Northern New York Agricultural Development Program
2019 Project Report

Quantifying Long-Term Agronomic and Water Quality Impacts of Tile Drainage in Northern New York Corn Fields, Year 2

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, Leanna Thalmann, Mark Haney, and Catherine Ballard, MS
- Mike Contessa, Champlain Valley Agronomics, Peru, NY

Cooperating Producer:

- Jon Rulfs, Adirondack Farms LLC, Peru, NY

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 greater drainage water export and N mineralization rates compared to undrained soils. However, 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 due to the fact that 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 areas. 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 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 0.32 mm of runoff and composited into a 15-L plastic container. Composite samples were collected two times per week and analyzed for soluble reactive P (SRP), total P (TP), nitrate-N, ammonium-N, total N (TN) and total suspended solids (TSS; an estimate of erosion).

Nutrient and sediment loads 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 two-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 were calculated for TD by dividing the total mass lost from each pathway by the corresponding total volume. The percent of precipitation recovered in drainage was calculated by dividing total rainfall by the total drainage from each field. Correlation analysis was performed on individual event sample concentrations using the Spearman rank order correlation test with significance declared at $\alpha = 0.05$.

The fields were left fallow following corn harvest in 2017. Liquid dairy manure was applied to the fields at a rate of 20 tons/ac on May 24, 2018. On June 24, 2019, 20 tons/ac of semi-solid dairy manure and 200 lbs/ac of 8-20-30 (N-P-K) fertilizer were applied and immediately incorporated with a disk harrow. Corn for silage was planted on May 26, 2018, and June 25, 2019, with 8 and 12 gal/ac of 24-8-0 (N-P-K) starter fertilizer, respectively. Corn was planted later than usual in 2019 due to challenging weather conditions that delayed field activities. A sidedress N application of 25 gal/ac 32% urea ammonium nitrate (UAN) solution occurred on August 5, 2019. Corn was harvested on

September 28, 2018, and November 25, 2019, and forage samples were collected from each field at harvest.

The data reported here consist of runoff events between March 28, 2018, and January 1, 2020. A large runoff event (2.9 in 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.

Results and Discussion:

Field Hydrology

Mean annual runoff from TD (surface + tile) was 16% greater than UD (surface), with 8.79 in/yr and 7.56 in/yr of linear runoff from each field, respectively (Table 1). Increases in total field drainage by 10-25% are common when pattern tile drainage is installed in agricultural fields (King et al., 2015). In addition to increasing total runoff, tile drainage also changes the primary runoff pathway. Surface runoff can be substantially reduced, 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).

Table 1. Mean annual runoff, nutrient and sediment loads from the tiled (surface + tile) and untiled (surface only) fields, March 28, 2018-January 1, 2020, NNYADP trials.

	Runoff	SRP	Total P	Nitrate-N	Amm-N	Total N	TSS
	in/yr	------------------------------lbs/ac/yr------------------------------					
Tiled Field	8.79	0.018	0.187	11.57	0.40	12.95	130.22
Untiled Field	7.56	0.010	0.230	3.86	0.31	5.33	178.21
Tiled - Surface	4.13	0.015	0.173	0.69	0.33	1.46	120.57
Tiled - Tile	4.66	0.002	0.014	10.88	0.07	11.49	9.66

Although surface runoff remained an active pathway, generating 47% of total runoff from TD, there was a 45% reduction in surface runoff relative to UD. Despite the differences in runoff pathways between the fields, the runoff generated during most events remained quite similar (Figure 1). The percentage of total precipitation recovered in drainage was similar between fields, with 26% and 23% recovered in TD and UD, respectively.

Throughout the study, the nongrowing season (NGS) from November 1 to April 30 was the dominant period of runoff. This pattern is illustrated by the long plateaus in runoff accumulation in Figure 1 during the two growing seasons. Despite 56% of the total precipitation occurring during the growing seasons, both fields generated 86% of their total runoff during the NGS. In TD, 91% and 81% of surface runoff and tile drainage, respectively, occurred during the NGS.

The NGS has been identified as a critical period for runoff and nutrient transport in northern humid climates and recent research in the northern US and Canada has been targeted at enhancing the understanding of the unique runoff and nutrient transport dynamics in these regions (Liu et al., 2019). Limited evapotranspiration due to cold temperatures and a lack of crop uptake, melting snowpacks, and periods of frozen soil and limited subsurface drainage capacity provide highly favorable conditions for the generation of substantial runoff events.

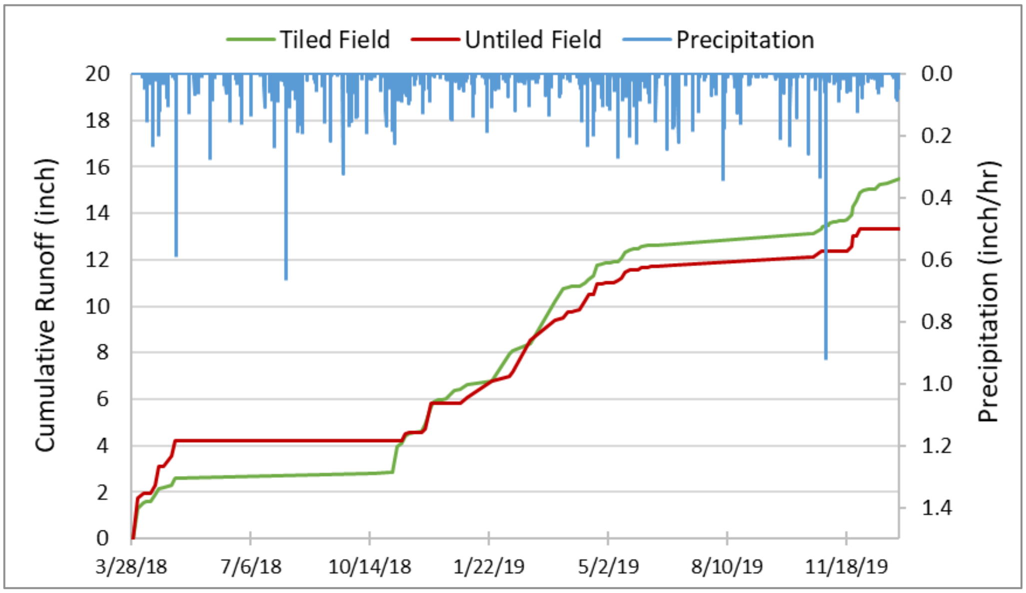

Figure 1. Precipitation and cumulative runoff from the tiled and untiled fields, March 28, 2018-January 1, 2020, NNYADP trials. Data collection to January 1, 2020, shows after the tick mark line.

Phosphorus Export

Throughout the study, low levels of P were exported from TD and UD (Table 1). The undrained field exported 0.010 lbs/ac/yr of SRP and 0.230 lbs/ac/yr of TP. While TD lost higher levels of SRP (0.018 lbs/ac/yr), it generated 19% less TP exports (0.187 lbs/ac/yr) than UD. Phosphorus losses followed a similar distribution as runoff, with 89% and 90% of TP losses occurring during the NGS for TD and UD, respectively. Overall, SRP exports were extremely low from both fields and total P losses were in the low range of those reported in the scientific literature (Gilliam et al., 1999; King et al., 2015).

Although tile drainage was responsible for 53% of the total drainage, only 13% of SRP and 8% of TP losses occurred via this runoff pathway. The low levels of P in the tile drainage flows were reflected by the very low flow-weighted mean (FWM) concentrations of SRP and TP (Table 2). Concentrations of 0.010 mg/L of SRP and 0.020 mg/L of TP in lakes and rivers are commonly cited threshholds 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 EPA recommends that drainage waters not exceeed 0.100 mg/L of TP. At 0.002 mg/L SRP and 0.015 mg/L TP, the FWM concentrations in tile drainage flows were not only below the recommendation for drainage waters, but also below the level of concern 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 TP FWM of 0.095 mg/L was below the EPA threshold.

While SRP FWM concentrations were low in UD, the TP FWM concentrations exceeded the EPA guideline. The elevated TP 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 TP 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.

Table 2. Nutrient and sediment flow-weighted mean concentrations from each field and by runoff pathway in the tiled field, March 28, 2018-January 1, 2020, NNYADP trials.

	SRP	Total P	Nitrate-N	Amm-N	Total N	TSS
	mg/L					
Tiled Field	0.009	0.095	5.88	0.21	6.58	66.19
Untiled Field	0.006	0.146	2.44	0.20	3.37	112.68
Tiled - Surface	0.018	0.205	0.82	0.39	1.73	142.62
Tiled - Subsurface	0.002	0.014	10.44	0.07	11.03	9.26

The reduction in overall P loss from TD is likely a result of two primary 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. This was evident in this study, with 37% more TSS lost from UD than TD and surface runoff producing 93% of losses from TD. Total P and TSS loads among all pathways were significantly correlated ($r_s = 0.78$, $P < 0.0001$), indicating that TP loads were being driven predominantly by TSS. Although soil test P (STP) concentrations (Morgan extractant) for both fields were 4.5 mg/kg, within the medium range according to Cornell University guidelines, the increased risk of TP loss with eroded soil was still evident. Given the strong relationship between TSS and TP, increasing the STP would further increase the risk of P loss, particularly in UD which produced more surface runoff and TSS loss.

Not only does surface runoff have an increased risk of erosion-induced P losses, but once the surface runoff is initiated, there is little opportunity for the particulate or dissolved P in the water to interact with reactive surfaces which could mitigate the P concentrations. In contrast, the soil profile, particularly the subsoil which tends to be lower in P, can act as a filter for drainage water that percolates downward before reaching the tile lines. While certain factors, such as preferential flow pathways or runoff events immediately following nutrient applications can increase the risk of P loss to tile drainage, there has been little P observed in tile drainage water 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. Nitrate-N and total N exports by TD were 11.57 lbs/ac/yr and 12.95 lbs/ac/yr, respectively, as compared to 3.86 lbs nitrate-N/ac/yr and 5.33 lbs TN/ac/yr from UD. Tile drainage produced 94% of nitrate-N and 89% of TN 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-N 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 slightly exceeded this standard with a nitrate-N FWM concentration of 10.44 mg/L. In both 2018 and 2019, event concentrations for tile drainage in TD and surface runoff from both fields were substantially higher during October and November than any other period, 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 also represents 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

The challenging growing season in 2019 was reflected in the substantially reduced corn yields compared to 2018, particularly for TD, and subsequently much lower rates of nutrient uptake (Table 3). While tile drainage can result in significant yield benefits due to earlier field trafficability, this potential advantage was not realized as both fields were planted on the same day. Tile drainage can also improve yields during wet growing seasons, but only 4 inches of rain fell from planting through September 30, 2019, so the enhanced drainage capacity in TD was unlikely to provide a significant benefit. An additional 2 inches of rain fell during October, though crop yield would have been largely determined by this point.

Table 3. 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	15.1	44.8	8.6	46.9	206.4	1.4	11.8
2018	UD	15.1	44.8	6.6	36.0	158.4	1.4	4.0
2019	TD	69.2	273.5	4.03	17.7	103.1	0.18	4.5
2019	UD	69.2	273.5	4.92	25.6	126.1	0.28	1.3

Nutrients were applied at a rate more closely aligned with expected crop removal in 2019 than the previous year. In 2018, crop uptake greatly exceeded P inputs. While this can be beneficial in fields with excessive levels of P, the STP levels are low enough in these fields (4.5 mg/kg) that a negative P balance is not desirable. Despite supplying 4.6 times greater P through manure and commercial fertilizer inputs than in 2018, TD and UD lost 85% and 13% less TP, respectively, in 2019. This is reflected in the extremely low percentages of P loss ([P lost in runoff/P applied]*100), with only 0.18% lost from TD and 0.28% from UD.

In 2019, there were also substantially higher N application rates to the two fields relative to 2018. Although the total N inputs substantially exceeded N uptake, 74% of the N was supplied as semi-solid manure. According to Cornell University guidelines, only 25% of the N in the manure will be plant available in the first year. Therefore, only 122.0 lbs/ac of plant available N (PAN) was applied to each of the fields, a very similar rate to crop removal. As with P, the percent of N lost relative to application rates dropped in 2019.

Conclusions:

During the first two years of the study, 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 TP exports from TD compared to UD. Despite generating approximately half of the total runoff from TD, tile drainage flows contributed just 15% TP exports from TD.

In contrast to P, TD lost much higher rates of N, with the majority of the losses occurring as nitrate-N in tile drainage. Both fields exported greater quantities of N in 2019 as compared to 2018 due to greater precipitation and runoff rates, as well as a shortened growing season that reduced crop yield and uptake of N. The majority of N losses from both fields occurred in October and November, 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 were presented at the Miner Institute Dairy Day on December 11, 2019, and at the joint annual meeting of the Soil Science Society of America, Crop Science Society of America, and American Society of Agronomy in San Antonio, TX on November 11, 2019. Results were used to inform the revision of the New York Phosphorus Index by Cornell University's Nutrient Management Spear Program.

Next Steps:

Monitoring efforts at the trial fields will continue through 2020. 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 add data to such conservation and production management tools as the statewide New York Phosphorus Index. Although there will be no significant changes to how the research fields are managed in 2020, the long-term dataset will provide valuable insight into the identification of future research priorities that will ultimately lead to a more comprehensive set of best management practices for improving water quality.

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*.

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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