Northern New York Agricultural Development Program
2021 Project Report

Quantifying Surface Runoff and Tile Drainage Flow Nutrient Losses in Edge-of-Field Plots, Year 4

Project Leader:

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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 Northern New York Agricultural Development Program (NNYADP) 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, 2021. 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 concentrations (FWMC) 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 2018-2020 and three times in 2021. Broadcast applications of 4,200 gal/ac of liquid dairy manure followed each harvest in 2019-2021. 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.

Results and Discussion:

Precipitation and Drainage

The 30-yr mean annual rainfall for Clinton County, NY, is 34.4 inches. The annual precipitation, surface runoff, and tile drainage amounts for the 4-yr monitoring period are summarized in Figure 1. Mean annual runoff from the plots (surface + tile) was 7.56 in/yr, ranging from a minimum of 5.64 in/yr to 11.20 in/yr in 2019. The 2020 runoff totals are likely a modest underestimate due to the missed weeks of monitoring in early spring due to the COVID-19 pandemic, though the likelihood of surface runoff events during this period was low as the snowpack had already melted and there were no large precipitation events.

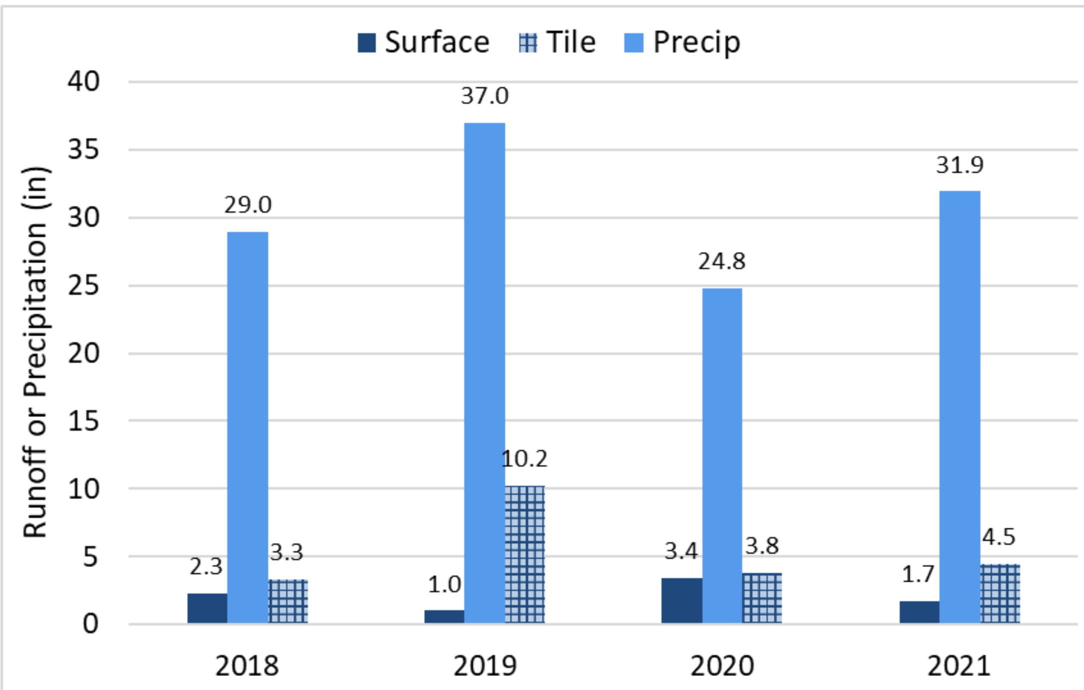

Figure 1. Annual precipitation, surface runoff, and tile drainage from March 28, 2018 to December 31, 2021. The precipitation in 2020 includes precipitation during the COVID-19 monitoring hiatus (March 27 – May 14), NNYADP Quantifying Surface Runoff and Tile Drainage Flow Nutrient Losses in Edge-of-Field Plots trials.

Annual tile drainage ranged from 3.3 inches to 10.2 inches. Annual surface runoff ranged from 1.0 inches to 3.4 inches. Although the relative contribution of tile drainage to the total varied considerably from year to year, on average, tile drainage was the dominant runoff pathway and contributed 72% of the total plot drainage.

Throughout the study, snowmelt events have been the primary driver of surface runoff. The spring snowmelt in 2021 once again produced the vast majority of annual surface runoff, delivering 96% of the 1.7 inches of surface runoff in 2021. The same 2-day snowmelt event also produced 25% of the annual tile drainage. The combination of snowmelt events, precipitation, and seasonally high water tables during the non-growing season (NGS), particularly in February through April, creates a high risk for surface runoff events.

Phosphorus Losses

Annual plot-scale (surface + tile) total P losses ranged from 0.167 lb/ac in 2021 to 0.515 lb/ac in 2018 (Table 1), with a 4-yr mean of 0.331 lb/ac/yr. Despite contributing just 28% of the total plot runoff, surface runoff generated significantly larger loads of SRP and total P than tile drainage every year except 2019. Of the 0.199 lb/acre/yr of exported SRP, 84.2% was lost in surface runoff. Similarly, 76.1% of total P exports (0.331 lb/acre/yr) were generated by surface runoff. Not surprisingly then, when annual surface runoff volumes increased (and the proportion of tile drainage decreased), the rates of SRP and total P increased as well.

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 majority of the runoff would have been baseflow, which is typically low in P. An estimated load from the tiles using the flow total from the preceding month and the FWMC during that same period would only have resulted in an additional 0.067 lb/ac of total P export, or a 14% increase.

Table 2. Mean annual runoff and exported nutrient and sediment loads by hydrologic pathway from January 1, 2018 – December 31, 2020, NNYADP Quantifying Surface Runoff and Tile Drainage Flow Nutrient Losses in Edge-of-Field Plots trials.

Year	Pathway	Runoff	SRP	Total P	TSS	Nitrate-N	Total N
		in	-------------------------		lb/acre/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
2021	Surface	1.73	**0.067**	**0.108**	0.93	**0.15**	**1.02**
	Tile	4.47	**0.016**	**0.059**	7.15	**2.87**	**3.53**
	Total	6.20	0.083	0.167	8.08	3.02	4.54
4-yr mean	Surface	2.11	**0.167**	**0.252**	6.27	**0.37**	**2.42**
	Tile	5.45	**0.031**	**0.079**	9.81	**15.61**	**17.22**
	Total	7.56	0.199	0.331	15.45	15.75	19.29

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

The substantially higher SRP and total P loads in 2018 relative to the other monitoring periods is likely due in large part to the difference in field and manure management. The field transitioned from corn to alfalfa/grass in 2018, which meant that the field was left fallow following corn harvest, manure application, and tillage in the fall until the field was planted with a perennial crop in spring 2018. Late fall manure applications and bare soil during the NGS are well-known risk factors for P loss given the lack of a growing crop to utilize manure nutrients and the high risk of runoff removing those applied nutrients before the start of the growing season (King et al., 2015). The high rates of P loss prior to the establishment of the perennial stand and manure applications to a growing crop demonstrates these risks and supports recommendations to limit bare soil and apply nutrients to a growing crop.

The significantly higher FWMC of SRP and total P in surface runoff led to larger P losses than those generated by tile drainage despite their differences in runoff contribution (Table 2). 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 FWMC from the tiles has consistently remained below this guideline, ranging from 0.027 mg/L in 2018 to 0.091 mg/L in 2020. Surface runoff has consistently exceeded this benchmark, ranging from 0.169 mg/L (2019) to 0.917 mg/L (2018). Given the continuous ground cover and in-season nutrient applications beginning in 2019, further reducing P exports 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.

Table 2. Mean annual nutrient and sediment FWMC from the runoff plots (surface, tile, and plot-level) from March 28, 2018 – December 31, 2020, NNYADP Quantifying Surface Runoff and Tile Drainage Flow Nutrient Losses in Edge-of-Field Plots trials.

Year	Pathway	Runoff	SRP	Total P	TSS	Nitrate-N	Total N
		in	---------------------------		mg/L		-----------------------------
2018	Surface	2.30	**0.669**	**0.917**	**23.1**	**1.63**	**6.54**
	Tile	3.34	**0.008**	**0.027**	**7.7**	**36.65**	**40.03**
	Total	5.64	0.277	0.390	14.0	22.37	26.37
2019	Surface	1.01	**0.068**	**0.169**	29.0	**0.72**	**2.41**
	Tile	10.19	**0.024**	**0.065**	11.2	**11.86**	**12.71**
	Total	11.20	0.029	0.075	12.8	10.86	11.78
2020	Surface	3.41	**0.282**	**0.458**	**11.5**	**0.34**	5.74
	Tile	3.79	**0.051**	**0.091**	**5.7**	**2.95**	4.20
	Total	7.20	0.160	0.265	8.5	1.72	4.93
2021	Surface	1.73	**0.166**	**0.268**	2.3	**0.38**	**2.52**
	Tile	4.47	**0.016**	**0.056**	6.8	**2.74**	**3.37**
	Total	6.20	0.057	0.115	5.6	2.09	3.13
Cumulative	Surface	8.44	**0.338**	**0.510**	**12.7**	**0.75**	4.90
	Tile	21.80	**0.025**	**0.062**	**7.7**	**12.24**	13.50
	Total	30.24	0.112	0.187	8.7	8.90	10.90

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

Nitrogen Losses

Total N losses were driven by nitrate-N losses through tile drainage in every year except 2020 (Table 1). Tile drainage contributed 90%, 98%, and 78% of total N losses in 2018, 2019, and 2021, respectively. Across the 4-yr monitoring period, 88% of total N exports and 98% of nitrate exports were transported in tile drainage.

Of the total N exported from 2018-2021, 81% was in the form of nitrate, a highly soluble and mobile bioavailable nutrient.

The 2020 monitoring period was the only year in which surface runoff exported more than tile drainage, but the inability to monitor in April and part of May likely resulted in an underestimation of N losses as a substantial portion of annual losses typically occurs between late February and early June. Adding to the uncertainty of this missing period, losses in 2020 were substantially lower than in the previous two years, and it was unclear to what extent the missing period led to these differences.

With no interruption in data collection during 2021, it is evident that 2020 began a shift towards a reduction in exported N. As the time since the last corn crop (in 2017) has increased, the total N exports have continually decreased. Although slow at the beginning, total exported N has dropped from a maximum of 34.8 lb/acre/yr in 2018 to a minimum of 4.5 lb/acre/yr in 2021.

This reduction in the risk of N loss in runoff is reflected in the FWMC of nitrate-N and total N (Table 2). While some variability in exports from year to year is expected and would be related in part to the quantity and pathways of runoff, if the N dynamics were stable, we would expect to see relatively consistent FWMC. However, the FWMC of both nitrate-N and of total N in tile drainage was reduced approximately 12-fold in 2021 compared to 2018, leading to the sharp reduction in N exports despite relatively similar runoff patterns. The FWMC of nitrate-N in tile drainage in 2020 and 2021 was also well below the drinking water standard (10 mg/L) set by the EPA due to the human health risk posed by high nitrate concentrations.

Nutrient Budgets

Mean crop yields from the research plots were similar in 2018, 2019, and 2021, despite there being a third harvest in 2021 (Table 3). Yields per cutting were greatest in 2018 and 2019. However, abnormally dry conditions during the growing season resulted in substantially reduced yields per cutting in 2020 and 2021. Yield per harvest was similar in 2020 and 2021, but the addition of a third harvest in 2021 led to the increased total annual yield and nutrient removal. Variations in the N and P content of manure, as well as the additional harvest and manure application in 2021 are the primary factors impacting the variability observed in P and N inputs.

These variations in yield and N and P content in the applied manure resulted in a wide variation in nutrient use efficiency [NUE = (applied/crop uptake)*100]. Phosphorus use efficiency dropped in 2020 (59%) and 2021 (63%) due to the below average yield per harvest. However, across the 4-yr 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 1.3%. Losses in 2018 were likely elevated due to the application in the 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. Despite the elevated losses in 2018 and 2019, the sharp reduction in exported N in 2020 and 2021 resulted in an overall NUE of 138%, indicating that more total N was removed with the harvested crop than was applied in manure. The reduction in the percentage of N lost also resulted in a reduction from a maximum of 32.6% in 2018 to a minimum of 2.0% in 2021 and an overall loss of 11.1% of the total N applied over the 4-yr study

Table 3. Mean phosphorus (P) and nitrogen (N) inputs and crop removal rates from the research plots across the 4-yr study; NNYADP Quantifying Surface Runoff and Tile Drainage Flow Nutrient Losses in Edge-of-Field Plots trials.

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
2021	36.1	228.3	4.1	22.8	259.7
Cumulative	102.8	705.0	15.6	100.5	945.4

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 across the 4-yr study; NNYADP Quantifying Surface Runoff and Tile Drainage Flow Nutrient Losses in Edge-of-Field Plots trials.

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
2021	63	114	0.5	2.0
Cumulative	98	138	1.3	11.1

Conclusions:

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

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 four-year monitoring period to within acceptable limits.

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

Non-growing season 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 from this project were presented at the 2022 virtual joint annual meeting of the Soil Science Society of America, Crop Science Society of America, and American Society of Agronomy. Data from this project will be presented at the North Country Crop Congress in 2023.

Next Steps:

The results demonstrate that with adherence to current best management practices, nutrient losses from perennial crop fields can be kept to very low rates as demonstrated by the very low percentage of applied P and N that was lost. Despite these rates of nutrient export, they can still be environmentally important, particularly with regard to P. Though costly to implement due to the need for new equipment and/or technology, additional in-field practices such as manure injection and variable-rate manure applications may provide further benefits to P reduction goals and should be the focus of future research.

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*. The results of the 4-yr study will also be submitted for publication in a peer-reviewed journal. Results reports from all four project years are posted on the NNYADP website at www.nnyagdev.org.

For More Information:

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