PRELIMINARY RESULTS REPORT

COMPARISON OF PHOSPHORUS LEACHING IN TILE DRAINAGE BETWEEN TWO CROPPING SYSTEMS IN A CLAY SOIL

Project Research Team:

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Ontario Ministry of Agriculture Food and Rural Affairs: D. Nemeth, K. McKague, R. Brunke

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Executive Summary:

The report summarizes the preliminary soil and water quality results from the two agricultural Best Management Practice (BMP) verification research sites located in the Jeannettes Creek subwatershed of the Thames River. The purpose of the research report and the monitoring conducted at the sites is to answer the following questions:

1. Do runoff volumes in tile drains differ between a no-till site with a cover crop and a tilled site with no cover crop in a Brookston clay soil?

2. Do dissolved and total phosphorus concentrations and loads in subsurface tile drainage differ between a no-till site with a cover crop and a tilled site with no cover crop in a Brookston clay soil?

The Lower Thames Valley Conservation Authority (LTVCA) partnered with two Jeannettes Creek farmers to conduct high frequency water quality sampling during runoff events and to collect climate data, soil data, and land use data over an 18 month period (January of 2017 - June of 2018). The collected samples were analyzed by the University of Guelph Ridgetown Campus and the statistical analysis and writing of the report was completed by Dr. Merrin Macrae and Dr. Janina Plach from the University of Waterloo. The project was also supported by Ontario Ministry of Agricultural and Rural Affairs (OMAFRA) water engineers, whom assisted with project design and instrumentation.

In Conclusion, concentrations and loads of Soluble Reactive Phosphorus (SRP) in tile drains were not significantly different between fields under two different management systems during the study period (2017-2018). In contrast, chemical concentrations of tile Total Phosphorus (TP) and Total Suspended Sediments (TSS) in the collected water samples were significantly different between sites, where TP and TSS were elevated at the MA (tilled site) relative to the MB (no till with cover crops site). The ratio of SRP:TP in the tiles were also significantly different between farms, with SRP:TP ratios lower at the MA (tilled site) (i.e., indicator of greater particulate P). However, despite these differences in concentrations, the differences in overall tile flow, and loads of SRP, TP, and TSS were all insignificant between farms at the annual scale. This largely reflects the low number for annual comparison (n = 4), and indicates a need for longer-term comparison of water quantity and water quality at these sites. It is also recommended that future research at these sites should include measurements of overland flow as well as characterization of subsurface soil properties to advance understanding of the timing and the controls of edge-of-field runoff and phosphorus loss in these clay loam sites.

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Research Team:

University of Waterloo: M. Macrae, J. Plach, W. Pluer
- Roles: project design, interpretation, writing of final report

Lower Thames Valley Conservation Authority: C. Little, A. Pratt
- Roles: sampling, data compilation and interpretation, writing of final report

University of Guelph: I. O'Halloran
- Roles: lab analyses

Ontario Ministry of Agriculture Food and Rural Affairs: D. Nemeth, K. McKague and R. Brunke
- Roles: project design, soil sampling, and instrumentation of sites

1.1 Background and Project Overview

Phosphorus losses from agricultural watersheds in the Great Lakes region are a major research area at this time due to algal blooms in the Lake Erie Basin. Both surface runoff and tile drains in agricultural fields have been identified as major pathways for phosphorus loss (P). Work done in Ohio and at the southwestern end of Lake Erie has suggested that dissolved (soluble) reactive P (SRP or DRP) losses through tile drainage are responsible for blooms in Lake Erie, whereas recent work in Ontario suggests that surface runoff can be a more significant pathway. At present there is an incomplete understanding of how runoff and P loss can vary across different Ontario regions and cropping systems, and, if/how this may be impacted by best management practices (BMPs). Recent work in Ontario has demonstrated low edge-of-field losses from farms in southwestern Ontario in which "stacked" BMPs are used (e.g. minimum rotational till, subsurface P placement, cover crops, nutrient management). However, the specific role of individual management practices is unclear. This project was a partnership among the Lower Thames Valley Conservation Authority, the Ontario Ministry of Agriculture Food and Rural Affairs and researchers at two Ontario universities to investigate the individual and combined roles of specific BMPs to reduce P losses at sites across Ontario.

Ongoing water quality monitoring work in midwestern Ontario has been conducted at fields under corn-soy-wheat rotations, where farmers employ BMPs including nutrient management, subsurface P placement or a conservation rotational till when P is broadcast following winter wheat, and cover crops are also used following winter wheat. Additional monitoring work has been conducted in Essex with the Essex Region Conservation Authority (ERCA), which explores P loss in surface and tile drainage from a Brookston clay field that experiences tillage with no cover crops, under a corn-soy rotation. The University of Waterloo's work to date has shown that while tile drainage is the dominant runoff pathway from the cropped fields in midwestern Ontario, surface runoff is the dominant P pathway (e.g. Van Esbroeck et al., 2016; Plach et al. 2019). In contrast, in clay soils that experience tillage, tiles represent the dominant hydrologic and P pathway (Plach et al., 2019). While this is in part linked to hydrology and preferential transport into tile drains (Macrae et al., 2019), combined with soil geochemistry (Plach et al., 2018), the impacts of land management practices on edge-of-field P losses in tile drainage are unclear. Until now, we did not have a clay field under corn-soy-soy-winter wheat rotation with cover crop use following corn, soy, and wheat (spring termination). This presented a significant gap in the Ontario research. This project has enabled us to explore the impacts of these management practices in a clay soil, which will be compared to sites with tillage and less frequent cover crop use (red clover following wheat, fall termination). Furthermore, the data can be compared to similar land management practices and water quality results from Ontario silt loam and clay loam fields in the future. The funded work permitted the instrumentation and monitoring of P in tile drainage over an 18 month period, and has facilitated the development of longer-term research sites, on which new research can continue to be conducted by our team (MA, MB sites).

1.2 Research Objectives:

The purpose of the preliminary results report is to address the following research questions:

1. Do runoff volumes in tile drains differ between a no-till site with a cover crop and a tilled site with no cover crop?
2. Do dissolved and total phosphorus concentrations and loads in tile drainage differ between a no-till site with a cover crop and a tilled site with no cover crop?

1.3 Study Site Locations:

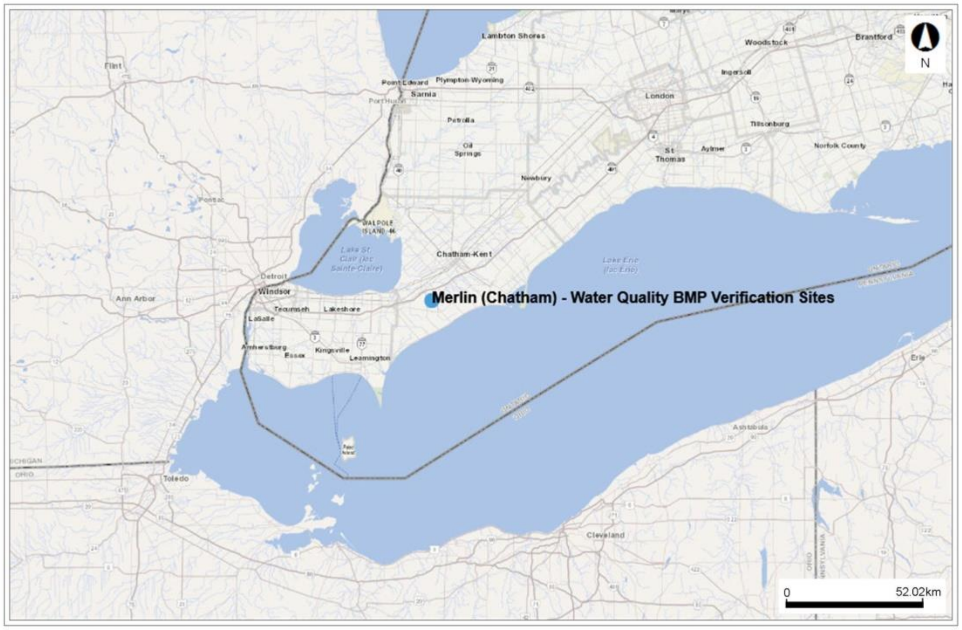

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Figure 1.1: Map identifying the location of the MA and MB study sites within Lake Erie basin.

1.4 Study Sites & Methods

Study Sites and Their Management Systems

This study was conducted in Merlin (Chatham-Kent), Ontario on two adjacent fields (Figure 1.1). The fields are located in the Thames River watershed, within the Lake Erie basin. Both fields were under corn-soy-soy-wheat rotation, but one field (MA) was tilled following P application, and the second site (MB) experienced no tillage and had more frequent use of cover crops in the non-growing season (NGS) (Figure 1.2). Although the two fields are under the same crop rotation, there are multiple practices that vary between the MerlinA (MA) and MerlinB (MB) sites, including fertility, tillage, and planting practices (Tables 1.1, 1.2, 1.3). The MA system involves surface broadcasting phosphorus and incorporating fertilizer through tillage practices. The MA system also utilizes tillage as a method to manage crop residue. The MB crop production system is designed to ensure cover crops are planted after each annual crop. Furthermore, at the MB site, phosphorus applications are generally surface broadcast onto a living cover crop and fertilizers are not incorporated through the use of tillage practices. The MB system also involves drill seeding soybeans and corn into cover crops at planting, a practice often referred to as “planting green”.

Table 1.1 Preferred/Ideal crop production and land management at the Merlin A (MA) and Merlin B (MB) sites.

Merlin A (MA) Crop Production System (C-S-S-WW)				
Rotation Crop	**Corn (C)**	**Soybeans (S)**	**Soybeans (S)**	**Winter Wheat (WW)**
Planting Practices	Corn Planter	No-Till Drill	No-Till Drill	No-Till Drill
Fertility	After WW harvest, surface broadcast MAP and Potash a rate of 250 lbs/acre (8-32-46). Incorporate within 48hrs.	No Fertilizer	No Fertilizer	24 hours prior to WW planting, surface broadcast MAP and Potash at 150 lbs/acre (8-32-46).
	Band MAP and Potash (8-32-16) at 150 lbs/acre when planting C.			Surface Broadcast liquid nitrogen on WW during Spring at 110 lbs/acre (28-0-0).
	Side dress C with liquid nitrogen at a rate of 165 lbs/acre (28-0-0).			

Tillage	Primary tillage occurs after WW harvest. 1 pass with disk, 2 passes with vertical tillage implement, 2 passes with land leveler.	No-Till	No-Till	No-Till
Cover Crop	N/A	N/A	N/A	Frost-Seed Red Clover. Fall tillage termination.

Merlin B (MB) - Crop Production System (C-S-S-WW)				
Rotation Crop	**Corn (C)**	**Soybeans (S)**	**Soybeans (S)**	**Winter Wheat (WW)**
Planting Practices	No-Till Drill into 18 Species Cover Crop (CC)	No-Till Drill into Cereal Rye CC	No-Till Drill into Cereal Rye CC	No-Till Drill
Fertility	After WW harvest, surface broadcast MAP and Potash at rate of 200 lbs/acre (0-50-50) on to cover crop, during the Fall.	No Fertilizer	No Fertilizer	24 hours prior to WW planting, surface broadcast MAP and Potash at 250 lbs/acre (0-40-60).
	Surface broadcast Ammonium Sulfate (AMS) at rate of 250 lbs/acre (21-0-0) on to cover crop during Spring pre-planting.			Surface Broadcast liquid nitrogen on WW during Spring at 33 gal/acre (28-0-0).
	Side dress C with liquid nitrogen at a rate of 51 gal/acre (28-0-0).			
Tillage	No-Till	No-Till	No-Till	No-Till

Cover Crop	Cereal rye planted after C	Cereal rye planted after S	Winter Wheat planted after S	18 species cover crop planted after WW

Actual Implemented Crop Production Systems over the study period

Over the duration of the study, unforeseen challenges caused variations in the implementation of the planned crop production systems on each field. These changes are outlined in the following sections.

Table 1.2 Modified crop production and land management at the Merlin A (MA) site over the study period.

Merlin A (MA) - Observed Crop Production Practices (Study Period: 2016-2018)			
	2016	**2017**	**2018**
***Crop Planted**	Soybeans	Soybeans	Soybeans
***Tillage**	Primary tillage occurred after WW harvest and subsurface tile lateral installation. 2 pass with disk, 2 passes with vertical tillage implement, 2 passes with land leveler. Secondary tillage occurred in spring of 2016, 1 pass with vertical tillage implement.	1 pass with vertical tillage implement 48 hrs prior to planting.	1 pass with vertical tillage implement in fall of 2017. 1 pass during spring of 2018 with vertical tillage implement to incorporate fertilizer.
***Fertility**	After WW harvest, surface broadcast MAP and Potash at rate of 250 lbs/acre (8-32-46). Incorporate within 48hrs.	No Fertilizer	Surface broadcast MAP and Potash at rate of 200 lbs/acre (8-32-46), during the Spring. Incorporate within 24hrs.
Cover Crop	Red Clover terminated during 2015 fall.	N/A	N/A
Yield (bu/acre)	54	41	55

The cropping practices that occurred at the MA site over the duration of the study differed from the participating farmers preferred rotation and management system (outlined in Table 1.1). The installation of new subsurface tile drainage laterals following wheat harvest in 2015, caused the farmer to alter his crop production practices from 2016-2018. Trenching and excavation work were required in the field to install the additional subsurface drainage. As a result of the soil being disturbed, the farmer had to increase the frequency of primary and secondary tillage passes to level the ground and achieve ideal soil planting conditions during the springs of 2016-2018 prior to Soybean planting. Furthermore, the poor field and soil conditions during the spring of 2016 caused the farmer to plant Soybeans, instead of Corn. This is an additional limitation of the comparative analysis of the system, as the farmer applied fertilizer rates in 2015 for a 2016 corn crop; however, soybeans were planted instead. Furthermore, it led to the farmer planting soybeans in three consecutive growing seasons.

It is possible that the increased tillage, modified rotation, and the settling of soil in the trenches that were excavated to install the subsurface tile drainage laterals, led to an increased TSS and particulate phosphorus load at the MA site. Thus, the initial TSS, TP, and DRP loads that have been observed to date, may not be representative of the normal crop production system of the MA site.

Table 1.3 Modified crop production and land management at the Merlin B (MB) site over the study period.

Merlin B (MB) - Observed Crop Production Practices (Study Period 2016-2018)			
	2016	**2017**	**2018**
Crop Planted	Corn	Soybeans	Soybeans
Tillage	No-Till	No-Till	No-Till
Fertility	After WW harvest, surface broadcast MAP and Potash a rate of 200 lbs/acre (0-50-50) on to established cover crop.	No-Fertilizer	No-Fertilizer
	Surface broadcast Ammonium Sulfate (AMS) at rate of 250 lbs/acre (21-0-0) on to cover crop during spring pre-planting.		
	Side dress C with liquid nitrogen at a rate of 51 gal/acre (28-0-0).		
Cover Crop	18 Species Cover Crop prior to C	*No CC prior to Soybeans	Cereal Rye CC prior to Soybeans
Yield(bu/acre)	*80	51	60

Over the duration of the study, there were minimal variations in the observed production practices at the MB site from the planned management system. However, the MB site experienced a failed corn crop during the 2016 growing season (Table 1.3). The failed crop may have reduced the nutrient use efficiency of the applied fertilizer. Furthermore, it delayed the farmer's corn harvest, which created a scenario where the conditions were not appropriate to plant a cereal rye cover crop during the Fall of 2017.

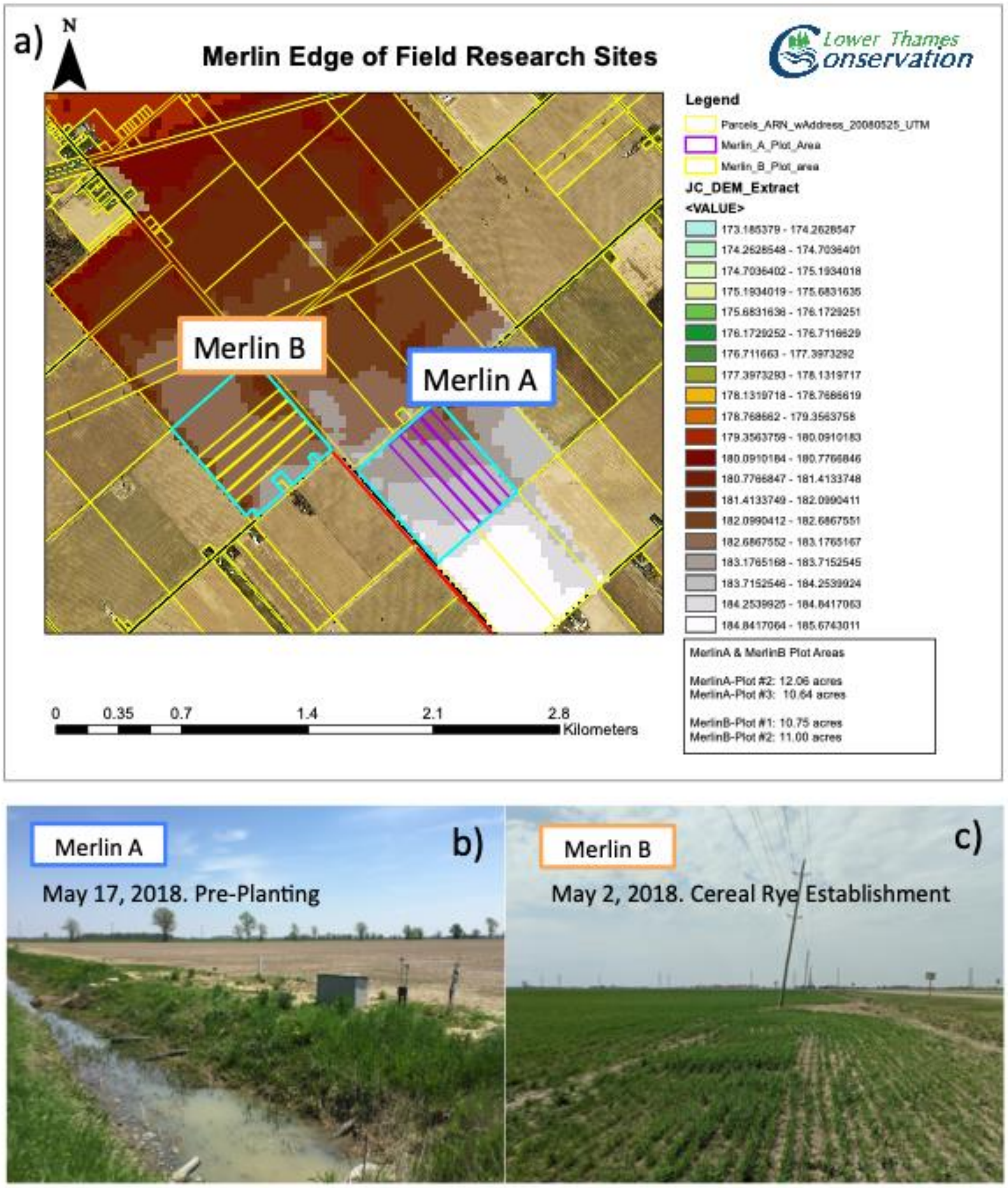

Figure 1.2: Overview of project. Map showing the location of the two adjacent study fields in Chatham, Ontario; Merlin A (Plot 2 & 3) and Merlin B (Plot 1 & 2) (a), Merlin A (MA) site with tillage and no cover crops (b), and Merlin B (MB) with no-till and cover crops (c). Weather (precipitation, air temperature), subsurface tile-flow and edge-of-field water quality (total

phosphorus, dissolved reactive phosphorus, and suspended sediments) from the tile drainage was monitored at these sites in 2017 and 2018.

Figure 1.3. Edge-of-field water quality in the tiles was measured using area flow velocity sensors, and tile water quality samples were collected using auto-samplers (ISCOs).

Field Data Collection Methods

Each site was instrumented with monitoring equipment to provide the research team with the capacity to collect the required data to evaluate the efficacy of each cropping system at reducing agriculturally sourced phosphorus loads. The monitoring instrumentation techniques used at the Merlin sites are comparable to the data collection methods used at other agricultural water quality monitoring sites in Ontario.(Figure 1.3). Briefly, hydrometric information (precipitation (snow and rain), air and soil temperature, soil moisture) were determined using an on-site meteorological station (ADCON). Recordings were obtained at 15-minute intervals. Tile drain “mains” were installed (2015, 2016) and connected to the existing subsurface tile laterals at each field to permit the instrumentation of the study plots. In the tile drain mains, flow was measured using area flow velocity sensors (depth, velocity, flow direction) recorded on an FL-900 data logger (Hach Ltd.), recorded at 15-minute intervals. Water samples were collected by ISCO 6712 auto-samplers at a high-frequency (2-12 hour intervals) during storm and thaw events. Water samples were retrieved by the LTVCA within 24-48 hours of collection, and promptly delivered to the University of Guelph where subsamples were immediately filtered (0.45 micron cellulose acetate filters) for the analysis of soluble reactive P (DRP). Water samples were analyzed colorimetrically (Lachat Instruments) for DRP (filtered sample) and total P (TP) (unfiltered sample) at the University of Guelph Ridgetown campus. Soil samples were collected in both fields for P analyses 2 times over the study period (2017 and 2018) and analyzed at the University of Guelph Ridgetown campus.

1.5 Results and Discussion

Site Soil Properties

Table 1.4 Summary soil characteristics in the top 6 inches (Olsen-P concentrations, pH, percent organic matter (OM), potassium (K), magnesium (Mg) nitrogen concentrations (top 12 inches), aggregate stability, soil texture) at the Merlin A (Plot 2 and Plot 3) and Merlin B (Plot 1 and Plot 2) in 2017 and 2018. “--” indicates data not available.

	Olsen P (ppm)	pH	OM (%)	N-Ammonium (ppm)	N-Nitrogen (ppm)	Aggregate Stability*	K (ppm)	Mg (ppm)	Sand (%)	Silt (%)	Clay (%)
MA P2 2017 2018	17 30**	6.6 5.7	4.5 3.9	-- 5.9	-- 9.8	46.67 24.56 74.29	139 210	187 230	-- 23	-- 42	-- 35
MA P3 2017 2018	14 41	5.8 5.6	4.1 4.2	-- 4.0	-- 10.8	31.80 24.48 23.53	132 210	220 220	-- 23	-- 42	-- 35
MB P1 2017 2018	16 14	6.0 6.4	3.9 3.9	-- 4.3	-- 11.3	73.05 36.49 21.62	135 185	265 292	-- 25	-- 43	-- 32
MB P2 2017 2018	13 18	6.2 5.7	3.9 4.2	-- 5.8	-- 9.9	68.78 28.01 17.95	126 173	231 209	-- 25	-- 43	-- 32

* *data collection 2016.*

** *increases in Olsen P&K from 2017-2018 at the MA site could be due to the fact that soil sampling occurred on October 24, 2018, two days after fertilizer application (October 22) prior to wheat planting on Oct. 24th.*

The soils are classified as clay loams at both study sites. Despite differences in long-term land management strategies, there was no clear difference in soil organic matter, pH, K, Mg, or nitrogen concentrations in the surface soils of MA and MB sites. Aggregate stability was slightly lower at MA relative to MB (i.e., 2016 and 2017 field survey), which may result from tillage at the MA site, and/or could reflect the recent installation of tiles (3 years prior to the start of this study). The lower aggregate stability at MA suggests the surface soils may be more prone to erosion relative to the soils at the MB site. At MA, Olsen-P concentrations in the surface soils were elevated in 2018 (P2 = 30 ppm; and P3 = 40 ppm) compared to the MB plots (P1 = 14 ppm; and P2 = 18 ppm), reflecting the application of fertilizer at the MA site on May 26, 2018 (200 lb/ac 50/50 MAP-Potash blend) and on Oct. 22nd, 2018, prior to the planting of winter wheat (soil sampling occurred 2 days following the October fertilizer application). The MB site did not receive fertilizer application during the study period (fertilizer was applied in October, 2018 at the MB site, after the end of sampling for the current project). It should be noted, however, that fertilizer was applied at the MB site in 2016 (May) and not at the MA site during that time. A failed corn crop in the summer of 2016 due to the drought conditions likely led to slightly elevated soil nutrient concentrations at the MB site, which presumably could have led to enhanced P losses in tile drains in the NGS of 2016-2017.

Temperature and Precipitation over the Study Period

Conditions over the study period were drier than normal in the summers of 2017 and 2018, but wetter than normal in the winter between them. Overall, total annual rainfall in 2017 was slightly lower (762 mm) than the 30-year average (803 mm), and total annual snowfall (67 cm) was similar to the 30-year average (70 cm) for the region (Figure 1.4). Total precipitation (rainfall + snowfall; 531 mm) was lower than the 30-year average (1131 mm) in 2018 (Jan-Aug). Total precipitation received at the sites (rainfall + snowfall) was 1359 mm during the entire study period.

A milder winter was observed at the sites in 2017 relative to 2018 and relative to the 30-year average for the Chatham region (Figure 1.4). Soil temperatures followed similar annual patterns to air temperature (Figure 1.5). Surficial soils froze (i.e., below 0°C) for a short period of time at both sites in January 2018, and January 2017 (Merlin A), and the depth and magnitude of frost did not differ between the sites. Soil temperatures were greater at the MB site in mid to late summer in both years. These differences may have been related to soil moisture content, given the higher heat capacity of water. Indeed, surface soil moisture (averaged at 5 and 15 cm depths between the two plots) was slightly higher and significantly greater ($p < 0.001$) at MA (12% volumetric moisture content (VMC)) compared to the MB site (VMC = 10%). This may reflect subtle differences in the bulk density of the two sites (MA = 1.21 ± 0.08 g/cm^3, MB = 1.00 ± 0.14 g/cm^3). Aside from this slight offset in VMC between the sites, VMC in the two fields followed similar temporal patterns with one notable exception: in both 2017 and 2018, there was an earlier drawdown in soil moisture in early summer at MB. This was seen in both years. It was not related to the growth of the cover crops as no cover crop was planted during the fall of 2016 following the failed corn crop, and the 2017 cover crop was not planted until after soybean harvest. Thus, the reasons for the earlier VMC drawdown at the MB site are unclear.

Tile flow was initiated at both sites across a wide range of soil moisture conditions, including dry conditions (Figure 1.6 3.5). This suggests that preferential transport flow from the surface to the tiles (e.g., through desiccation cracks) may occur at these clay sites. This is in contrast to findings from Ontario sandy loam soils, whereby a clear threshold in soil moisture content (field capacity) was required prior to the initiation of tile flow (Lam et al., 2016). These hydrologic differences may lead to differences in the timing of P loss across different soil textures, such as those observed by Plach et al. (2019) and provides valuable insight to our growing understanding of P export dynamics across different regions of Ontario.

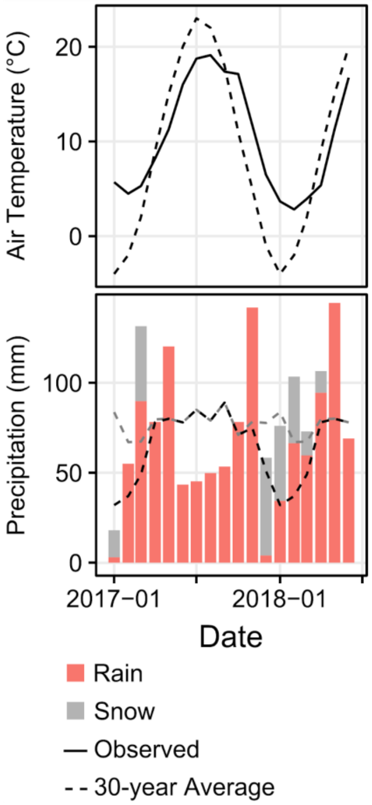

Figure 1.4 Average (a) air temperature from the meteorological station at the Merlin field sites (solid line), and the 30-year monthly average temperature (dashed line) for the region, and (b) Total monthly rainfall and snowfall (grey) at the field sites over the study period, compared with 30-year monthly averages (dashed line).

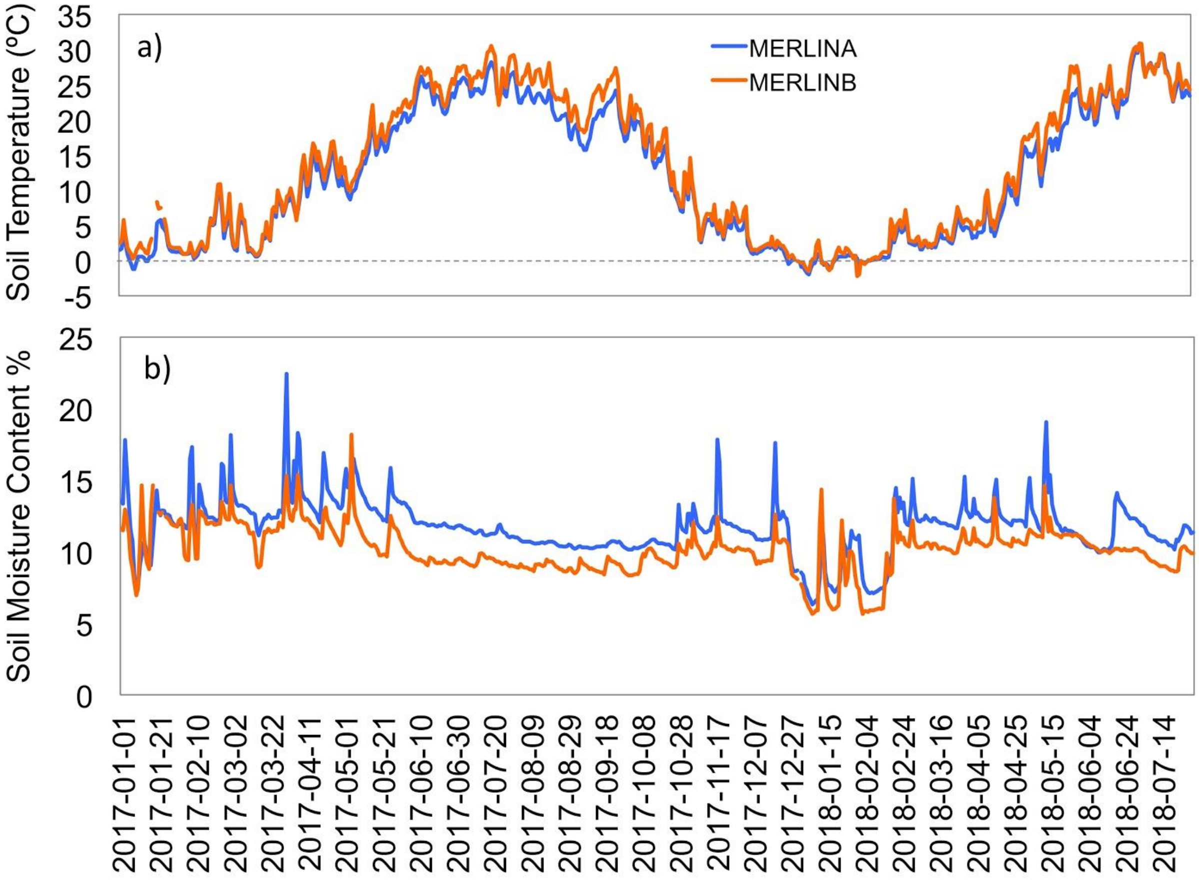

Figure 1.5 (a) Soil temperature (5 cm depth), and (b) average soil moisture conditions (5 and 15 cm depth) at Merlin A (P2 & P3 averaged) and Merlin B (P1 & P2 averaged) in 2017 and 2018. Note soil moisture probe at MB failed on 05-05-18 (5 cm depth), and thus data not included in this plot.

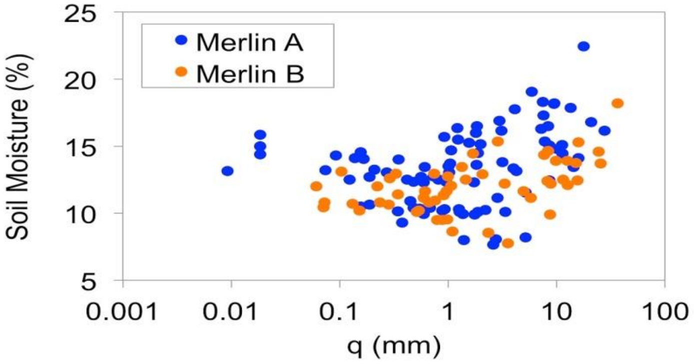

Figure 1.6 Daily soil moisture (averaged 5 and 15 cm depths) and tile flow (q) at MA and MB sites during the study period (2017 and 2018). Tile flow is plotted on a log scale. Note soil moisture probe at MB failed on 05-05-18 (5 cm depth), and thus data not included in this plot.

Annual Total Runoff and Total Phosphorus Losses

No significant difference in tile runoff ($p = 0.67$) was observed between the two fields (Figure 1.7). Total cumulative tile runoff for the entire study period (Jan. 2017 - July 2018) was ~ 268mm, of which 182 ± 24mm occurred between July 1, 2017 and July 1, 2018 when all 4 plots were operational and being sampled. Over the entire study period, MA (305 mm) had greater runoff volumes than MB (232 mm), though this was not consistent across all months (*i.e.*, some particular events resulted in greater runoff at MB than MA). For the 4 plots (12-month period, July 1, 2017-June 30, 2018), MA lost 193 mm of runoff (average of 2 plots), and MB lost 172 mm of runoff (average of 2 plots). Thus, MA appears to be more hydrologically responsive than MB on an annual basis; however, this is not true of all events across the data set. Although other studies have suggested that no-till and cover crops increase infiltration by increasing preferential transport pathways along root channels and earthworm networks (e.g. Kleinman et al., 2015), surprisingly, this did not translate to a significant difference on overall runoff between the study sites, nor did it result in a difference in tile drain responses under variable soil moisture content regimes (e.g., tile drain responses under low VMC, Figure 1.6). At the same time, enhanced soil drying can increase connectivity between the surface and tiles through desiccation cracks. Previous research on tile drains in clay soils has reported elevated P concentrations in tile drains when surface runoff is rapidly routed into tile drains through preferential pathways (e.g. Smith et al., 2014). However, such pathways are less active during the NGS when soils are wetter and more swollen (Macrae et al., 2019; Grant et al., 2018).

Although surface runoff is not measured at these sites, it was observed during the study period, although this was infrequent. Research done at the nearby Essex site (Plach et al., 2019) indicates that tile drains account for approximately 80% of the runoff a similar clay soil. It is strongly recommended that surface runoff is included in future research at these sites to provide a more complete understanding of edge-of-field losses at the site.

Total cumulative tile DRP loads ranged from 0.024 to 0.034 kg ha^{-1} yr^{-1} across the four study plots during the 12-month period of the study during which all plots were being sampled (Figure 1.7). If this period is extended to January, 2017 for the 2 plots that were being sampled early in the study, total losses were 0.047 kg ha^{-1} (MA) and 0.053 kg ha^{-1} (MB). Similar to runoff, no significant difference in SRP concentrations (p = 0.099) and no apparent difference in annual loads were observed between MA and MB sites during the study (Figure 1.7 and 1.8). This lack of difference in SRP loads is likely explained by the fact that (a) there were no apparent significant hydrologic/transport differences between the sites (discussed above) and (b) the soil P concentrations were similar at the sites at the time that this data was collected. Although surface soils at MA were slightly more nutrient rich in 2018 (see Olsen-P concentrations; Table 3.1), this did not translate to higher SRP concentrations or loads in tile drains; however, this is because the P fertilizer was applied in May and October 2018 and the study ended in July 2018, and thus, very little of this P application would have been flushed from the site due to the time of year. Similarly, fertilizer had been applied at the MB site in May 2016, prior to a failed corn crop due to drought conditions, which would had left enriched soil nutrient concentrations during the 2016-2017 NGS. But, the sampling for this study was not initiated until January 2017, and autumn rainfall in 2016 may have provided enough moisture for the soil P to either be incorporated into the soil matrix or be leached from soils. Indeed, most of the runoff events occurred when soil P concentrations were comparable between the sites. Thus, we likely didn’t capture the P application at either site within our sampling window. However, this is optimal for a site-site comparison as our sampling window would have captured long term/legacy patterns in P and site-site differences would not have been swamped out by P application at one of those sites.

Moving forward, we can now explore more acute losses associated with P application (under future sampling programs). In contrast, tile total TP loads were elevated at the MA site (1.94 kg ha^{-} yr^{-1} yr^{-1}), compared to the MB site (1.19 kg ha^{-1} yr^{-1}) (64% more TP at the MA site over the 12-month period during which all 4 plots were being sampled). Over the duration of the study period (18-months), the single plots exported 3.08 kg ha^{-1} at MA and 1.97 kg ha^{-1} at MB. Overall, daily flow-weighted TP concentrations were significantly higher (p = 0.034) at the MA plots compared to the MB plots (Figure 1.8). This likely reflects the greater soil particulates i.e., TSS concentrations (p = 0.0001) leaving the tiles at MA relative to MB. Average DRP:TP ratios in tile runoff were lower at MA (Plot 2 = 0.021; Plot 3 = 0.018) compared to MB plots (Plot 1 = 0.031; Plot 2 = 0.022), which further suggests a greater proportion of the total P exported from the tiles at MA was leaving the tiles in a particulate form.

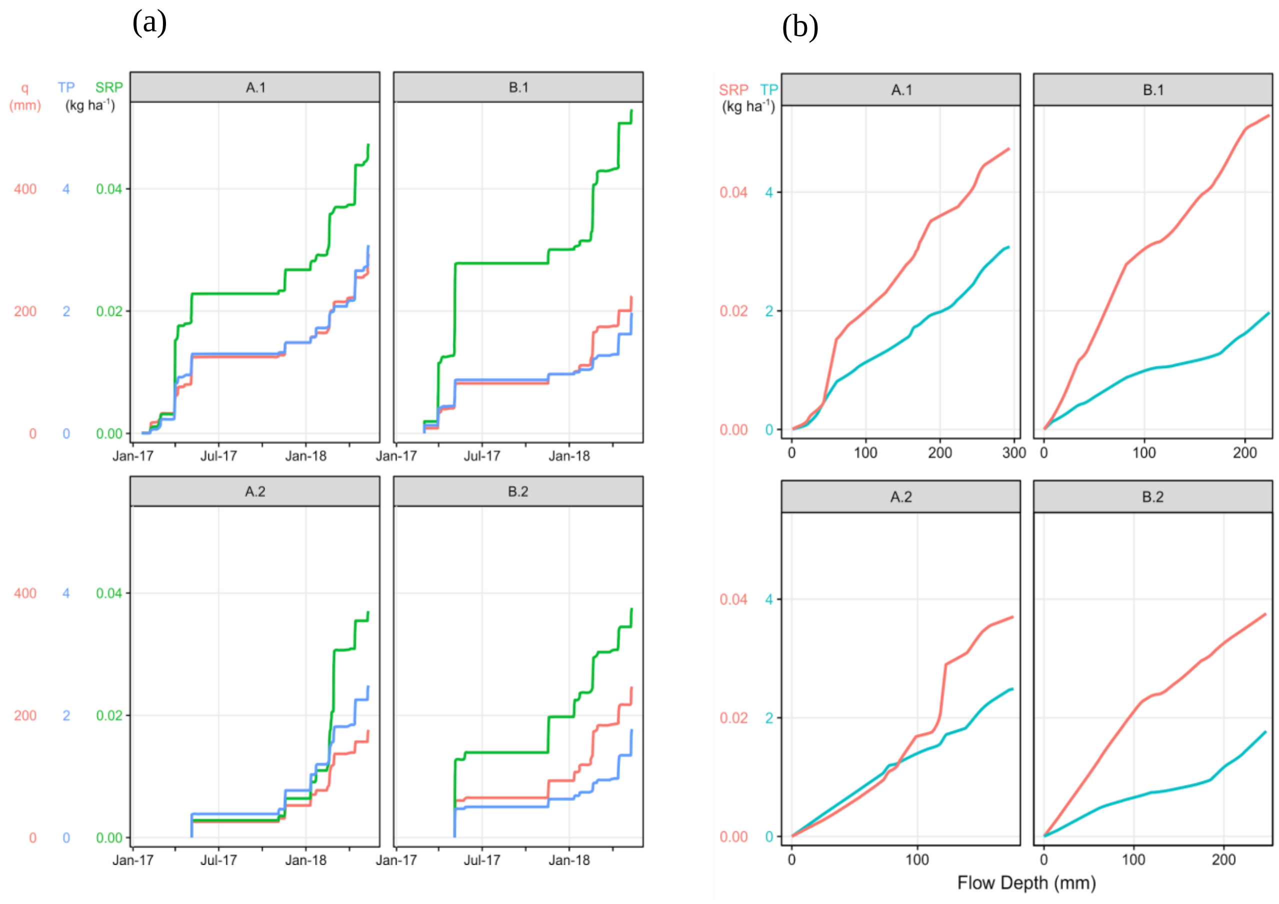

Figure 1.7. Edge-of-field cumulative tile runoff (q), total phosphorus (TP) and soluble reactive phosphorus (SRP) losses at Merlin A and Merlin B field sites (a). Cumulative tile TP and SRP (dissolved) loads with cumulative tile runoff at Merlin A and Merlin B sites (b).

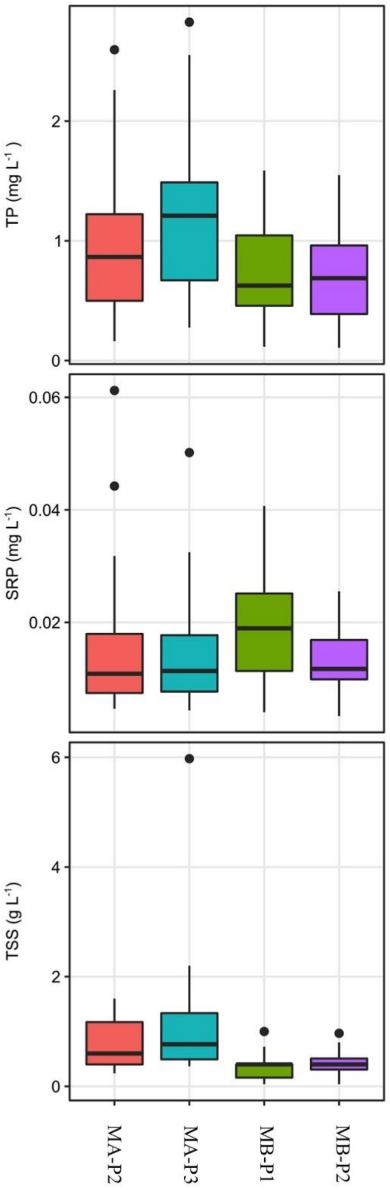

Figure 1.8 . Total phosphorus concentrations (a), soluble reactive phosphorus concentrations (b), and total suspended sediment concentrations (c) a Merlin A Plot 2 (P2) and Plot 3 (P3) and Merlin B Plot 1 (P1) and Plot 2 (P2). All observed data (samples collected) are included in this plot.

The elevated TSS concentrations in the tiles at the Merlin A site may reflect the management practices (i.e. tillage), however; the more recent installation of the drainage tiles (3 years prior to the start of this study) compared to the installation at the MB site (1996 4" laterals, 2016 for main) may contribute particulates to the tiles in the short-term, although this is less likely the driver of these patterns compared to the effects of tillage. As such, long-term monitoring will be required to determine if TSS in the tiles declines as the soil in the fields settle over time.

Seasonal Water Quantity and Water Quality

The majority of tile flow and P losses (TP and DRP) occurred during the NGS across study plots at both the MA and MB sites (Figures 1.9, 1.10). This corresponded to generally lower precipitation during the summer (Figure 1.10).

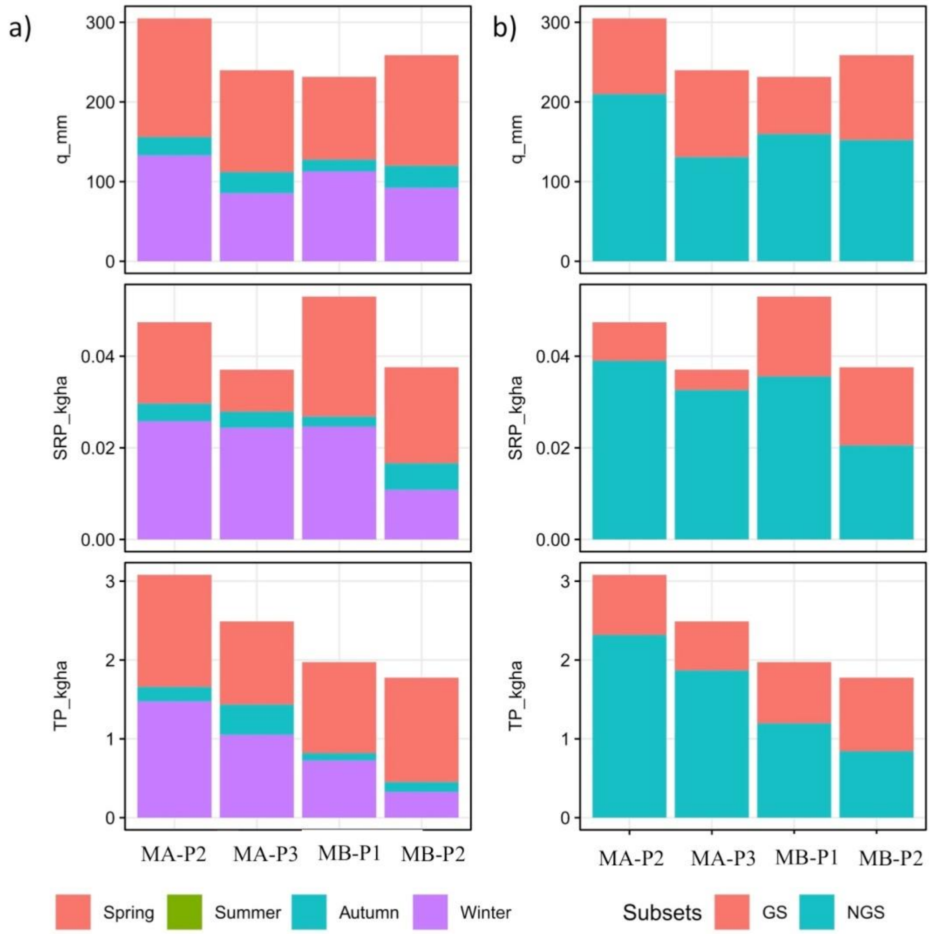

Figure 1.9. Tile runoff (q), soluble (dissolved) reactive phosphorus (SRP) loads, and total phosphorus (TP) loads at Merlin A (Plot 2 & Plot 3) and Merlin B (Plot 1 & 2). Seasons are separated by winter (Jan-Mar), Spring (Apr-Jun), Summer (July-Sept) and Autumn (Oct-Dec) in panel (a), and separated by the non-growing season (Oct-Apr) and the growing season (May-Sept) in panel (b). Note that lower runoff volumes and masses of P were lost from MA-P3 and MB-P2 because these only had data from July 2017 onwards (~7 months less than the other plots).

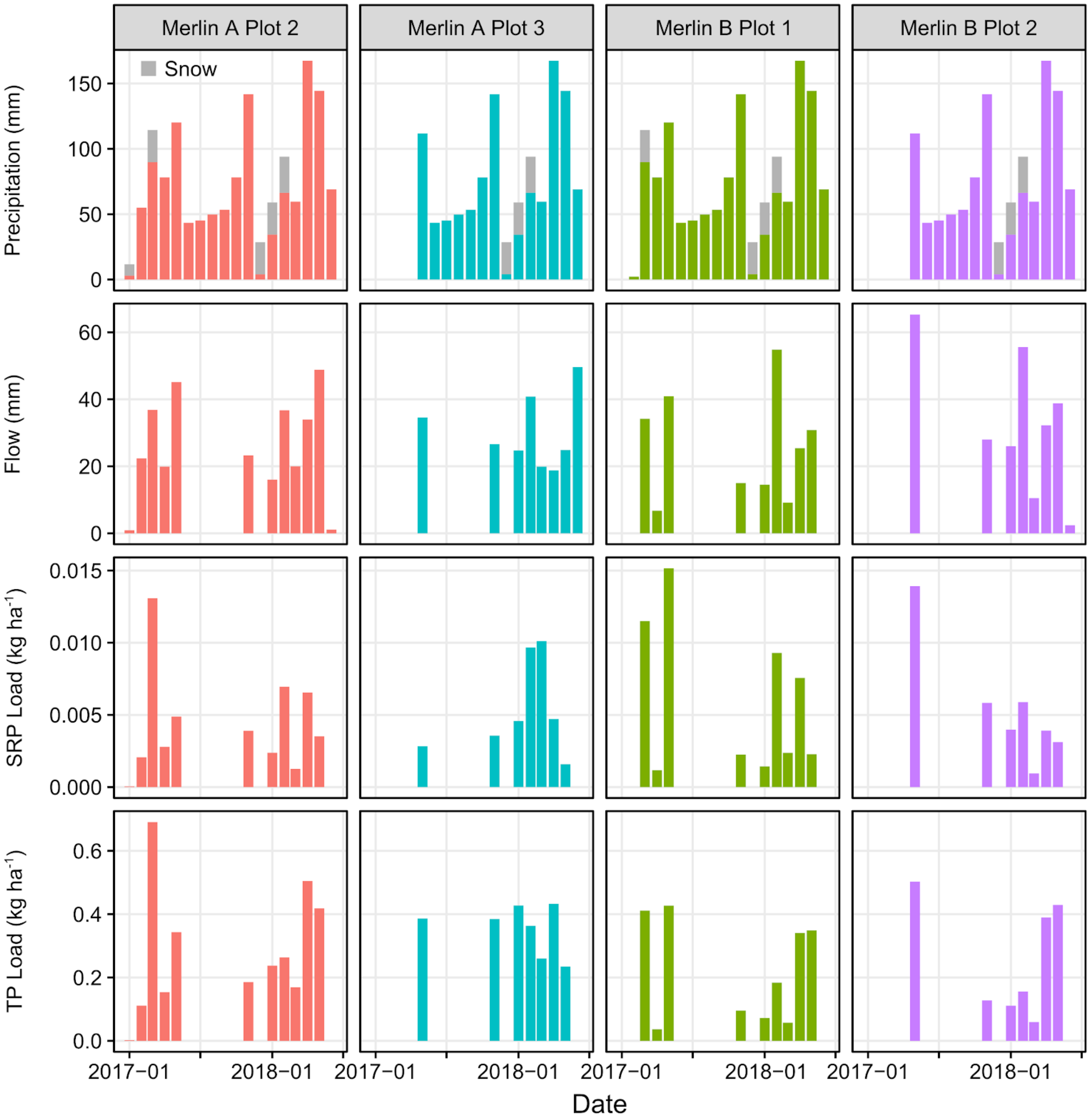

Figure 1.10. Monthly precipitation (rainfall and snowfall (grey bars)), tile runoff (q), soluble reactive phosphorus loads and total phosphorus loads at Merlin A (Plot 2 & 3) and Merlin B (Plot 1 & 2).

In contrast, substantial volumes of flow and large quantities of P were lost from the tiles during the winter and early spring, linked to both rainfall and snowmelt events (Figures 1.9 and 1.10). It is interesting to note that the MA field was more hydrologically responsive in early 2017 than the MB field, coincident with the higher soil moisture relative to the MB site. Unfortunately, additional study years will be needed before we can address the drivers of this inherent variability.

1.6 Conclusions

Concentrations and loads of SRP in tile drains were not significantly different between fields under two different management systems during the study period (2017-2018). In contrast, concentrations of tile TP and TSS were significantly different between sites, where TP and TSS were elevated at the MA (tilled site) relative to the MB (no till with cover crops site). The ratio of SRP:TP in the tiles were also significantly different between farms, with SRP:TP ratios lower at the MA site (i.e., indicator of greater particulate P). However, despite these differences in concentrations, the differences in overall tile flow (Q), and loads of SRP, TP, and TSS were all insignificant between farms at the annual scale. This largely reflects the low number for annual comparison (n = 4), and indicates a need for longer-term comparison of water quantity and water quality at these sites. It is also recommended that future research at these sites should include measurements of overland flow as well as characterization of subsurface soil properties to advance understanding of the timing and the controls of edge-of-field runoff and P loss in these clay loam sites.

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