PHOSPHORUS LOSS FROM TILE DRAINS: SHOULD WE BE CONCERNED?

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Introduction

Subsurface P loss is of greatest concern in areas with P-rich flat, clayey soils and P-rich tile-drained soils (Beauchemin et al., 1998). Eastern Wisconsin farmland fits the criteria for high subsurface P emitting soils. Soil tests conducted between 1995 and 1999 indicated that the average soil P levels in eastern Wisconsin counties were in excess of the recommended levels for most crops (Laboski et al, 2006). Additionally, considerable portions of eastern Wisconsin's cultivated acres are tile-drained. The highest concentration of tile drainage is along the shore of Lake Michigan. The 1992 United States Census of Agriculture estimates the portion of cultivated acres that are tile drained to range from 20 to 60% among all of Wisconsin's far-eastern counties (Kewaunee, Manitowoc, Sheboygan, Ozaukee, Milwaukee, Racine, and Kenosha).

Current tile drainage systems provide no filtration of intercepted water. If nutrient-rich soil solution enters the tile drain, nutrient-rich water is discharged. While tile drain P concentrations are typically lower than surface P concentrations, annual P loads from drains have exceeded loads from surface pathways (Algoazany et al., 2007). Areas of active hydrological connectivity where natural preferential flow channels connect to artificial drainage systems may be P loss hotspots (Beauchemin et al., 1998; Sharpley et al., 2009).

The possibility of P leaching was discounted historically because orthophosphate, the biologically active form of P, rapidly sorbs onto soil surfaces. It was thus assumed that P would be held by the soil as long as P amendments were incorporated (such that P was allowed to interact with the soil) and P-enriched soils were not eroded away. Work by Beauchemin et al. (1998) on P-saturated soils revealed that P loss via subsurface pathways was a reality. The objectives of this study were to quantify P losses and concentrations in tile drainage in Wisconcin and to evaluate P loss dynamics after manure applications.

Materials and Methods

The study was conducted between 2005 and 2009 on four tile-drained, in-field basins at three farmsteads in eastern Wisconsin. All farms are working dairies that participated in the UW-Extension Discovery Farms program during the monitoring period. Two of the sites were located 1 km apart on a farm in Kewaunee County and were managed as chisel-plow continuous corn cropping systems. The third site was managed as a no tillage corn-soybean cropping system and located in Waukesha County. The fourth site, located in Manitowoc County, was managed as a grazed pasture. The sites will be referred to according to their management type: chisel-plowed (CP1 and CP2), no-till (NT), and grazed pasture (GP). Slopes ranged from 1 to 3% at NT and 2 to

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6% across the CP and GP study sites. The CP1, CP2 and NT sites were within the Lake Michigan watershed and the NT site was located within the watershed of the Rock River, a tributary of the Mississippi River (Fig. 1). According to state nutrient requirement guidelines, all sites were excessively high in P (Laboski et al., 2006) (Table 1).

Drain tile at CP1 and CP2 was installed underneath grassed waterways. Drain placement at the NT site includes both parallel and randomly-spaced drains. The GP site has a randomly-spaced drainage system. Drains were installed at the CP and GP sites between prior to 1990; the NT drains were installed prior to 2000. The drain lines are 0.15 m (6-inch) diameter ceramic tile at CP1 and CP2, 0.15 m diameter PVC tile at NT, and 0.3 m (12-inch) diameter concrete tile at GP. All drains are installed to a depth of approximately 1 m. Surface and subsurface basin boundaries were determined by the United States Geological Survey (USGS).

Permanent monitoring stations were installed by the USGS to continuously quantify and sample edge-of-basin surface runoff and tile drainflow at each site. The following description of field equipment and sampling procedures used at the Discovery Farm sites was condensed from Stuntebeck et al (2008). Surface runoff and tile drainflow were monitored with non-submersible pressure transducers, coupled with nitrogen bubbler systems. All sampling data were organized annually by hydrologic year beginning on 1 October and ending on 30 September (e.g., water year 2005 is from 1 Oct 2004 to 30 Sept 2005). Surface runoff and tile drainflow data were collected at sites CP1 and CP2 from 2005-2008 and sub-surface data only were collected in 2009. Surface runoff and tile drainflow data were collected at NT and GP during 2006-2008 and 2007-2009, respectively.

Surface runoff and tile drainflow sub-samples were flow-weighted by volume into composite samples that represented discrete drainage events. All surface and tile samples were collected by an automated, refrigerated, 24-bottle ISCO 3700R sampler; samples were retrieved within 24 hours of runoff events, placed in coolers, and transported to the University of Wisconsin-Stevens Point Water and Environmental Analysis Laboratory (UWSP-WEAL). All samples were held at 4°C until analysis by the UWSP-WEAL. Samples were shaken vigorously before discharge-weighted portions of the discrete samples were combined into one composite sample for each runoff event. Dissolved reactive P (DRP) was measured after filtering through a 0.45 µm filter and analyzed using the ascorbic acid colorimetry method as described by Murphy and Riley (1962). Total P (TP) samples were digested with mercuric sulfate prior to colorimetry analysis. Surface and tile event DP and TP loads were determined by multiplying the event DP and TP concentration by the respective event volume. Event loads were aggregated into monthly and annual loads. Monthly and annual P loads were divided by their respective flow volumes, to give monthly and annual flow-weighted (FW) concentrations.

Results and Discussion

Across all sites, both surface and tile drainflow TP and DRP loads were characterized by high inter-annual variability across all sites (Table 1, Table 2). Like annual variability, monthly variability in loading was largely influenced by the volume of water moving through these pathways. Overall, tile drainflow contributed 17 to 41% of cumulative TP loads. Tile contributions to DRP loads were slightly higher and ranged from 16 to 58% of total loads. In 2006 and 2008, annual tile DRP loads at the CP sites exceeded respective annual surface DRP loads.

The highest annual surface FW-TP concentrations were consistently measured at the GP site (Table 3). At all sites, surface FW-TP and FW-DRP concentrations were greater, and demonstrated more inter-annual variability, than tile FW-TP and FW-DRP concentrations (Tables 3 and 4). Average annual tile FW-TP concentrations were 1.2 to 1.8 times greater than average annual tile FW-DRP concentrations. The relative ratio of DRP to TP was lowest at the CP indicating that a greater amount of TP was held in the particulate fraction at the CP sites. The NT site consistently exhibited the lowest tile FW-TP concentrations as well as the greatest disparity between surface and tile FW-TP concentrations. The lowest surface and tile FW-P concentrations at this site were measured in 2007, the year that no manure was applied (Tables 3 and 4).

Surface runoff, with much higher P concentrations than those measured in tile discharge, was the dominant P loss pathway at each site. In NR151, the Wisconsin Department of Natural Resources set an eight-year average maximum delivery limit of P from agricultural fields at 6 lb a^{-1} yr^{-1}, as predicted by the Wisconsin Phosphorus Index. Tile drainage can reduce surface P losses by diverting surface runoff into subsurface pathways; however, on these P-rich soils, it is evident that tile drainage is not a sufficient to remove their risk to neighboring freshwater ecosystems.

Annual tile P loads, although lower than surface loads, were consistently higher than those previously reported in many tile drainage studies. Unfortunate for comparison, many studies that monitored subsurface P losses from tile-drained soils did not measure annual P loads from surface runoff (Grant et al., 1996; Brye et al., 2002; Macrae et al., 2007; Oquist et al., 2007). Field studies that monitored both surface runoff and tile P loads reported lower average annual surface losses than those measured at the Discovery Farm sites. Eastman et al. (2010) reported average annual surface TP loads of 0.50 and 1.35 kg ha^{-1} on two fields with tile drainage that received inorganic P additions. In Illinois, measurements of average annual soluble P surface loads ranged from 0.04 to 0.12 lb ac^{-1} across six fields (Algoazany et al., 2007).

Excessively high STP levels at the Discovery Farm sites likely contributed to the high P loads at these sites. A study that compiled annual P load data from forty studies reported significant positive relations between STP and annual dissolved P (DP), PP, and TP surface runoff loads (Harmel et al., 2006). Measures of STP in column and plot studies have repeatedly been found to correlate with concen-trations of DRP in leachate and annual TP- and DRP-FW (Andraski and Bundy, 2003; Chapman et al., 2003; Maguire and Sims, 2002; Matula, 2009). Tile FW-P concentrations at the Discovery Farm sites were high relative to literature values. Tile TP concentrations repeatedly exceeded 1 mg L^{-1}; this is 10 times the concentration that the USEPA recommends for freshwater streams and lakes (USEPA, 1986). Across all study sites, the percent of tile samples that were greater than 1 mg L^{-1} ranged from 11-55% (CP1: 32/129 (25%); CP2: 13/107 (12%); NT: 10/95 (11%); GP: 42/76 (55%)).

Conclusion

Tile drain P loads contribute considerably to total basin loads and may respond negatively to the practices designed to reduce surface P losses. Minimizing preferential flow transport or controlling tile drainage may be investigated as methods to reduce tile P loading. Once P reaches the tile, tile drains are direct conduits to surface water bodies.

It is clear that extrapolations from studied systems to all tile-drained fields must acknowledge the large degree of variability among drainage systems in eastern Wisconsin. Within farm differences in tile system behavior underscore the unpredictability of tile systems.

Parallels in soil, precipitation, and management led CP1 and CP2 to perform more similarly to each other than to the other sites. Yet even between CP1 and CP2, annual tile contributions to total basin drainage and P load varied extensively. It is possible that the loading behavior of the irregular and randomly-spaced tile systems common in Wisconsin will be more difficult to predict than the parallel grid tile designs present in other artificially-drained regions of the United States.

In the tile drainage study, the GP site highlights the risk of excessive manure application. Phosphorus additions at this site were on the order of five to ten times greater than those at the other study sites. The landowner's decision to till and re-seed this pasture during the study period was partially in response to the high P losses. This management act was an attempt to improve the quality of the pasture, reduce P stratification, and decrease soil and nutrient losses. The actions of this farmer demonstrate the potential for education to prompt behavioral change. After seeing the field monitoring data, the farmer was compelled to take action to reduce the amount of P that his farm was releasing into local waterways. Providing farmers with a report of actual field nutrient losses for a given year is extremely powerful. While widespread monitoring is not practical, but widespread modeling is both practical and possible. The incorporation of tile drainage losses into the WPI, the next step of this research, will enable producers to make decisions based on more complete knowledge of the impacts of their management practices.

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Table 1. Annual total phosphorus loads in tile flow and surface runoff.

	2005		2006		2007		2008		2009	
	Tile	Surface	Tile	Surface	Tile	Surface	Tile	Surface	Tile	Surface
	--- lb ac^{-1} ---									
CP1	1.28	1.49	1.31	2.24	0.41	0.54	1.26	2.00		
CP2	0.21	1.04	1.31	4.06	0.44	1.88	1.37	1.27		
NT			0.44	2.03	0.47	0.94	2.44	6.19		
GP					1.12	3.70	2.35	8.69	0.24	3.87

Table 2. Annual dissolved reactive phosphorus loads in tile flow and surface runoff.

	2005		2006		2007		2008		2009	
	Tile	Surface	Tile	Surface	Tile	Surface	Tile	Surface	Tile	Surface
	--- lb ac^{-1} ---									
CP1	0.70	0.85	0.77	0.37	0.24	0.20	0.72	0.34		
CP2	0.14	0.68	0.56	0.30	0.19	0.78	0.76	0.36		
NT			0.32	1.83	0.43	0.46	1.88	5.23		
GP					0.83	2.96	1.86	7.00	0.12	2.96

Table 3. Annual flow-weighted total phosphorus concentrations in tile flow and surface runoff.

	2005		2006		2007		2008		2009	
	Tile	Surface	Tile	Surface	Tile	Surface	Tile	Surface	Tile	Surface
	--- mg L^{-1} (ppm) --									
CP1	1.76	3.09	0.61	5.38	0.55	1.14	0.60	5.27		
CP2	0.61	1.17	0.54	4.10	0.58	3.25	0.55	2.03		
NT			0.19	5.28	0.08	2.00	0.37	4.45		
GP					0.84	6.32	1.78	6.64	1.34	5.83

Table 4. Annual flow-weighted dissolved reactive phosphorus concentrations in tile flow and surface runoff.

	2005		2006		2007		2008		2009	
	Tile	Surface	Tile	Surface	Tile	Surface	Tile	Surface	Tile	Surface
	--- mg L^{-1} (ppm) --									
CP1	0.85	1.57	0.32	0.79	0.29	0.38	0.30	0.79		
CP2	0.36	0.68	0.21	0.27	0.28	1.23	0.28	0.51		
NT			0.13	4.26	0.06	0.87	0.26	3.36		
GP					0.56	4.53	1.26	4.78	0.56	3.99