Northern New York Agricultural Development Program
2018 Project Report

Quantifying Surface Runoff and Tile Drainage Flow Nutrient Losses in Edge-of-Field Plots

Project Leader(s):

- Laura Klaiber, Nutrient Management Researcher, Miner Institute, 1034 Miner Farm Road, PO Box 90, Chazy, NY; 518-846-7121, klaiber@whminer.com

Collaborator(s):

- Miner Institute personnel: Eric Young, Stephen Kramer, Mark Haney, Charles Hacker, and Katie Ballard

Cooperating Producers:

- Miner Institute Dairy Farm, Chazy, NY

Background:

Tile drainage is a critical practice for many farms with naturally poorly-drained soils in northern New York. Research has demonstrated that tile drainage can significantly increase crop yield and quality as well as reduce yield variability (*Blann et al., 2009*). However, as watersheds continue to struggle with recurring water quality issues (e.g., harmful algae blooms), agricultural tile drainage has come under increased scrutiny as a potential source of excess nutrients (e.g., phosphorus (P) and nitrogen (N)). Although tile drainage does export some nutrients, there have been few studies in our region designed to continuously monitor losses in both surface runoff and tile drainage.

The installation of systematic tile drainage systems in agricultural fields can drastically reduce or eliminate the occurrence of surface runoff. As concentrations of P in surface runoff tend to be much greater than those in tile drainage flows, minimizing surface runoff events can result in an overall reduction of exported P. Conversely, the increased rate of drainage tends to increase the export of nitrogen as nitrate-N is soluble in water and therefore highly mobile. Tile drainage systems also have the potential to export elevated levels of P under certain conditions (e.g., excessive levels of soil test P).

Total runoff and nutrient concentrations can be highly variable across events as well as on an annual basis and therefore long-term studies are necessary to estimate losses from each runoff pathway. The interaction of weather, cropping system, field management, soil type and fertility, landscape position and other factors will affect the partitioning of runoff and overall levels of nutrient export from surface and tile drainage. Edge-of-field monitoring projects enable the impacts of management practices to be quantified by measuring the amount of nutrients and sediment that are transported beyond the field boundaries in surface and subsurface runoff.

The objective of our project was to quantify the N, P, and sediment loads in surface runoff and tile drainage from four edge-of-field runoff plots in an alfalfa-grass field.

Methods:

Surface runoff and tile drainage from four replicate edge-of-field plots were continuously monitored from January 1, 2018, to December 31, 2018. Automated water samplers were used to sample runoff every 30 minutes when weather forecasts indicated that runoff would be likely due to precipitation or snowmelt events. Periods of persistent low flow were manually sampled.

Tile and surface samples from each plot were individually composited on a flow-weighted basis when autosamplers were used. Samples were analyzed for total P (TP), soluble reactive P (SRP), total N (TN), and nitrate-N, and total suspended solids. Composite sample concentrations were multiplied by flow volumes to estimate nutrient loading from each runoff pathway for individual runoff events. Annual flow-weighted mean (FWM) concentrations were calculated for surface and subsurface runoff by dividing the total nutrient and sediment loads by total flow. A "plot" FWM was calculated by dividing the the total nutrient and sediment loads (surface + subsurface) by the total runoff (surface + subsurface) from the plots. Differences in mean nutrient loads and flow-weighted mean concentrations in surface runoff and tile drainage were analyzed with a two-tailed t-test. Significance was declared at $P \leq 0.05$ and trends at $0.05 < P \leq 0.10$.

Corn was harvested for silage from the plots in fall 2017. Following corn harvest, 8,000 gal/ac of liquid dairy manure was surface applied and incorporated the same day. Plots were disc harrowed prior to planting a 60/40 mixture of alfalfa and cool season grasses on 5/10/18. No starter fertilizer or manure was applied in 2018 as per the farm's typical management for a first-year alfalfa-grass field. The plots were harvested on 7/28/18 and 9/4/18 for hay crop silage.

Results and Discussion:

Precipitation and Drainage

The experimental site received 29.2 inches (in) of precipitation in 2018, similar to the annual average for Clinton County (30.5 in). The mean total runoff from the plots was 5.64 in, accounting for 19.3% of the total precipitation. There was no significant difference ($P = 0.402$) in surface runoff and tile drainage. Tile drainage represented 59.2% of the total runoff (Table 1).

The majority of losses from both surface and subsurface pathways occurred during relatively short periods of time. A 54 hour snowmelt event initiated on 2/21/18 by a 0.5 in rainfall and temperatures that reached a maximum of 58 degrees Fahrenheit, resulted in 77% (1.77 in) of all surface runoff (Figure 1). Due to a frost layer in the soil, there was no tile drainage during this event.

Most runoff from tile drainage also occurred during an uncharacteristically short period of time relative to previous monitoring years at this site. Tile drainage flows between 3/28/18 and 5/11/18 (42 days) represented 94% of cumulative subsurface runoff (Figure 1). Late winter and early spring runoff is often responsible for a majority of total runoff, but the tiles typically flow for a longer duration in spring and early summer and during larger rainfall events later in the year.

Table 1. Mean runoff and exported nutrient and sediment loads from the runoff plots in 2018. Quantifying Surface Runoff and Tile Drainage Flow Nutrient Losses in Edge-of-Field Plots, NNYADP project, 2018.

	Runoff	SRP	Total P	TSS	Nitrate-N	Total N
	in	---------------------------	lb/ac	---------------------------		
Surface	2.30	0.360[□]	0.494[□]	10.55	0.88[*]	3.52[*]
Tile	3.34	0.006[□]	0.021[□]	5.08	28.66[*]	31.30[*]
Total	5.64	0.366	0.515	15.63	29.54	34.82

[*] Means significantly different at $P \leq 0.05$

[□] Trends at $P \leq 0.10$

Although the total precipitation was near average for the region, the distribution between the growing and nongrowing season was not. Precipitation during the growing season (May 1 – Oct 30) is typically about 60% of annual precipitation. However, only 13.1 in of the total precipitation (45%) in 2018 occurred during the growing season.

Additionally, temperatures during the growing season were higher than average in this area of Northern New York in 2018. This is reflected in above-average growing degree days during the majority of the 2018 growing season. Between May 1, 2018, and September 1, 2018, there was an accumulation of 2076 growing degree days. In comparison, the average accumulation during this same period over the previous five years was 1895 growing degree days.

The combination of below-average rainfall and above-average temperatures in 2018 likely resulted in below-average soil moisture levels throughout the summer months. As a result, when rainfall did occur, the soil had the capacity to store the rainfall and not generate runoff.

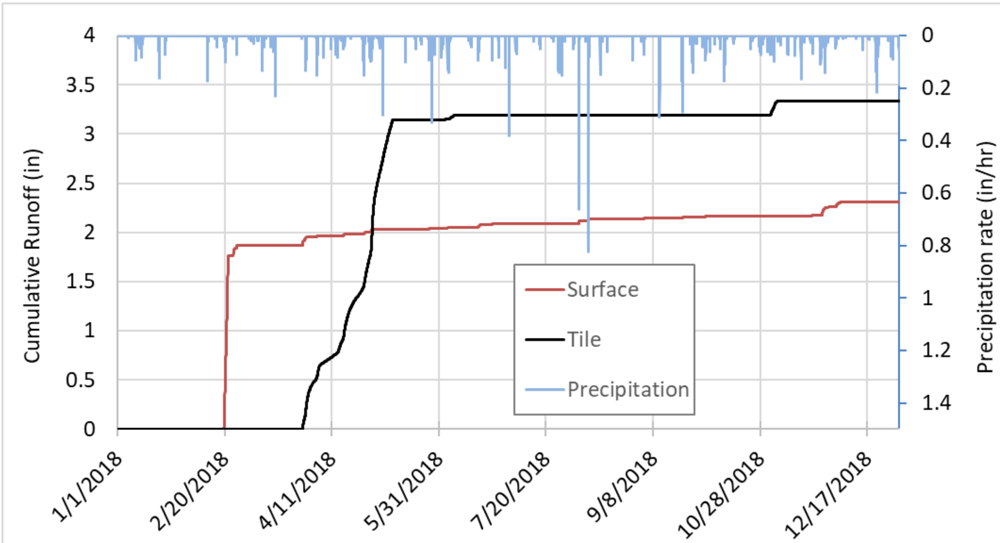

Figure 1. Precipitation and cumulative runoff from surface runoff and tile drainage in 2018. Quantifying Surface Runoff and Tile Drainage Flow Nutrient Losses in Edge-of-Field Plots, NNYADP project, 2018.

Phosphorus Losses

A combined mean (surface + tile) of 0.5 lb P/ac was exported from the runoff plots (Table 1). Surface runoff during the snowmelt event in February generated 90.5% of TP losses in 2018. As this event was only responsible for 77% of all surface runoff, it demonstrates that infrequent, high-volume runoff events can be responsible for the majority of annual losses.

Nongrowing season runoff events, and snowmelt events in particular, have the ability to produce high rates of runoff at a time when evapotranspiration rates are low and there is not a growing crop to provide ground cover, stabilize soil, and uptake nutrients. This surface runoff event was the first event since the November 2017 manure application, and the high concentrations of SRP and TP indicate that there was a pool of available P at the soil surface from that application, even though the manure was incorporated.

Despite contributing 60% of total runoff volumes, tile drainage contributed just 1.6% and 4.0% of SRP and TP losses, respectively (Table 1). Despite the large differences between surface and tile loads, statistical analysis only found a trend of greater mean losses of SRP and TP from surface runoff (SRP, $P = 0.075$; TP, $P = 0.100$). There was high variability in the data, as one of the plots rarely produced surface runoff (0.7 in). Therefore, the low P and TSS surface runoff loads from this plot likely prevented the detection of statistically significant differences in relation to P and TSS. Regardless, cumulative total P export in 2018 (0.02 lb/ac) from the tiles was much lower than what was reported in a comprehensive review by King et al., (2014), who found the typical range of annual total P losses from tile drains ranged from 0.4 lb/ac to 1.4 lb/ac.

The unusually dry growing season likely resulted in fewer runoff events than average. However, the low annual flow-weighted mean (FWM) concentrations of SRP and TP reflect that even when tile drainage did occur, P concentrations were low (Table 2).

The FWM concentrations of SRP and TP were 0.008 mg/L and 0.031 mg/L, respectively, lower (SRP, $P = 0.075$; TP, $P = 0.100$) than those in surface runoff (SRP = 0.587 mg/L; TP = 0.780 mg/L).

The FWM concentrations of the tile drainage were also well below the EPA recommendation of 0.1 mg/L of total P for waters draining to surface water bodies.

The elevated SRP and TP concentrations in surface runoff demonstrate that there is a risk of P loss from the plots. Had there been higher rates of precipitation and runoff during 2018, the rate of P loss could have increased as well.

Table 2. Mean nutrient and sediment flow-weighted mean concentrations from the runoff plots in 2018. "Plot" refers to FWM concentration when surface and tile data are combined. Quantifying Surface Runoff and Tile Drainage Flow Nutrient Losses in Edge-of-Field Plots, NNYADP project, 2018.

	SRP	Total P	TSS	Nitrate-N	Total N
	mg/L				
Surface	0.587□	0.780*	22.53*	1.89*	5.74*
Tile	0.008□	0.031*	7.09*	37.39*	40.65*
Plot	0.284	0.386	11.69	24.84	29.14

*Means significantly different at $P \leq 0.05$

□Trends at $P \leq 0.10$

A mean of 15.6 lb/ac of total suspended solids (largely sediment; abbreviated as TSS) was lost from the runoff plots. Flow-weighted mean concentrations of tile drainage were significantly lower ($P = 0.008$) than those in surface runoff However, there was no statistically significant difference between TSS loads in surface runoff and tile drainage ($P = 0.301$), though two-fold greater TSS was lost from surface runoff than tile drainage.

Erosion can be an important factor in P loss from fields as P readily adsorbs to soil particles. Therefore, TP and TSS losses can be correlated. Since the relative contributions of TSS and P by tile drainage were very different, it is unlikely that the majority of the P load was from soil-bound P. Soil samples from the plots in fall 2017 had a mean soil test P (Modified Morgan extractant) of 4.5 lb/ac, falling into the medium range of Cornell University's soil test P classification. Had there been higher levels of soil test P, the rate of P export may have been elevated further in both surface runoff and tile drainage to a level of greater concern than the observed 0.5 lb/ac (McDowell and Sharpley, 2001). This demonstrates the importance of nutrient management and preventing the buildup of excessive P levels in the soil in order to minimize P transport.

Nitrogen Losses

In contrast to P losses, tile drainage was the primary transport pathway for N. Tiles exported significantly greater mean cumulative nitrate-N ($P = 0.021$) and total N losses ($P = 0.028$) than surface runoff (Table 1). The high solubility of N makes it susceptible to loss in subsurface drainage and this was reflected in the mean nitrate-N loss (34.8 lb/ac). Tile drainage accounted for 90% of those losses, 92% of which was lost as nitrate-N. In contrast, only 25% of the N lost in surface runoff was as nitrate-N. Surface runoff had significantly greater flow-weighted mean concentrations of nitrate-N ($P = 0.001$) and total N ($P = 0.002$) than tile drainage (Table 2).

The elevated N concentrations may be due to a combination of factors. First, 97% of total N export from tile drainage occurred between 3/28/18 and 5/9/18. The field was not planted until 5/10/18 and, therefore, there was not a growing crop to remove any N that was mobilized by subsurface drainage during this period.

Second, as is common on dairy farms, manure is fall-applied in order to create enough capacity for manure storage throughout winter and early spring. The manure application in fall 2017 following corn harvest delivered approximately 127.2 lb/ac of nitrogen to the field and there was no growing crop until the spring planting.

Additionally, the plots received 5 and 10 ton/ac of composted dairy manure in 2015 and 2016 respectively. The composted manure had an average of 45% dry matter versus 5% dry matter in the liquid dairy manure and provides much more organic N than liquid dairy manure. Ketterings et al. (2001) estimate that 5% of organic N will be available in the second year after application, which would have provided an additional 3 lb/ac of inorganic N in 2018 from the fall 2016 composted manure application. Mineralization of soil organic matter (plot mean = 3.8%) could have also provided up to 38 lb N/ac/yr. With no major runoff events since the beginning of July 2017, N likely accumulated from these mineralized N sources and was available to be leached to subsurface drainage in the spring.

Finally, the dominant soil series in the experimental plots is a coarse-textured soil (Colosse-Trout River complex) with high saturated hydraulic conductivity. This allows water to rapidly move through the soil and interact with nitrate-N in the soil pore water before removal through the tile lines. When this rapid hydraulic conductivity is coupled with the relatively shallow (3 ft depth) tile lines, the rate of loss can be even greater. Also, when fields are poorly drained and oxygen-deficient, a greater percentage of N exports may occur through loss to the atmosphere (nitrate-N converted to gaseous N forms via denitrification). Subsequently, less N is available for removal in runoff.

The combination of the timing of runoff, available N sources, nutrient management, and soil characteristics may have contributed to the elevated losses experienced during 2018.

Conclusions:

Although surface runoff generated 45% less runoff than tile drainage, it was the primary source of P exports in our study. Conversely, the majority of N losses occurred through the tiles. These data are consistent with previous research conducted at this and other edge-of-field monitoring sites at the Miner Institute.

Overall, P losses were consistently low across plots and FWM concentrations of P in tile drainage were below threshholds for freshwater eutrophication. The elevated FWM SRP concentrations in the surface runoff indicates that there is an available pool of SRP at the soil surface which poses a risk for greater losses during a year with more precipitation and runoff. The high concentrations of nitrate-N and the associated losses from the tiles demonstrate the potential for high rates of N loss from well-drained soils. In fields such as these, careful attention must be paid to N application rates and N applications should be limited to periods of high crop N need.

The nongrowing season is often the period of the highest drainage rates and nutrient exports. The majority of runoff and N and P loss from both hydrologic pathways occurred during spring 2018. Best management practices must be developed and utilized to minimize nutrient loss during this period. Practices such as cover cropping that have previously demonstrated efficacy at targeting these periods should be implemented when possible.

Outreach:

A summary of the findings presented here will be published in a future issue of the Miner Institute *Farm Report*. Phosphorus results were provided in a presentation to the House Agriculture and Forestry Committee during a legislative session in Montpelier, VT, on February 15, 2019. A summary of these results will be shared at the Crop Congress at Miner Institute in Chazy, NY, in 2019, and with the Vermont Agency of Agriculture, Food and Markets Tile Drainage Advisory Group on 4/8/18.

Next Steps:

The below average precipitation in 2018 resulted in fewer runoff events than have typically been observed at this site. Edge-of-field monitoring studies typically benefit from multiple years of observation as variable weather conditions can generate a range of results. Additional funding provided for 2019 will allow for continued monitoring at this site with the same experimental design. The additional data collected will allow us to characterize losses under different weather conditions and expand on our conclusions from this reporting period.

Acknowledgments:

Miner Institute Dairy Farm; NNYADP (funding).

For More Information:

- Laura Klaiber, Nutrient Management Researcher, Miner Institute, 1034 Miner Farm Road, PO Box 90, Chazy, NY; 518-846-7121, klaiber@whminer.com

References:

Blann, K.L., J.L. Anderson, G.R. Sands, and B. Vondracek. 2009. Effects of agricultural drainage on aquatic ecosystems: A review. Crit. Rev. Environ. Sci. Technol. 39:909–1001.

Ketterings, Q.M., S.D. Klausner, and K.J. Czymmek. 2001. Nitrogen Recommendations for Field Crops in New York. Department of Crop and Soil Sciences Extension Series EO1-04. September 2001. 45 pages.

King, K.W., M.R. Williams, M.L. Macrae, N.R. Fausey, J. Frankenberger, D.R. Smith, P.J.A. Kleinman, and L.C. Brown. 2015a. Phosphorus Transport in Agricultural Subsurface Drainage: A Review. J. Environ. Qual. 44(2):467-485.

McDowell, R.W. and A.N. Sharpley. 2001. Approximating Phosphorus Release from Soils to Surface Runoff and Subsurface Drainage. J. Environ. Qual. 30(3): 508-520.