Northern New York Agricultural Development Program
2020 Project Report

Quantifying Long-Term Agronomic and Water Quality Impacts of Tile Drainage in Northern New York Corn Fields, Year 3

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Background:

Tile drainage is an important practice in northern climates with short growing seasons where improved field trafficability can extend the growing season, significantly increase crop yields, and minimize soil compaction by field equipment. The extended growing season and reduction in the duration of soil saturation can also provide greater flexibility in the timing of manure applications and an ability to adopt conservation practices such as cover cropping.

With proper installation and nutrient management, phosphorus (P) concentrations in tile drainage water are typically substantially lower than in surface water runoff. In addition to enhanced crop production and soil quality, tiling can reduce soil erosion and total P losses. Increased export of nitrogen (N) to surface waters can occur with tile drainage due to enhanced drainage efficiency and N mineralization rates compared to undrained soils. However, a longer growing season and enhanced root growth from tiling poorly-drained soils generally results in greater crop yields and uptake of nutrients over time compared to undrained soils.

Tiling has received heightened scrutiny from some agencies because some degree of nutrient export can occur in tile flows. However, few long-term, year-round, side-by-side comparisons of tile-drained and undrained fields have been performed in Northern New

York (NNY) to evaluate nutrient losses and crop yields under these different management approaches. Since some level of nutrient loss is inevitable with field crop production, benefits of tiling must be evaluated with respect to both farm economics and measured water quality impacts.

Methods:

Beginning in 2016, an edge-of-field monitoring project was established and conducted on two adjacent farm fields in Keeseville, NY. The fields are similar in size (5.8 and 5.9 acres), composed of the same soil type (somewhat poorly drained silt loam; Tonawanda series) and have mild slopes to direct surface runoff to monitoring stations at a corner of each field. Interceptor ditches and berms around the perimeter of each field ensure that each field is hydrologically isolated from adjacent land. Tile drainage was installed in one of the fields in 2016 at 35 ft. lateral spacing and an average 4 ft. depth.

Both fields were equipped with pre-calibrated H-flumes and flow-based sampling and monitoring equipment for measuring surface runoff. The tile-drained field was equipped with a tile pumping station and flow-based sampling and monitoring equipment. All sampling locations are connected to the power grid, enabling year-round monitoring. Surface runoff and tile drainage were sampled for every 0.67 mm of runoff and composited into a 15-L plastic container. Composite samples were collected two times per week and analyzed for dissolved reactive P (DRP), total P (TP), nitrate-N, ammonium-N, total N (TN) and total suspended solids (TSS; an estimate of erosion).

Nutrient and sediment loads in runoff from the tile-drained (TD) and undrained (UD) fields were estimated by multiplying sample concentrations by flow volumes for each event. Flow-weighted mean (FWM) concentrations over the three-year monitoring period were calculated at the field scale (TD = surface + tile; UD = surface) by dividing the total mass of nutrient and sediment lost by the total runoff. Individual runoff pathway FWM concentrations were calculated for TD by dividing the total mass lost from each pathway by the corresponding total volume.

Corn planting, harvest, and nutrient application data are summarized in Table 1. Fertilizers are shown on an N-P-K basis. Manure and pre-plant fertilizer were applied on the same date and immediately incorporated with a disk harrow. Corn was harvested for silage and the fields were left fallow through the following spring. Manure was sampled at the time of application and analyzed for P and N content. Based on these results and commercial fertilizer application rates, annual nutrient inputs to each field were calculated. Nutrient removal rates for each field were calculated based on individual forage samples and dry matter yields.

Table 1. Summary of field activities throughout project. Pre-plant and starter fertilizers are shown on a N-P-K basis. Sidedress nitrogen was a 32% solution of urea ammonium nitrate (UAN); Quantifying Long-Term Agronomic and Water Quality Impacts of Tile Drainage in Northern New York; NNYADP.

Year	Plant Date	Manure Application Date	Manure Rate	Pre-Plant Fertilizer (8-20-30)	Starter Fertilizer (24-8-0)	Sidedress Nitrogen (32% UAN)	Harvest Date
2018	May 26	May 24	4,500 gal/ac	NA	8 gal/ac	NA	Sept. 28
2019	June 25	June 24	4,500 gal/ac	200 lb/ac	12 gal/ac	10 gal/ac	Nov. 25
2020	May 26	May 18	4,500 gal/ac	100 lb/ac	10 gal/ac	NA	Oct. 7

The data reported here consist of runoff events between March 29, 2018, and December 31, 2020. A large runoff event (2.9 inches of rain) from October 31, 2019 to November 2, 2019, was excluded from the study due to a power outage at the site. The power outage occurred during peak rainfall and monitoring equipment did not function during a critical period in the event. Additionally, due to New York State business closures in response to the COVID-19 pandemic, samples were not collected during a 24-day period from March 29, 2020 to April 21, 2020. Runoff rates continued to be logged by the flow monitoring equipment during this period and were downloaded when research activities resumed.

Results and Discussion:

Field Hydrology: During the COVID-19 sampling hiatus, two rainfall events generated 0.82 in of surface runoff at UD. No surface runoff occurred at TD during this period. These events also contributed to 1.5 inch of tile flow in TD. Approximately 70% of the tile flow was storm flow and the remainder was baseflow. Stormflow generates higher peak flow rates and contains a combination of groundwater and rainwater that has rapidly moved through the soil to the tile lines during a runoff event. Stormflow is typically responsible for the majority of nutrient and sediment loading though the quantity can vary widely depending on the type of storm and the field's nutrient application history. Tile baseflow occurs when the groundwater table rises to the level of the tile drains, is typically low in P and sediment, and can have varying levels of N depending on the season and nutrient application history.

These events, in addition to the October 31, 2019 event, were excluded from the data presented in this report as the corresponding nutrient and sediment loads could not be quantified or reliably estimated. The analysis within this report primarily focuses on average annual runoff and nutrient losses that have been observed over the nearly three-year monitoring period, thus reducing the impacts of missing individual events.

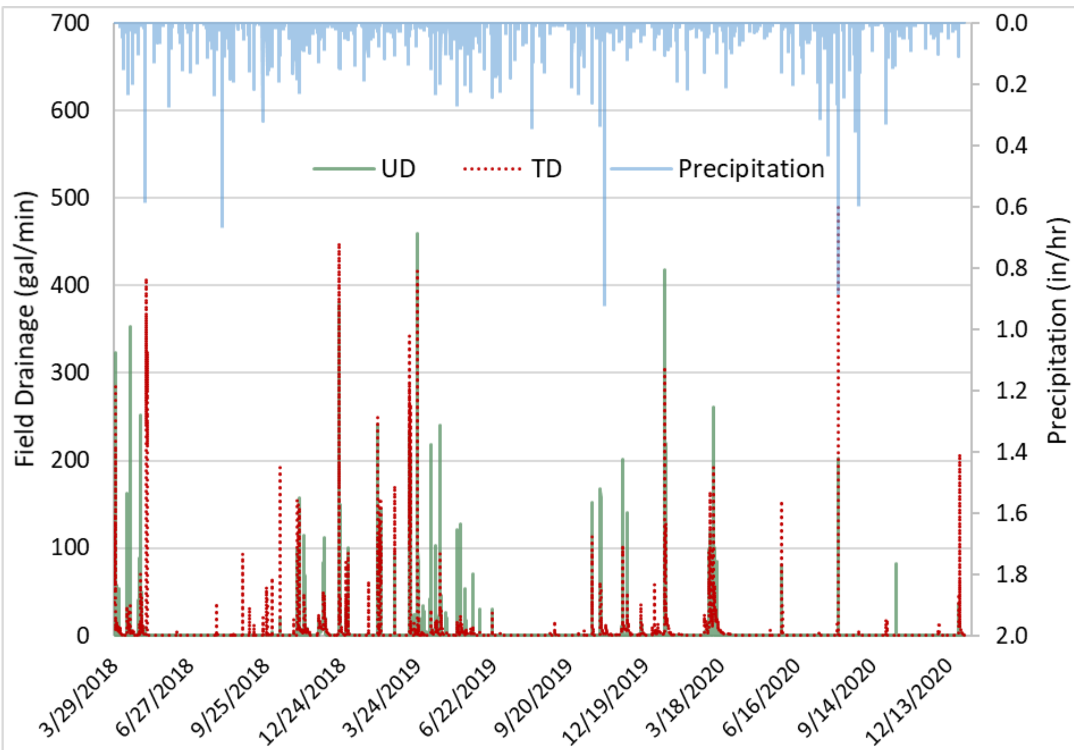
Mean annual runoff from TD (surface + tile) was 26% greater than UD (surface), with 7.62 in/yr and 6.05 in/yr of linear runoff from each field, respectively (Table 2). These results align with a review of agricultural drainage research that reported increases of 10-25% when pattern tile drainage is installed in agricultural fields (King et al., 2015). In addition to increasing total runoff, the installation of tile drainage also changes the primary runoff pathway from surface to subsurface drainage. Surface runoff can be substantially reduced due to the increased rate of subsurface drainage, often occurring only when rainfall or snowmelt exceeds the soil infiltration rate or when frozen soil prevents the downward movement of surface water (Skaggs et al., 1994). Although surface runoff remained an active pathway in TD, generating 40% of the total field drainage, there was a 49% reduction in surface runoff relative to UD.

Table 2. Mean annual runoff, nutrient and sediment loads from the tiled (surface + tile) and untiled (surface only) fields, March 29, 2018-December 31, 2020, NNYADP trials.

	Runoff	SRP	Total P	Nitrate-N	Amm-N	Total N	TSS
	in/yr	---------------------------lb/ac/yr---------------------------					
Tiled Field	7.62	0.019	0.167	11.02	0.30	12.11	126.2
Untiled Field	6.05	0.010	0.214	2.56	0.27	4.35	127.4
Tiled – Surface runoff	3.08	0.016	0.141	0.54	0.24	1.17	116.9
Tiled – Tile drainage	4.54	0.003	0.027	10.48	0.06	10.93	9.3

Much of the increase in drainage from TD was due to tile drainage during baseflow periods and tile flow increases in response to small to moderate rainfall events that did not generate surface runoff. However, during larger runoff events that produced surface runoff in UD, total drainage rates tended to be very similar between the two fields. In some cases, subsurface drainage was sufficient to prevent the occurrence of any surface runoff in UD. During the majority of the largest events, the primary difference between the two fields was that the drainage from TD was divided similarly between surface runoff and tile flow.

Throughout the study, the nongrowing season (NGS; October 16–April 15) was consistently the dominant period of runoff from both fields (Figure 1). Despite 54% of the total precipitation occurring during the growing seasons over the three-year monitoring period, 79% and 88% of the drainage occurred during the NGS in UD and TD, respectively. In TD, 91% of surface runoff and 86% of tile flows occurred during the NGS. Limited evapotranspiration due to cold temperatures and a lack of crop uptake, snowmelt events, and periods of frozen soil with limited subsurface drainage capacity provide highly favorable conditions for the generation of large runoff events.



nd tile-drained (TD) fields, March 29, 2018-December 31, 2020, NNYADP trials.

Phosphorus Export

Despite the higher rates of total field drainage from TD, the field exported 22% less total P (0.167 lb/ac/yr) than UD (0.214 lb/ac/yr) (Table 2). There was considerable variation from year to year for both UD and TD, with annual total P exports from TD ranging from 0.050 lb/ac in 2019 to 0.214 lb/ac in 2018. In UD, the lowest total P load was observed in 2020 with 0.084 lb/ac exported while the highest losses occurred in 2019 with an annual load of 0.232 lb/ac. These levels are at or below the low range of those reported in the scientific literature (Gilliam et al., 1999; King et al., 2015).

In contrast to total P, DRP losses were nearly two times greater from TD than UD. However, exports were very low from both fields and losses of this magnitude are unlikely to have an impact on surface water quality. A concern regarding the use of tile drainage is that the proportion of total P as DRP could increase, even if total P losses were similar. This could have negative water quality implications because DRP is the form of P that is immediately available for biological uptake. Although this initially appears to have occurred given the difference in export rates between the two fields, DRP comprised 11% of total P in both surface runoff and tile drainage from TD. Additionally, tile flows from TD were responsible for just 16% of the field's DRP export.

The reduced risk for both DRP and total P loss from the tiles is demonstrated by the flow-weighted mean (FWM) concentrations, which represent the average drainage water quality throughout the study (Table 3). The greater concentrations of total P and DRP during individual runoff events that were frequently observed in surface runoff from both TD and UD than in tile drainage is evident in these FWM concentrations. The DRP and total FWM concentrations in the tile drainage in TD were 0.003 mg/L and 0.026 mg/L, respectively. In contrast, the surface runoff FWM concentrations for UD and TD ranged from 0.007 mg/L to 0.023 mg/L for DRP and 0.154 mg/L to 0.204 mg/L for total P.

Table 3. Nutrient and sediment flow-weighted mean concentrations from each field and by runoff pathway in the tiled field, March 29, 2018-December 31, 2020, NNYADP trials.

	DRP	Total P	Nitrate-N	Amm-N	Total N	TSS
	---------------------------------mg/L-------------------------------					
Tiled Field	0.011	0.098	6.46	0.17	7.09	73.9
Untiled Field	0.007	0.154	1.85	0.19	3.14	92.0
Tiled - Surface	0.023	0.204	0.78	0.34	1.70	169.6
Tiled - Subsurface	0.003	0.026	10.30	0.06	10.74	9.1

Concentrations of 0.010 mg/L of DRP and 0.020-0.030 mg/L of TP in lakes and rivers are commonly cited thresholds for an increased risk of harmful algal blooms (Gilliam et al., 1999). However, as drainage waters will be diluted as they flow into receiving water bodies, the U.S. Environmental Protection Agency recommends that drainage waters not exceed 0.100 mg/L of total P. At 0.003 mg/L SRP and 0.024 mg/L total P, the FWM concentrations in tile drainage flows were not only below the recommendation for drainage waters, but also at or below the level of concern for accelerated eutrophication in lakes and rivers. Consequently, the tile drainage water would be unlikely to have a negative impact on water quality with respect to P levels. Additionally, although surface runoff from TD exceeded the recommended levels, the field-scale total P FWM of 0.098 mg/L was below the EPA threshold.

While DRP FWM concentrations were low in UD, the total P FWM concentrations exceeded the EPA guideline. The elevated total P FWM concentrations in surface runoff from both fields relative to what was observed in tile drain flows indicates that surface runoff had a greater ability to generate P loss than the tiles. The substantially lower field-scale total P FWM from TD demonstrates that while the increased subsurface drainage capacity of TD resulted in greater total runoff, the average P concentration in the drainage waters was reduced.

The increased P and TSS concentrations in surface runoff from TD are likely due in part to occurrence of surface runoff in only the most severe storms because of the field's increased subsurface drainage capacity. Erosion and nutrient exports often increase with the severity of the storm due to the higher erosive capacity of the rainfall and runoff. The less severe events that resulted in surface runoff in UD but not TD likely generated runoff with lower P and TSS concentrations and those events had a dilution effect on the FWM concentrations when all events were combined. With these smaller events contributing to tile drainage volume, but not surface runoff in TD, considering the combined impact of both pathways in TD provides a more complete understanding of the impact on surface water quality. When considering field-scale exports, total P and TSS FWM concentrations are lower in TD than UD and DRP FWM concentrations are similar.

The reduction in overall P loss from TD is likely a result of two factors. First, surface runoff greatly increases the risk of erosion, which can detach and transport P-enriched sediments and organic matter as it flows over the field surface. Additionally, once surface runoff is initiated, there is little opportunity for the dissolved P in the water to interact with the soil. In contrast, the soil profile, particularly the subsoil which tends to have lower P levels, can act as a filter for subsurface drainage water as it percolates downward before ultimately reaching the tile lines. While certain factors, such as preferential flow pathways and runoff events immediately following nutrient applications, can increase the risk of P loss through tile drains, overall, there have been low rates of P transport in tile flow during this study.

Nitrogen Export

The increased subsurface drainage in TD resulted in substantially greater transport of nitrate-N and total N relative to UD (Table 2). Nitrate-N and total N exports by TD were 11.02 lb/ac/yr and 12.11 lb/ac/yr, respectively, as compared to 2.56 lb. nitrate-N/ac/yr and 4.35 lb. total N/ac/yr from UD. Tile drainage produced 95% of nitrate-N and 90% of total N losses from TD. These results are consistent with previous drainage research, in which increased subsurface drainage via tile systems has consistently resulted in greater nitrate loss (Gilliam et al., 1999).

The FWM concentrations of nitrate-N from TD and UD were below the EPA drinking water standard of 10 mg/L (Table 2). However, tile drainage from TD exceeded this standard with a nitrate-N FWM concentration of 10.74 mg/L. In both 2018 and 2019, individual event sample concentrations for tile drainage in TD and surface runoff from both fields were substantially higher during October and November than any other period (minimal flow occurred in fall 2020), indicating that particular attention should be paid to this time period with respect to N mitigation efforts.

The increased rates of N loss from TD can have a negative impact on water quality and human health and also represent an economic loss to the farm. Increased retention of N in the soil could help offset the need for commercial N fertilizer purchases. Implementing practices such as cover crops and drainage water management that have been shown to immobilize and retain residual soil N after the growing season until crop growth and nutrient uptake resumes the following spring could help mitigate these N loss concerns in tiled fields.

Nutrient Budgets

Corn silage yields were greater in TD than UD in 2018 and 2020. Delayed planting in 2019 resulted in substantial yield reductions in both fields, leading to much lower rates of nutrient uptake (Table 4). Once both fields were planted, there was limited precipitation and thus TD had no crop growth benefit over UD. While tile drainage can result in significant yield benefits due to improved field trafficability and earlier planting, this potential advantage was not realized as both fields were planted and harvested on the same day in all three years. Crop uptake of P and N exceeded the application rates in 2018 and 2020. The fields have similar fertility (4.0 lb/ac Morgan P; 3.0% organic matter), therefore the higher average yields and nutrient uptake in TD are likely due to the benefits of tile drainage to the growing corn crop.

Table 4. Total P and N inputs, corn yield, crop uptake, and percentage of P and N lost in runoff relative to nutrient applications for TD and UD in 2018 and 2019, NNYADP trials.

Year	Field	P inputs lb/ac	N inputs lb/ac	Corn yield DM ton/ac	P uptake lb/ac	N uptake lb/ac	P Loss %	N Loss %
2018	TD	16.1	89.0	8.6	34.3	206.0	1.3	11.3
2018	UD	16.1	89.0	6.6	26.4	158.5	1.4	4.0
2019	TD	26.4	183.5	4.0	17.7	103.1	0.2	6.2
2019	UD	26.4	183.5	4.9	25.6	126.1	0.3	2.6
2020	TD	36.4	129.2	9.7	42.7	232.9	0.5	10.8
2020	UD	36.4	129.2	9.1	47.3	174.7	0.2	3.0

The proportion of applied P lost in runoff has been similar for both fields in all three years, ranging from 0.2% to 1.4% for UD and 0.2% to 1.3% for TD. The higher proportion of applied P lost in 2018 is due to a higher loading of P in runoff combined with the lowest rates of P additions in all three years. The losses occurred prior to nutrient additions in 2018 and correspond to the year with the highest rate of TSS loss, indicating the losses are not a result of nutrient application, but of erosion-induced soil-bound P.

In 2019, there were also substantially higher N application rates to the two fields relative to 2018 and 2020 and the lowest rates of crop removal. Despite this imbalance, the percent of applied N lost was the lowest of all three years. While it is important to balance crop need with input, these data demonstrate the influence that weather patterns can have on nutrient losses.

Conclusions:

During the three years of monitoring, TD generated more total runoff volume than UD, but experienced much lower rates of surface runoff than were observed in UD. This reduction in surface runoff has resulted in lower rates of TSS and total P exports from TD compared to UD. Despite generating approximately half of the total runoff from TD, tile drainage flows contributed just 16% total P exports from TD.

In contrast to P, TD lost much higher rates of N, with the majority of the losses occurring as nitrate in tile drainage. The majority of N losses from both fields occurred in the NGS, demonstrating the need to implement practices such as cover crops that promote the retention of residual soil N at the end of the growing season. Limiting N losses is necessary to achieve water quality goals as well as improving farm profitability.

Overall, tile drainage continues to have mixed water quality impacts. The reductions in exported P and sediment are promising and can have important implications for the P reduction efforts ongoing in the Lake Champlain Basin. However, the improved P retention comes at the cost of an increased risk for N mobilization and future research is needed to identify practices, or, more likely, suites of practices, that can improve these water quality parameters simultaneously.

Outreach:

Results from this project were presented at the 2020 virtual joint annual meeting of the Soil Science Society of America, Crop Science Society of America, and American Society of Agronomy; the New York State Agribusiness Association & Certified Crop Advisor Advanced Training, December 1, 2020; Miner Institute/Cornell Cooperative Extension Crop Congress, February 24, 2021.

Next Steps:

Monitoring efforts at the trial fields will continue through 2021. Long-term data collection is crucial when evaluating the impacts of management practices on nutrient budgets and water quality as results can vary significantly with changing weather patterns and infrequent, extreme events. Continued monitoring of these sites will enhance our understanding of the impacts of tile drainage on water quality and farm economics and provide insight for the development and refinement of such conservation and production management tools as the statewide New York Phosphorus Index. After the 2021 monitoring period, the implementation of additional conservation practices to enhance nutrient mitigation at this site will be considered following discussion with the cooperating farmer and the gathering of input from other New York State stakeholders.

Acknowledgments:

We thank Adirondack Farms for the opportunity to establish a research site at these fields and its ongoing cooperation in our monitoring efforts. We would also like to thank the Northern New York Agricultural Development Program for funding this research.

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*. A Master's thesis will be submitted to the University of Vermont for publication by Leanna Thalmann in 2021.

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