., 2006). Additionally, considerable portions of eastern Wisconsin's cultivated acreage are tile-drained and receive annual applications of animal manure. However, P losses from tile drains in this landscape have not been quantified. Current conservation efforts in this region are focused on reducing surface P losses (e.g. Wisconsin Phosphorus Index); a greater understanding of tile P losses can aid in improving future conservation efforts.

The overall goal of this study was to quantify P losses from surface and tile drain pathways in this unique region, and identify key factors of the P losses. Collaboration among private landowners, the United States Geological Survey (USGS), and the UW-Discovery Farms program was used to identify field locations for intensive surface and tile monitoring. Specific objectives include: (i) determination of total and dissolved P loads and flow-weighted (FW) concentrations from surface and tile drains at an annual, monthly, and event-based time scale; (ii) evaluate the relationship between surface P losses and tile P losses; and (iii) evaluate drivers for P loss in these landscapes.

2. Materials and methods

2.1. Study area

The study was conducted between 2005 and 2009 on four tile-drained, in-field basins at three farms in eastern Wisconsin (Table 1). All farms are working dairies that participated in the UW-Extension Discovery Farms (www.uwdiscoveryfarms.org) program during the monitoring period and include two chisel plowed (CP) sites (CP1 and CP2), one no-tillage (NT) site, and one grazed pasture (GP). The CP1 and CP2 sites were located near Kewaunee in Kewaunee County. The NT site was located near Oconomowoc in Waukesha County and the GP site was located near Cleveland in Manitowoc County. The CP1, CP2, and GP site are within the Lake Michigan Watershed, while the NT site is within the Mississippi River Basin. Slopes ranged from 1% to 3% at NT and 2% to 6% across the CP and GP study sites. These fields were also selected because the soil test P concentrations were in the excessively high soil test category (Laboski et al., 2006) and because of the known historic annual or biennial manure applications (Table 1). Soil and crop management characteristics are summarized in Table 1.

The drain tiles at CP1 and CP2 were installed underneath grassed waterways and included randomly-spaced lateral drains. Drain placement at the NT site includes both parallel and randomly-spaced drains connected to a main lateral drain. The GP site has a randomly-spaced drainage system connected to a main lateral drain. Drains were installed at the CP and GP sites prior to 1990; the NT drains were installed prior to 2000. The drain lines are 0.15 m diameter clay tile at CP1 and CP2, 0.15 m diameter plastic tile at NT, and 0.3 m diameter concrete tile at GP. All drains are installed to a depth of approximately 1 m. There were no surface inlets upstream at any of our monitoring sites. At CP1 a tile blow-out was observed in 2007, but it is uncertain when the blow-out originally occurred.

The USGS determined surface and subsurface basin boundaries using personal communication with the producers and verification of the surface basin boundaries for CP1, CP2, and GP (Table 1, Stuntebeck et al., 2011). The tile drainage in each of these basins is located in an upland area in which the drainage tile was established above the groundwater table. The subsurface basin was estimated to be equivalent to that of the respective surface basin and descriptive maps are published in Stuntebeck et al. (2011). However, at the NT site, the boundaries for surface and subsurface basins were not the same based on site observations as well as annual runoff amounts. For the subsurface basin at NT, a regional groundwater model (GFLOW; Haitjema 1995) was used estimate the potential groundwater contributing area, which was determined to be 16.2 ha. Caution should be used when interpreting rainfall to runoff ratios and P loads per unit area from this site due to the uncertainty in subsurface drainage size. However, the uniqueness of this site's drainage characteristics warrant inclusion in this study. The agricultural management described in this study was performed across 60% of the NT surface watershed and 40% of the NT subsurface watershed, respectively. The remainder of the NT basin included a wood-lot and adjacent fields that were planted in corn and soybeans in 2006 and 2007 and corn and alfalfa in 2008. Field and surface boundaries for the NT site are provided in Stutebeck et al. (2011).

Table 1
Site characteristics of fields in eastern Wisconsin where surface and tile monitoring occurred.

Site	Years monitored[a]	Area drained (ha)	Soil test phosphorus (ppm)	Cropping system	Tillage practices	Dominant soil
CP1	2005–08	8.30	89[b], 70[c]	Continuous corn silage	Chisel plowed	Fine-loamy, mixed, active, mesic Haplic Glossudalfs
CP2	2005–08	5.30	64[b], 47[c]	Continuous corn silage	Chisel plowed	Fine-loamy, mixed, active, mesic Haplic Glossudalfs
NT	2006–08	16.20 (tile) 2.50 (surface)	85[d]	Corn–soybean	No-tillage	Fine, mixed, active, mesic Typic Hapludalfs
GP	2007–09	6.20	75[b], 140[d]	Pasture	NA[e]	Fine-loamy, mixed, superactive, mesic Typic Argiaquolls

[a] Water year (for example, 2005: October 1, 2004–September 30, 2005).
[b] October 22, 2007 sample date.
[c] April 21, 2009 sample date.
[d] November 2006 sample date.
[e] The GP site was tilled in the spring of 2009 for reseeding.