Effect of crop type and season on nutrient leaching to tile drainage under a corn-soybean rotation

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Abstract: Subsurface tile drainage is a significant pathway for nitrogen (N) and phosphorus (P) transport from agricultural fields. The objective of this study was to evaluate N and P loss through tile drainage under corn (*Zea mays* L.) and soybean (*Glycine max* L.) production in a corn-soybean rotation typical of agricultural management across the eastern Corn Belt of the US Midwest. Differences in nutrient concentrations and loadings between crop type and between growing (GS) and nongrowing seasons (NGS) were assessed. From 2005 through 2012, discharge and water quality were monitored at three end-of-tile locations that had estimated contributing areas ranging from 7.7 to 14.9 ha (19.0 to 36.8 ac) in a headwater watershed in central Ohio, United States. Nitrate-N (NO_3-N) and dissolved reactive P (DRP) were the primary (>75%) forms ofN and Pin drainage water. DRP concentration and loading was not significantly different between crop types, but differed significantly by season. Mean weekly DRP concentration (0.22 mg L-1 [0.22 ppm]) was greater during the GS, while mean weekly DRP load (0.010 kg ha^{-1} [0.009 lb ac^{-1}]) was greater in the NGS. In comparison, NO3-

N concentration and load was dependent on the interaction between crop type and season, with the greatest NO_3-N concentration (17.l mg L-1) observed during the GS under corn production. Differences in N and P loss to tile drains were attributed to the timing of nutrient application and differences in seasonal discharge. Practices such as cover crops and drainage water management that target nutrient transport in the NGS should be explored as a means to decrease annual N and P loads.Adherence to reconunended 4R nutrient stewardship (right fertilizer source, right rate, right time, and right placement) practices should also help minimize nutrient leaching to tile drains under a corn-soybean rotation.

Key words: agriculture—crop rotation—nutrients—seasonal variability—subsurface drainage—water quality

Artificial drainage through subsurface tile drains is a common water management practice in agricultural areas across the US Midwest and Canada (Skaggs et al. 1994). Without artificial drainage, agricultural production on the poorly drained soils in the north-central region of the United States would not be economically feasible. It is estimated that greater than 37% of agricultural land in the US Midwest benefits from subsurface drainage (Zucker and Brown 1998), although, the extent of tile drainage is likely much greater (Blann et al. 2009). Improved drainage provides for trafficable conditions and an aerated root zone for plant development by preventing prolonged exposure to flooded conditions (Fausey 2005). Research has shown, however, that tile drainage is a significant pathway for nutrient transport from agricultural fields (Sims et al. 1998; Royer et al. 2006), which can lead to negative impacts on water quality in receiving surface waters. Indeed, nitrate-nitrogen (NO_3-N} concentrations in the Mississippi River are generally greatest in tributaries where artificially drained soils dominate the landKape (Burkart and James 1999). Dissolved reactive phosphorus (DRP) transport through tile drainage has also been linked to harmful algal blooms (HABs) in Lake Erie (Ohio Lake Erie Phosphoms Task Force 2010).

Agricultural management practices such as nutrient applications often determine the potential for N and phosphorus (P) leaching to subsurface drainage waters. Jaynes et al. (2001) bserved that NO_3-N concentrations and loads in tile discharge increased as N application rate increased from 67 to 202 kg ha^{-1} (59.8 to 180.3 lb ac^{-1}). Aside from application rate, crop type may have a greater effect on nutrient leaching than any other agricultural production practice (Zhu and Fox 2003). Rooting depths, root densities, water use rates, nutrient requirement characteristics, and nutrient uptake efficiencies vary among crop types (Peterson and Power 1991), which can influence nutrient leaching. According to the National Agricultural Statistics Service (USDA NASS; 2014), approximately 90% of farmed land in the US Midwest is planted in a rotation that includes corn (*Zea mays* L.) and soybean (*Glycine max* L.). Continuous corn production usually leads to greater NO_3-N leaching losses (Kinley et al. 2007) when compared to other crop rotations, but the specific effect of soybean in a crop rotation is still not clear. Some research suggests that corn-soybean rotations decrease NO_3-N leaching compared with continuous corn (Rekha et al. 2011). Others have found that rotating soybeans to corn increased NO_3-N leaching (Klocke et al. 1999). In terms of P, Algoazany et al. (2007) did not find a significant crop effect on total P (TP) leaching; yet, other studies have indicated that crop type significantly affects DRP leaching (Brye et al. 2002; Kinley et al. 2007). Discrepancies between studies are most likely due to differences in fertilizer source, rate, and timing of application, as well as the soil, climate, and drainage system under which the study was conducted. For example, soil, climate, and tile drainage systems vary spatially across a latitudinal gradient as well as a longitudinal gradient.

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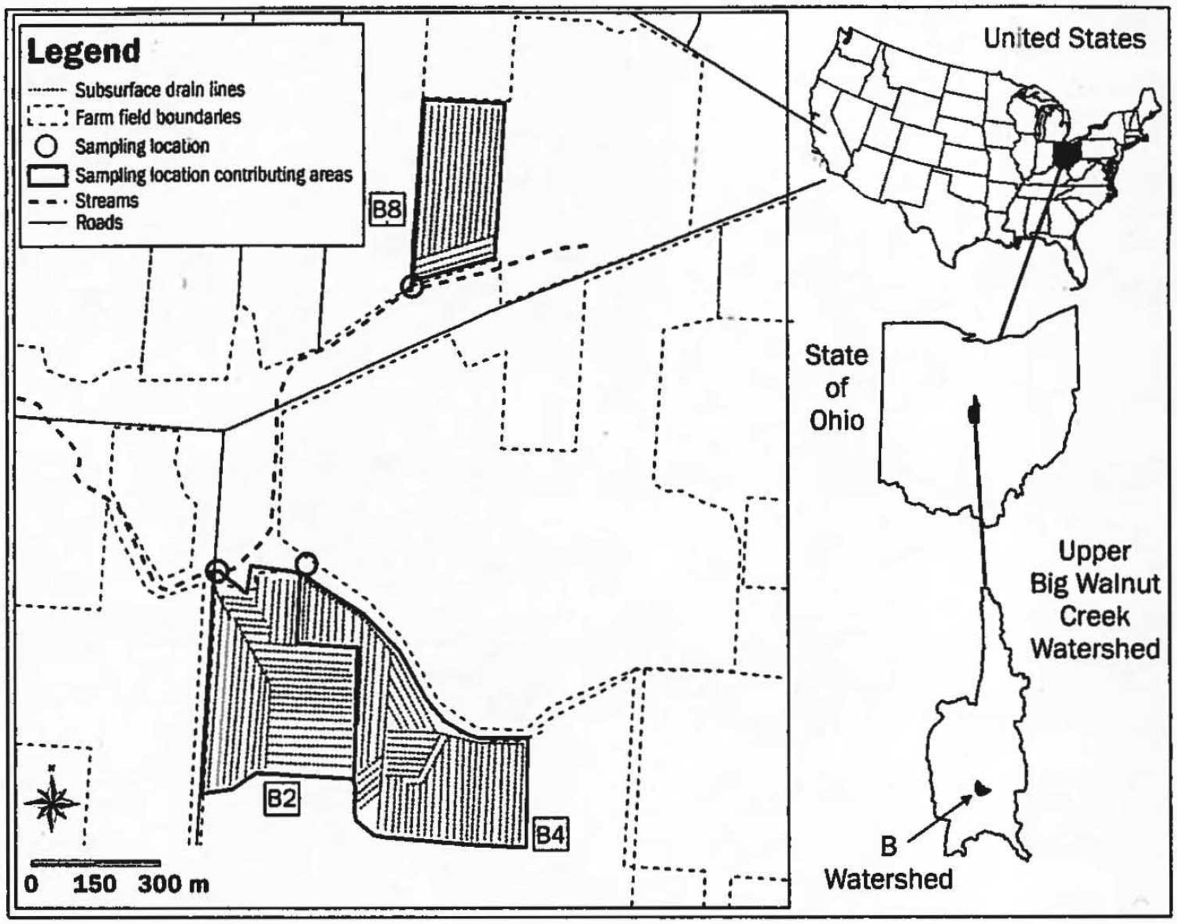
In addition to crop type, seasonal patterns in tile flow can significantly affect nutrient transport in drained landscapes. Tile hydrology is dependent on antecedent soil water conditions (Macrae et al. 2007) and climatic variables including precipitation timing, amount, and intensity (King et al. 2014). Tile discharge in northern latitudes is generally greatest in spring and associated with winter thaw and snow melt (Macrae et al. 2007), whereas in temperate climates tile flow is typically greatest from late fall to early spring due to greater precipitation amounts and lower potential evapotranspiration (Kladivko et al. 2004). Bjorneberg et al. (1996) found that 50% to 85% of annual drain flow and 45% to 85% of annual NO_3-N loads from continuous corn and corn-soybean rotations in Iowa, United States, occurred during the nongrowing season (NGS). Similarly, Macrae et al. (2007) observed seasonal patterns in tile flow and DRP in Ontario, Canada, with the greater P loads occurring during the winter months. Concentrations of N and P in drainage water may also vary seasonally based on land use practices (i.e., amount and tinting of fertilizer application, cropping system), soil properties (i.e., presence of preferential flow paths), and soil biogeochemistry (i.e., soil nutrient concentrations and mineralization/denitrification) (Bjorneberg et al. 1996; Sims et al. 1998).

While several studies report discharge and nutrient transport through tile drainage systems, the temporal resolution and duration of the data is often linlited to a single season or short periods (i.e., a couple of years), and only focus on N or P losses, but not both. Longterm (>5 years) studies conducted on crop production enterprises under prevailing conditions are not widely documented. However, long-term studies are more suited to capturing water quality impacts of production management under varying weather conditions (Jaynes et al. 1999). In this study, we evaluate N and P leaching to tile drains under a corn-soybean management rotation typical of prevailing agricultural management across the US Midwest over an eight-year period (2005 through 2012) to better understand the effects of crop type and seasonal variability on nutrient concentrations and loads. Understanding how crop type and seasonal variability impact nutrient leaching is essential for identifying and developing best management practices to reduce nutrient delivery to surface waters from tile drained landscapes. Specific objectives of this study were to

1. Determine the amount of N and P lost to tile drainage under both corn and soybeans in a corn-soybean crop rotation
2. Quantify seasonal (growing season fGSJ and NGS) tile discharge, nutrient concentrations, and nutrient loads under typical corn and soybean production in a corn-soybean rotation.

Figure 1

Location, contributing area, and tile drainage layout associated with the three study tile outlets near Sunbury, Ohio, United States.



Materials and Methods

Site Description. The study was conducted in the southern portion of the Upper Big Walnut Creek (UDWC) Watershed located in Delaware County, Ohio, United States (figure 1). UBWC is located in the humid continental climatic region of the United States. The climate provides for approximately 160 growing days per year generally lasting from late April to mid-October. Normal daily temperatures for Delaware County, Ohio, range from an average minimum of -9.6°C (14.7°F) in January to an average maximum of 33.9°C (93.0°F) in July (NCDC 2014). Normal rainfall recorded near the southwest point of the watershed was 985 mm (38.8 in; NCDC 2014). Moisture in the form of frozen precipitation or snow averages 500 mm (19.7 in) annually and occurs primarily from December to March (NCDC 2014). For a detailed description of the UBWC Watershed, see King et al. (2008).

From 2005 through 2012, differences in tile drainage discharge, nutrient concentrations, and nutrient loads between crop type (corn and soybeans), and between GS and NGS were assessed from three tile drain outlets located in two different crop production fields on a privately owned farm in Delaware County, Ohio. All fields were managed by a single producer. The estimated drainage area associated with each of the three tile outlets ranged in size from 7 .7 to 14.9 ha (19.0 to 36.8 ac; table 1). The fields from which the tile drainage originated have historically been used for row crop production. Each field was comprised of the somewhat poorly drained Bennington silt loam and the very poorly drained Pewamo clay loam (table 1; USDA NRCS 2014). Tile drainage is a key agricultural land improvement in the watershed and permits crop production on these poorly drained soils. Previous watershed assessments indicate that 47% of the watershed discharge can be accounted for in tile drainage (King et al. 2014).

The drainage area associated with each of the three outlets was determined using a combination of tile drainage plans on record with the Delaware County Ohio Soil and Water Conservation District (DSWCD), the Delaware

County Ohio Auditor's 2010 0.3 m (1 ft) resolution color orthophoto, and on-site visit(with the landowner. When tile drainage plans were available, the installation of the tile drainage as planned was confirmed with the landowner. The 2010 photos were taken briefly after a precipitation event and provided a color contrast between the soil immediately above a tile drain (lighter in color) and the soil between tile drains (darker color). However, even with this three pronged approach, contributing area delineations are difficult to ensure because when new tile systems are installed they may intersect previous tile that drain areas outside the planned area. Additionally, uncertainty in the shallow groundwater and/or presence of seeps may also increase the volume of water drained through the drainage network. Laterals were centered on 15 m (50 ft) spacing and main outlets were approximately 0.9 m (3 ft) deep. The tiles were installed in the early to mid-1970s using both clay (mains) and plastic (laterals).

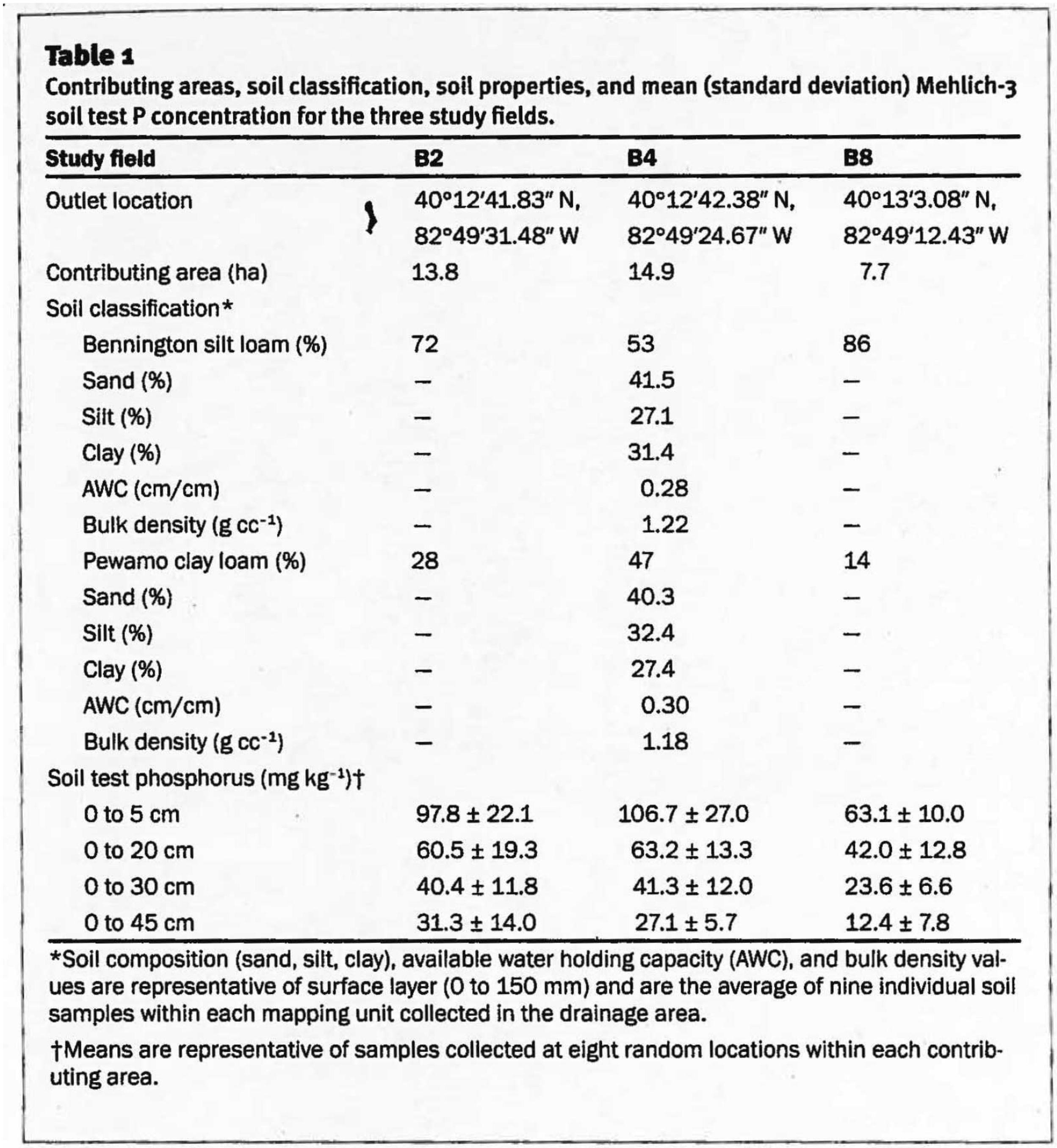


Table 1

Contributing areas, soil classification, soil properties, and mean (standard deviation) Mehlich-3 soil test P concentration for the three study fields.

Study field	B2	B4	B8
Outlet location	40°12′41.83″ N, 82°49′31.48″ W	40°12′42.38″ N, 82°49′24.67″ W	40°13′3.08″ N, 82°49′12.43″ W
Contributing area (ha)	13.8	14.9	7.7
Soil classification*			
Bennington silt loam (%)	72	53	86
Sand (%)	–	41.5	–
Silt (%)	–	27.1	–
Clay (%)	–	31.4	–
AWC (cm/cm)	–	0.28	–
Bulk density (g cc^{-1})	–	1.22	–
Pewamo clay loam (%)	28	47	14
Sand (%)	–	40.3	–
Silt (%)	–	32.4	–
Clay (%)	–	27.4	–
AWC (cm/cm)	–	0.30	–
Bulk density (g cc^{-1})	–	1.18	–
Soil test phosphorus (mg kg^{-1})†			
0 to 5 cm	97.8 ± 22.1	106.7 ± 27.0	63.1 ± 10.0
0 to 20 cm	60.5 ± 19.3	63.2 ± 13.3	42.0 ± 12.8
0 to 30 cm	40.4 ± 11.8	41.3 ± 12.0	23.6 ± 6.6
0 to 45 cm	31.3 ± 14.0	27.1 ± 5.7	12.4 ± 7.8

*Soil composition (sand, silt, clay), available water holding capacity (AWC), and bulk density values are representative of surface layer (0 to 150 mm) and are the average of nine individual soil samples within each mapping unit collected in the drainage area.

†Means are representative of samples collected at eight random locations within each contributing area.

The three tile drainage outlets, designated here as B2, B4, and B8, were associated with two distinct row crop fields and drained a subarea of the larger field. Sites B2 and B4 drained distinct areas from one field, while B8 drained a portion of the second field (figure 1). The fields were generally in a corn-soybean rotation (table 2). However, in 2008 the field associated with outlets B2 and B4 was planted to a second year of soybeans rather than corn, altering the rotation cycle between fields. Soybeans were no-till planted into corn stubble while prior to planting corn, the soil was chisel tilled in the spring. Nutrient management for corn-soybean rotation on the fields in this study generally included a single application of P fertilizer at corn planting time and a split application of N: a portion at planting followed by side-dress N approximately one month later (table 2). No additional fertilizer was applied for the soybean crop. In fall of 2007, a single application of chicken litter was applied to both fields and incorporated. The general fertility approach on these two fields was consistent with tri-state (Ohio, Indiana, and Michigan) nutrient recommendations for corn in the Eastern Cornbelt region (Vitosh et al. 1995). However, tri-state recommendations with respect to soybeans call for nutrient applications to be made during the crop year rather than applying on a two year basis; that is, applying P fertilizer for the soybean crop at the time P is applied to the corn crop. Additionally, the study fields had soil test P concentrations greater than 46 mg L^{-1} Mehlich 3P, which according to the tristate recommendations should not receive additional P inputs because a crop response would not be expected due to adequate plant available P. Soil test P concentrations were variable across fields in the 0 to 5 cm (0 to 2 in) surface layer. Soil P concentrations at the 0 to 20 cm (0 to 8 in) depth were at the upper end or greater than recommended levels for additional P application (table 1), and composite sampling at 30 cm (11.8 in) and 40 cm (15 .7 in) depths suggests that soil test P levels at these greater depths was minimal.

Data Collection. Each tile outlet was instrumented with hydrology and water quality measuring equipment. The original 20 cm (8 in) diameter tile outlets were cut and fitted with a 30 cm (12 in) diameter pipe that could accommodate a weir insert. For the first two years of the study, orifice weir inserts were used as the control volume (Teledyne Isco, Lincoln, Nebraska). At the end of the second year of study, the orifice weirs were replaced with compound weirs (Thel-Mar, LLC, Brevard, North Carolina) to improve accuracy at low flows. Each tile insert was instrumented with a bubbler flow meter (Isco 4230, Teledyne Isco, Lincoln, Nebraska), which was programmed to record water depth behind the insert at 10 minute intervals. To aid in the development of rating curves during periods of pipe submergence, an area velocity sensor (Isco 2150, Teledyne Isco, Lincoln, Nebraska) was also installed in each tile. Discharge for each tile was measured throughout the year and determined as a combination of the standard rating curve for the weir insert and data from the area velocity sensor.

Discharge from each tile outlet was sampledfor water quality using an automated water sampler from March 1 to December 15 each year (Isco 6712, Teledyne Isco, Lincoln, Nebraska). Water samples were collected every six hours and four aliquots were placed in each bottle to comprise a 24 hour sample. Once samples were brought to the laboratory, they were composited on a weekly basis for analysis. In the winter, when sample lines were frozen and automated samplers could not be used (approximately December 16 to February 28), weekly grab samples were collected from each tile outlet. Research quantifying the uncertainty in measured water quality data from tile drain outlets in Ohio, United States, and Ontario, Canada, indicates that collecting weekly grab samples for N yields similar results to weekly composited samples collected with an automatic sampler (Williams et al. 2015). However, the uncertainty associated with weekly grab samples for P is somewhat greater (Williams et al. 2015). The uncertainty associated with different sampling strategies is minimized when continuous discharge data is collected (Birgand et al. 2010), as was the case in the immediate study.

Water Quality Analysis. All water samples were handled according to USEPA (US Environmental Protection Agency) method 353.3 for N analysis and USEPA method 365.1 for P analysis (USEPA 1983). Following collection, samples were stored below 4°C (39°F) and generally analyzed within 28 days. From 2005 through 2009, samples were refrigerated in the field at the time of collection. Starting in 2010, samples were not refrigerated until collected, at least once per week. While in situ or rapid analysis following collection is desired, high costs and remote locations often confound these protocols (Jarvie et al. 2002; Kotlash and Chessman 1998). However, the uncertainty associated with storage at ambient temperatures compared to refrigeration suggests minimal differences in DRP with storage times up to one month for samples with little to no sediment (Griesbach and Peters 1991). Furthermore, internal quality assurance and quality control measures show a 10% to 15% decrease in DRP concentration between refrigerated and nonrefrigerated samples when stored up to 10 days. For N, minimal loss in concentration has been reported for nonpreserved samples when initial concentrations exceed 1 mg L^{-1} (Kotlash and Chessman 1998), which is consistent with samples collected in the immediate study.

Samples were vacuum filtered (0.45 μm) prior to analysis for dissolved nutrients. Nitrate plus nitrite (NO_3 +NO_2-N) and dissolved reactive P (PO_4-P) concentrations were determined colorimetrically by flow injection analysis using a Lachat Instruments QuikChem 8000 FIA Automated Ion Analyzer. The concentration of NO_3+NO_3-N was determined by application of the copperized-cadmium reduction, while $P0_4$-P concentration was determined by the ascorbic acid reduction method (Parsons et al. 1984). Total N (TN) and TP analyses were performed in combination on unfiltered samples following alkaline persulfate oxidation (Koroleff 1983) with subsequent determination of NO_3-N and PO_4-P. From this point forward, NO_3+NO_2-N will be expressed as NO_3-N and $P0_4$-P will be designated as dissolved reactive P (DRP).

Analysis and Statistical Approach. Nitrogen and P loads were calculated by multiplying the analyte concentration by the measured water volume for that respective sample. The volume of water associated with any one sample was determined using the midpoint approach; that is, the temporal midpoint between each sample was determined and the volume of water calculated for that time duration. The analyte concentration was assumed to be representative over the sampling interval.

Tile discharge and water quality data were analyzed on a weekly basis that corresponded to the weekly sampling and composite strategy. Data were also summarized based on the season in which they were collected. The GS was identified as the period associated with planting until harvest, while the NGS included the period from harvest until planting. The NGS crop type was determined by the residue that was present during that period of time. For example, if corn was planted in April and harvested in October, corn would be the designated crop for the following NGS period.

Graphical techniques as well as standard statistical analyses were used to assess the effect of crop type and seasonal variability on nutrient loss through tile drainage. Prior to analysis, weekly discharge and loads were transformed using a log + 1 approach. The "+1" was required to address weeks in which there was zero discharge volume and load. For nutrient concentrations, weeks with zero discharge were removed prior to analysis and the data log transformed. The effects of season (GS versus NGS) and crop type (com versus soybean) on weekly discharge, nutrient concentration and load were evaluated using a generalized linear mixed effects model in R (R Development Core Team 2011). A random effect was included in the model to account for differences in nutrient concentrations and loads among study sites. The AR(1) correlation structure was also included in the model to account for nonindependence due to the potential for temporal autocorrelation of nutrient data (Premrov et al. 2012). Pairwise comparisons were made using Tukey's Range test in order to separate treatment means. A probability level of 0.05 was used to evaluate statistical significance.

Results and Discussion

Precipitation and Tile Flow. Annual precipitation measured at the study sites from 2005 through 2012 was between 773 and 1,239 mm (30.4 and 48.8 in), with 2010 being the driest year and 2011 the wettest year (table 3). The average annual precipitation was 1,003 mm (39.5 in), which was slightly greater than the 30-year average (985 mm [38.8 in]) measured at the southern portion of the UBWC Watershed. From December to March moisture was typically in the form of frozen precipitation or snow. Thunderstorms were common during the late-spring and summer, and produced short duration intense rainfall events. During the study period, February (45.3 mm [1.78 in]) was the driest month and June (121.6 mm [4.78 in]) was the wettest month. However, mean precipitation during the GS and NGS was similar (table 3).

Mean tile drainage discharge from the three study sites was greater in the NGS (198 to 436 mm (7.8 to 17.1 in]) compared to the GS (42 to 104 mm [1.6 to 4.1 in); figure 2; table 3). Estimated annual discharge from individual tile outlets ranged from 241 mm to 539 mm (9.5 to 21.2 in), which Was equivalent to 24% to 54% of the average annual precipitation. Variations in tile drainage discharge between sites B2 and B4 were likely due to differences in soil properties, but significantly greater tile drainage discharge at site B8 compared to sites B2 and B4 was most likely due to errors in contributing area estimation. The volumetric depth of discharge calculated at site B8 was approximately twice that of B2 and B4 and was consistent throughout the study. While a tile plan existed for the site B8, indicating a drainage area of7.7 ha (19 ac), the plan does not account for additional tile drainage that may have inadvertently been intercepted at the time of installation and is contributing to the drainage volume. Another explanation may be the interception of a seep, which would lead to greater discharges, but this is not likely the case because discharge at site B8 was not observed during periods when other tiles were not flowing. In addition, for two years of the study period, the ratio of discharge to precipitation at site B8 during the NGS exceeded one and approached one in other years (table 3). If the contributing area delineation was accurate and there were no seeps or additional sources of water entering the drainage network, discharge expressed as a fraction of precipitation should not approach one during an extended period such as the GS or NGS.

Table 2

Crop production management including operation, nutrient source and rate, and date of operation for the fields associated with tile outlets B2, B4, and B8. Detailed management data was not available from 2009 to 2012; however, based on history, we do not anticipate any differences from past fertility strategies. Planting and harvest dates from 2009 to 2012 were approximated based on weekly observations.

Tile outlet	Year	Date	Operation	Crop/nutrient source*	N rate (kg ha^{-1})	P rate (kg ha^{-1})
B2 and B4						
	2004	May 11	Tillage	—	—	—
		May 13	Planting	Corn	—	—
		May 13	Fertilizer	12-15-20	26.9	14.7
		June 13	Fertilizer	28-0-0	167.3	
		Nov. 13	Harvest	—	—	—
	2005	May 7	Planting	Soybean	—	—
		Oct. 5	Harvest	—	—	—
	2006	Apr. 30	Tillage	—	—	—
		May 1	Planting	Corn	—	—
		May 1	Fertilizer	10-34-0	82.1	48.7
		June 20	Fertilizer	28-0-0	167.3	—
		Oct. 27	Harvest	—	—	—
	2007	May 9	Planting	Soybean	—	—
		Oct. 10	Harvest	—	—	—
		Oct. 16	Fertilizer	Chicken litter	456.1	117.4
		Oct. 17	Tillage	—	—	—
	2008	May 7	Planting	Soybean	—	—
		Oct. 2	Harvest	—	—	—
	2009	May 18	Planting	Corn	NA	NA
		Nov. 2	Harvest	—	—	—
	2010	May 10	Planting	Soybean	—	—
		Oct. 4	Harvest	—	—	—
	2011	June 6	Planting	Corn	NA	NA
		Nov. 11	Harvest	—	—	—
	2012	May 14	Planting	Soybean	—	—
		Oct. 15	Harvest	—	—	—
B8						
	2004	May 11	Tillage	—	—	—
		May 11	Planting	Corn	—	—
		May 11	Fertilizer	12-15-20	26.9	14.7
		June 12	Fertilizer	28-0-0	167.3	—
		Nov. 10	Harvest	—	—	—
	2005	May 7	Planting	Soybean	—	—
		Oct. 5	Harvest	—	—	—
	2006	Apr. 28	Tillage	—	—	—
		Apr. 28	Planting	Corn	—	—
		Apr. 28	Fertilizer	10-34-0	82.1	48.7
		June 17	Fertilizer	28-0-0	167.3	—
		Oct. 25	Harvest	—	—	—
	2007	May 7	Planting	Soybean	—	—
		Oct. 2	Harvest	—	—	—
		Oct. 5	Fertilizer	Chicken litter	456.1	117.4
		Oct. 6	Tillage	—	—	—
	2008	Apr. 21	Tillage	—	—	—
		Apr. 21	Planting	Corn	—	—
		Apr. 21	Fertilizer	28-0-0	33.6	
		Apr. 21	Fertilizer	10-34-0	13.1	19.5
		June 4	Fertilizer	28-0-0	167.3	—
		Sept. 29	Harvest	—	—	—
	2009	May 26	Planting	Soybean	—	—
		Oct. 19	Harvest	—	—	—
	2010	Apr. 30	Planting	Corn	NA	NA
		Oct. 11	Harvest	—	—	—
	2011	June 6	Planting	Soybean	—	—
		Nov. 5	Harvest	—	—	—
	2012	May 12	Planting	Corn	NA	NA
		Nov. 8	Harvest	—	—	—

*Fertilizer listed as nitrogen-phosphorus-potassium (N-P-K).

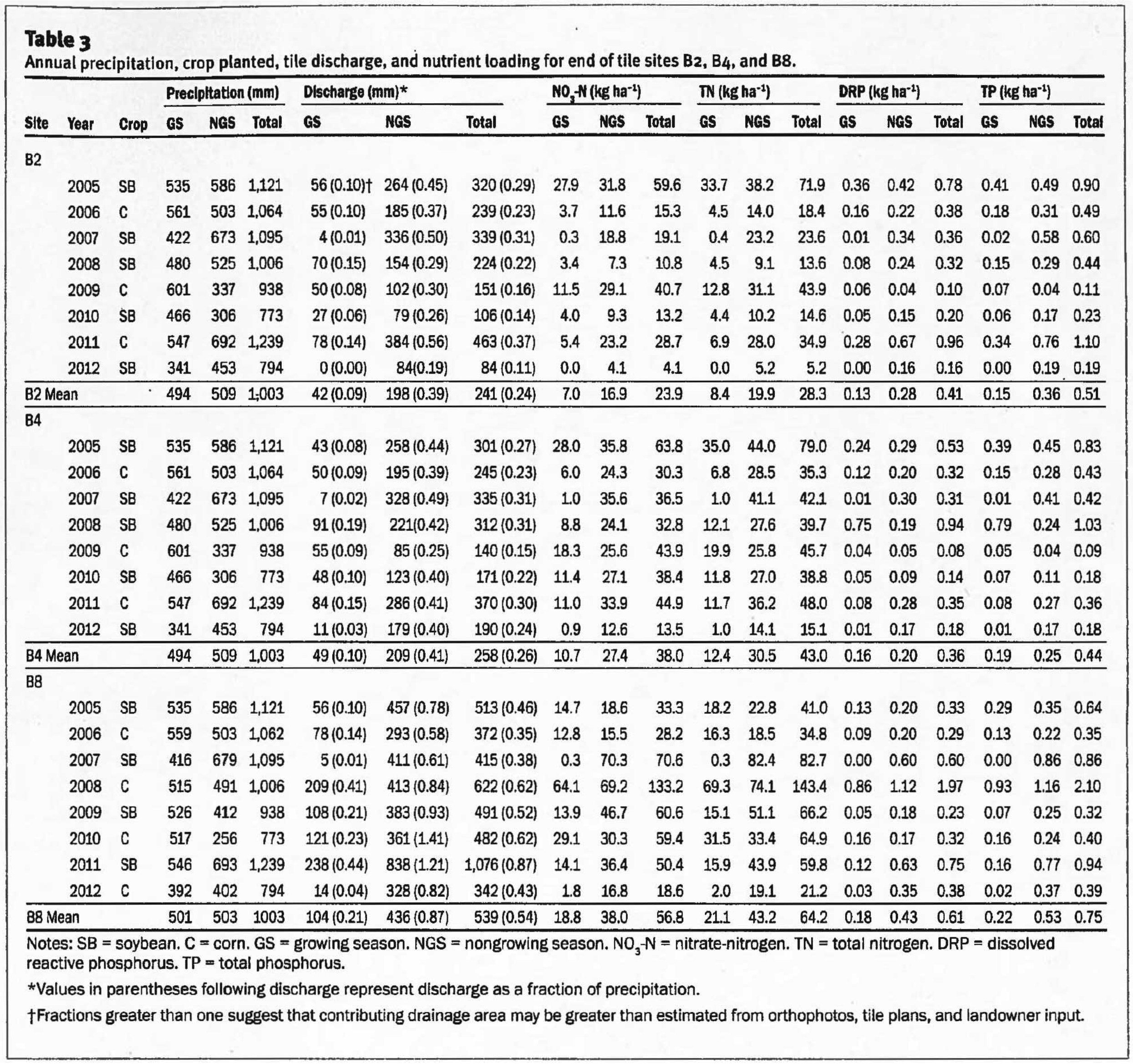


Table 3

Annual precipitation, crop planted, tile discharge, and nutrient loading for end of tile sites B2, B4, and B8.

			Precipitation (mm)			Discharge (mm)*			NO_3-N (kg ha^{-1})			TN (kg ha^{-1})			DRP (kg ha^{-1})			TP (kg ha^{-1})		
Site	Year	Crop	GS	NGS	Total	GS	NGS	Total	GS	NGS	Total	GS	NGS	Total	GS	NGS	Total	GS	NGS	Total
B2																				
	2005	SB	535	586	1,121	56 (0.10)†	264 (0.45)	320 (0.29)	27.9	31.8	59.6	33.7	38.2	71.9	0.36	0.42	0.78	0.41	0.49	0.90
	2006	C	561	503	1,064	55 (0.10)	185 (0.37)	239 (0.23)	3.7	11.6	15.3	4.5	14.0	18.4	0.16	0.22	0.38	0.18	0.31	0.49
	2007	SB	422	673	1,095	4 (0.01)	336 (0.50)	339 (0.31)	0.3	18.8	19.1	0.4	23.2	23.6	0.01	0.34	0.36	0.02	0.58	0.60
	2008	SB	480	525	1,006	70 (0.15)	154 (0.29)	224 (0.22)	3.4	7.3	10.8	4.5	9.1	13.6	0.08	0.24	0.32	0.15	0.29	0.44
	2009	C	601	337	938	50 (0.08)	102 (0.30)	151 (0.16)	11.5	29.1	40.7	12.8	31.1	43.9	0.06	0.04	0.10	0.07	0.04	0.11
	2010	SB	466	306	773	27 (0.06)	79 (0.26)	106 (0.14)	4.0	9.3	13.2	4.4	10.2	14.6	0.05	0.15	0.20	0.06	0.17	0.23
	2011	C	547	692	1,239	78 (0.14)	384 (0.56)	463 (0.37)	5.4	23.2	28.7	6.9	28.0	34.9	0.28	0.67	0.96	0.34	0.76	1.10
	2012	SB	341	453	794	0 (0.00)	84(0.19)	84 (0.11)	0.0	4.1	4.1	0.0	5.2	5.2	0.00	0.16	0.16	0.00	0.19	0.19
B2 Mean			494	509	1;003	42 (0.09)	198 (0.39)	241 (0.24)	7.0	16.9	23.9	8.4	19.9	28.3	0.13	0.28	0.41	0.15	0.36	0.51
B4																				
	2005	SB	535	586	1,121	43 (0.08)	258 (0.44)	301 (0.27)	28.0	35.8	63.8	35.0	44.0	79.0	0.24	0.29	0.53	0.39	0.45	0.83
	2006	C	561	503	1,064	50 (0.09)	195 (0.39)	245 (0.23)	6.0	24.3	30.3	6.8	28.5	35.3	0.12	0.20	0.32	0.15	0.28	0.43
	2007	SB	422	673	1,095	7 (0.02)	328 (0.49)	335 (0.31)	1.0	35.6	36.5	1.0	41.1	42.1	0.01	0.30	0.31	0.01	0.41	0.42
	2008	SB	480	525	1,006	91 (0.19)	221(0.42)	312 (0.31)	8.8	24.1	32.8	12.1	27.6	39.7	0.75	0.19	0.94	0.79	0.24	1.03
	2009	C	601	337	938	55 (0.09)	85 (0.25)	140 (0.15)	18.3	25.6	43.9	19.9	25.8	45.7	0.04	0.05	0.08	0.05	0.04	0.09
	2010	SB	466	306	773	48 (0.10)	123 (0.40)	171 (0.22)	11.4	27.1	38.4	11.8	27.0	38.8	0.05	0.09	0.14	0.07	0.11	0.18
	2011	C	547	692	1,239	84 (0.15)	286 (0.41)	370 (0.30)	11.0	33.9	44.9	11.7	36.2	48.0	0.08	0.28	0.35	0.08	0.27	0.36
	2012	SB	341	453	794	11 (0.03)	179 (0.40)	190 (0.24)	0.9	12.6	13.5	1.0	14.1	15.1	0.01	0.17	0.18	0.01	0.17	0.18
B4 Mean			494	509	1,003	49 (0.10)	209 (0.41)	258 (0.26)	10.7	27.4	38.0	12.4	30.5	43.0	0.16	0.20	0.36	0.19	0.25	0.44
B8																				
	2005	SB	535	586	1,121	56 (0.10)	457 (0.78)	513 (0.46)	14.7	18.6	33.3	18.2	22.8	41.0	0.13	0.20	0.33	0.29	0.35	0.64
	2006	C	559	503	1,062	78 (0.14)	293 (0.58)	372 (0.35)	12.8	15.5	28.2	16.3	18.5	34.8	0.09	0.20	0.29	0.13	0.22	0.35
	2007	SB	416	679	1,095	5 (0.01)	411 (0.61)	415 (0.38)	0.3	70.3	70.6	0.3	82.4	82.7	0.00	0.60	0.60	0.00	0.86	0.86
	2008	C	515	491	1,006	209 (0.41)	413 (0.84)	622 (0.62)	64.1	69.2	133.2	69.3	74.1	143.4	0.86	1.12	1.97	0.93	1.16	2.10
	2009	SB	526	412	938	108 (0.21)	383 (0.93)	491 (0.52)	13.9	46.7	60.6	15.1	51.1	66.2	0.05	0.18	0.23	0.07	0.25	0.32
	2010	C	517	256	773	121 (0.23)	361 (1.41)	482 (0.62)	29.1	30.3	59.4	31.5	33.4	64.9	0.16	0.17	0.32	0.16	0.24	0.40
	2011	SB	546	693	1,239	238 (0.44)	838 (1.21)	1,076 (0.87)	14.1	36.4	50.4	15.9	43.9	59.8	0.12	0.63	0.75	0.16	0.77	0.94
	2012	C	392	402	794	14 (0.04)	328 (0.82)	342 (0.43)	1.8	16.8	18.6	2.0	19.1	21.2	0.03	0.35	0.38	0.02	0.37	0.39
B8 Mean			501	503	1003	104 (0.21)	436 (0.87)	539 (0.54)	18.8	38.0	56.8	21.1	43.2	64.2	0.18	0.43	0.61	0.22	0.53	0.75

Notes: SB = soybean. C = corn. GS = growing season. NGS = nongrowing season. NO_3-N = nitrate-nitrogen. TN = total nitrogen. DRP = dissolved reactive phosphorus. TP = total phosphorus.

*Values in parentheses following discharge represent discharge as a fraction of precipitation.

†Fractions greater than one suggest that contributing drainage area may be greater than estimated from orthophotos, tile plans, and landowner input.

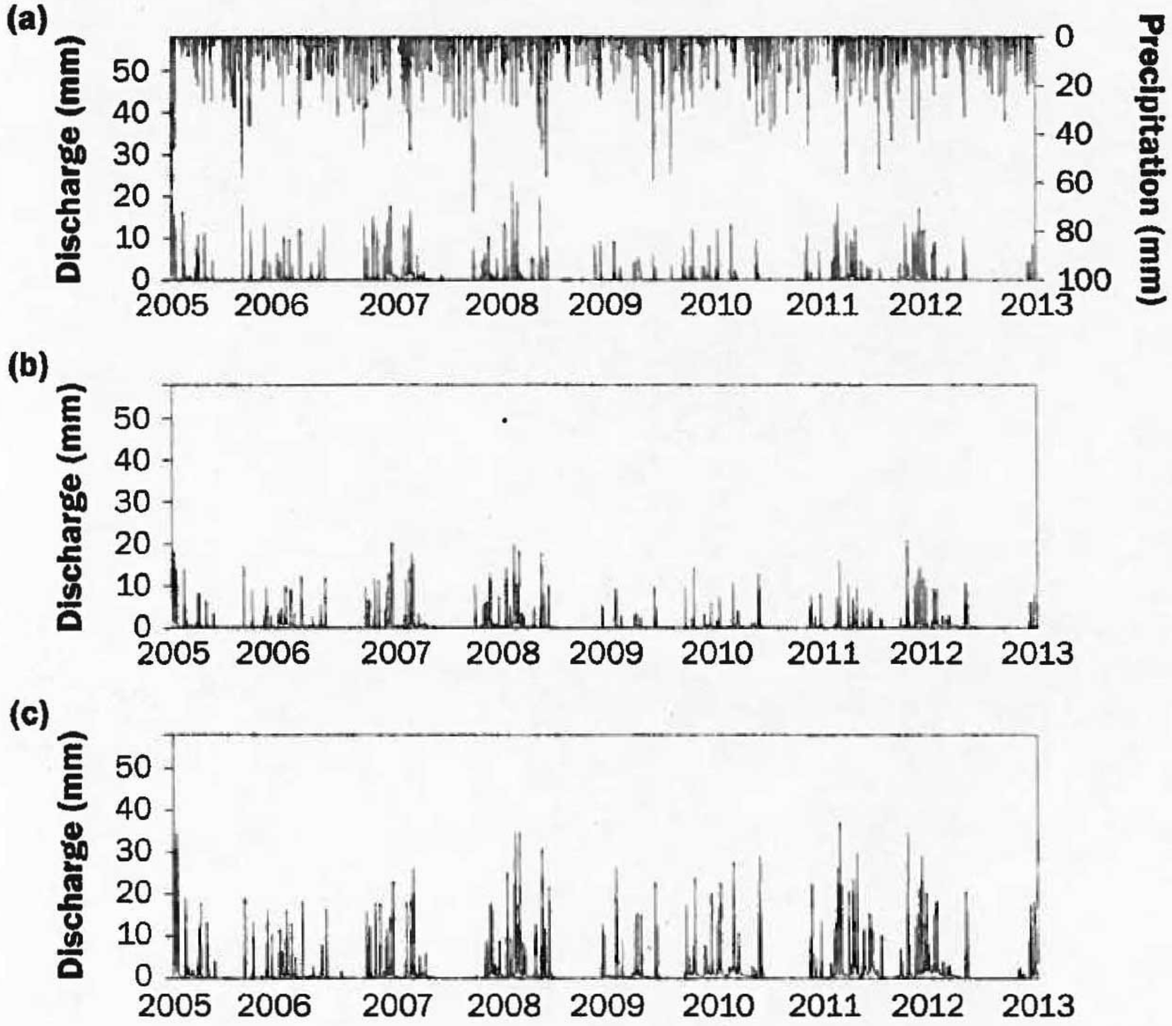
Using existing tile plans to delineate drainage areas indicated that tile discharge across study sites accounted for 34% of the annual precipitation over the eight year study. Annual rainfall recovery from individual tiles, however, ranged from 11 % to 87% (table 3). Similar results for individual tile drains have been observed in several other tile drainage studies. Over a seven year period in Illinois, 13% to 19% of precipitation was recovered in tile drains from four different corn-soybean production fields with a mixture of silty loam and silty clay loam soils (Algoazany et al. 2007). Similarly, Logan et al. (1980) monitored several tile drains in crop production fields across the Midwest. They found that annual tile discharge expressed as a fraction of rainfall was 13%, 17%, and 26% in Iowa, Minnesota, and Ohio, respectively.

There was a minimal yet significant (*p* = 0.021) effect of crop type on discharge amount with discharge volumes being greater under corn than soybeans (table 4). Since corn and soybean consume similar amounts of water for their growth (Hattendorf et al. 1988; Copeland et al. 1993) it follows that minimal differences in tile flow between corn and soybean years should be observed. Small differences in tile discharge between corn and soybean years have also been reported in Iowa by Kanwar et al. (1997) and in Ohio by Owens et al. (2000). Kladivko et al. (2004) also found that changing a continuous corn rotation to a corn-soybean rotation in Indiana had little effect on tile discharge. In contrast; leachate volumes may vary between corn-soybean rotations and other cropping systems, such as perennial crops (Brye et al. 2002).

Similarly, there was a significant (*p* = 0.001) effect of season on weekly discharge (table 4). On average, 81½, of tile discharge from the three study sites occurred in the NGS, while only 19% occurred in the GS (table 3). On loam plots in Iowa under corn-soybean and continuom corn production, Bjorneberg et al. (1996) reported for a three year period that 50% to 85% of the tile drainage discharge occurred in the NGS. Similarly, Macrae et al. (2007) measured dischargefrom a single agricultural tile in the Strawberry Creek Watershed in southern Ontario and indicated that the majority of discharge occurred during periods when crops were not growing. Intra-annual variability in tile discharge has been shown to be dependent on antecedent conditions, precipitation characteristics, and evapotranspiration (Macrae et al. 2007; King et al. 2014). Tile drains tend to respond rapidly to precipitation events during the NGS (Macrae et al. 2007), and discharge is limited by soil properties and the hydraulic capacity of the tile system (Dolezal et al. 2001). In comparison, tile drains often cease to flow for extended periods of time during the GS, as crop water uptake and potential evapotranspiration often exceed precipitation. Differences in precipitation characteristics, such as duration and intensity, between the GS and NGS can also significantly influence tile hydrology.

Figure 2

Daily time series (2005 through 2012) of precipitation and discharge for tile drainage outlet sites (a) B2, (b) B4, and (c) B8.



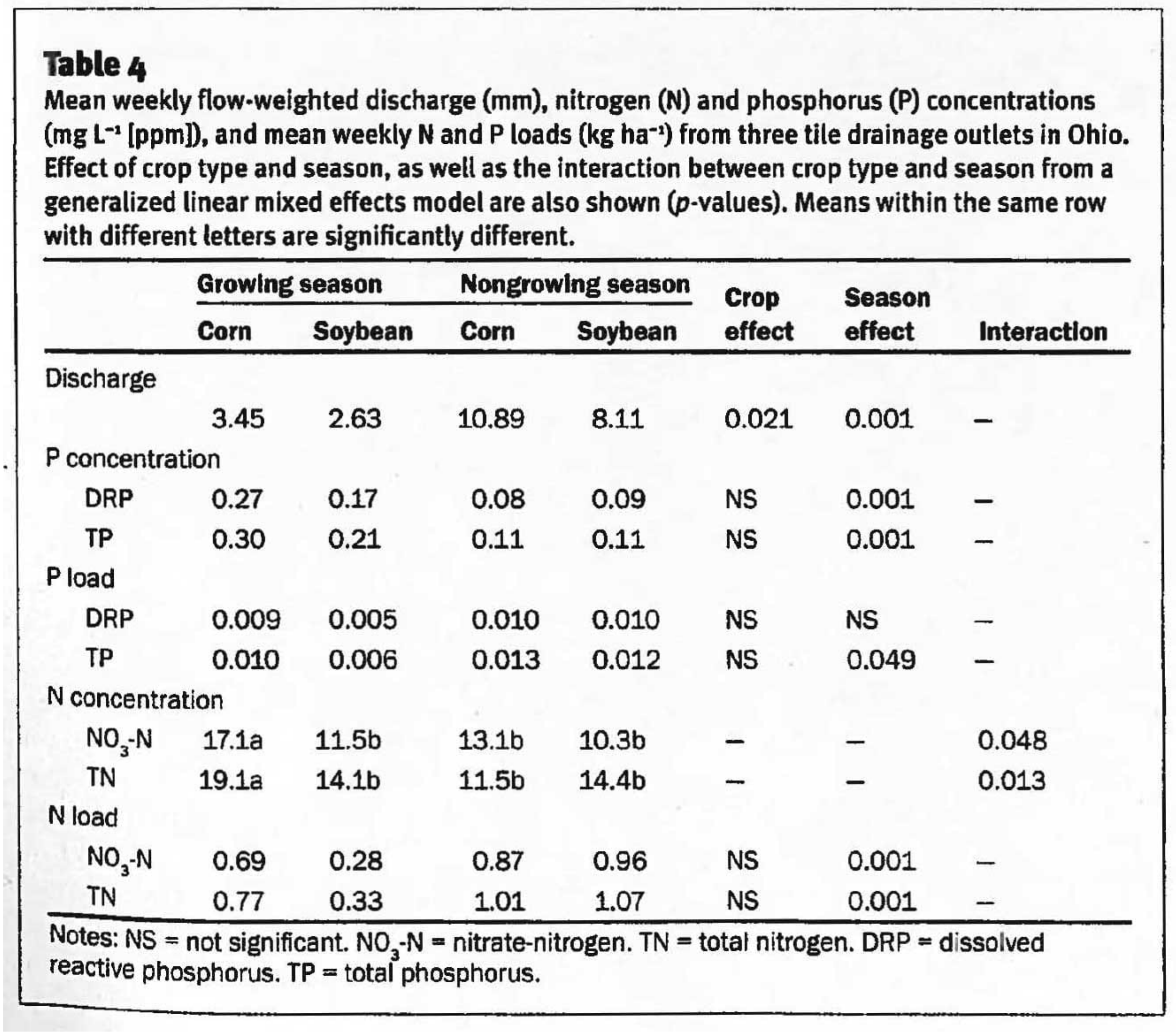


Table 4

Mean weekly flow-weighted discharge (mm), nitrogen (N) and phosphorus (P) concentrations (mg L^{-1} [ppm]), and mean weekly N and P loads (kg ha^{-1}) from three tile drainage outlets in Ohio. Effect of crop type and season, as well as the interaction between crop type and season from a generalized linear mixed effects model are also shown (*p*-values). Means within the same row with different letters are significantly different.

	Growing season		Nongrowing season		Crop effect	Season effect	Interaction
	Corn	Soybean	Corn	Soybean			
Discharge							
	3.45	2.63	10.89	8.11	0.021	0.001	–
P concentration							
DRP	0.27	0.17	0.08	0.09	NS	0.001	–
TP	0.30	0.21	0.11	0.11	NS	0.001	–
P load							
DRP	0.009	0.005	0.010	0.010	NS	NS	–
TP	0.010	0.006	0.013	0.012	NS	0.049	–
N concentration							
NO_3-N	17.1a	11.5b	13.1b	10.3b	–	–	0.048
TN	19.1a	14.1b	11.5b	14.4b	–	–	0.013
N load							
NO_3-N	0.69	0.28	0.87	0.96	NS	0.001	–
TN	0.77	0.33	1.01	1.07	NS	0.001	–

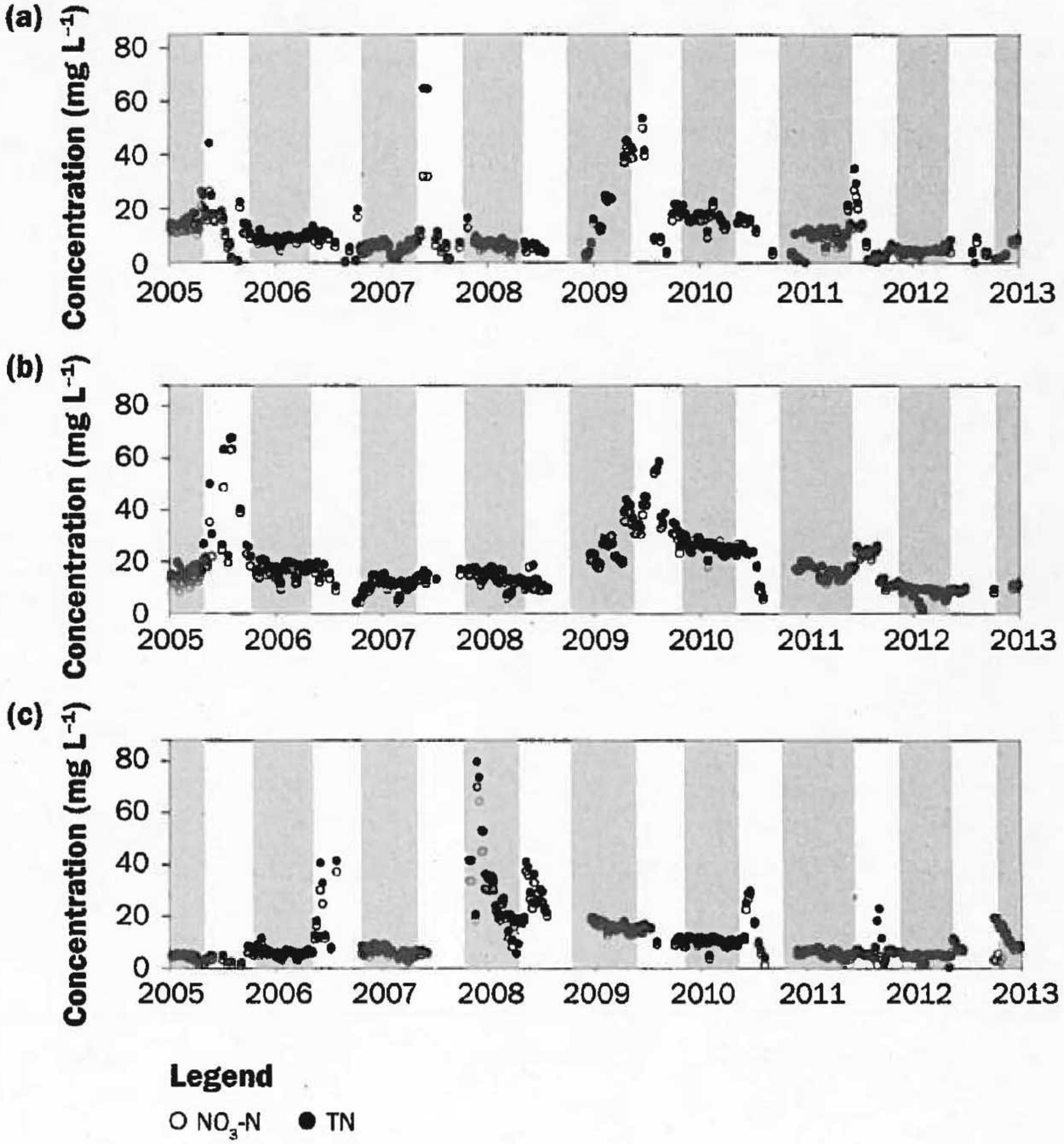
Notes: NS = not significant. NO_3-N = nitrate-nitrogen. TN = total nitrogen. DRP = dissolved reactive phosphorus. TP = total phosphorus.

Nitrogen Concentration and Load. Tile drainage N concentrations varied considerably throughout the study period and tended to be greater in the GS compared to the NGS (figure 3). Measured NO_3-N concentrations ranged from 0.1 to 70.7 mg L^{-1}, while TN concentrations ranged from 0.1 to 80.5 mg L^{-1} (figure 3). Mean weekly NO_3-N concentration was generally greater at site B4 (17.3 mg L^{-1}) compared to sites B2 (9.7 mg L^{-1}) and B8 (10.3 mg L^{-1}). Nitrate-N accounted for approximately 90% of TN across all sites, with mean annual flow-weighted concentrations of 12.5 and 14.1 mg L^{-1} for NO_3-N and TN, respectively. For both NO_3-N and TN concentration, a significant interaction effect was observed between crop type and season (table 4). Pairwise comparisons indicate that mean weekly NO_3-N and TN concentration for corn during the GS was significantly greater than all other combinations of crop and season (table 4). Mean weekly NO_3-N and TN concentrations for corn during the GS were 17.1 and 19.1 mg L^{-1}, respectively (table 4).

Elevated NO_3-N concentrations in drainage water from fields planted with corn and soybean are common and often exceed the USEPA drinking water standard (10 mg L^{-1}). For example, annual flow-weighted NO_3-N concentrations of 15.2 mg L^{-1} were observed in tile drainage water over a 42 year period under continuous corn grown on a clay loam soil in Ontario, Canada (Tan et al. 2002). Under corn-soybean rotations in Illinois, Kalita et al. (2006) measured NO_3-N concentrations over a 10 year period from four different random tiled fields with mixtures of silty day loams and silt loams and found NO_3-N concentrations ranging from 15 to 20 mg L^{-1} Similarly, over a three year period in Illinois, Gentry et al. (1998) found NO_3-N concentrations between 8 and 14 mg L^{-1} in tile drainage from a silty clay loam soil in a corn-soybean rotation. Many of these studies have observed NO_3-N concentrations in drainage water that increased following fertilizer application prior to corn planting, similar to the increases found during the GS in the current study. The differences in NO_3-N leaching to tile drains that were observed between corn and soybean years in the present study and elsewhere may depend on the N application rate applied to corn. Zhu and Fox (2003) found that at N application rates to corn less than 100 kg ha-1 (89.3 lb ac^{-1}), annual flow weighted NO_3-N concentrations in leachate were greater for soybean compared to corn, but at rates greater than 200 kg ha^{-1} (178.6 lb ac^{-1}), there was no difference in annual NO_3-N concentration between corn and soybean. In the current study, N application rates to corn estimated at 170 kg ha^{-1} (151.8 lb ac^{-1}) resulted in NO_3-N concentrations that typically increased dfter planting under corn but decreased to prcapplication levels over the remainder of the GS. After the initial flush of excess NO,-N during the GS for corn, N fixation by soybeans, soil N mineralization, and similar tile flows likely resulted in annual NO_3-N concentrations in drainage water that were not different between corn and soybean. The only significant increase in N concentrations outside the GS occurred following a single application of chicken litter in fall of 2007. However, the significant increases were only detected at the B8 site. Thus, the potential for elevated NO_3-N concentrations in drainage water under a corn-soybean rotation is generally greatest during the GS for corn compared to all other crop and season combinations.

Figure 3

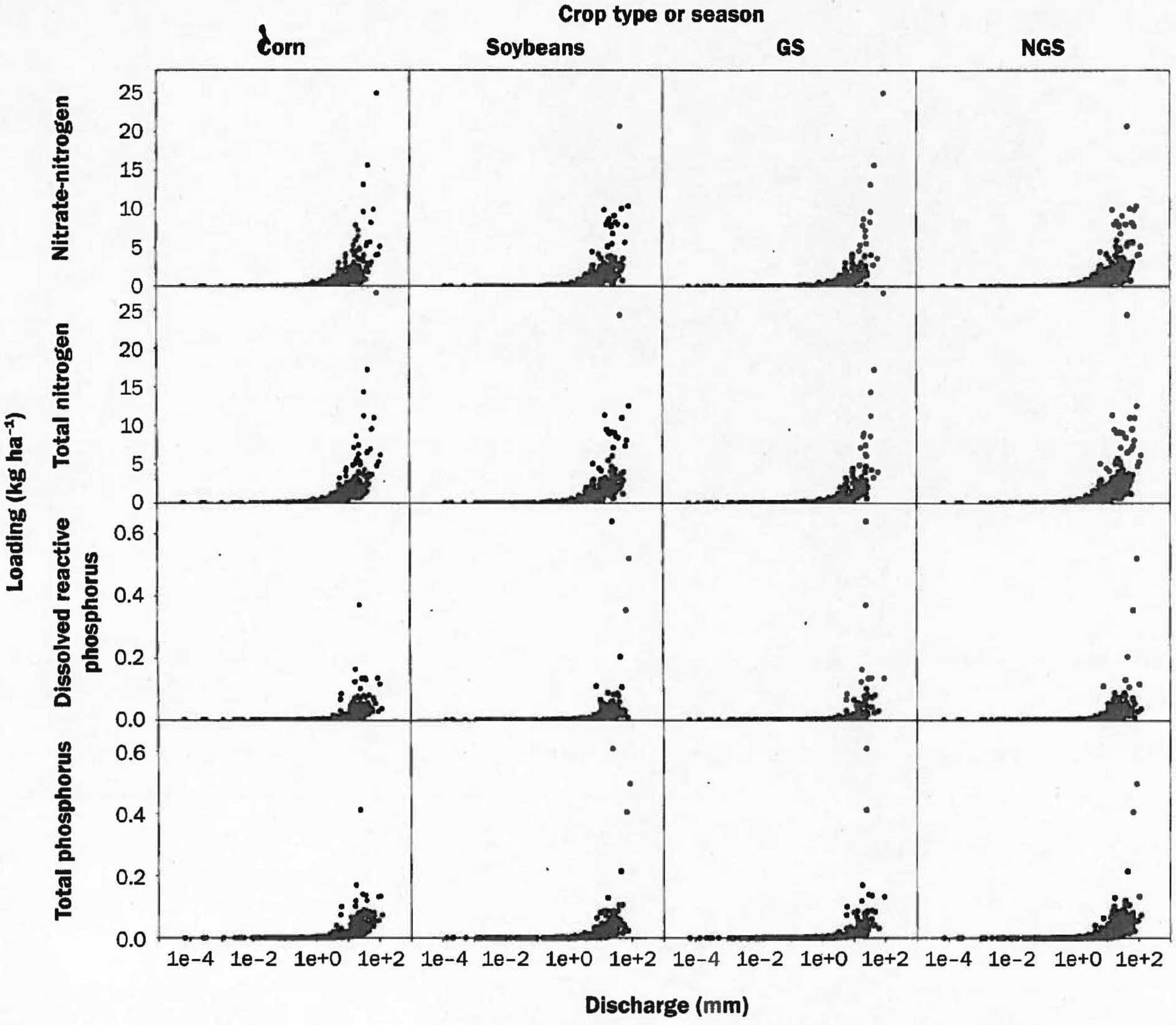
Weekly time series (2005 through 2012) of nitrate-nitrogen (NO_3-N) and total N (TN) concentration collected at tile outlet sites (a) B2, (b) B4, and (c) B8. Shaded areas represent the nongrowing season (NGS), while unshaded areas represent the growing season (GS).



Annual NO_3-N loads from individual tile sites ranged from 4 kg ha^{-1} to 133 kg ha^{-1} (3.5 to 118.7 lb ac^{-1}), while annual TN loads ranged from 5.2 kg ha^{-1} to 143 kg ha^{-1} (4.6 to 127.6 lb ac^{-1}; table 3). Mean annual NO_3-N loads from the three sites ranged from 24 kg ha^{-1} to 57 kg ha^{-1} (21.4 to 50.9 lb ac^{-1}) and TN loads ranged from 28 kg ha^{-1} to 64 kg ha^{-1} (25 to 57 lb ac^{-1}; table 3). The NO$_3$-N loads of the immediate study were comparable to the 38 kg ha^{-1} to 64 kg ha^{-1} (33.9 to 57 lb ac^{-1}) loads reported from three tile drainage outlet from fields in Illinois under a corn-soybean rotation (Gentry et al. 1998). For both NO$_3$-N and TN, the NGS loading was more than twice the loading in the GS (table 3). Additionally, the relationship between discharge volume and loading indicates that NO$_3$-N and TN loads were greater with greater discharge volumes as would be expected (figure 4). Across sites, weekly NO$_3$-N loads were between O and 25.0 kg ha^{-1} (0 and 22.3 lb ac^{-1}), while weekly TN loads ranged from 0 to 27.0 kg ha^{-1} (0 to 24.1 lb ac^{-1}). On average, weekly NO$_3$-N loads were 0.4 (B2), 0.7 (B4), and 1.0 (BS) kg ha^{-1} (0.35 (B2], 0.6 [B4], and 0.89 [BB] lb ac^{-1}), while TN loads were 0.5, 0.8, and 1.2 kg ha^{-1} (0.4, 0.7, and 1 lb ac^{-1}) for sites B2, B4, and BS, respectively. Weekly NO$_3$-N load was significantly affected by the interaction between crop type and season (table 4). Pairwise comparisons indicate that mean weekly NO$_3$-N load for soybean during the GS was significantly less than all other combinations of crop and season (table 4). Mean weekly NO$_3$-N load for soybean during the GS was 0.28 k.g ha^{-1} (0.25 lb ac^{-1}), whereas all other combinations of crop and season were between 0.69 and 0.96 kg ha^{-1} (0.61 and 0.86 lb ac^{-1}). In comparison, weekly TN load was not significantly different between corn and soybean years, but significant seasonal differences were observed (table 4). Weekly TN loads of 0.53 kg ha^{-1} (0.47 lb ac^{-1}) and 1.04 kg ha^{-1} (0.92 lb ac^{-1}) were observed in the GS and NGS, respectively, and were most likely a result of increased discharge in the NGS.

Figure 4

Combined (B2, B4, and B8) scatterplot of weekly nutrient loads versus cumulative weekly discharge by crop type (corn or soybeans) and season (growing [GS] or nongrowing [NGS]) for period of study 2005 through 2012.



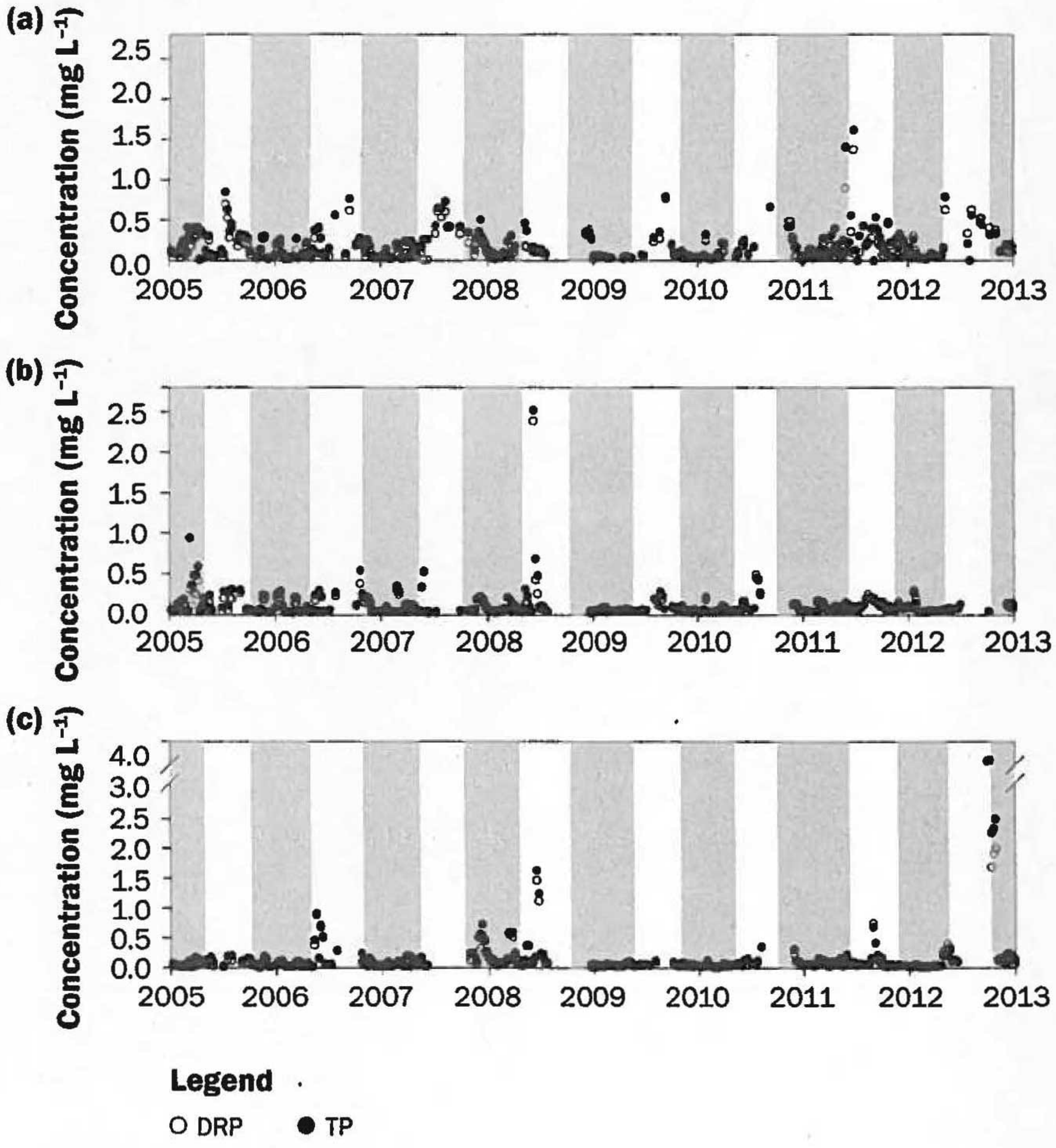
Greater NO_3-N and TN loads often occur in the NGS compared to the GS due to increased tile flow volumes. Indeed, Bjorneberg et al. (1996) reported over a three year period in Iowa that up to 85% of annual tile flow and NO_3-N loads from a corn-soybean and continuous corn rotation on loam soils occurred during the NGS. Approximately 66% of annual NO_3-N loading in the current study was during the NGS; however, loads were not different for corn and soybeans due to similarities in NO_3-N concentrations and despite a significant difference in discharge with respect to crop (table 4). In contrast, NO_3-N loads during the GS were significantly greater for corn compared to soybeans due to higher NO_3-N concentrations for corn as well as greater discharge (table 4). Weekly, NO_3-N loads for corn during the GS were not significantly different from NO_3-N loads for either corn or soybean in the NGS (table 4). These results suggest that seasonal differences in tile discharge determine the magnitude of NO_3-N loads for fields planted with soybean. However, increased NO_3-N concentrations following N application to corn counterbalances the seasonal differences in discharge and, as a result, NO_3-N loads for corn are similar throughout the year. Overall, the mean annual NO_3-N loads observed in the current study under a corn-soybean rotation were comparable to NO_3-N loads under similar rotations reported in Illinois and Indiana (Gentry et al. 1998; Kladivko et al. 2004).

Phosphonus Concentration and Load. Phosphorus concentrations in tile discharge were variable throughout the study period (figure 5). Measured DRP concentrations ranged from 0.01 to 4.64 mg L^{-1}, while TP concentrations ranged from 0.01 to 5.48 mg L^{-1}. Mean weekly flow-weighted DRP concentration was similar among study sites (0.09 to 0.16 mg L^{-1}) and comprised, on average, 86% of the TP in drainage water. Mean weekly flow-weighted DRP and TP concentrations were not significantly different between corn and soybean years (table 4). However, significant differences in DRP and TP concentrations were observed between the GS and NGS (table 4). Mean weekly DRP concentration in the GS under corn (0.27 mg L^{-1}) was approximately three times greater than NGS concentration (0.08 mg L^{-1}; table 4). For soybeans, the GS concentration of DRP was two times greater compared to the NGS (table 4). Similarly, mean weekly TP concentration tmder com was significantly greater in the GS (0.30 mg L^{-1}) compared to mean weekly TP concentration in the NGS(0.11 mg L^{-1}; table 4). The GS concentration ofDRP for soybeans (0.21 mg L^{-1}) was approximately twice that measured during the NGS (0.11 mg L^{-1}; table 4).

Across sites, mean weekly DRP load in drainage water was 0.008 kg ha^{-1} (0.007 lb ac^{-1}), while the average weekly TP load was 0.01 kg ha^{-1} (0.008 lb ac^{-1}). Regardless of crop or season, DRP and TP loads increased with increasing discharge (figure 5). Annual DRP loads between 0.08 and 1.97 kg ha^{-1} (0.07 and 1.7 lb ac^{-1}) were observed, with site B8 having a greater average annual DRP load (0.61 kg ha^{-1} [0.54 lb ac^{-1}]) compared to sites B2 (0.41 kg ha^{-1} [0.36 lb ac^{-1}]) and B4 (0.36 kg ha^{-1} [0.32 lb ac^{-1}; table 3). The greater loading at B8 was attributed to the uncertainty in contributing drainage area delineation. Mean annual DRP load in tile discharge across sites and crop types was 0.46 kg ha^{-1} (0.41 lb ac^{-1}) , and mean annual TP load averaged 0.57 kg ha^{-1} (0.5 lb ac^{-1}). No significant differences were found for DRP or TP loading between corn and soybean years (table 4). Significant seasonal differences in tile loads were detected for TP, but not DRP (table 4). In contrast to P concentrations, DRP and TP loads were greater during the NGS compared to loads during the GS. Mean weekly end-of-tile DRP load during the NGS (0.010 kg ha^{-1} [0.009 lb ac^{-1}) tended to be greater than (p = 0.096) DRP load in the GS (0.007 kg ha^{-1} [0.006 lb ac^{-1}]; table 4). Mean weekly TP load in the GS was significantly less (0.008 kg ha^{-1} [0.007 lb ac^{-1}]) than TP load in the NGS (0.013 kg ha^{-1} [0.011 lb ac^{-1}]; table 4).

Figure 5

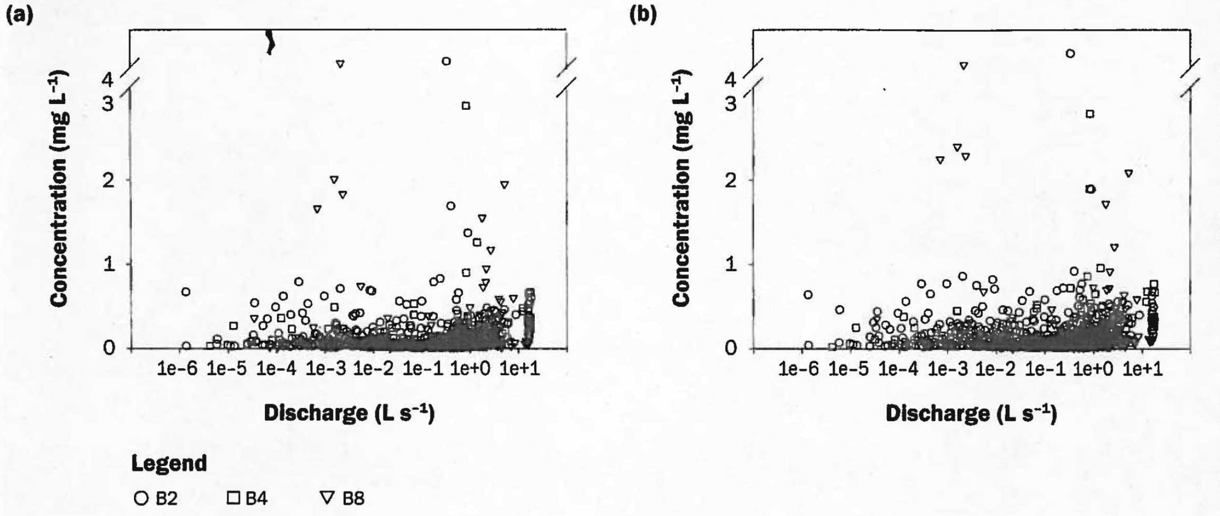
Weekly time series (2005 through 2012) of dissolved reactive phosphorus (DRP) and total P (TP) concentration collected at tile outlet sites (a) B2, (b) B4, and (c) B8. Shaded areas represent the nongrowing season (NGS), while unshaded areas represent the growing (GS). Refer to table 2 for specific cropping information.



Results from this study suggest that P concentrations and loads in tile discharge were not different between corn and soybean years. In contrast, Algoazany et al. (2007) reported a significant crop (soybean or corn) effect on DRP concentrations in tile drainage discharge from four different fields over a seven-year period. Similarly, Bottcher et al. (1981) found that P loads from corn were nearly three times greater compared to P loads for soybean. Their study was conducted in back to back years on a 17 ha (42 ac) field with a silty clay soil. Previous research has indicated that P concentrations and loads in drainage water vary between crops in a rotation when one of the crops requires greater P inputs (Pierzynski and Logan 1993). For instance, Kimmell et al. (2001) found that P loads were generally lower for soybean compared with grain sorghum (*Sorghum bicolor* L.) because P was only applied to the sorghum. However, splitting P application between two years of a rotation (i.e., both corn and soybean) has been shown not to have an effect on DRP concentration in drainage water compared to a single application (i.e., corn only; Algoazany et al. 2007). Kinley et al. (2007) further suggests that fields receiving swine manure or poultry litter generally have greater soil test P concentrations, which results in consistently higher P concentrations and loads in drainage water regardless of the crop that is planted. Thus, high soil test P concentration may negate any differences in P concentrations and loads in tile drainage that would potentially be observed between crop types or rotations if soil test P concentrations were at agronomic levels. In the immediate study, soil test P concentrations were at or slightly greater than the recommended agronomic levels of 46 ppm Mehlich III P (Vitosh et al. 1995). Site B8 had the lowest soil test P value, but the greatest load, again suggesting that drainage area estimates might be errant. Additionally, a single application of chicken litter in fall of 2007 did not significantly affect DRP and TP concentrations across sites (figure 5).

Figure 6

Relationship between mean discharge and concentration for (a) dissolved reactive phosphorus (DRP) and (b) total P (TP) at sites B2, B4, and B8 during the study period 2005 through 2012.



Seasonal differences in DRP and TP concentration have been reported in previous research. Dils and Heathwaite (1999) in the United Kingdom (UK) and Gelbrecht et al. (2005) in Germany both found greater DRP concentrations in the GS compared to the NGS. Similar to the current study, both of these studies found that fertilizer application to corn in the spring increased P concentrations in the GS relative to the NGS. Increases in P concentration during the GS, for both corn and soybean, have also been attributed to the connectivity between surface soils, which typically have high soil test P concentrations and tile drains. Preferential flow paths resulting from either fissures and cracking of the soil due to desiccation (Peron et al. 2009) or biological activity, such as root channels or earthworms (Nielsen et al. 2010), can provide a direct connection between surface soils and tile drains. Fine textured soils found at the three study sites in the current study (Pewamo and Bennington series) and in fields across the US Midwest and Canada are more prone to cracking compared to coarse textured soils due to the high clay content. On similar soils in Indiana, Vidon and Cuadra (2011) found that DRP and TP transport to tile drains during spring storm events was primarily regulated by preferential flow. Evidence of fast flow or preferential flow processes in the immediate study are evidenced by the relationship between discharge rate and concentration; greater concentrations with greater discharge rates suggest preferential flow (Gentry et al. 2007; figure 6).

Dissolved reactive P and TP loads in drainage water observed from the three tile drain outlets in the present study were comparable to tile drains in the Big Ditch Watershed in Illinois, United States (Gentry et al. 2007). In Sweden, Djodjic et al. (2004) also measured annual TP loads ranging from 0.4 to 0.8 kg ha^{-1} (0.35 to 0.71 lb ac^{-1}). Despite TP concentrations in the NGS that were approximately half of the TP concentrations measured in the GS, TP loading in the current study was significantly greater in the NGS. This approximate 1.5 times increase in TP load during the NGS compared to the GS can be attributed to differences in seasonal tile discharge. The magnitude of tile drainage discharge measured at this site during the NGS was approximately 3 times greater than the GS. A similar relationship between P loading and tile discharge has been reported across the US Midwest (Kladivko et al. 2004), Canada (Macrae et al. 2007), and the United Kingdom (Dils and Heatl1waite 1999).

Summary and Conclusions

A better understanding of nutrient leaching to tile drains with respect to both crop type (corn versus soybeans) and season (GS versus NGS) is important for the development and identification of conservation practices that address the adverse water quality impacts associated with offiite nutrient transport. Using a long-term field scale approach on privately owned lands provides a unique water quality assessment of prevailing practices under varying climatic conditions. This approach also points out the difficulty and uncertainty related to field scale assessments, particularly the contributing area delineations of tile drained networks. The results of the current study provide insight into the timing and extent of N and P leaching to tile drain systems under a corn-soybean rotation typical of prevailing agricultural management across the eastern corn belt of the US Midwest. Seasonal differences in both N and P concentrations and loads were more important than crop differences. In the GS, larger N and P concentrations in tile drainage discharge were generally detected following fertilizer application. Significantly greater discharge as well as N and P loads were measured during the NGS compared to the GS. Greater loads in the NGS were attributed to differences in discharge between seasons. Thus, practices that target the NGS should have a positive impact on reducing nutrient delivery. Based on these findings it is recommended that further studies investigate cover crops (Strock et al. 2004), drainage water management (Skaggs et al. 2012), and 4R (right rate, right time, right source, right place) nutrient management (Bruulsema et al. 2012) as possible strategies to reduce N and P transport from tile drainage discharge.

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