Northern New York Agricultural Development Program
2020 Project Report

Quantifying Surface Runoff and Tile Drainage Flow Nutrient Losses in Edge-of-Field Plots, Year 3

Project Leader:

- Laura Klaiber, MS, 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: Stephen Kramer, MS, Mark Haney, Ashton Nelson, and Catherine Ballard, MS

Cooperating Producer:

- Miner Institute Dairy Farm, Chazy, NY

Background:

Tile drainage is a critical practice for many farms in northern New York with naturally poorly-drained soils. 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.

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. Most edge-of-field research in the region has been conducted in fields managed as corn for silage, however, the impact of drainage on nutrient transport in row crop fields may be substantially different than in fields with continuous cover. Differences in crop growth and nutrient removal characteristics, continuous ground cover, absence of tillage, timing and method (no incorporation) of manure applications are among the primary differences often observed in these systems (Gilliam et al., 1999; King et al., 2015).

The objective of this project was to quantify the N, P, and sediment losses in surface runoff and tile drainage from four 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, 2020. Due to New York State business closures in response to the COVID-19 pandemic, monitoring ceased from March 27, 2020 to May 14, 2020.

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 (baseflow) 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), nitrate-N, and total suspended solids (TSS). Each composite sample concentration represents the event mean concentration (EMC). For each event, the EMC was multiplied by the event flow volume to estimate nutrient loading from each runoff pathway for individual runoff events. For baseflow samples, concentrations were assumed to be constant from halfway between the previous sample and subsequent sample for each collection time point and these estimates were multiplied by the corresponding flows.

Annual flow-weighted mean (FWM) concentrations were calculated for surface runoff and tile drainage by dividing total nutrient and sediment loads by total flow. Differences in mean nutrient loads and FWM concentrations in surface runoff and tile drainage were analyzed with a two-tailed t-test. Significance was declared at $P \leq 0.10$ due to the inherent variability present in runoff response at this scale and low number of replicates.

Corn was harvested for silage in fall 2017. Following corn harvest, 8,000 gal/ac of liquid dairy manure was surface applied and incorporated the same day with a disk harrow. Plots were disk harrowed prior to planting a 60/40 mixture of alfalfa and cool season grasses on May 10, 2018. No nutrients were applied in 2018.

The field was harvested two times per year for hay crop silage in each of the three years and broadcast applications of 4,200 gal/ac of liquid dairy manure followed each harvest in 2019 and 2020. Manure was sampled at each application to enable nutrient input calculations. Prior to each harvest, four biomass samples were collected from each plot with a 1 ft by 2 ft frame. A composite sample from each plot was analyzed for dry matter (DM) and P and N content.

<u>Results and Discussion:</u>

Precipitation and Drainage

The experimental site received average precipitation in 2018 (29.2 in), above average in 2019 (36.7 in), and below average in 2020 (24.8 in) relative to the 30-year Clinton County average (30.5 in). The elevated precipitation in 2019 was reflected in greater rates of total runoff from the plots than in 2018 and 2020. The average total runoff from the plots (surface + tile) was 11.2 inches in 2019 as compared to 5.6 inches in 2018 and 7.2 inches in 2020 (Figure 1).

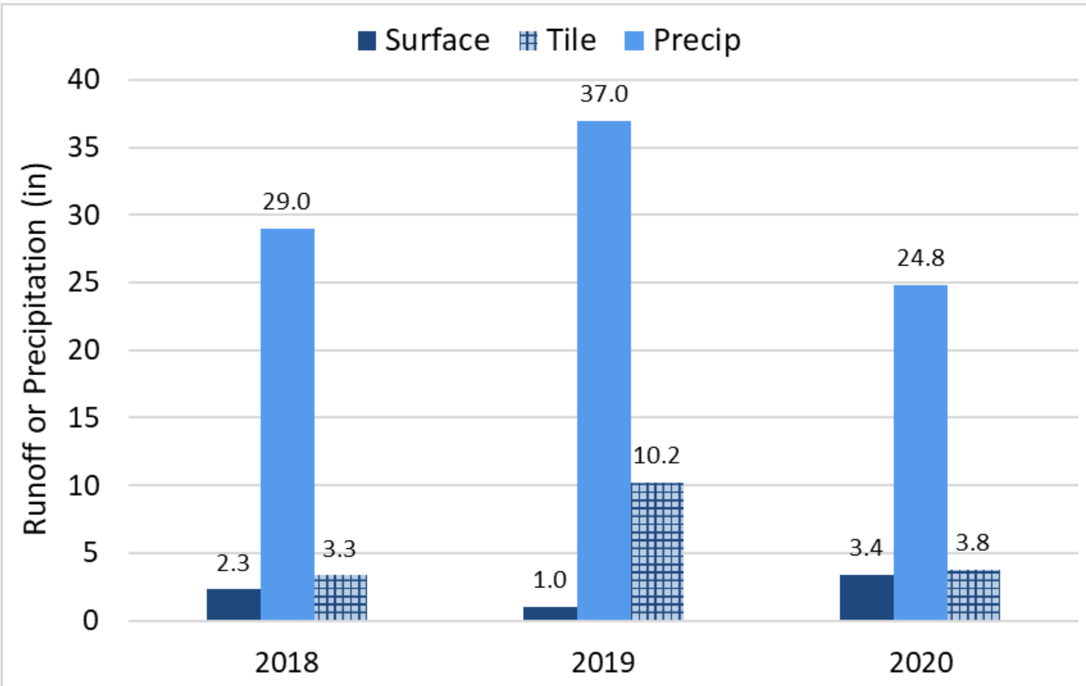

Figure 1. Annual precipitation, surface runoff, and tile drainage from January 1, 2018 to December 31, 2020. The precipitation in 2020 includes precipitation during the COVID-19 monitoring hiatus (March 27 – May 14), NNYADP trials.

During the COVID-19 monitoring hiatus, there was 3.11 inches of rain, including two storms that each generated 0.8 inches and could have potentially generated medium-scale runoff events. The remaining precipitation occurred at low rainfall intensity rates and was relatively evenly distributed throughout the entire period and therefore was unlikely to have produced stormflows. Although the water table is typically elevated during the spring and produces a high percentage of the annual tile flow, the absence of snowmelt events or larger, high intensity rainstorms makes it likely that a high percentage of the flows would have been baseflow. Tile baseflow is the drainage of shallow groundwater, as opposed to stormflow, which is transported directly from the surface during runoff events.

In addition to unaccounted for runoff during the monitoring hiatus, the reduction in runoff relative to 2019 was likely a result of the below average runoff in 2020. The U.S. Drought Monitor classified Clinton County, New York, as abnormally dry or in a moderate drought from June 2 through October 27, 2020 and precipitation in November and December was 50% less than the 30-yr mean. Consequently, 97% of tile drainage and 96% of surface runoff in 2020 occurred prior to March 27.

Runoff generation in 2020 was similar to 2018 with minimal difference in runoff generation between the two pathways, though the difference between surface runoff and tile drainage likely would have been greater had monitoring continued uninterrupted in the spring months of 2020. Total plot runoff was substantially greater in 2019 than in 2018 and 2020 and the tiles also generated significantly more drainage than surface runoff (Table 1; $P = 0.004$).

Despite the possibility of missed surface runoff events in 2020, the quantity of surface runoff was the greatest of all three years due to a period of substantial snowmelt in late February through mid-March. During two snowmelt events that spanned 11 days, the plots generated 3.2 inches of surface runoff. Throughout the study, the vast majority of surface runoff has consistently occurred during snowmelt events.

Phosphorus Losses

Plot-scale (surface + tile) total P losses ranged from 0.196 lb/ac in 2019 to 0.515 lb/ac in 2018 (Table 1). Despite significantly greater runoff from the tile system compared to surface runoff in 2019, there were no significant differences in the export of DRP and total P between the two pathways, though the tile did contribute the majority of losses. Conversely, in 2018 and 2020 when the runoff volumes were similar, a significantly greater amount of DRP ($P = 0.075$; $P = 0.069$) and total P ($P = 0.100$; $P = 0.060$) was exported by surface runoff. Total P losses from the tiles were 96% and 78% less than surface runoff in 2018 and 2020, respectively.

Table 1. Mean annual runoff and exported nutrient and sediment loads by hydrologic pathway from January 1, 2018 – December 31, 2020, NNYADP trials.

Year	Pathway	Runoff	DRP	Total P	TSS	Nitrate-N	Total N
		in	-------------------------		lb/ac/yr		-------------------------
2018	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
2019	Surface	**1.01**	0.016	0.040	**5.81**	**0.17**	**0.57**
	Tile	**10.19**	0.058	0.156	**22.72**	**28.30**	**30.32**
	Total	11.20	0.075	0.196	28.53	28.47	30.89
2020	Surface	3.41	**0.225**	**0.365**	**7.77**	**0.27**	4.58
	Tile	3.79	**0.045**	**0.081**	**4.30**	**2.62**	3.73
	Total	7.20	0.270	0.446	12.08	2.89	8.31

* Means highlighted in bold text are significantly different at $P \leq 0.10$.

Although the actual total P export in 2020 may be greater than reported as a result of the unmonitored period, it is unlikely that losses would be substantially greater had monitoring continued uninterrupted. The snowpack had completely melted by mid-March and the rainfall events were unlikely to have generated substantial surface runoff events. Therefore, the majority of the runoff would have been baseflow, which is typically low in P. While tile flow would have likely been less than in the month preceding the sampling pause, calculating an estimated load from the tiles using the flow total from the preceding month and the flow-weighted mean (FWM) during that same period would only have resulted in an additional 0.067 lb/ac of total P export, or a 14% increase.

The limited accumulation of snow in 2019 compared to 2018 and 2020 contributed to the reduction in surface runoff. Due to the large disparity in runoff generation between the two pathways, the primary transport pathway of P in 2019 was tile drainage. However, the total P FWM concentrations (Table 2), which represent the annual average concentration, were significantly higher for surface runoff in 2018 ($P = 0.051$), 2019 ($P = 0.050$), and 2020 ($P = 0.002$). Therefore, while the relative contribution by the tiles in 2019 was the greatest of the three years, the reduction in surface runoff due to enhanced subsurface drainage rates in 2019 may have contributed to the overall reduction in total P losses.

Table 2. Mean nutrient and sediment flow-weighted mean concentrations from the runoff plots in 2018, 2019, and 2020, NNYADP trials.

Year	Pathway	DRP	Total P	TSS	Nitrate-N	Total N
		------------------------mg/L---------------------------				
2018	Surface	**0.587**	**0.780**	**22.53**	**1.89**	**5.74**
	Tile	**0.008**	**0.031**	**7.09**	**37.39**	**40.65**
	Total	0.284	0.386	11.69	24.84	29.14
2019	Surface	**0.063**	**0.182**	10.56	**0.67**	**2.02**
	Tile	**0.024**	**0.066**	35.01	**11.14**	**11.97**
	Total	0.028	0.075	10.88	10.86	11.78
2020	Surface	**0.282**	**0.458**	**11.5**	**0.34**	5.74
	Tile	**0.051**	**0.091**	**5.7**	**2.95**	4.20
	Total	0.160	0.265	8.5	1.72	4.93

* Means highlighted in bold text are significantly different at $P \leq 0.10$.

The U.S. Environmental Protection Agency (EPA) recommends that drainage waters not exceeed 0.100 mg/L of total P to limit the risk of accelerated eutrophication in receiving surface waters. The annual total P FWM concentrations from the tiles have consistently remained below this guideline, ranging from 0.031 mg/L in 2018 to 0.091 mg/L in 2020. Surface runoff has consistently exceeded this benchmark, ranging from 0.182 mg/L (2019) to 0.780 mg/L (2018). Given the continuous ground cover and in-season nutrient applications in 2019 and 2020, further reducing P concentrations and loads in surface runoff would likely require manure injection in order to limit the availability of the applied P to surface runoff. This could potentially increase the rate of subsurface P losses but further research is necessary to more fully understand the the water quality implications of this practice.

Nitrogen Losses
Total N losses were driven by nitrate-N losses through tile drainage in both 2018 and 2019 (Table 1). Tile drainage contributed 90 and 98% of total N losses in 2018 and 2019, respectively, with an average of 92% of the total N in tile flow occurring as nitrate-N. In contrast, 55% of the total N losses occurred in surface runoff in 2020. This is likely due in part to the unsampled period in 2020, a period which is often responsible for a substantial portion of tile flow and N losses. However, nitrate-N and total N concentrations prior to the sampling pause were also lower than have previously been observed during spring runoff, resulting in reduced N losses when flows were monitored. Using the same method of load estimation for tile flows as was previously described for P, total N losses would have doubled as nearly 100% of total N losses from the tiles occurred during that period. However, even with that estimated load, losses would still be 61% less than 2019 and 65% less than 2018.

Despite the much higher drainage volume in 2019, there was slightly less total N export in 2019 (30.89 lb/ac) than in 2018 (34.82 lb/ac). This is reflected in the substantially higher total N FWM concentration for tile drainage in 2018 (40.65 mg/L) versus 2019 (11.97 mg/L) (Table 2). These FWM concentrations are substantially greater than was observed in 2020 (3.73 mg/L) and partially explain the reduction in loading despite similar tile drainage rates in 2018 and those monitored in 2020.

Although the total N FWM concentrations were much lower in 2019, they were still at a level of concern and total exports remained elevated. In 2018 and 2019, the tile drainage nitrate-N FWM concentrations were above the drinking water standard (10 mg/L) set by the EPA. These N losses represent a risk to human health and water quality, as well as a financial opportunity for the farm. Although commercial fertilizer has not been added to the field, high rates of N loss could have a negative impact on soil fertility, resulting in lower crop yield and quality.

The high rates of N loss in 2018 and 2019 are likely related in part to the soil characteristics of the plots. The plots consist of a combination of a coarse-textured soil and a fine-textured, poorly drained soil. The coarse-textured soil is classified as excessively well-drained, and mineralization (conversion of organic N to ammonium) and nitrification (conversion of ammonium to nitrate) processes in these soils will occur more rapidly than in poorly drained soils (Ketterings et al., 2001). With this rapid transformation of organic N to soluble forms of N, there is an increased risk of loss. When tile drainage is installed in these soils, there is a very high risk of nitrate loss as the tiles increase the rate of drainage and intercept subsurface water before the crop has a chance to utilize the plant available N. The coarse-textured soil in the upslope area of the plots likely contributed the majority of the N load. Tile-draining already well-drained soils does not make economic sense, but as the data demonstrate, can also have a negative impact on water quality.

The substantial reduction in total N losses and FWM concentrations from the tile drains in 2020 is surprising. The reduction of the proportion of alfalfa in the stand may contribute to these differences. The alfalfa-grass stand is now in its third-year and the alfalfa is often out-competed by the grass during the rotation. Alfalfa is a legume which can utilize atmospheric N for growth and maintenance and is therefore less reliant on nutrient inputs and soil N supplies. While the proportion of alfalfa and grass in the plots has not been measured, a reduction in the alfalfa population could lead to a higher rate of N uptake from the soil. This would then result in a lower quantity of N remaining in the soil at the end of the growing season where it is vulnerable to runoff.

Nutrient Budgets

Mean crop yields from the research plots were similar in 2018 and 2019 with 4.3 and 4.1 tons DM/ac, respectively (Table 3). Yields were substantially lower in 2020 due to the moisture deficit during the growing season. Variation in the N and P content of manure created the difference in inputs in 2019 and 2020.

Table 3. Mean phosphorus (P) and nitrogen (N) inputs and crop removal rates from the research plots in 2018, 2019, and 2020.

Year	P Inputs lb/ac	N Inputs lb/ac	Yield tons DM/ac	P Removal lb/ac	N Removal lb/ac
2018	17.5	106.8	4.3	34.9	263.1
2019	19.3	223.4	4.1	25.2	235.4
2020	29.9	146.6	3.1	17.6	217.2

Variations in yield and N and P content in the applied manure resulted in a wide variation in nutrient use efficiency [(applied/crop uptake)*100]. Phosphorus use efficiency in 2020 (59%) was the only instance of input exceeding the rate of crop removal. Over the three-year monitoring period, P use efficiency was 117% and N use efficiency was 150%. Phosphorus losses as a percentage of the total amount applied were low across all three years, with an overall loss rate of 1.7%. Losses in 2018 were likely elevated due to the application in the nongrowing season (NGS) following corn harvest in 2017 and the presence of bare soil in the 2017-2018 NGS. In contrast, manure was applied prior to regrowth of the hay crop and fields had continuous vegetative cover in both 2019 and 2020, resulting in lower rates of P and N loss. Both the total losses and the percent of applied N lost decreased continuously from 2018 to 2020.

Table 4. Mean crop use efficiency of applied phosphorus (P) and nitrogen (N) and mean percentage of applied P and N lost in runoff (surface + tile) from the research plots in 2018, 2019, and 2020.

Year	P Efficiency	N Efficiency	P Loss	N Loss
	----------------------------	%	---------------------------	
2018	200	246	2.9	32.6
2019	131	105	1.0	13.6
2020	59	148	1.5	5.7
Overall	117	150	1.7	15.4

Conclusions:

The majority of P losses have occurred in surface runoff despite tile drainage providing 72% of the total runoff and the enhanced subsurface drainage rates appear to be effective in reducing P loss from the plots.

Nitrogen losses have predominantly occurred through tile drainage, though the rate of loss and average nitrate-N and total N concentrations have steadily decreased throughout the three-year monitoring period.

The proportion of applied P and N lost in runoff was highest in 2018, but following the establishment of the alfalfa-grass stand and in-season nutrient applications, the rates decreased.

The non-growing season (NGS) events, particularly snowmelt events, have consistently generated the majority of P and N losses in both surface and tile flows. Reducing the manure application rate following the final harvest could help limit the supply of available P and N in the soil that is vulnerable to runoff in the NGS and further reduce nutrient losses.

Outreach:

Results were presented at the New York State Agribusiness Association & Certified Crop Advisor Advanced Training on December 1, 2020. Data from this project will also be presented at the 25th Annual North Country Crop Congress on February 24, 2021.

Next Steps:

Edge-of-field monitoring studies benefit from multiple years of observation as variable weather conditions can generate a range of results. Data collection will continue through the fourth year of the alfalfa-grass rotation in 2021. Previous research at this site and other regional edge-of-field monitoring sites have focused on corn fields and continuing research will provide valuable insight into nutrient cycling in hay fields, an essential component of most NNY dairy farm crop rotations.

Acknowledgments:

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Reports and/or articles in which results of this project have been published:

A summary of the findings presented here will be published in a future issue of the Miner Institute *Farm Report*.

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

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